

THREE-DIMENSIONAL PROPERTY MODELING OF A COMPLEX FLUVIO-DELTAIC ENVIRONMENT: RHINE-MEUSE DELTA, THE NETHERLANDS

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INTRODUCTION

The Geological Survey of the Netherlands aims at building a 3D geological property model of the upper 50 meters of the Dutch subsurface. This 3D model provides a basis for answering subsurface related questions on, amongst others, groundwater extraction and infrastructural issues. modeling is carried out per province using a digital core-database containing several hundreds of thousands of core-descriptions and a context of geological maps created during the last few decades. Following the completion of a model of the province of Zeeland (Stafleu et al., 2008), modeling focussed on the province of Zuid-Holland where major cities like Rotterdam and The Hague are situated, and the Rivers Rhine and Meuse enter the North Sea. The area is characterised by a thick Holocene coastal wedge that is underlain by a stack of Pleistocene (sandy) units. The Holocene sequence is the main focus of our paper.

A stepwise procedure consisting of automated database queries, 2D modeling of stratigraphic surfaces and 3D property modeling, resulted in a schematisation of the Zuid-Holland subsurface in using 50 million grid cells (blocks), each measuring 100 by 100 meters in horizontal directions and 0.5 meters in the vertical direction. Each grid cell of the final model includes estimates of stratigraphy, lithology (clay, sand, peat) and if applicable, sand-grain size class data, all up to a depth of 60m below the Dutch Ordnance Datum. The use of stochastic techniques allowed us to compute probabilities for these parameters, providing a quantification of model uncertainty. In a final model step (not further discussed in this paper), the 3D lithological model is used as a basis for the parameterisation of physical and chemical properties, such as hydraulic conductivity and chloride content.

In contrast to its predecessors (DGM, REGIS), the Zuid-Holland model is no longer a layer-based model consisting of stratigraphical layers with uniform properties, but a cell-based model where individual cells have uniform properties. The cell-based nature of the model allows modeling of the internal heterogeneity of lithostratigraphical units in terms of lithology, sand-grain size classes, and other parameters.

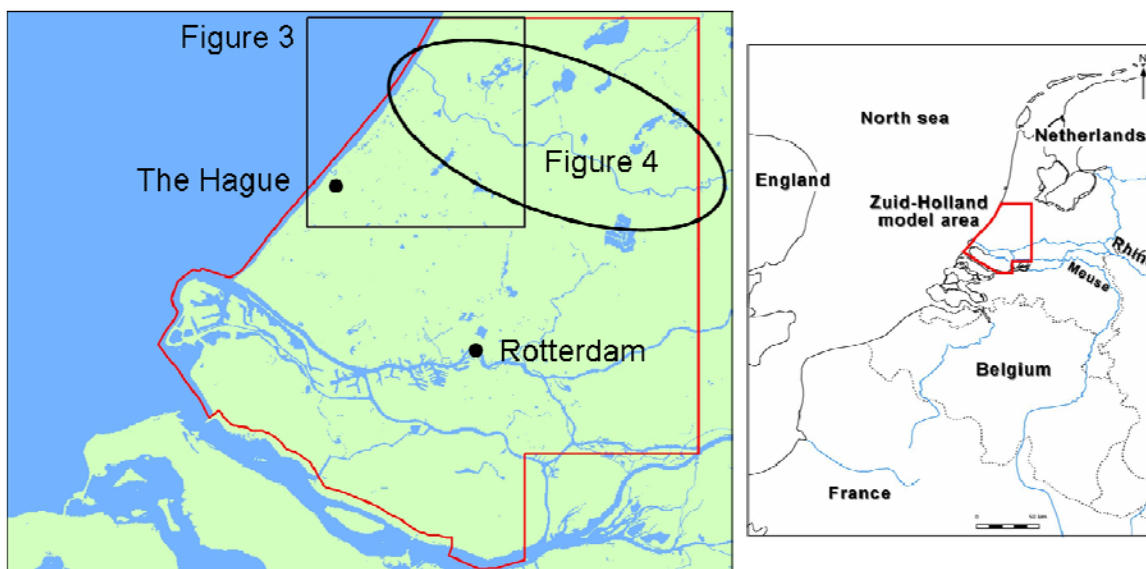


Figure 1. (a) Location maps showing (a) the position of the Province of Zuid-Holland in the west of the Netherlands and (b) in the southern North Sea area.

GEOLOGICAL SETTING

The province of Zuid-Holland is positioned at the southern rim of the North Sea sedimentary basin. Its subsurface (upper tens of meters) mainly consists of fluvial and estuarine sediments that were deposited by the Rhine and Meuse throughout the Pleistocene and Holocene. The Pleistocene deposits mainly consist of fluvial sands that will not be further discussed here.

The Holocene coastal wedge reaches thicknesses of 5 to 20m. Sea-level controlled Holocene sedimentation in the area started with the formation of a distinctive peat layer (Basal peat Layer, Figure 2). The peat covers Late Pleistocene eolian sands (Wierden Member) and a clay layer that formed prior to sea-level rise (Wijchen Member). Widespread aggradation of fluvial sediments on top of the peat initiated about 8500 years BP (base Echteld Formation). In the western portion of the area, an open coastal barrier system developed (Zandvoort Member). Deposition of tidal channel and tidal flat sediments occurred in the back barrier area (Wormer Member). East of this zone, fluvial aggradation continued as reflected in the presence of fluvial channel belt (dotted lines in Figure 2), overbank, and floodbasin sediments. Closure of the barrier inlets after ~4000 years BP lead to widespread peat formation (Hollandveen Member). Re-opening of the barrier inlets system after ~2500 years BP led to a continuation of marine sediment deposition (Walcheren Member) in the western part of the area. Natural sedimentation of rivers and estuaries largely ended after 1000-1200 AD when dikes were established throughout the area.

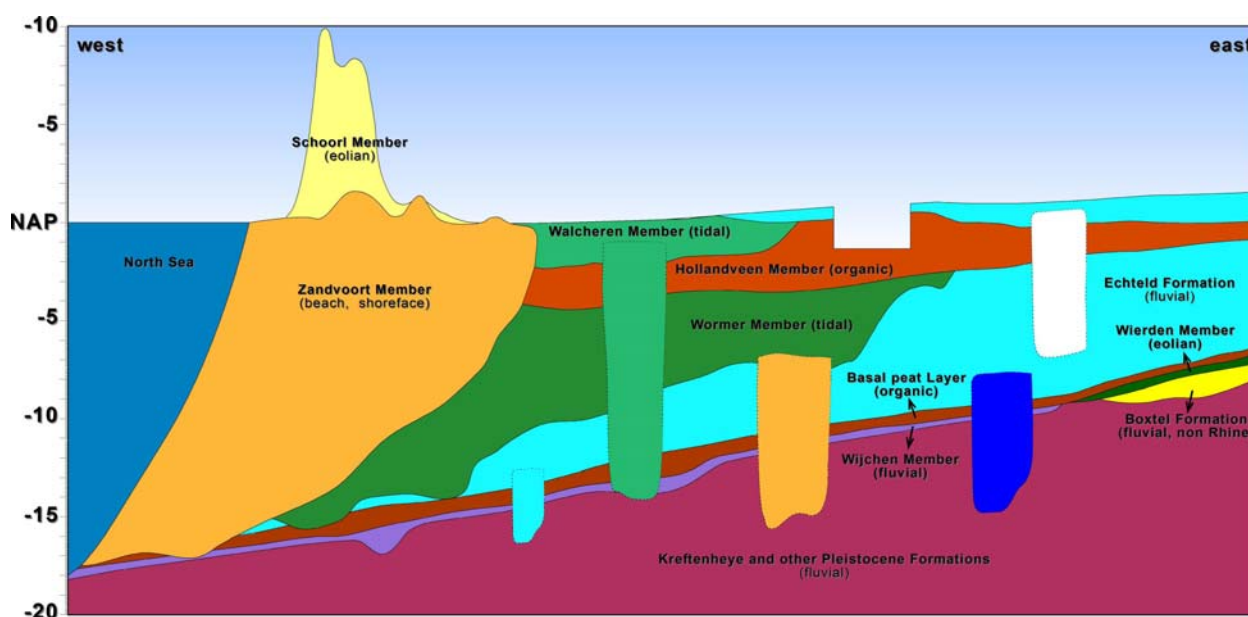


Figure 2. Schematic east-west oriented cross-section through the Holocene deposits in the Province of Zuid-Holland. The horizontal distance is about 70 km, while the vertical distance runs down to 20 meters below Dutch Ordnance Datum. See text for discussion of the units.

METHODS

The starting point for the Zuid-Holland model are the borehole descriptions stored in the DINO database, the Dutch national database for Data and Information of the Subsurface (www.dinoloket.nl). This database provides us with over 50,000 borehole descriptions for the model area (65 by 65 km). Each borehole description reveals detailed information of the subsurface at one particular location. The modeling procedure involves a number of steps.

The first step is a geological schematisation of the boreholes into units that have uniform sediment characteristics, using both lithostratigraphical and lithological criteria. During the second modeling step, 2D bounding surfaces are constructed. These surfaces represent the top and base of the lithostratigraphical units and are used to place each 3D grid cell in the model within the correct lithostratigraphical unit. The lithological units in the boreholes were used to perform a final 3D stochastic interpolation of lithology within each lithostratigraphical unit. After this step, a cell-based (100 by 100 by 0.5 meter) three-dimensional geological model is obtained. The 3D interpolation is carried out for each lithostratigraphical unit separately. Fluvial and estuarine channel belts in the area were modelled as separate lithostratigraphical units. The location of the belts was derived from detailed maps published by the Geological Survey and the University of Utrecht (Berendsen and Stouthamer, 2001). Newly developed, Python-based scripts were used

to determine the top and base of the belts within the boreholes. Finally, the use of stochastic techniques, such as Sequential Gaussian Simulation and Sequential Indicator Simulation (Goovaerts, 1997), allowed us to compute probabilities for both lithostratigraphy and lithology for each grid cell, providing a measure of model uncertainty.

RESULTS

Part of the lithostratigraphical model of Zuid-Holland is shown in Figure 3. The model shows the Pleistocene substratum covered by the complex of Holocene fluvial, marine, and organic sediments.

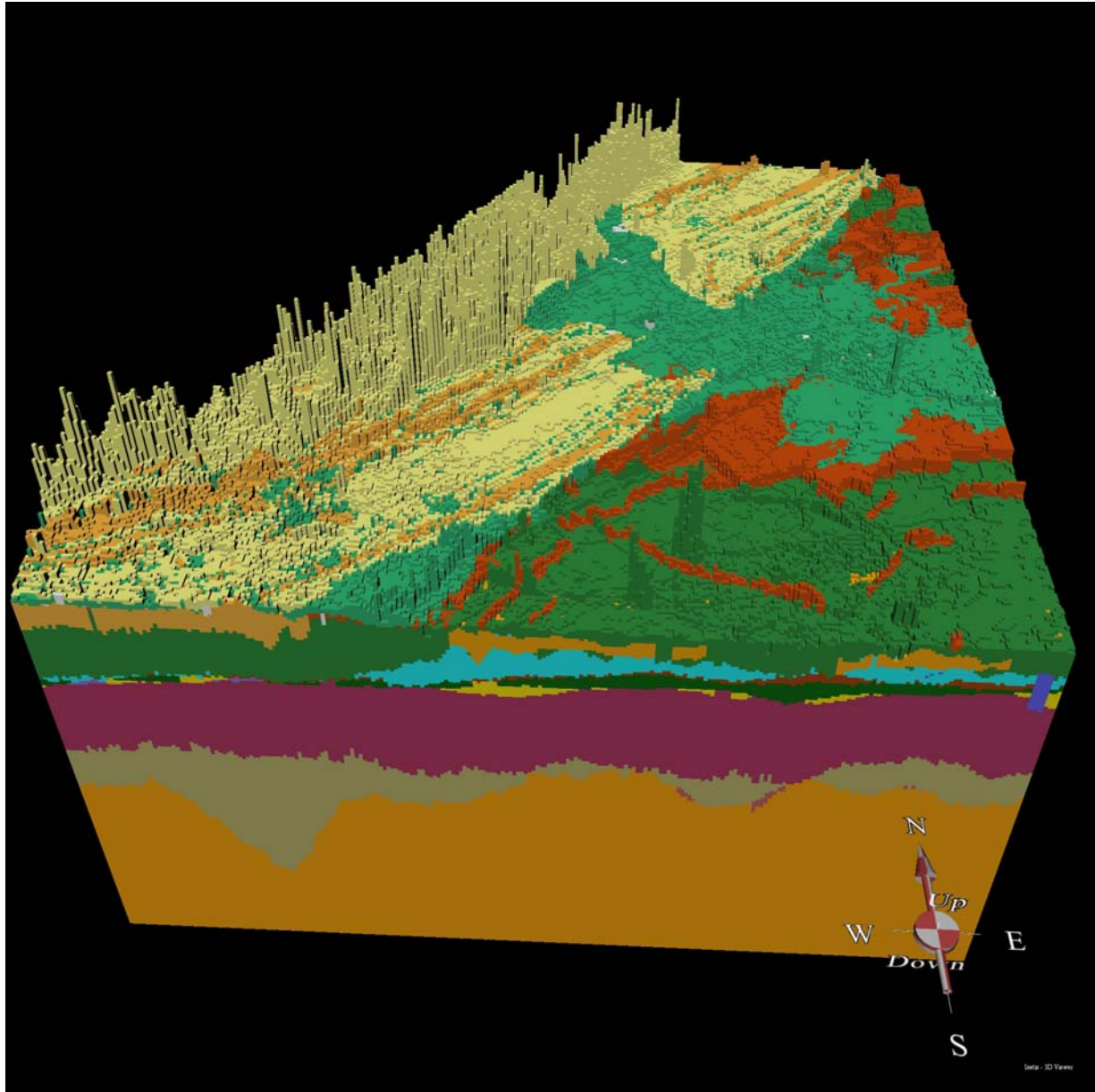


Figure 3. Part of the 3D lithostratigraphical model of Zuid-Holland (see Figure 1 for location). See Figure 2 for information on unit colour codes.

The Holocene deposits of Zuid-Holland are characterised by complex fluvial channel systems of the Rhine and Meuse Rivers. By modeling the channel belts as separate lithostratigraphical units, a 3D model of the geometry of the channel belts was obtained. The colours in Figure 4 represent channel belt generations (relative ages). For example, Generation B (white in Figure 4a) corresponds to the course of the Rhine in Roman times. Figure 4b shows the same channel system with grid cells filled with lithology and sand-grain size classes, providing more insights into the

internal build-up of the channel belts and occurrence of grain-size trends in vertical and horizontal (downstream) directions.

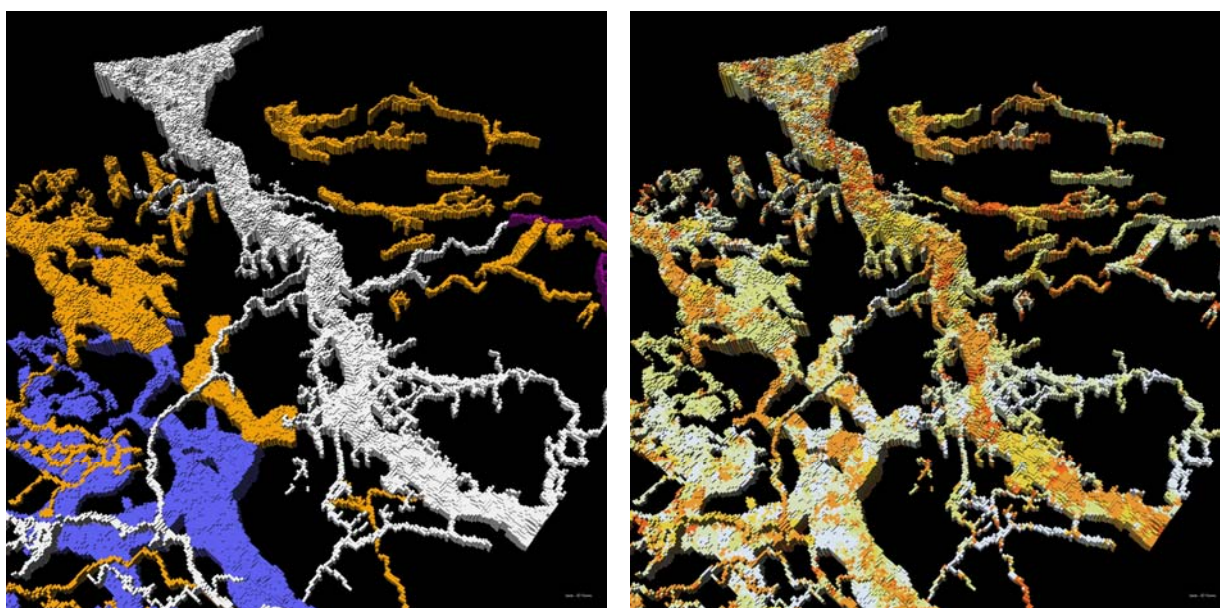


Figure 4. (a) Holocene channel belt systems in Zuid-Holland (see Figure 1 for location). The colours represent generations (relative ages) of the channel belts. (b) Same channel system as in (a) with colours representing lithology and sand-grain size classes. Darker colours are coarser sediments.

APPLICATIONS AND FUTURE DEVELOPMENTS

The Zuid-Holland model serves as a source of subsurface information and provides the regional, geological composition as well as the spatial variability in lithology and sedimentation patterns. An example of the use of the model is the planning of a new subway in the city of Rotterdam. Here the model is used as a background (frame) model in order to plan detailed studies of sediment variation at the sub-grid scale (1-10m).

In addition to the modeling described above, we collected and measured physical and chemical parameters. The sampling strategy is such that measured values can be assigned to lithostratigraphical and lithological units, making it possible to obtain insights into the spatial variability of physical and chemical properties in three dimensions. Examples of physical and chemical parameters include horizontal and vertical hydraulic conductivity, which are crucial in groundwater models and the reactivity of sediments, which is used in the modeling of contaminant plumes.

In the future, we will extend the models towards the north, east, and south of the Netherlands, ultimately leading to a full model cover of the Netherlands (41,000 km²).

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