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Archaeological prediction map; Quarternary landscape; subsurface; LIDAR; GIS.

In the Netherlands, archaeological research is government-controlled and performed under the Treaty of Valetta. As part of the planning for urban and rural developments, the effect of soil disturbance on (possible) archaeological sites has to be considered. For this purpose, municipalities require archaeological prediction/risk maps (Fig. 1).

The Holocene rising of the sea level resulted in substantial accumulation of sediments in the western half of the Netherlands. The Pleistocene (Late-Palaeolithic) subsurface may currently lie up to 12m below surface.[1] This makes predictions considering archaeological remnants highly dependent on the historic landscape variations over time.[2]

Information about known archaeological sites, their landscape and settlement factors forms the foundation of the research. A Quaternary landscape reconstruction was performed using available data which varies depending on the time period and depth of the sediments.

Data from the Pleistocene subsurface were collected from core samples and geological maps. The maps were geo-referenced and compared with the core sample data. The relevant data were digitalized. The periglacial landscape was dominated by braided rivers and aeolian coversands.[3] Dunes up to 20m high were blown out of the braided channels during the Late Dryas period.[4] Indicators for human occupation during the Late Palaeolithic mainly comprise charcoal, flint stone or botanical remnants from small hunting camps.[5]

In the early Holocene, the rivers changed from braided systems to meandering systems. Due to rapid sea level rise, (approximately 8m in 3500 years[6]) rivers in the back barrier coastal plain in the West of the Netherlands started exhibiting anastomosing flow patterns.[7] An anastomosing river is composed of several interconnected channels which enclose floodbasins. During floods, crevasse splays are formed when the natural levees break. On the natural levees and crevasse splays, which form subtle elevations, occupation is possible. Remnants of Mesolithic camps are also found on Pleistocene river dunes which now form high and dry areas within the floodplains.[8]

Pressure and oxidation cause more shrinkage in clay and peat sediments than in sandy sediments. Over time, the sandy riverbeds and crevasses become elevated ridges in the terrain. Due to this relief inversion, the sandy channels of anastomosing river systems,

1 Van Dijk, Berendsen, and Roeleveld 1991.
2 Buesink et al. 2010; Boshoven et al. 2012.
3 Berendsen 2008a.
4 Berendsen and Stouthamer 2001.
5 Louwe Kooijmans et al. 2005.
6 Törnqvist 1993.
7 Berendsen and Stouthamer 2001.
8 Mol 2001b; Mol 2001a.

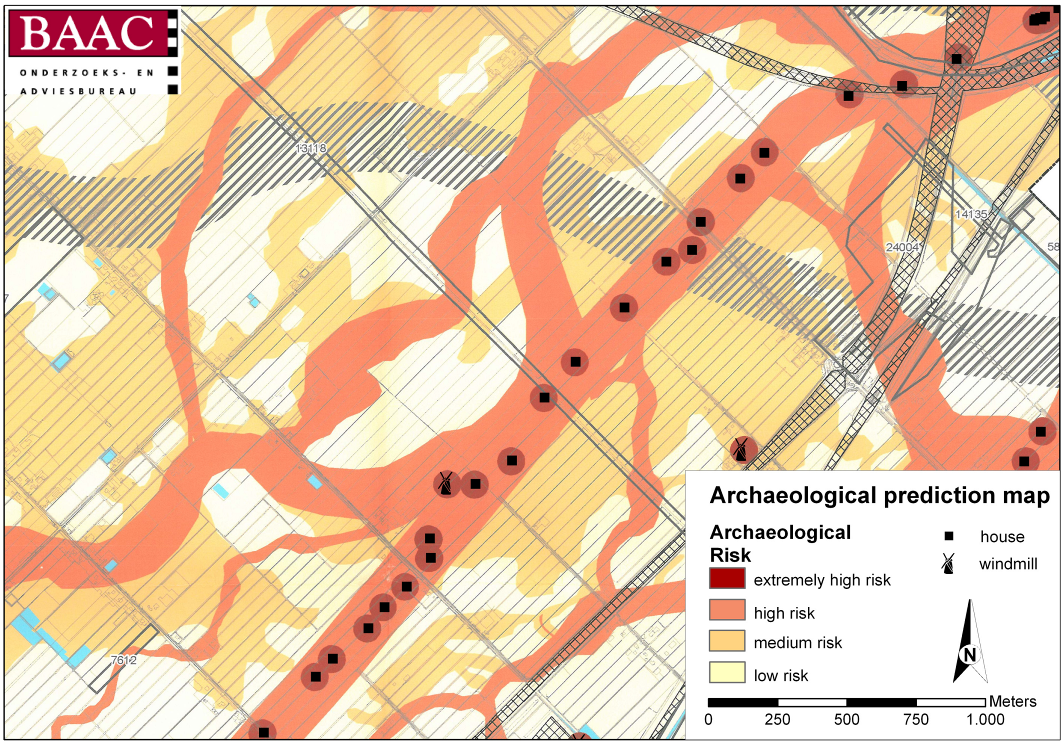

Fig. 1 | Example of an archaeological risk map. The locations with an extremely high risk of archaeological remnants are locations of known historical elements. These historical elements were almost all located along an exploitation axis. Since other remnants may also be present along this axis a high risk of archaeological remnants is given to the exploitation axis itself. A high risk was also given to the former river channels. The crevasse splays have a medium risk. A low risk is given to the floodplains where no river or crevasses are present in the subsurface. The hatched area on the map represents the location of the edge of a Pleistocene river terrace in the subsurface. The double hatched areas represent locations where soil disturbance has occurred due to infrastructural works. The numbers in the maps refer to locations where archaeological research has been performed. ©BAAC bv.

crevasses and dunes are visible on LIDAR data, even when they are situated several meters below the present surface. Hillshades at various angles were calculated with GIS to accentuate the elevation differences (Fig. 2). Core sampling of the subsurface archaeological levels was used as a first research method to obtain archaeological data.

As the sea level keeps rising, tidal influence starts affecting water levels in the rivers. Tidal creeks find their way land inwards[9] and perimarine sediments are deposited. Creek development originates at the former river mouths and continues land inwards, largely following the river channel deposits, which are susceptible to erosion. In other areas, clay is deposited on top of older sediments. As a result of relief inversion, the tidal creeks are also visible on LIDAR data (Fig. 2). Because LIDAR does not provide information about the depth of subsurface sediments and creek patterns often resemble the patterns of crevasses, creek and crevasse deposits are often difficult to discern. All available data, such as detailed maps, core sample data and archaeological data, were digitalized and used to discern the sediments from different time periods and their depth below surface as well as possible. Neolithic remnants are found in tidal deposits and in the top of the Pleistocene river dunes which still surface at several places. Hunting and fishing probably provided the main food source for the hunter-gatherer cultures.

When the coastal barriers close, the environment becomes less dynamic. Fresh water starts to displace the salt and brackish water behind the coastal barriers and peat formation starts in the floodplains. As soon as the peat starts rising above the (ground)

9 Hijma 2009.

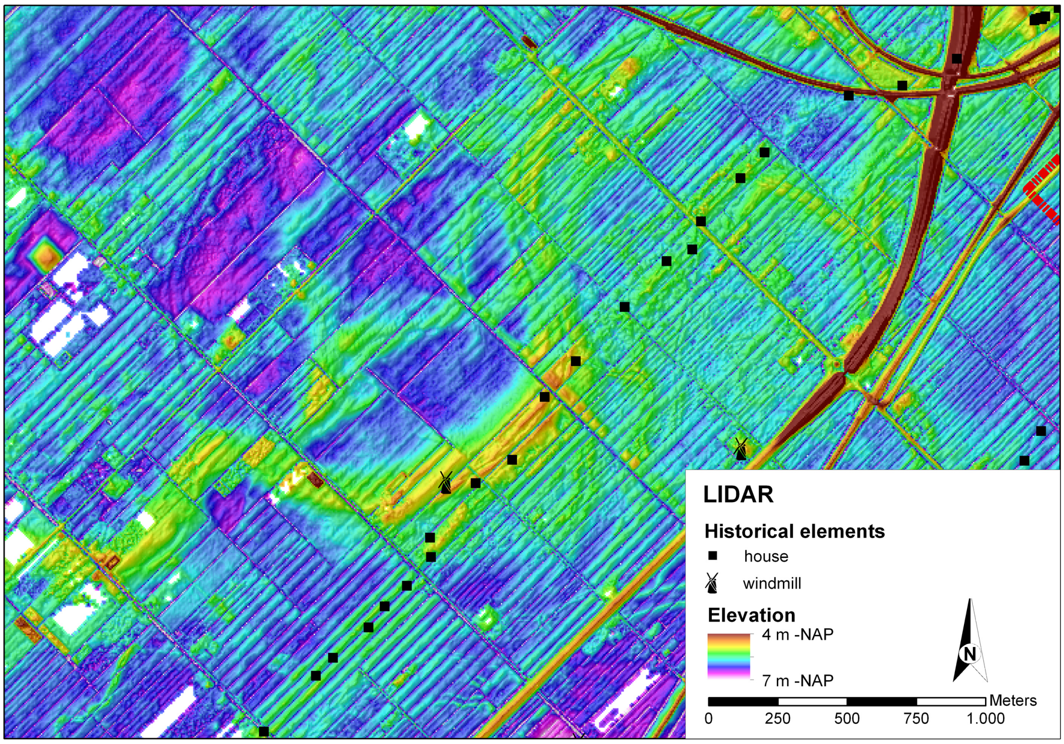

Fig. 2 | LIDAR with hillshade from the same area as exposed on the archaeological risk map in Figure 1. NAP (Normaal Amsterdams Peil) is the national elevation reference scale for the Netherlands. All areas on the map are below sea-level and therefore minus NAP. The exploitation axis, river channels and crevasse splays are visible on the LIDAR map. LIDAR was used to determine the exact location of these elements. Other sources, such as geological maps, core sample data and historical maps were necessary to make the distinction between the elements and to determine their depth below surface. ©Rijkswaterstaat and de Unie van Waterschappen.

water table and becomes oligotrophic, it becomes independent of former hydrological conditions. The landscape changes. In the center of the sphagnum peat domes, lakes are formed. Small streams start draining the precipitation influx from these lakes.[10] Archaeological remnants from the Bronze Age up to the Roman period can be found alongside these streams, where agriculture, hunting and fishing were practiced. Historical maps were used to provide information on the location of the lakes and streams, and areas with a higher potential for archaeological remnants were identified. These historical maps date from later time periods, but cultivation patterns and toponyms often reveal the location of these former lakes and the corresponding streams.

From the Roman period onwards, means of regulating the water levels and draining the peat have been known of. From the Early Middle Ages, peat formation stopped because the peat was systematically drained and cultivated. Cultivation was initiated at the streams that formed the lowest part of the peat landscape. Drainage and subsequent oxidation resulted in subsidence of the surface. Dikes were raised and ditches were dug along the back and side boundaries of the cultivated areas to protect them against seepage from the natural peat lands. When agricultural conditions degrade, barren land is cultivated and the exploitation axis moves land inwards. New dikes and ditches were made. The villages along the exploitation axis (Fig. 1) were moved to the new axes. Historical maps from different time periods display the exploitation axes. LIDAR was used to optimize geo-referencing of the historical maps, as the former dikes and settlements are elevated with respect to the surrounding agricultural lands due to differential subsidence.

10 Mulder, Groot, and Beekman 1986.

The ongoing rise in sea level resulted in an increase in tidal influence on the water levels of rivers. In combination with the subsidence of the surface, this resulted in an increased risk of flooding. From the Late Middle Ages onwards, dikes became important in reducing the flood risk. Terps were also created to protect houses from flooding.

From the 16th century onwards, peat was extracted as fuel for the large cities and industries in the West of the Netherlands.[11] As a result of the mining, lakes were formed. Small islands were left to dry the peat. During storms, islands disappeared and dikes were damaged: the lakes expanded. In total, several meters of peat were excavated and large lakes were formed. Historical maps show the lakes and the remaining dikes that separate them. Archaeological remnants from the Bronze Age to Middle Ages are likely to have been damaged and removed with the peat. LIDAR data displays elevation differences, thus indicating areas where peat and archaeological sites may still be present.

In the 16th century, reclamation commenced[12] and several lakes were drained using the now world-famous Dutch windmills. Multiple windmills were needed to pump the water from below sea level to the surrounding canals that drained the water into rivers. Historical villages and objects such as the windmills were located using historical maps and archaeological research data. Once the peat was excavated and the water pumped out, the Neolithic sediments surfaced again. Flow patterns from rivers and tidal creeks from the Meso- and Neolithic times can therefore be seen on the LIDAR data today (Fig. 2)

Geographical Information Systems (GIS) are used to combine, synthesize and visualize the different archaeological, historical and landscape data. The resulting archaeological prediction map[13] shows the currently known archaeological sites within the municipality as well as the predicted risk of archaeology present at the surface and the different levels in the subsurface (Fig. 1). The municipal policy for archaeological research is subsequently based on these archaeological risk maps.

11 Graaf 1970.
12 Berendsen 2008b.
13 Buesink et al. 2010; Boshoven et al. 2012.

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