CASE STUDY 3M – (WAASLAND) SCHELDT POLDERS, BELGIUM

Case Study Area: Scheldt Polders

Main geomorphological types: Estuary (partially embanked), tidal basin

Main coastal change processes: Natural Flooding, Breaching, Human induced

Primary Resources used: Archaeological/Palaeoenvironmental Data and Historical Maps

Summary: The Scheldt polder area, located in the NW of Belgium at the Dutch border, is mainly made up of estuarine tidal marsh and embanked areas. The area is known for human occupation since prehistoric times (Late Palaeolithic). The case study demonstrates the use of (new) techniques for detailed palaeo-landscape reconstruction, on two different time scales: (1) natural evolution of the landscape during the Holocene (last 10.000 years, pre-medieval), based on geotechnical and geophysical data; and (2) man-induced evolution of the landscape since the Middle Ages, based on historical maps.

Recommendations: This novel approach is especially valuable in view of the ongoing harbor extension and nature compensation works in the Scheldt polder area.

Coastal managers face an ongoing battle to moderate impacts from the sea in the face of a changing climate and pressures from human use of the coastal zone. The challenges that lie ahead are forecast to increase while resources are being forced to go further.

This case study report is part of the technical report on the Arch-Manche project, which quantifies the value of under-used coastal indicators that can be applied as tools to inform long term patterns of coastal change. In addition, it provides instruments to communicate past change effectively, model areas under threat and interpret progressive coastal trends.

Scheldt polders is one of two Belgium case study areas for the Arch-Manche project. This case study report introduces the study area and why it was chosen as part of the project, the results of the archaeological and palaeoenvironmental study are then presented along with the results of the map and chart studies. The analysis of these results and the potential for demonstrating the scale and rate of coastal change are then presented. For further details about the project methodology see Section 2.

The case study “Scheldt polders” has the intention to demonstrate, use and evaluate (new) techniques for palaeogeographical landscape reconstruction. This will be done on two time scales: (1) palaeogeographical Holocene (pre-medieval) reconstruction based on geotechnical and geophysical data; and (2) post-medieval landscape reconstruction based on historical maps.

The aim of applying these (new) techniques is to improve and facilitate (especially time wise) current methods of landscape reconstruction, based on for instance extensive and time consuming coring.

Based on the results of the analysis of historical maps and the results of the fieldwork, complemented with existing corings, the final part of this report will present maps of the landscape evolution of the study area since the start of the Holocene to the late 19th century.

3M.1 Introduction to the Scheldt polders Study Area

The Scheldt (also called Waasland) polder area (which comprises the Doelpolder) is located in the northern part of Belgium, at the Dutch border (Figure 3M1). It is an area where interactions between nature and humans are intensely intertwined and it is a beautiful example of how environmental change affects human life, but also the astonishing capability of mankind to sculpt a landscape to his own needs. The area is an almost flat, low lying region on the western bank of the river Schelde. Geographically it is limited by the Dutch/Belgian border in the northwest. North of the border lies the Drowned Land of Saeftinghe, an extensive tidal marsh (Figure 3M1).

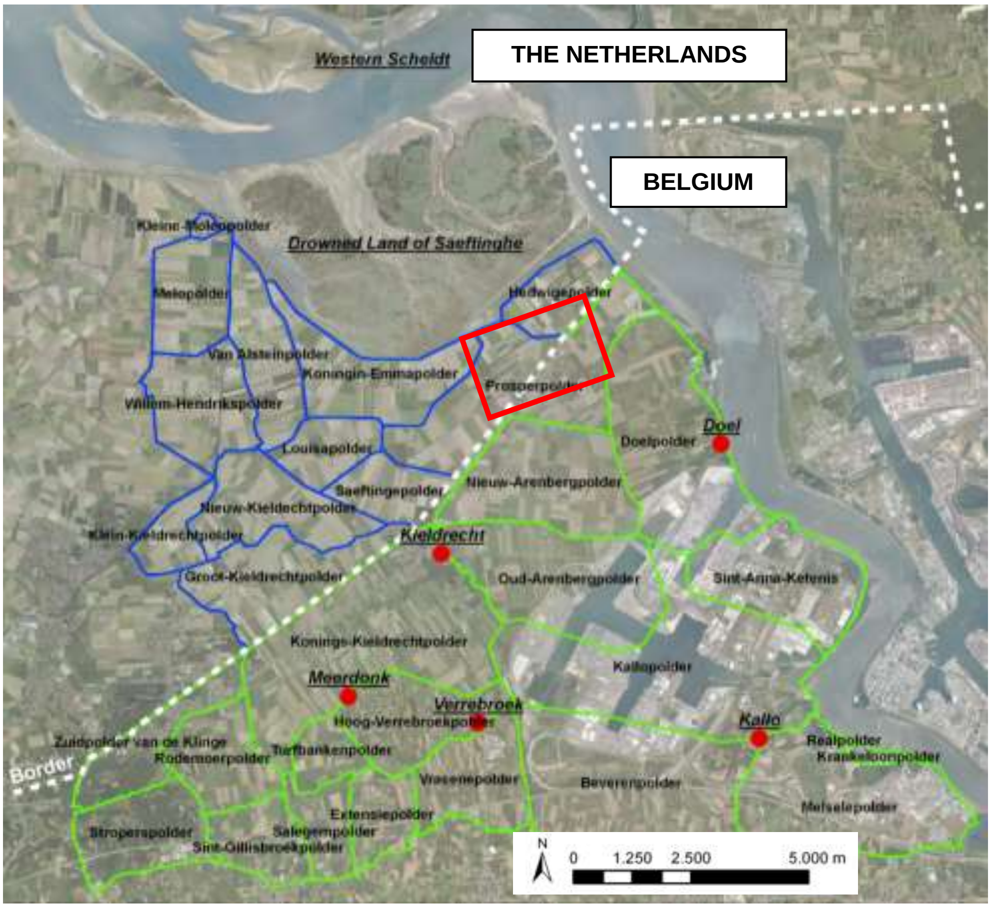

Figure 3M1: Overview of Waasland study area, the different polders included (green: Waasland polders, blue: Dutch polders) and the Drowned Land of Saeftinghe in the north. Note that some of the Waasland polders have (partly or completely) disappeared due to the Antwerp harbor extension. The red rectangle marks the site of Doelpolder-Noord (background: Google Earth).

The elevation in the polder area varies between roughly 0.5 and 5m TAW (Dutch level approximate to lowest astronomical tide or LAT) (Figure 3M2). This means that the majority of the region would be flooded by high tide if no dikes were present. In the Early Middle Ages, this landscape used to be a tidal flat environment that changed into dry land due to drainage and the creation of polders. The faint microrelief in the Digital Elevation Model (DHM) is due to old creeks and dikes. In general the younger polders have a higher elevation as they silted up for a longer period of time (Figure 3M2).

The typical polder landscape is, however, only partially preserved, because of the expansion of the harbour of Antwerpen. Locally the elevation has been changed by adding up to 10 m of soil on top of the original topography.

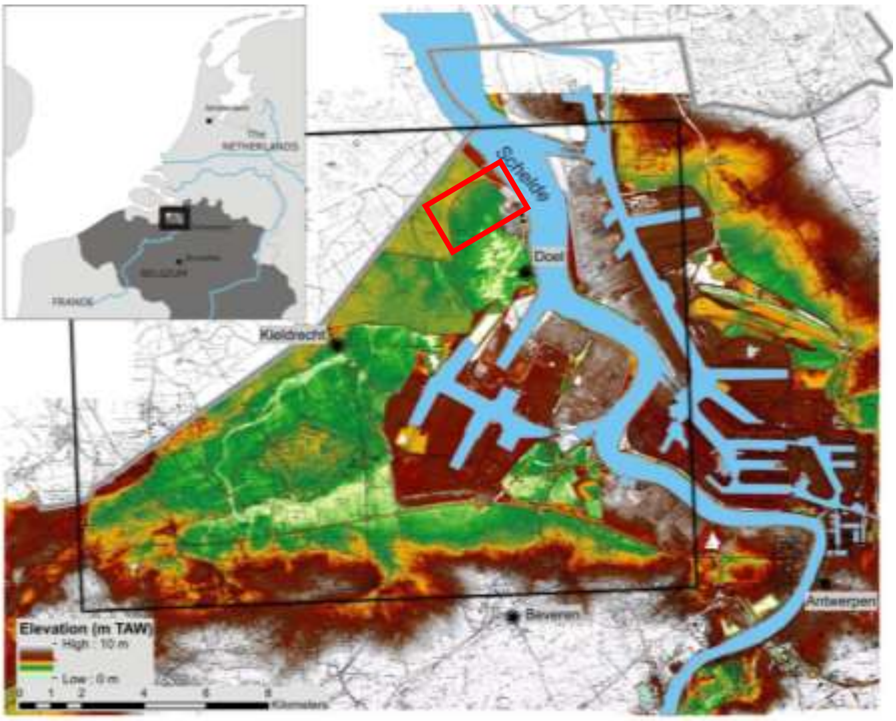

Figure 3M2: Digital elevation model (DHM) of the Waasland (Scheldt) polder area. The black box indicates the extent of the study area. The grey line indicates the Dutch-Belgian border. The inset in the top left shows the location of the study area. The red rectangle marks the site of Doelpolder-Noord. (Digitaal Hoogtemodel Vlaanderen, AGIV (2003)).

3M.1.1 Geology of the Study Area

The Waasland polder area is a geologically young region. The current landscape and shallow deposits are of Late Quaternary age and are highly influenced by the proximity of the North Sea and the river Scheldt. Over the past 30.000 years the river has changed its course and pattern, greatly impacting the depositional environment and river-sea interactions. The delicate balance between sea-level rise and river sedimentation has led to phases of transgressions and regressions. More recently, ca. 1000 years ago, the impact of man has become dominant by building and rebuilding dikes. This battle between man and water left traces in the current landscape.

Tertiary sediments

The Tertiary geology in the study area consists of sandy deposits (Formation of Lillo, in the extreme southeast also the Formation of Kattendijk and Formation of Boom). No Tertiary outcrops are present. The depth (top surface) ranges from less than 5m below the current topography in the southwest, to 25-30m in the northeast.

The Formation of Lillo (Mid to Upper Pliocene) consists of shell-rich sand deposits (Jacobs et al., 2010a). The Formation of Kattendijk (Lower Pliocene) consists of glauconitic sand (with shell fragments), locally rich in clay (Jacobs et al., 1993; Jacobs et al., 2010b). The Member of Putte (Formation of Boom) (Early Oligocene) consists of organic-rich clay (Jacobs et al., 1993; Jacobs et al., 2010b).

Quarternary sediments

The Quaternary sediments in the Waasland polder area were all deposited in a dynamic environment. This implies a lot of lateral variability.

In the central part of the study area Late Glacial and Holocene deposits lie directly on top of the Tertiary formations. In the eastern and western part a sandy deposit forms the transition between the Tertiary and Quaternary (Holocene) deposits. The sand was deposited by a braided river system in the Mid Weichsel (ca. 30 000 years ago) in a periglacial environment (Adams et al., 2002; De Moor and van de Velde, 1995; Bogemans, 1997) (Figure 3M3). Due to the cold and windy climate during the Late Glacial the vegetation cover was limited, creating a surface extremely vulnerable to wind erosion (Verbruggen et al., 1991) and a thin layer of sandy deposits covered the entire study area. Furthermore, sand dunes were formed due to these aeolian processes, the largest being the sand-ridge Maldegem-Stekene, of which the eastern end reached into the study area. The braided river systems were only seasonally active, and locally river dunes and cover sand ridges were created (Kiden, 2006). At the end of the Late Glacial (ca. 13.000 years ago) temperatures started to rise and the braided Scheldt river transformed into a meandering river and depending on the location fine sand, silty clay and clay were deposited (Bogemans, 1997) (De Moor and van de Velde, 1995).

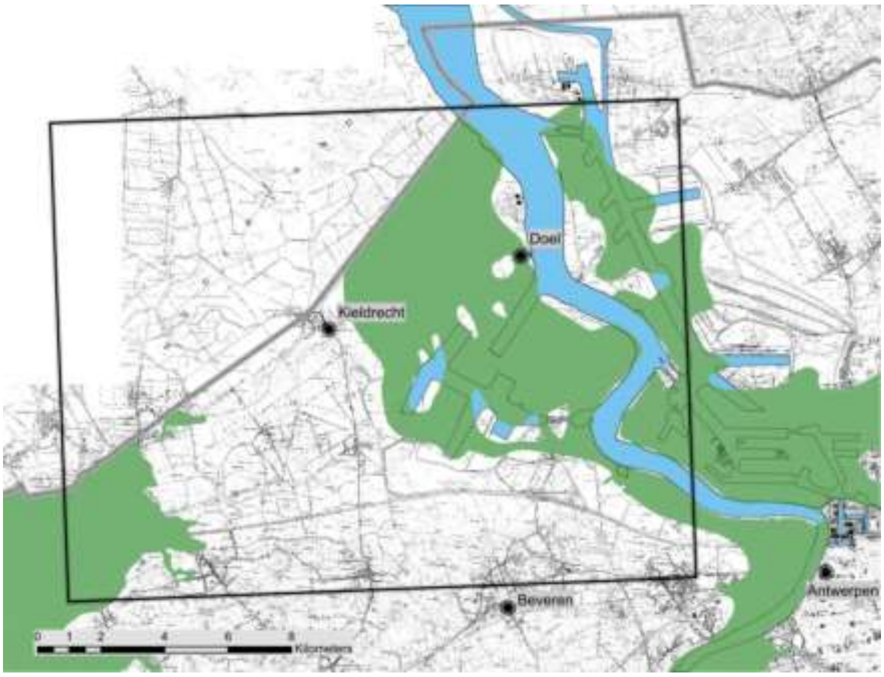

Figure 3M3: Presence of the Mid Weichsel braided river deposit in the Scheldt polders (Bogemans, 2005). The black box indicates the extent of the study area. The grey line indicates the Dutch-Belgian border.

The Holocene sediments consist of peat, marine and estuarine deposits. Most of the peat was deposited in a marsh environment along the river Scheldt estuary. The peat marshes were groundwater fed and the level of the groundwater table was most likely determined by the height of the mean sea level at that time (Kiden, 2006; van de Plassche, 1982). However, peat was also growing in higher locations. These peat fens were probably also groundwater fed, due to the bad drainage of the Pleistocene surface (van de Plassche, 1982). Locally the peat sequence is intercalated by marine deposits related to a marine transgression in de Mid Holocene (Vos and van Heeringen, 1997); in some places this marine incursion eroded the peat. It consists of mainly grey to almost black clay, often with peat fragments. The overlying estuarine deposits consist of sand and clay often with remains of organic matter or marine shell fragments. These sediments were deposited in a dynamic tidal flat environment with salt marshes, mud flats and creeks. Consequently there is a lot of lateral variability within this deposit.

During the Holocene the river Scheldt flowed northward through the present-day Eastern Scheldt. The Western Scheldt came into being when during the Middle Ages (ca. between 800 and 1000 AD) the tidal channel *Honte* expanded further landward and became connected to the Scheldt river just north of Antwerpen (Vos and van Heeringen, 1997). However for centuries after this the Eastern Scheldt still remained the main outlet of the river Scheldt to the sea; the Western Scheldt being only navigable at high tide due to the presence of a large sand bar between Saeftinghe and Bath.

For more information about the local geology and the geological history of the Scheldt polders we refer to the report “Holocene palaeogeographical evolution of the Waasland Scheldepolders” by Heirman, Missiaen & Vos (2013).

3M.1.2 Summary of the Archaeology and History of the Study Area

During harbour construction works at the *Verrebroek* and *Deurganck docks*, the late Pleistocene landscape proved to be well-preserved under the more recent deposits. On the tops and flanks of (micro) sand ridges, numerous traces of prehistoric archaeological sites, dating as far back as the Final Paleolithic and Early Mesolithic , were found. (Crombé, 2005). Mesolithic/Neolithic traces have been found at three well-preserved settlements (Crombé et al., 2009; Sergant et al., 2006; Crombé, 2005). These sites have been attributed to the Swifterbant culture (Crombé et al., 2011), during which an adaption from a hunter-fisher-gatherer economy to an extended broad spectrum economy, involving cattle-breeding and small-scale agriculture, took place. So far no direct archaeological proof of human activity was found that dates from the Middle Neolithic to the Middle Ages, when the area was a large peat marsh, but archaeological records from nearby locations in the Netherlands suggest that occupation took place even in these wet situations (De Clercq, 2009).

History of the study area since the late Middle Ages

During the late Middle Ages large-scale flooding (partly due to embankment tactics) shifted the local current pattern of the river and the Western Scheldt now became the main outlet, whereas the Eastern Scheldt slowly started to silt up (Soens, 2013). Still the Western Scheldt was probably not deep and wide enough to allow the navigation of large ships until the early sixteenth century.

Landscape development of the Waasland polder area became more and more intertwined with human activity. Large-scale inundations caused the need for (re-)embankments, which were often carried out by mighty abbeys. The embankment history between the thirteenth and sixteenth century is tightly intertwined with large-scale peat extractions. Indeed population growth and economic welfare had resulted in an increasing demand for fuel (in the form of dried peat or *turf*). Large centers of peat exploitation were set up (e.g. in Kieldrecht, Verrebroek and Meerdonk) (Augustyn, 1985; Augustyn, 1999), and ditches and roads were built to transport the peat.

During the early peat extractions (12th-13th C) so called *moerdijken* (‘peat dikes’) were constructed for peat transport. This gradually changed in the 14th and 15th C when (larger) dikes were primarily built for flood defense (Van Gerven, 1977). The embankment activities resulted in an almost entirely embanked situation of the Waasland area by 1570. During the subsequent Eighty Years’ War however the dykes of Saeftinghe were breached and the entire area was inundated (De Kraker, 2002; Guns, 2008), resulting in a large tidal marsh (Figure 3M4). This inundation was facilitated by the lowered surface of the former embanked areas due to peat extraction, drainage and soil compaction.

Figure 3M4: The church of Verrebroek in 1602, arising in the inundated area (Algemeen Rijksarchief Brussel, ARA in the following, Arenberg, LA n° 4413) (for location see Figure 3M1).

In the following centuries the Waasland area was gradually re-embanked (also made possible by the more stable (political) situation after the end of the end of the Eighty Years' War). One particular family, the Arenberg family, played a crucial role in this. At first only as land owner, later also as embanker and finally as direct exploiter. The main focus of these new embankments, often performed from large exploitation centers (such as the Prosperhoeve, Figure 3M5), was on agriculture since the peat was now covered by a (thick) layer of tidal sediments resulting from the inundation.

Figure 3M5: The Prosperhoeve in Prosperpolder, second half nineteenth century (www.inventaris.onroerenderfgoed.be (02/01/2014))(for location see Figure 3M1).

For more information about the recent (late and post-Medieval) history of the Scheldt polders we refer to the report "Recent landscape evolution of the Waasland Scheldepolders based on historical maps" by Jongepier, Missiaen & Soens (2013).

3M.1.3 History of Mapmaking in the Waasland polder Area and Surroundings

Coastal Flanders has known an exceptionally large map production, often (but not solely) linked to the numerous embankment enterprises. References to land surveyors in Flanders can be found as early as 1190 (Janssens, 2006), and the oldest cartographical products date from the 14th C (Augustyn, 1999; Gottschalk, 1955-1958). Also the Waasland area had an early tradition of land surveying, as documented by trial documents from 1469 concerning the measuring and selling of tidal marsh and peat lands by Duke Filips the Good (Rijksarchief Beveren, P13, n°1).

Over the next centuries the number of land surveyors grew, but still could not keep up with the large demand for measurements and maps (often related to embankment practices). This is not surprising in the light of the large embankment works in the area that required a great number of detailed maps (e.g. Figure 3M6), which were mostly obliged in the embankment licenses.

The combination of the rapid development of mapping techniques (De Maeyer et al., 2004), the need for measurements for new embankments and the certified quality of land surveyors resulted in a large number of maps for the Waasland area. Luckily, numerous maps have been preserved. It is perhaps important to note that the most interesting maps are often not to be found in open access internet databases but in (local) archives, for instance the (State) Archives in Brussels, Ghent, Beveren and Middelburg. Many of these maps were ordered by (or linked to) the Arenberg family since they took part in numerous embankments.

Figure 3M6: Example of an embankment map of the Nieuw-Arenbergpolder (1783, ARA, Kaarten & Plans, n° 8573)(for location see Figure 3M1).

For more information about the late and post-Medieval map production of coastal Flanders and the Scheldt polders we refer to the report “Development of a uniform methodology for evaluating historical maps and their use for coastal research” by Jongepier, & Missiaen (2013).

3M.2 Current Environmental Impacts/ Threats and Coastal Management Approach

Most of the Waasland polder is under imminent threat of harbour extension, since it is located near to the Antwerp harbour. In 2013 the Flemish government approved a new plan for the extension of the harbour zone, which comprises the construction of a large dockyard (Saeftinghedok) at the location of Doel-town, stretching through the Doelpolder up to the

Nieuw-Arenbergpolder. Surrounding the dockyard an industry zone is to be constructed. As a compensation for this industrial expansion part of the Doelpolder area is to be converted into a nature compensation zone (some parts have already been converted), including the expropriation of most inhabitants. Recently however the Council of state (Raad van State) has demanded a temporarily suspension of these plans, asking for revisions. In the meanwhile, almost the entire village of Doel-town is already deserted.

In the north of the study area, plans have been approved by the Flemish and Dutch governments to de-embank the Hedwigepolder and part of the Prosperpolder, thus creating one large intertidal area that will join the exiting Drowned Land of Saeftinghe (Figure 3M7). Extending this tidal marsh will create important new (water) storage capacity, which will help to minimize inundation risks in the Western Scheldt estuary.

Figure 3M7: Schematic of the Hedwige- and Prosperpolder before (top) and after (bottom) the de-embankment plans (http://www.hedwigeprosper.be (18/09/2014)).

3M.3 Archaeological and Palaeoenvironmental Fieldwork

3M.3.1 Key research questions in relation to coastal change to be addressed via fieldwork

Buried palaeolandscape reconstruction is conventionally based on detailed in-situ information such as sediment cores and (archaeological) augerings. These techniques however are very time consuming, and therefore often expensive. Furthermore they are not always easy to perform in coastal or estuarine sites that include intertidal marsh and subtital areas, especially where the landscape is buried relatively deep (more than a few metres). The fieldwork presented here focuses on the application of other geotechnical techniques (cone penetration testing) and geophysical techniques (land and marine seismics) for geoarchaeological & palaeogeographical research and coastal change studies. How efficient are these techniques to obtain reliable field data, in a less time consuming way than the conventional methods?

3M.3.2 Field Data Gathering Methods

Cone Penetration Testing (CPT)

Cone Penetration Testing is a geotechnical method to sound the composition of the subsurface. The method allows us to obtain information regarding the geology (nature and sequence of the subsurface strata) and hydrology (groundwater conditions) as well as the physical and mechanical properties of the subsurface strata (Lunne et al., 1997; Robertson and Cabal, 2012). The CPT method allows fast and continuous profiling of the subsurface with repeatable (and reliable) data, and is highly economical (Lunne et al., 1997).

In Cone Penetration Tests (CPT) a cone is pushed into the ground at a constant rate while continuous measurements are made of the cone resistance (i.e. resistance of the cone tip to penetration) and the sleeve friction (i.e. resistance of the sleeve) (Figure 3M8). The ratio of sleeve friction divided by cone resistance, called the friction ratio, is used to classify the soil.

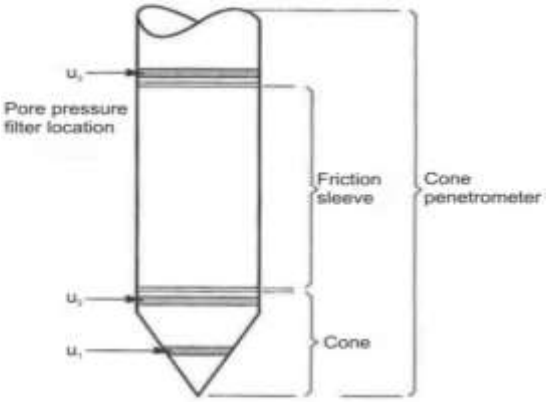

Figure 3M8: Terminology for cone penetrometers (from Lunne et al, 1997).

Additional sensors may be added to the cone. For instance in piezocone penetrometer tests (CPT-U) also the in-situ pore pressure u is recorded with depth (Figure 3M8). The latter may give valuable added information regarding the permeability of the subsoil sediments. Resistivity penetrometers (R-CPT) additionally measure the electrical conductivity of the soil with depth which may give valuable information regarding the lithology. Seismic penetrometer tests (S-CPT) combine CPT sounding with downhole velocity measurements using geophones installed into the cone rod. The velocity data will give more information regarding the soil.

For the case study, various CPT measurements were carried out in Doelpolder-Noord (DPN) (CPT, CPT-U, R-CPT, S-CPT). An overview is given in Figure 3M9. Measurements in the polder were carried out using a common CPT truck (Figure 3M10, left). This was not possible in the marsh, due to the limited accessibility and uneven terrain, and therefore an adapted mobile CPT rig was used. Moving the vehicle on the marsh proved very risky: due to a hidden gully the vehicle toppled over and had to be hauled out using a big crane (Figure 3M10, right).

For the seismic CPT measurements a heavy plate and sledge hammer were used to generate the seismic waves (Figure 3M10, left). Measurements were carried out at depth intervals of 0.5 - 1m. At each depth between 4 and 8 different hammer blows were done for each direction and these were stacked in order to improve the signal-to-noise ratio.

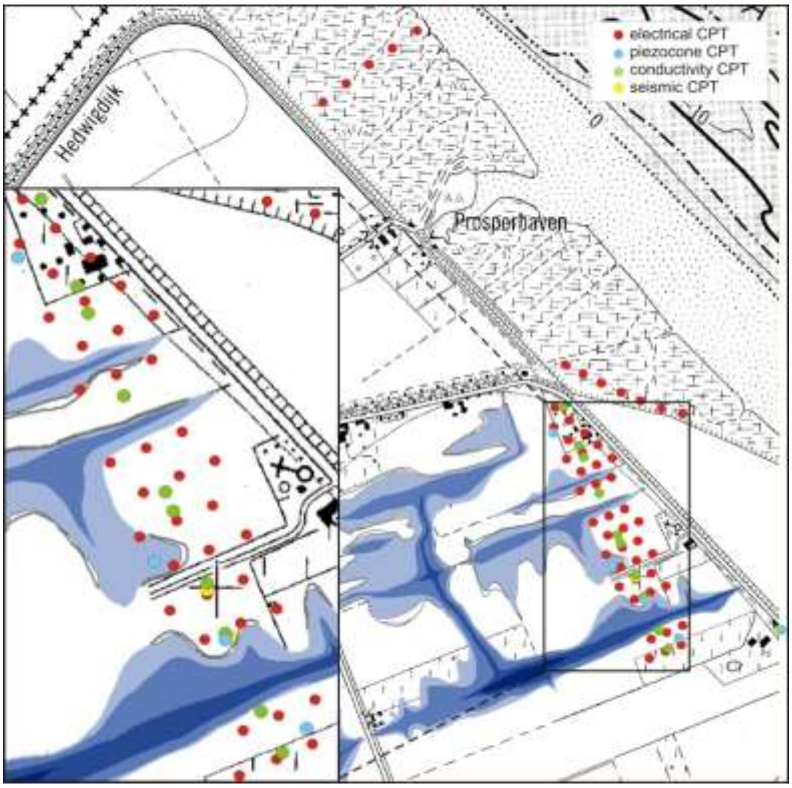

Figure 3M9: Overview of CPT measurements in Doelpolder-Noord. Different colours refer to various types CPT measurements.

Figure 3M10: Left – CPT truck used for CPT measurements in the polder. A hammer blow is used to generate seismic waves. Right - Mobile CPT rig used for CPT measurements on the marsh. Due to a hidden gully the rig toppled over and had to be hauled out by a crane.

Land seismic investigations

Reflection seismic investigations on land involve the use of a controlled seismic source and an array of receivers (geophones). The generated seismic pulse travels through the sediments and will be reflected at the interfaces between two materials with different densities. The reflected waves create an image of the subsurface. This image, or model, is not unique (more than one model adequately fits the data, typical for inverse problems) and therefore great care must be taken in data processing and interpretation.

Apart from the common compressional (P-) waves also shear (S-) waves can be generated on land. S-waves have lower velocities than P-waves and therefore shorter wavelengths which should allow an increase in resolution compared to P-waves. However S-waves also often exhibit lower frequencies than P-waves which may partly cancel the increase in resolution.

For the tests at Doelpolder-Noord a sledge hammer and a seismic vibrator system were used to generate the seismic waves (Figure 3M11). Both of these sources have shown good results in resolving the shallow subsurface layering at Saeftinghe (Missiaen et al. 2008). Because the terrain was relatively flat in the polder recording was done here using a land streamer containing 24 geophones spaced 1 meter apart. A reflection seismic profile of roughly 300 m was recorded in the central part of the study zone. Ground-truth of the seismic data was provided by three deep (mechanical) corings and various CPT located closeby.

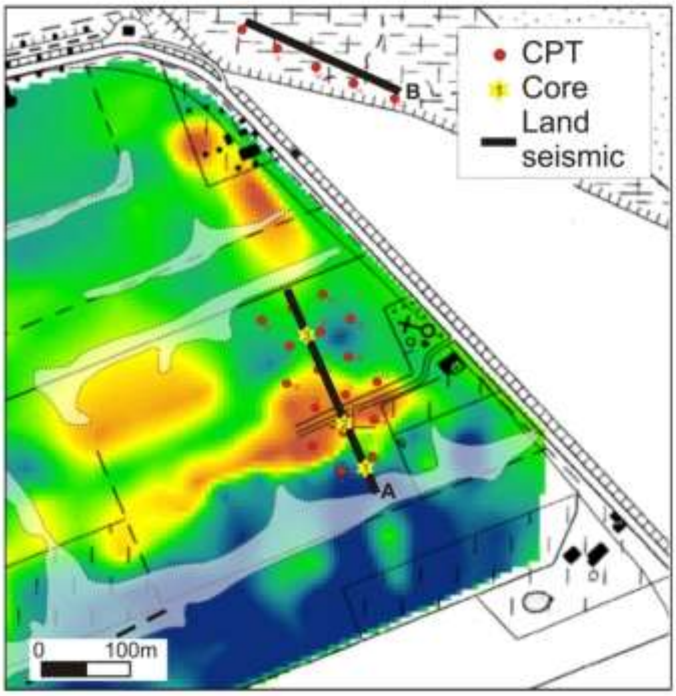

Figure 3M11: Location of the two land seismic lines recorded at Doelpolder-Noord. The deep core locations are marked by the yellow stars. Red dots indicate electrical CPTs.

On the tidal marsh (so-called ‘Paardenschor’) the use of the land steamer was not possible due to the uneven terrain and the amount of vegetation, and instead an array of 48 hand geophones was used. Unfortunately it was not possible to perform any mechanical coring on the marsh. Ground-truth was therefore only provided by a number of CPTs located along the seismic profile.

Marine seismic investigations

As on land, reflection seismic measurements at sea involve the use of a sound source, towed behind a vessel or mounted to the hull, to generate acoustic waves that travel through the soil. Part of the acoustic signal is reflected from the seafloor but the remainder penetrates the seafloor and is reflected when it encounters boundaries between layers with different elastic properties (Figure 3M12). The recorded reflected acoustic waves result in a continuous record of the sub-seafloor stratigraphy.

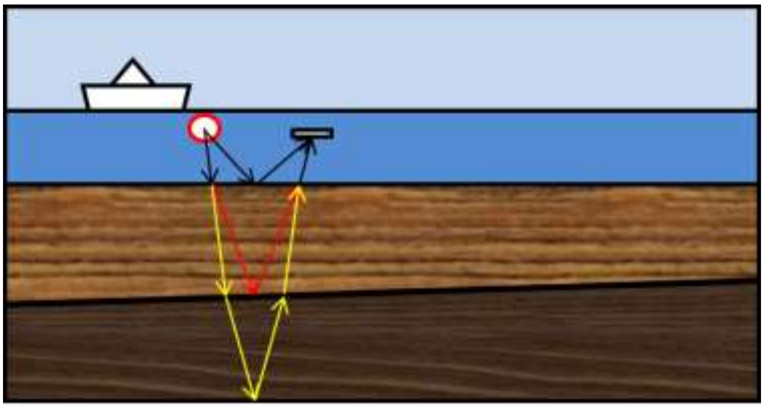

Figure 3M12: Marine seismic reflection principle.

Marine seismic measurements were carried out on the Scheldt river (subtidal and intertidal part, Figure 3M13, left) and on the inland creeks. For all surveys a parametric echosounder was used. A motion sensor was used to correct for the swell caused by wave movement. Positioning involved a DGPS antenna with an accuracy of ca. 1m. For the inland creeks a small inflatable boat was used that could be transported over land (Figure 3M13, right).

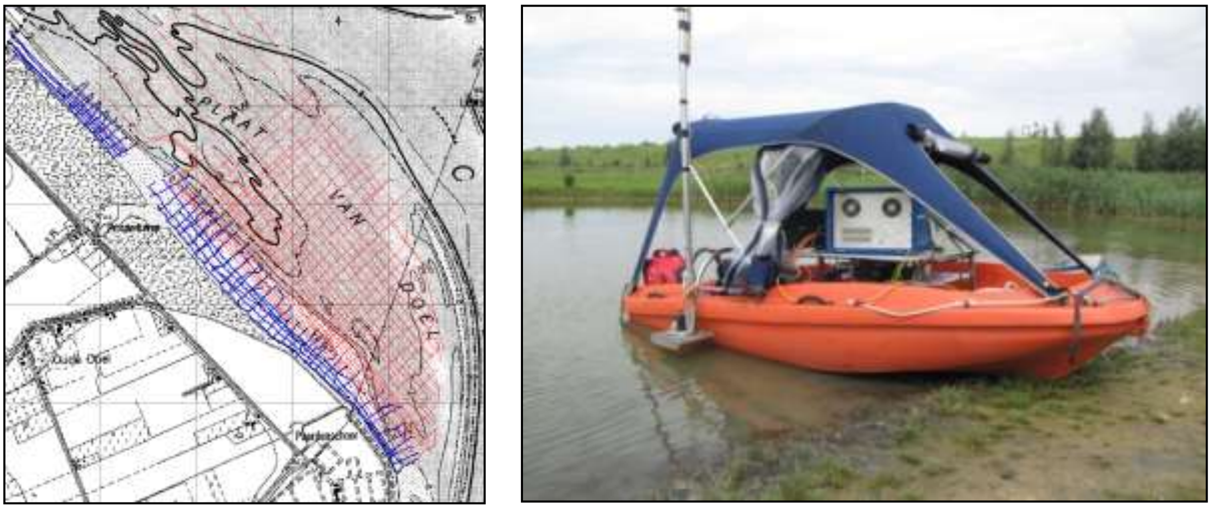

Figure 3M13: Left – seismic network on the Scheldt river (blue: intertidal; red: subtidal). Right – boat used for measurements on the inland creeks of Doelpolder-Noord.

3M.4 Field Data Analysis and Results

3M.4.1 Cone penetration test measurements (CPT)

An important focus of CPT interpretation was the identification of peat layers, since these play a major role in palaeogeographical and archaeological mapping. At Doelpolder Noord the peat sequence stood out well on the data; locally two distinct peat layers were even observed. The CPT data also allowed to differentiate between peat and intercalating organic-rich clay or sand layers (Figure 3M14). The transition from peat to the underlying (aeolian) sand deposits was generally very sharp and clear. Unfortunately the CPT data did not always allow us to distinguish between the intercalating (sand and clay) estuarine deposits.

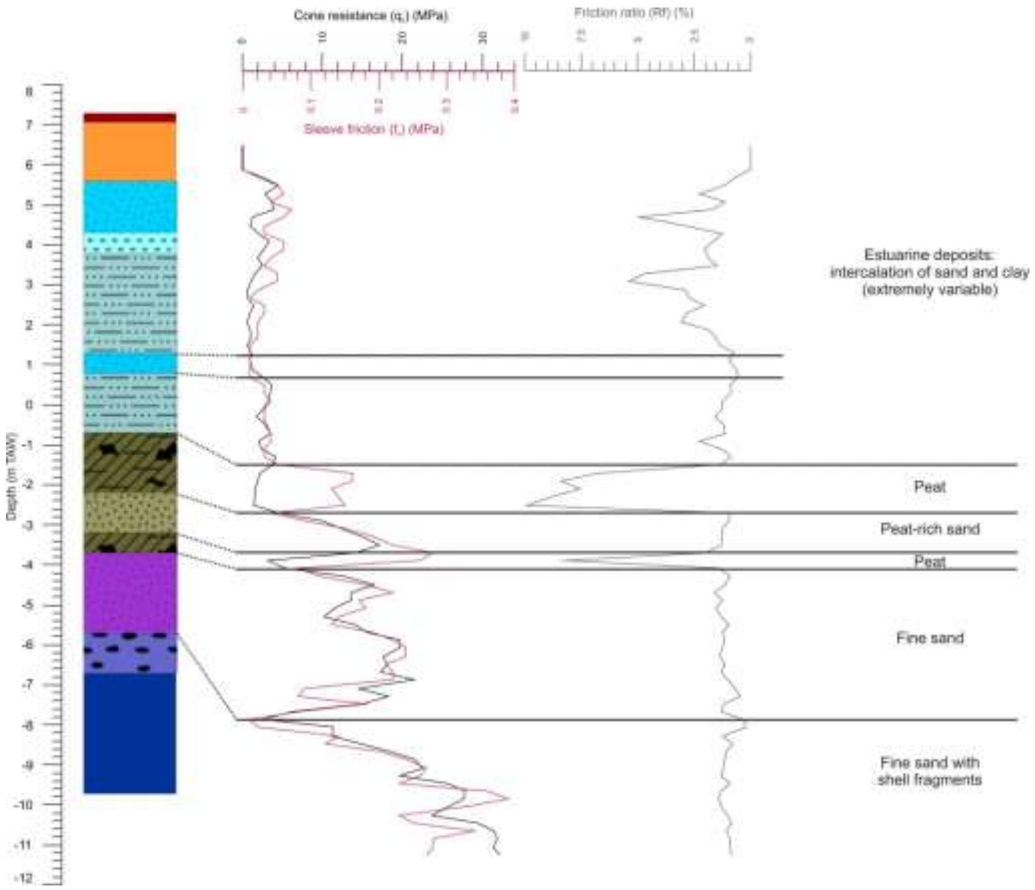

Figure 3M14: Comparison of a sediment core litholog (left) and nearby electric CPT measurement (middle and right) in Doelpolder-Noord.

It was hoped that the pore pressure and conductivity data from the CPT-U and R-CPT measurements would add valuable new information on the subsoil. However, this proved not to be the case. The seismic CPT measurements were more successful. Based on the arrival times of the seismic waves (recorded by the different geophones in the cone rod) the S-wave velocity through the subsoil could be calculated. The results fully confirm the local lithology as inferred from the CPT data (Figure 3M15), as the presence of a peat layer correlates exactly with a sharp velocity drop.

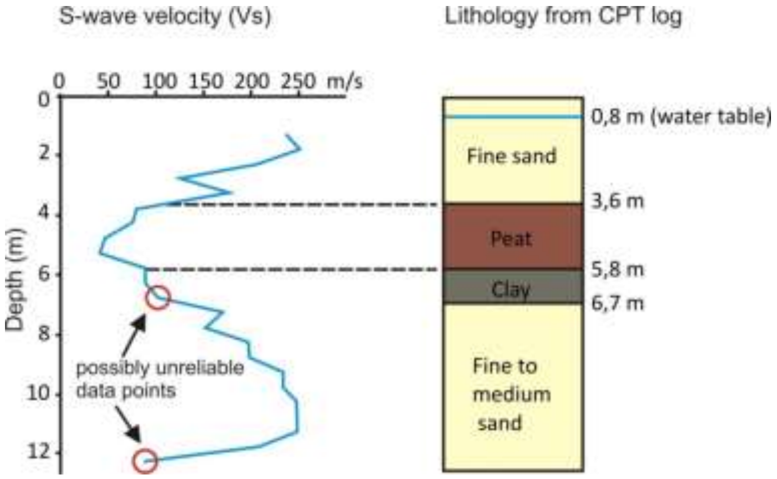

Figure 3M15: Shear wave velocities calculated from the arrival times in the seismograms (left) and corresponding lithology. The red circles are possibly erroneous data due to noise preventing accurate picking of the signal.

3M.4.2 Land seismic investigations

Interpretation and correlation of the land seismic data was only possible after extensive data processing. Important steps in the processing included a.o. the muting of surface (Love) waves, the creation of a velocity model, bandpass frequency filtering, stacking of the data and time (ms) to depth (m) conversion.

The resulting data from the polder profile shows a dome-like structure (Figure 3M16). The structure fully confirms the palaeotopography. Correlation of the seismic data with nearby deep cores (Figure 3M16, top) was not easy in view of the limited length of the cores (~ 13 m) compared to the depth of the seismic section (~ 50m) but the transition from sand to peat deposits seems to correlate well with a prominent shallow reflector.

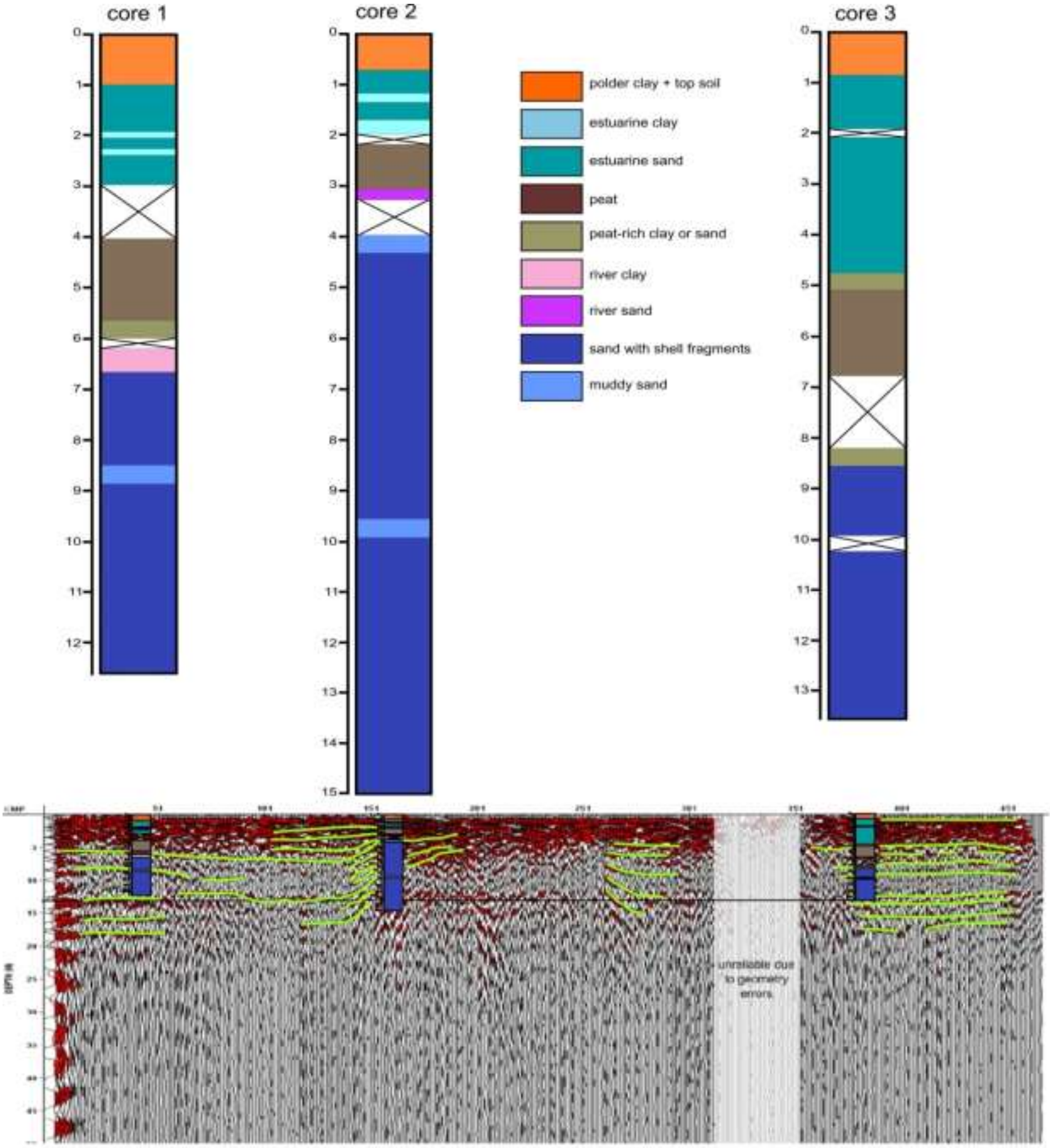

Figure 3M16: Correlation of land seismic data in Doelpolder-Noord (bottom) with nearby deep cores (top).

The seismic data obtained in the marsh proved to be more complicated. It was expected that the shallow water table at the marsh would allow a good resolution of the shallow deposits, but this was not the case. This was most likely due to the extremely weak top sediments in the marsh (upper 5-6 m), and resulting insufficient coupling between the source/geophones and the ground. As a result the image quality in the upper 20 meters was extremely low and no comparison with CPT data was possible.

3M.4.3 Marine seismic investigations

The marine seismic data obtained on the river Scheldt were highly affected by the abundant presence of (biogenic) gas in the shallow subbottom sediments. As a result the data quality was often very poor with a limited seismic penetration (often less than 1 meter). This was also the case for the data obtained on the inland creeks. The best penetration was obtained in the extreme southeastern corner of the Scheldt network and in the northern part of the intertidal area. Here a number of shallow reflectors and palaeochannels (indicating ancient tidal gullies) could be observed (Figure 3M17). However due to their extremely patchy pattern the spatial continuation of the observed seismic reflectors (including possible peat layers) was highly uncertain, and a reliable correlation with the CPT or core data nearby on land was not possible.

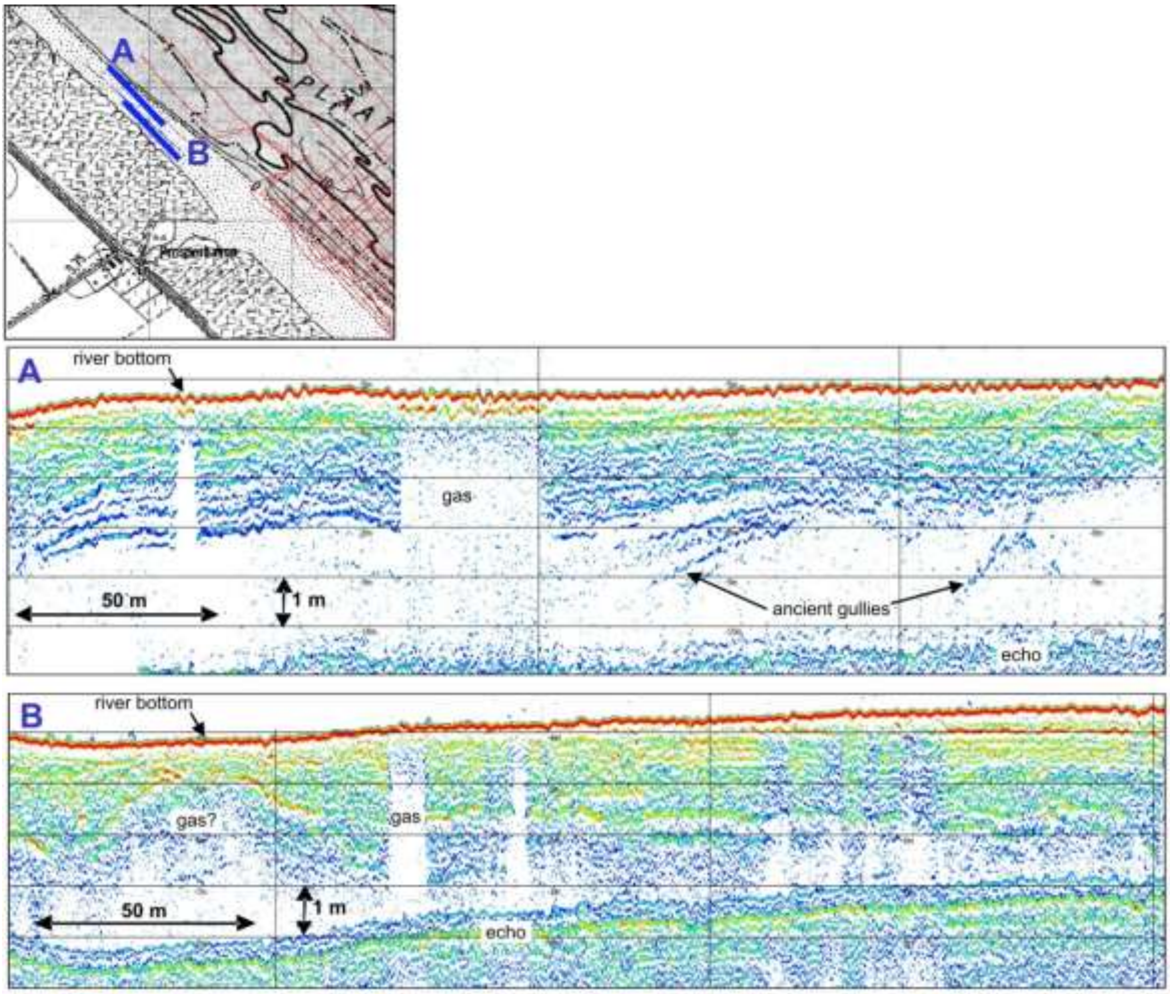

Figure 3M17: Examples of two seismic profiles in the intertidal area. A large number of (sub-) parallel reflectors can be observed in the upper meters. Below this ancient tidal gullies show up. Further offshore the gassy patches become increasingly prominent. The location of the profiles is shown in the top left.

3M.4.4 Comparison of the usefulness of the different methods

Comparison of the three geotechnical/geophysical methods (CPT, land seismic, marine seismic) shows that by far the CPT technique seems to be the most applicable and efficient method for geoarchaeological research and palaeoenvironmental reconstruction.

Land seismic investigations in estuarine and polder areas are time consuming and do not give the high resolution that is needed. Furthermore the results are highly dependent on the type of subsoil, and soft top layers such as those frequently encountered in marshy areas, will seriously decrease the data quality. Marine seismic investigations in estuarine environments seem a good alternative because this method is very quick (a close profile network can be recorded in 1-2 days) and provides very high resolution images of the sub-seafloor, also in intertidal areas. However on the Scheldt river this method was highly affected by the presence of shallow gas (likely due to a combination of thick organic-rich top layer and peat deposits in the subsoil). As a result no continuation of the geological (peat) layers below the river bottom could be obtained.

CPT measurements allow fast profiling of the soil stratigraphy, much quicker than the collection of sediment cores. Especially when peat is present, the depth measurements of the sediment layers will also be more correct as peat deposits have a tendency to compress/expand during/after coring. Nevertheless CPT data should always be ground-truthed with sufficient sediment samples from a nearby location, and the interpreter should have a good knowledge of the local geology and the geotechnical technique. Piezometric CPT (CPT-U) and resistivity CPT (R-CPT) do not seem to add a lot of significant detail compared to regular electric CPT. Seismic CPT provides valuable information on the layer velocities but it is a time consuming method, and should therefore only be applied when this information is actually required.

3M.5 The use of Historical Maps for (post-) Medieval Landscape Reconstruction

3M.5.1 Introduction

For more recent (medieval and post-medieval) landscape reconstructions, historical maps provide an important source of information. In order to use these maps for coastal research they have to be *georeferenced* (fitting the historical map on the present day situation) and *digitized* in a GIS (Geographical Information System). However, the quality and detail may vary widely between different maps, and simply using them with the assumption that they depict an accurate image of the former (coastal) situation would probably induce large mistakes in the coastal reconstruction.

Digitalization of the maps involved the following steps (using *ArcGIS 9*.3):

- Creation of shapefiles in ArcCATALOG. Three types of data are available: points (useful for villages), lines (useful for dikes) and polygons (useful for the tidal area and embankments). Fields can be added, for instance to store the data on geometric accuracy. The coordinate system should be set to the same as the base maps.
- Adding the shapefiles to ArcMAP.
- Digitalization of all relevant items. In this case each feature of the tidal marsh and the surrounding embankments was digitalized as a polygon. In the attribute table, data on the historical map used for this particular feature is stored.
- Layout of the maps, and exportation as figures.

In order to analyse the map quality a “ranking methodology” was developed (see Section 2). The following sections focus on the overall results of the ranking of maps from the Waasland Scheldepolder area. For detailed ranking outcome of individual maps we refer to the Arch Manche portal www.archmanche-geoportal.eu. The analysed maps were chosen out of a database of around 300 historical maps, found in the (State) Archives of Brussels, Ghent, Beveren and Middelburg.

3M.5.2 Ranking Results and Discussion of Historical Maps

The *topographical accuracy* of the maps varied widely (Figure 3M18) but many proved to be rich in detail. The factors that seemed most determining for this accuracy are the scale and the purpose of the map. Small-scale supraregional maps provided very schematic depictions of the tidal area, while large-scale maps showed subdivisions of higher/lower tidal marsh (sometimes even containing measurements of their size) and detailed depictions of the tidal channels. Some maps were especially made to depict the outer dike area for future embankments; these maps proved to be the most accurate and useful maps in our selection.

Figure 3M18: Topographical details in various historical maps (ARA, Kaarten & Plans, n° 176; ARA, Kaarten & Plans, n° 441; ARA, Arenberg, n° 842).

The *geometric accuracy* also varied widely between supraregional (small-scale), regional (medium-scale) and local scale (large-scale) maps.

- Supraregional maps have the lowest accuracy. Mean positional errors (MPE) varied between 500 and 1600 meters. Although positional errors could be reduced by focusing on parts of the map, their use for detailed coastal evolution reconstruction remains restricted. Nevertheless they contain a lot of information regarding more general aspects of the Scheldt estuary.
- Regional maps proved to be far more accurate and became more and more accurate over time although a large variation is also noticeable here.
- Local maps proved to be ideal for coastal research. Not only did they provide enough topographical details (especially when the maps were related to embankment activities), but they also showed a high geometric accuracy with mean positional errors of less than 50 meters (in some cases down to 20 meters).

Variation in positional errors also occurs within maps: an interesting observation is that the purpose of a map often also defines which parts of the map are more reliable. For instance the map depicted below (Figure 3M19) (copied by Coeck in 1664) showing the military frontier zone between the northern and southern Low Countries is marked by a higher MPE for the military installations (e.g. forts) (black circles) than for places further away from the frontier zone (red circles).

Figure 3M19: Distortion grid and displacement circles for the map of Coeck (copy 1664).

Also the *chronometric accuracy* varied largely over the maps. The major reason for this variation is to be found in the fact that some maps had a detailed "cartouche" (Figure 3M20) describing the date of manufacturing or the date of the originals in case of a copy and other maps did not have this information. In addition, for some maps distances were noted on the map (pointing to a land survey) or the "cartouche" mentioned the actual land surveying undertaken before the map was produced. Especially for large-scale maps, the chronometric accuracy of the outer dike area could be contested, since tidal channel structures did not have a logical pattern (compared to other, more accurate maps) or seem to be simply copied from an earlier map. Therefore this chronological aspect should be regarded carefully when conducting further analysis.

Figure 3M20: part of a "cartouche" mentioning both measured surfaces as the exact date of manufacturing of a map of the Doelpolder (ARA, Arenberg, 842)

Total map ranks were plotted against manufacturing date of original maps (Figure 3M21). A general rise in score over time can be noticed, although a lot of variation around the trendline (R^2=0,6395) exists. Therefore, an older map is not necessarily less good then a more recent map.

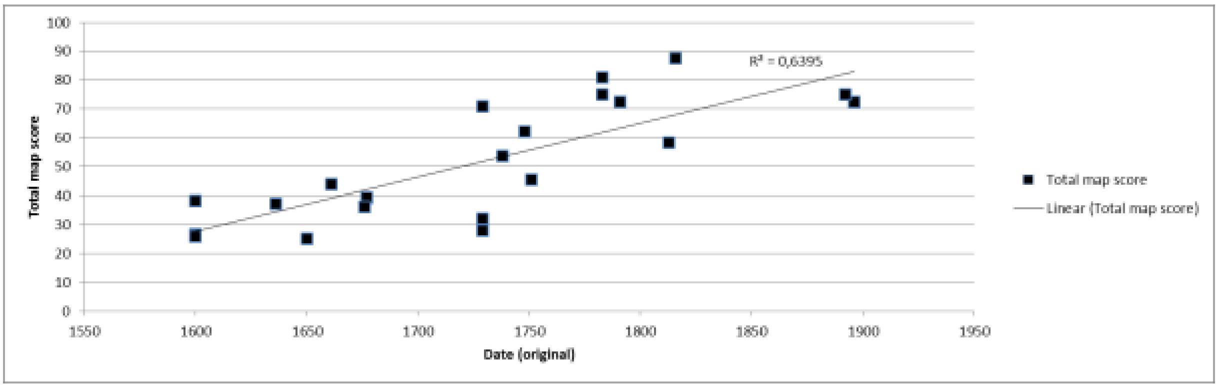

Figure 3M21: Total map rank according to manufacturing date of the original maps.

As an example of the possible effects of using lower ranking maps, Figure 3M22 compares the location of mapped tidal channels for a low- ranking and high- ranking maps, with the “true” location as given by the DHM. Clearly, the high ranking map depicts those channels far better. Note that the higher ranking map was made just prior to embankment (and therefore “fossilization” of the former tidal channel pattern, the other map was made 16 years earlier.

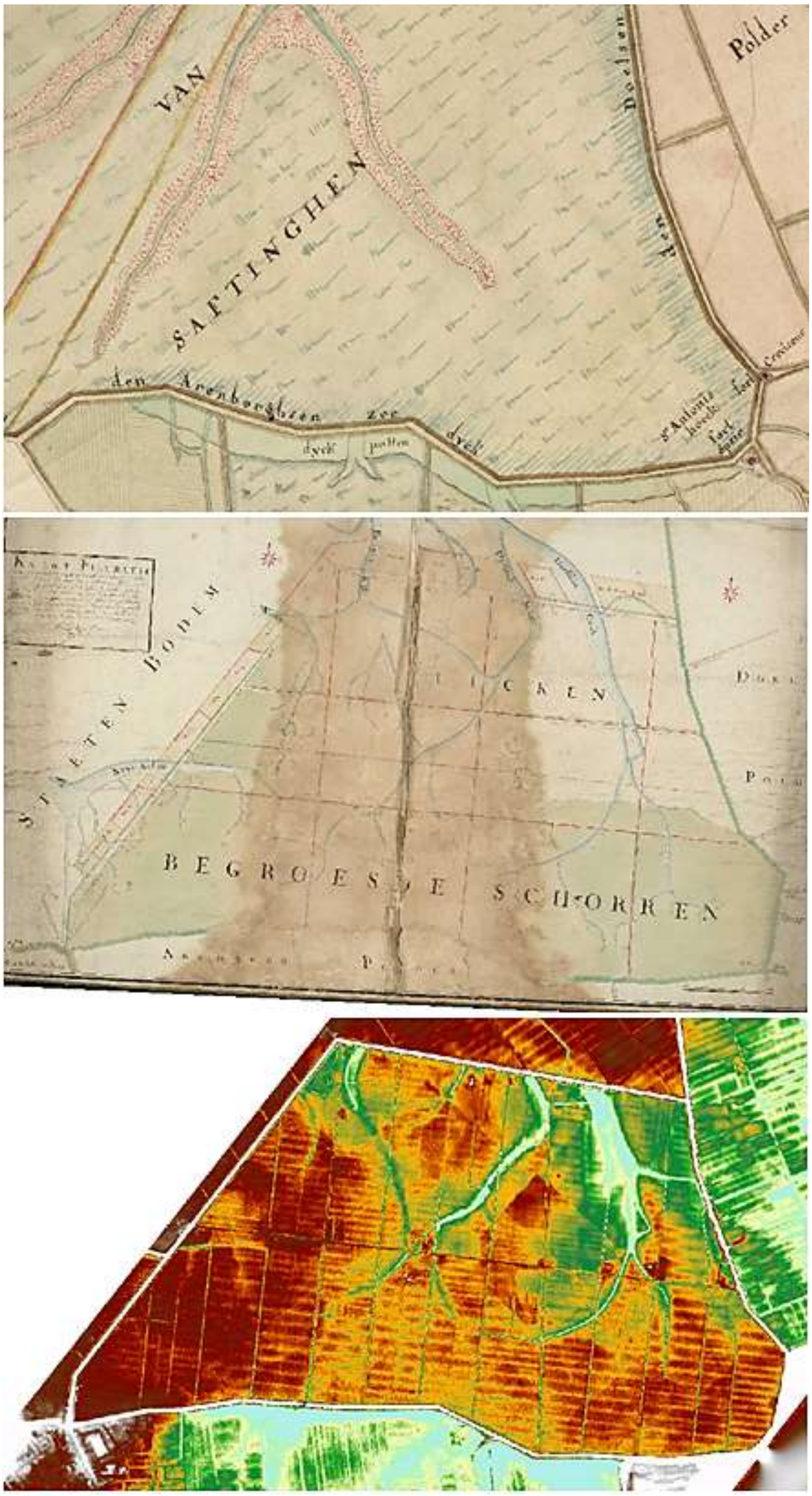

Figure 3M22: Comparison of a low ranking map (ARA, Kaarten & Plans, n° 410,1767, top) high ranking map (ARA, Kaarten & Plans II,8573,1783, middle) and actual former location of the tidal channels (DHM, right),

3M.6 Results – Palaeogeographical Landscape Reconstruction Based on Field Data and Historical Maps

This section is subdivided two parts: (1) palaeolandscape analysis and reconstruction for Holocene period (10000 BP - 1000AD), based on physical (in situ) data; and (2) recent post-medieval evolution of the palaolandscape, based on historical maps.

3M.6.1 Holocene Palaeogeographical Landscape Reconstruction Based on Physical In-situ Data (CPT, corings)

Methodology

The data obtained from the field studies (described in section 3M.4) only provided local information (restricted to Doelpolder-Noord), insufficient for a regional palaeogeographical study. Additional geological information was needed from existing data (sediment cores, archaeological augerings, CPT). The vast majority of these data was obtained from the subsurface database of the Flemish Government (Databank Ondergrond Vlaanderen, DOV). The Department of Archaeology of Ghent University provided all the geological information from augerings taken during archaeological site surveys in the area.

A major difficulty in the data integration proved to be the high diversity of the type and date (some over a 100 years old) of data, the diversity in data resolution and also the diversity of the observers (i.e. geologists, engineers, archaeologists). Consequently not only the quality of the data varied greatly, but also the interpretation of the geological data. Where possible the raw data and the original descriptions or measurements were studied and reinterpreted taking into account the current geological knowledge of the area. The total data set contained 6423 data points, of which 5783 reach the Pleistocene/Holocene boundary (Figure 3M23).

The first step in the reconstruction was the creation of an isohypse map of the top-Pleistocene relief using both geostatistical software and geological interpretation. More details on how this was done can be found in the report “Holocene palaeogeographical evolution of the Waaslad Scheldepolders” by Heirman, Missiaen & Vos (2013). In order to allow correct integration with Dutch palaeogeographical maps the NAP level was used instead of TAW.

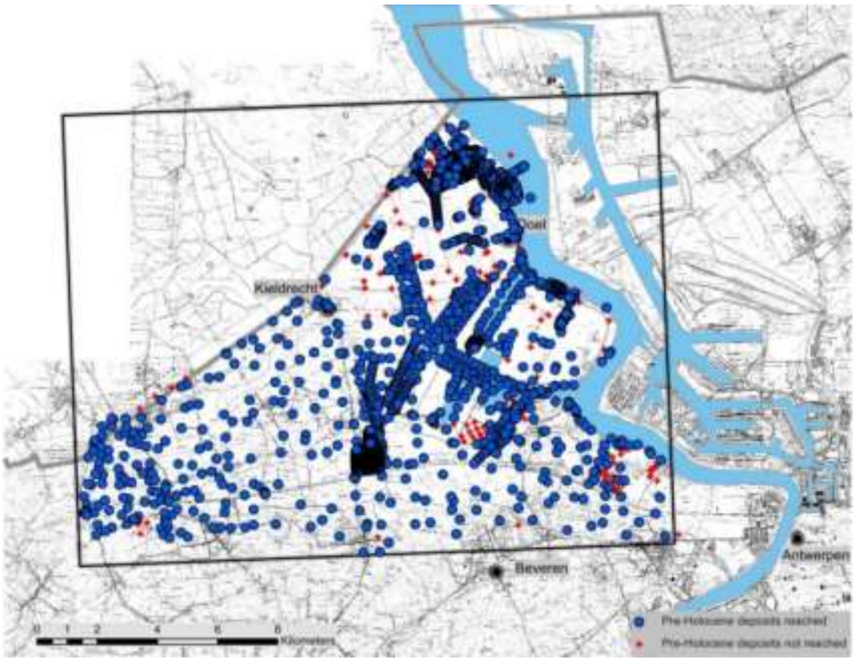

Figure 3M23: Location of data points used for the reconstruction (blue: data reaching the top of the Pleistocene; red: shallow data). The black box indicates the extent of the study area. The grey line indicates the border between Belgium and The Netherlands.

To obtain a timeframe for the reconstructions two additional sources of information were used: (1) a relative sea-level curve for the Netherlands (Kiden, 2006; van de Plassche, 1982; Hijma and Cohen, 2010; van de Plassche et al., 2010), and (2) a dated peat growth evolution model for the Waasland Scheldepolders (Verhegge at al., 2014). These finally provided an age for the altitude to which the marine influence was present or how the peat bogs expanded.

Palaeogeographical reconstructions

Early Holocene - 11000 yrs BP

At the beginning of the Holocene (ca.11000 yrs BP), sea level was still lower than -50 m. Low sea level and the disappearance of the permafrost enhanced the vertical erosion of the rivers (Mathys, 2009). Late Glacial/Early Holocene river channel erosion can be detected in the top-Pleistocene palaeotopography. Most likely only the channels deeper than -4 m NAP were active river channels, while the area between -2 and -4 m NAP might have flooded occasionally during heavy rainfall.

Early to middle Holocene – 7500-7000 yrs BP

In the early to middle Holocene (ca. 7500 – 7000 yrs BP), when temperatures kept on rising, a dense forest vegetation developed. Due to the dense vegetation, soil erosion and run off was reduced to a minimum. Consequently the river discharge lowered more and more. The late glacial alluvial planes dried out and were vegetated, only in the lowest gullies and valleys some water was present. In these areas peat started to grow (Kiden and Verbruggen, 2001). The Early Holocene landscape of the Waasland polder area consisted of a Scheldt river which was still a fresh water environment. In the deeper channels peatbogs started to develop (Figure 3M24, top left).

Middle Holocene – 7000-5000 yrs BP

During the middle Holocene (ca. 7000-5000 yrs BP) the sea reached its most inland position (Vos and van Heeringen, 1997). By 6000 yrs BP the fresh water Schelde had turned brackish south of the Dutch/Belgian border. The area changed into an extended tidal landscape with mud flats and salt marshes (Figure 3M24, top right). The limit of the marine ‘invasion’ in the area was determined using the occurrence of the Holocene marine deposits and the relative sea level determined from the van de Plassche et al. (2010) relative sea-level reconstruction. Most of the Early Holocene peat bogs drowned and were covered with an organic-rich marine clay. Peat bogs were still present, but they were confined to the transition zone between the tidal areas and the higher Pleistocene cover sands. The peat most likely grew in areas below -2 m NAP.

Middle and late Holocene – 5000-2500 yrs BP

During the middle to late Holocene (ca. 5000 – 2500 yrs BP) the relative sea-level rise seriously slowed down (Mathys, 2009) and this had a major effect on the lagunal environment in the area. Extensive peat expansion took place (Figure 3M24, bottom left). Over time the peat bogs most likely expanded slowly further to higher grounds. During the Late Holocene peat growth continued in the region (Figure 3M24, bottom right). Based on radiocarbon measurements on peat samples of the Waasland polder area, peat growth might have continued until at least 600 AD (1350 cal a BP) (Gelorini et al., 2006; Kiden, 1989; Van Strydonck, 2005).

The extent of the peat growth is much debated in Belgium. Jongepier et al. (2011) showed that the combination of geographical and historical data may provide an answer here. Indeed often the patterns of peat reclamations can still be identified (e.g. at Verrebroek) on the Digital Elevation Model or on aerial pictures. The low sampling resolution of cores is likely the main reason why thin peat layers that were generally left behind during the exploitation are missed out.

Early middle ages – 1000 yrs AD

It is generally assumed that man started to construct dikes in the Waasland Scheldepolders in the 10th or 11th century (Guns, 2008). It is however unclear what the landscape looked like prior to the man-induced landscape changes. The thin peaty clay cap which is sometimes found on top of the peat was dated to the 10th-11th century based on archaeological findings (Crombé et al., 2005) and the presence of cereals' pollen (Gelorini et al., 2006).

Until the Early Middle Ages the landscape must have looked similar to the landscape of the previous reconstruction, except for some tidal flats and salt marshes close to the river Scheldt. It had already been stated in the past that in the Early Middle Ages the Waasland polder area consisted of a very swampy landscape with some small sand ridges with small pools in between in the Early Middle Ages (Augustyn, 1977). This could well be a correct description.

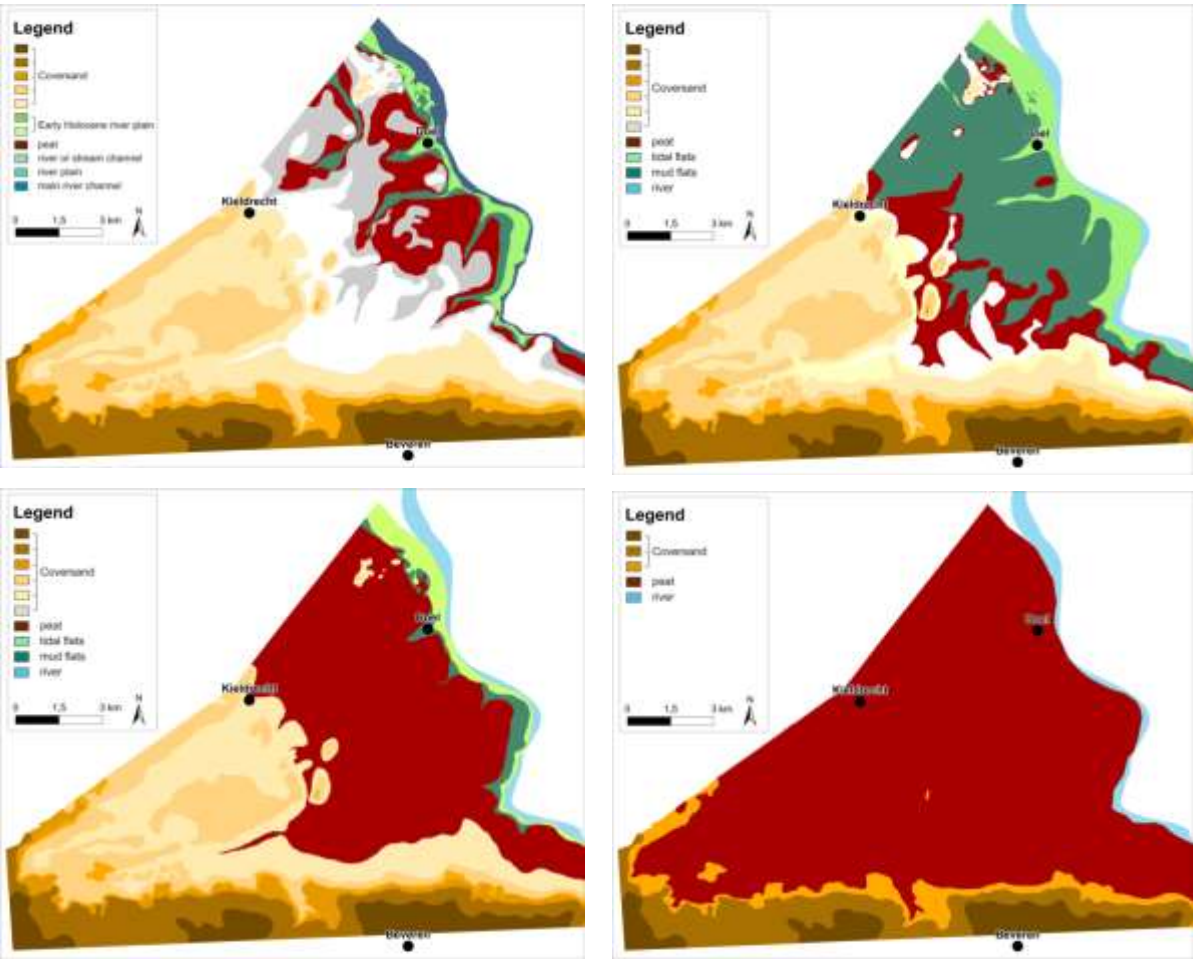

Figure 3M24: Palaeogeographical maps of the Waasland Scheldepolders around 7500 BP (top left), 6500 BP (top right), 3500 BP (bottom left), 2500 BP (bottom right).

3M.6.2 Post-Medieval Palaeolandscape Reconstruction Based on Historical Maps

Methodology

Based on historical maps, landscape reconstructions for certain time periods (depending on the availability of the maps) were made. For the Waasland Scheldepolders test-case five time sections were selected (1570, 1625, 1700, 1790 and 1850) that represent major landscape changes. The maps were selected based on their ranking results and an inherent additional criterion: the date of manufacturing should be as close to the chosen time frame as possible, in case of analysis based on multiple maps per time section. This implies a crucial role of qualitative interpretation, since a trade-off of the above mentioned factors should be made in order to acquire the best possible reconstruction. It also implies it is not always possible to use the most accurate map available.

Each time section was based on multiple historical maps, making it necessary to conduct a few interpolations, in order to “match” the different maps into one continuous reconstruction. In the following sections the different landscape reconstructions, and the maps on which they were based, will be briefly discussed. For more details regarding the landscape evolution and the choice of maps we refer to the report “Recent landscape evolution of the Waasland Scheldepolders based on historical maps” by Jongepier, Missiaen & Soens (2013).

Landscape reconstructions and discussion of the most important maps used

_1570 AD_

Finding maps for this time period was not easy. Logically, late medieval maps are not abundant: the older the map, the smaller the chance of conservation. Furthermore, detailed local and regional maps were only produced in large quantities from the seventeenth century onwards. Luckily, land surveyor *François Horenbault* was ordered to show the impact of late medieval small-scale inundations. One of his maps (copied in 1695, RAG, Kaarten & plans, n° 2454, see Figure 3M25), proved to be suitable for the reconstruction. It has an MPE of 722.40 meters.

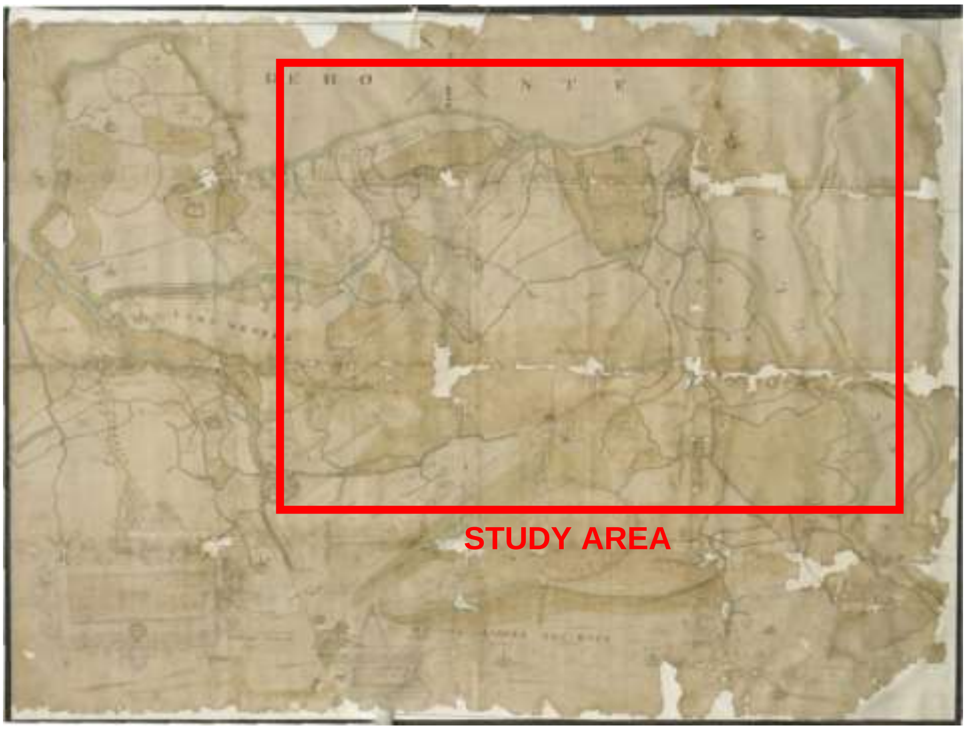

Figure 3M25: Map of 1575, made by land surveyor François in 1575 (copy by B. Speelman, 1695, Rijksarchief Gent, RAG in the following, Kaarten & Plans, n° 2454).

The resulting reconstruction (Figure 3M26) shows almost the entire study area was embanked, due to dike building during the period of large-scale peat extractions. Central in the area, remains of the former peatlands (indicated as “swamp”) are found. The breakthrough of the “Honte” is apparent and several small villages appear to have been founded. The area of tidal marsh is only limited, except for the far north of the area.

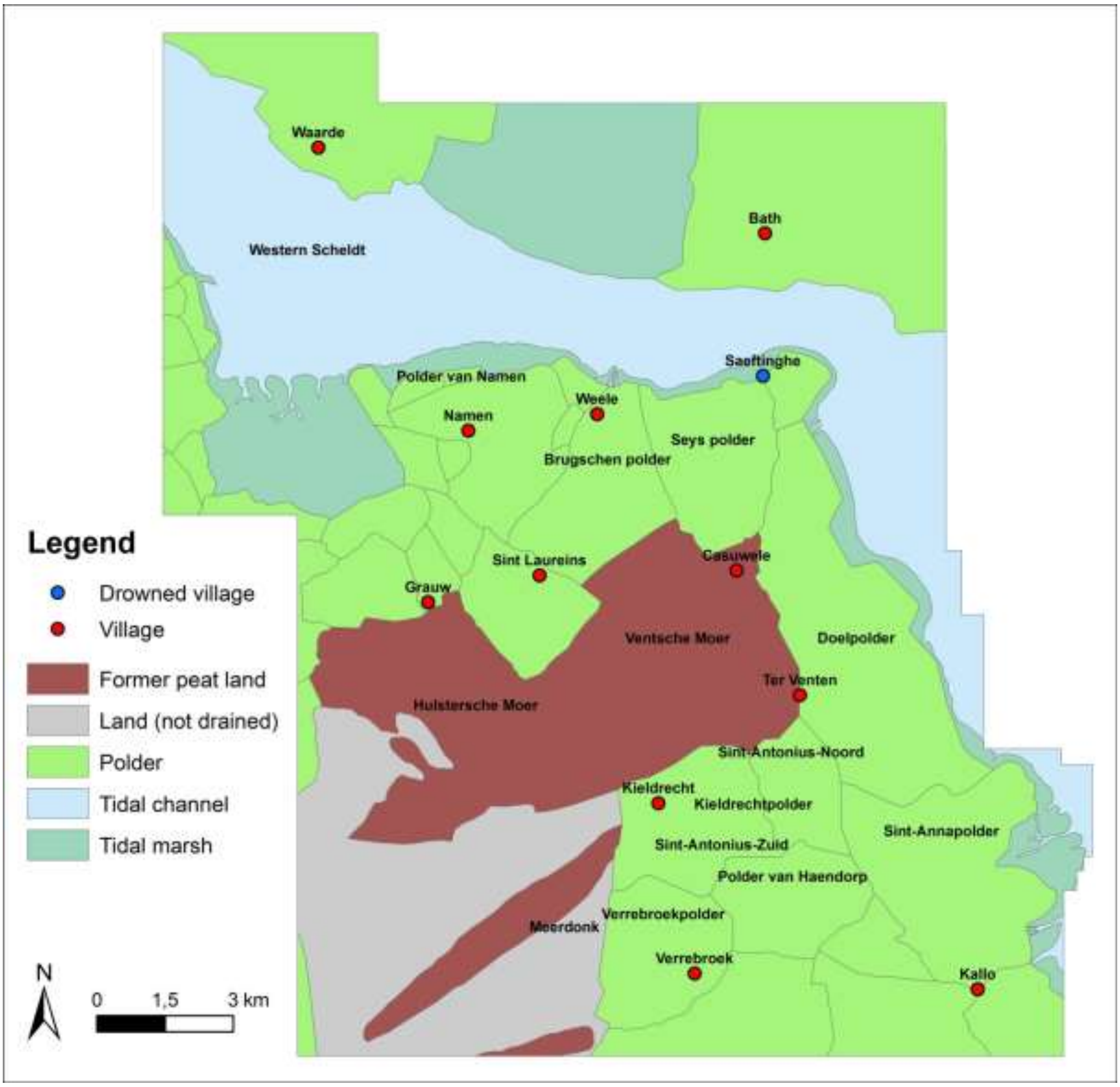

Figure 3M26: GIS-landscape reconstruction of the Waasland polder area around 1570

<u>1625 AD</u>

The second landscape reconstruction dates to around 1625. The most important map available for this period is the “map of Coeck” (as displayed in the *Atlas van Loon* preserved in the Scheepvaartmuseum, Amsterdam, Figure 3M27) which shows the inundations of the late sixteenth century and the first re-embankments in the south of the study area with great detail.

Geometric accuracy is only limited (1383 meters), as is for instance shown in the shape of the *Doelpolder*. However, since the first re-embankments are still present in the landscape, accurate and elaborated georeferencing results (after *splining*) in a useful depiction of the tidal marsh. Only the location of the *Polder van Namen* and surroundings (upper north) remains a bit uncertain, since no present-day GCP´s (points visible for both the historical as the present day situation, used for rectification of the historical map) could be found. The map also makes a clear division between the higher and lower tidal marsh. The map is undated, but probably dates to around 1625.

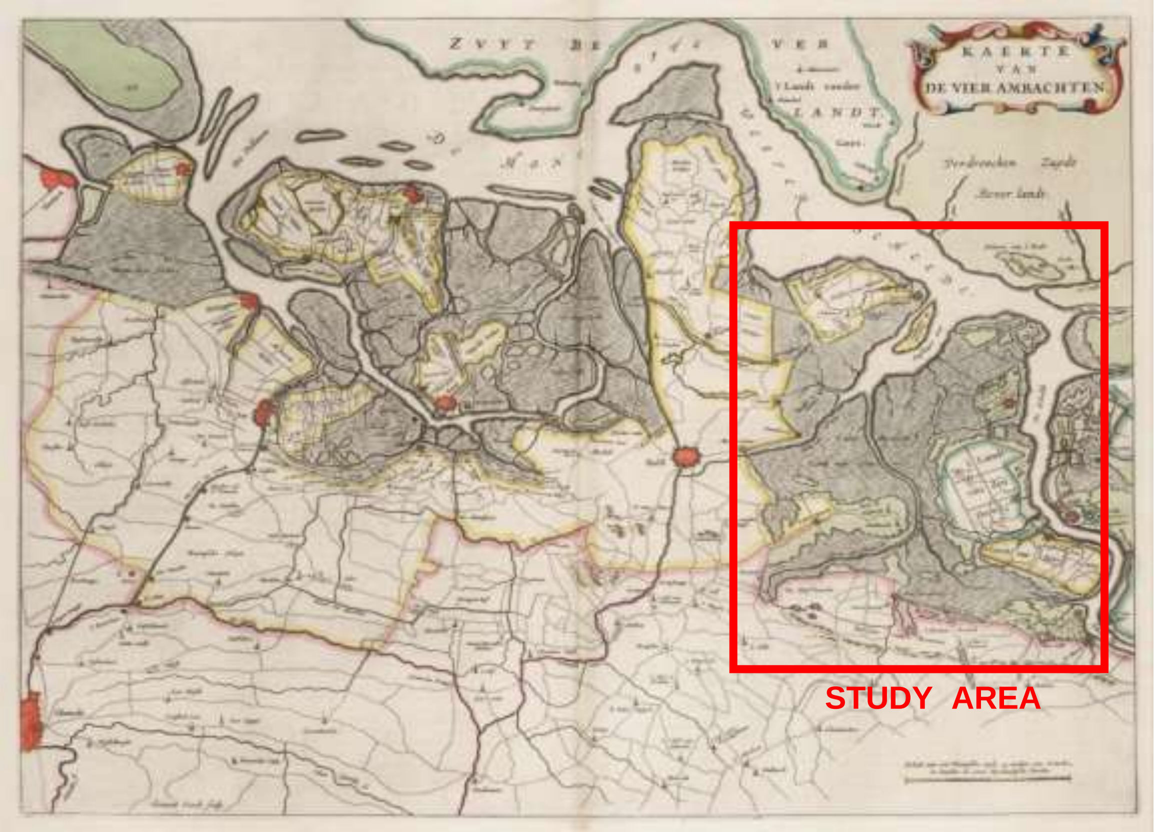

Figure 3M27: Map of Coeck (dating around 1600, Atlas van Loon, Scheepvaartmuseum Amsterdam).

The landscape reconstruction (Figure 3M28) shows the extensive tidal marsh (*Drowned Land of Saeftinghe)* formed after the inundations. A large tidal channel (the so-called *Saeftinger Gat)* crossed the entire area. Since *Kieldrecht* was located on a sandy ridge, it was not completely flooded. The largest part of the *Doelpolder* also remained intact (first as sort of an ‘island’, due to a higher elevation than that of the central area, later re-embanked during 1613/1614), just as the *Polder van Namen* and *St. Anna-polder* (the latter by then called *St. Anna-Ketenisse* or the *Land of Ketenissa*, both with a higher elevation than Mean High Water Level). The villages that were founded by 1570 appear to have been drowned.

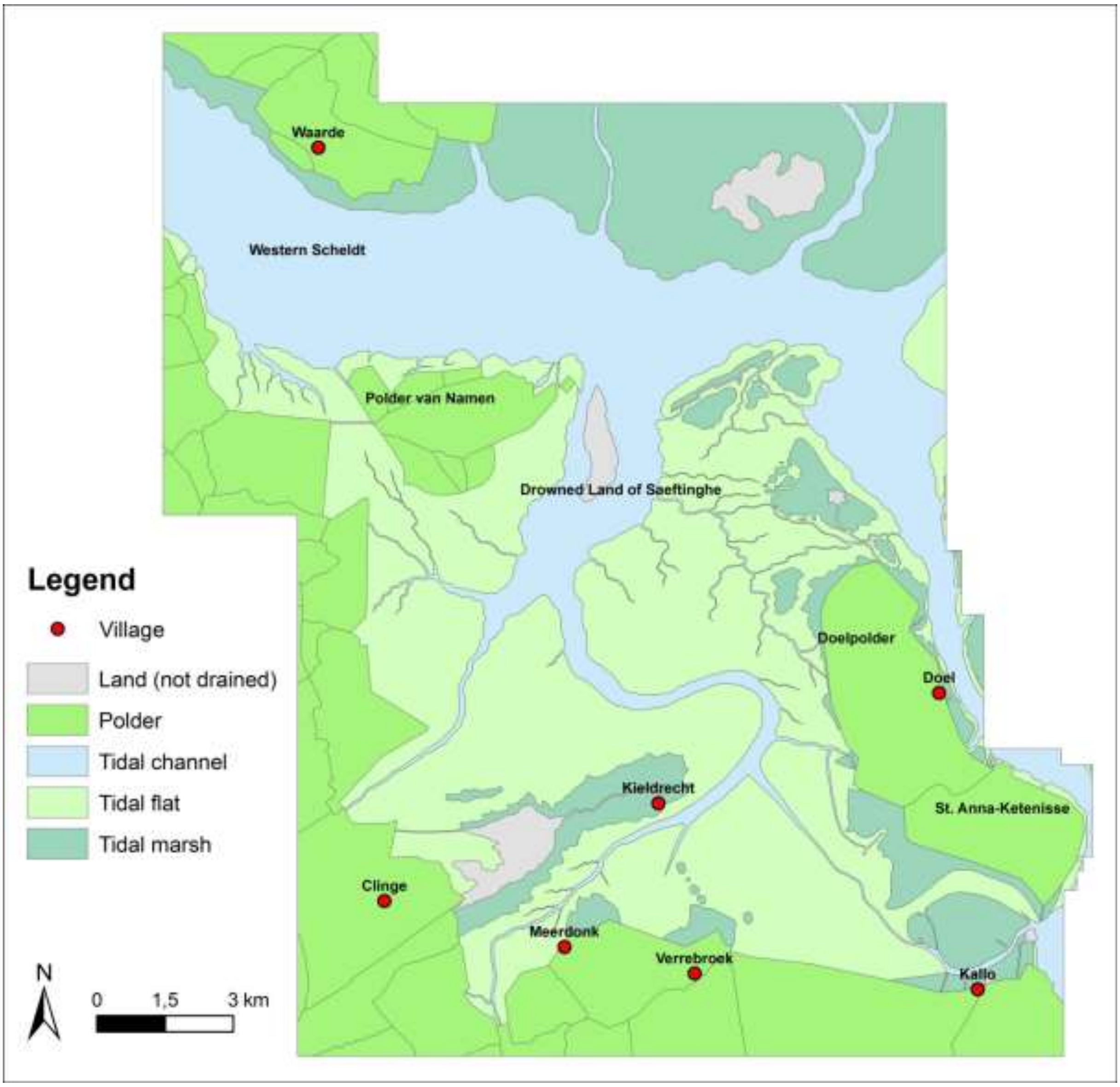

Figure 3M28: GIS-landscape reconstruction of the Waasland polder area for 1625

<u>*1700 AD*</u>

The third landscape reconstruction dates to around 1700. By then, an increasing number of highly detailed large-scale maps appear to have been made. Two high quality local maps were used for the southwestern and eastern (*Peerdenschor*) area. Map ZA-504 dates from 1710, and displays the later drowned polder *Peerdenschor* and its surrounding tidal marsh (Figure 3M29, top). Although probably highly accurate (as most local maps are), a proper mean positional error (MPE) assessment could not be conducted since only very few MPE´s could be found that correspond with the actual landscape, since the entire embankment drowned in the eighteenth century. The other local map (Figure 3M29, bottom) dates from 1687 and shows the southwestern tidal marsh (near Kieldrecht). MPE-value amounts to an outstanding 53 meters. Both maps are derived form the so-called *Atlas of Hattinga*. This atlas was made around 1750 by the famous land surveyor W.T. Hattinga and his two sons. Most of the maps concern high quality copies of older maps. The entire atlas is preserverd in the *Zeeuws Archive Middelburg.*The rest of the GIS-landscape reconstruction in the study area is based on two supraregional maps with higher MPE-values.

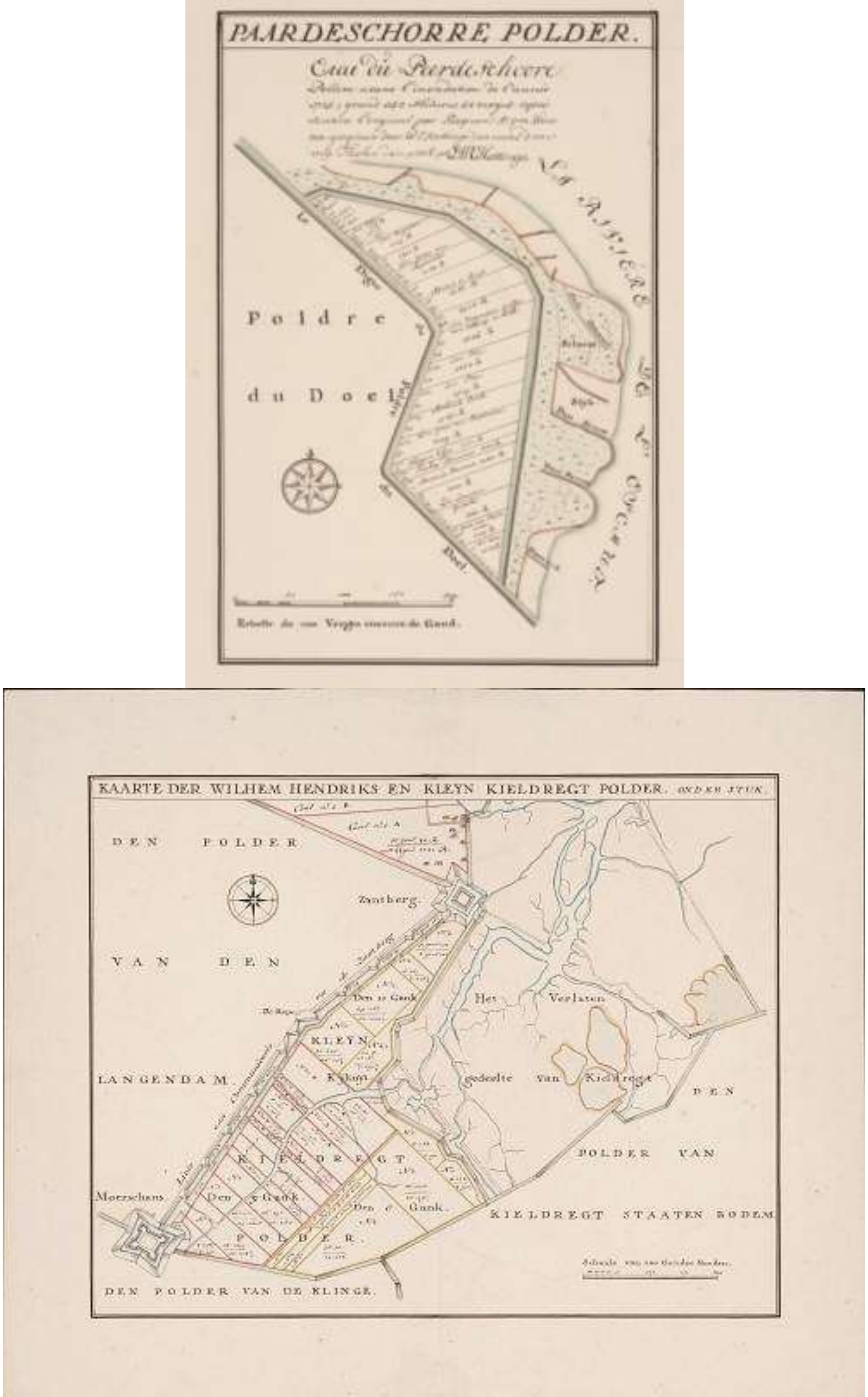

Figure 3M29: Maps of the Peerdenschor (top, 1710, Zeeuws Archief Middelburg, ZA in the following,-293-n° 504) and southwestern tidal marsh (bottom) 1687, ZA-293-n°497(495)).

The GIS-reconstruction of 1700 (Figure 3M30) shows a large continuity with the landscape in 1625. In the north the large tidal channel '*Saeftingher Gat',* originating from the Eighty Years´ War inundations, still intersects the area. The eastern course of the channel, however, had changed and now runs due east till the *Doelpolder* where an internal connection to the Scheldt river was established (the so-called *Deurganck*), probably in order to facilitate future tactical inundations. The northern frontier of the *Land of Saeftinghe* is marked by an elevated part of the tidal marsh, located near the former location of the drowned village of Saeftinghe. Most of the tidal marsh was indicated as low-lying mudflats. Due to the successive embankments, sedimentation seaward of the new sea dikes was re-initiated time and time again, leaving only little time for higher tidal marshes to be formed. Only north of the Western Scheldt, larger areas of higher elevated tidal marsh were found.

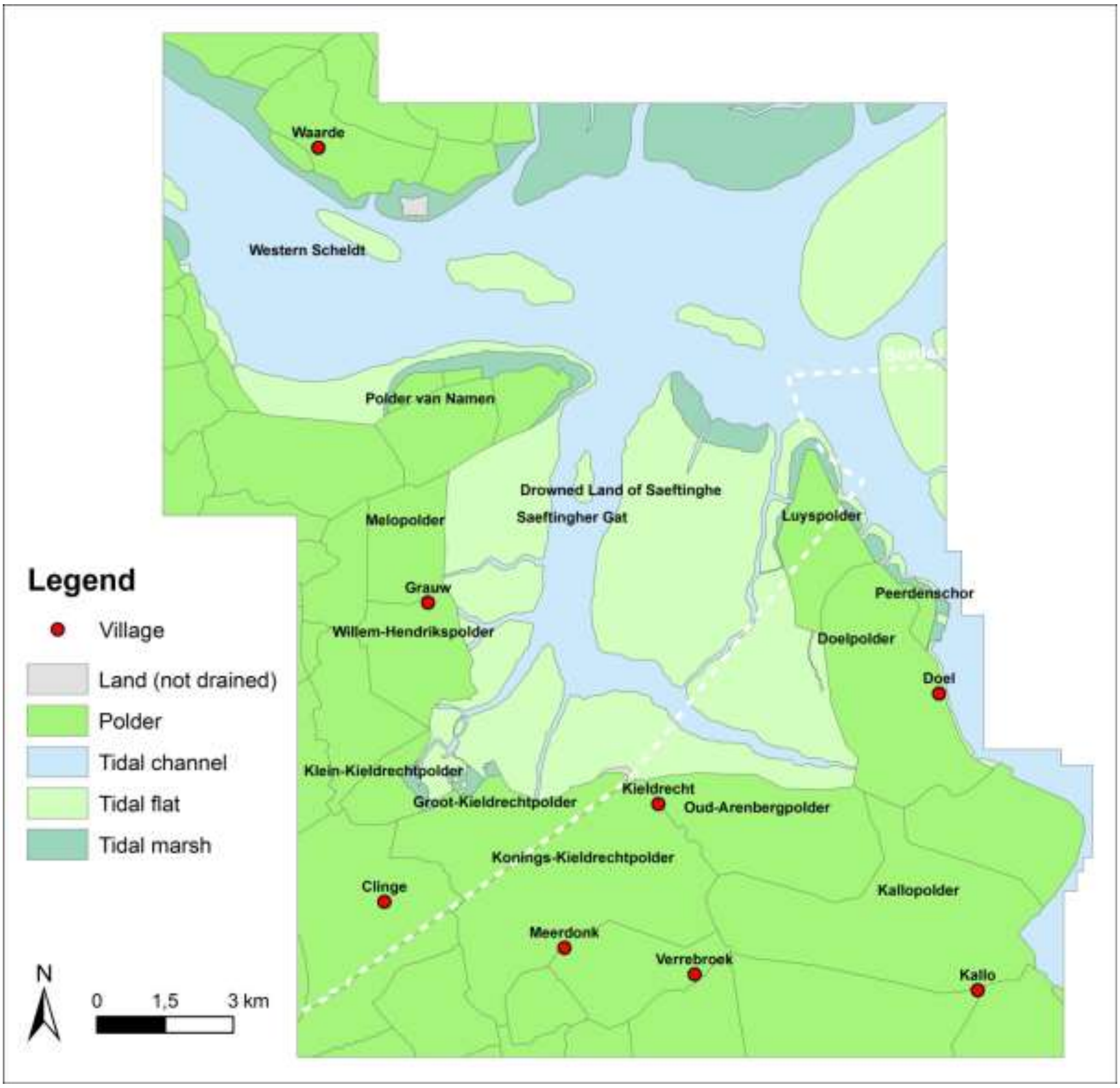

Figure 3M30: GIS-landscape reconstruction of the Waasland polder area for 1700.

<u>*1790 AD*</u>

The fourth landscape reconstruction dates to around 1790. Even more high quality maps appear to have been made for this period. For instance, for the eastern part of the tidal marsh, located at the *Doelpolder,* a local map was used (Figure 3M31). Land surveyor *J. Coppens* measured and drew the tidal marsh. Perpendicular distances from the dikes to the border of the higher tidal marsh were also indicated. This resulted in a detailed map with a good mean positional error of 103 meters.

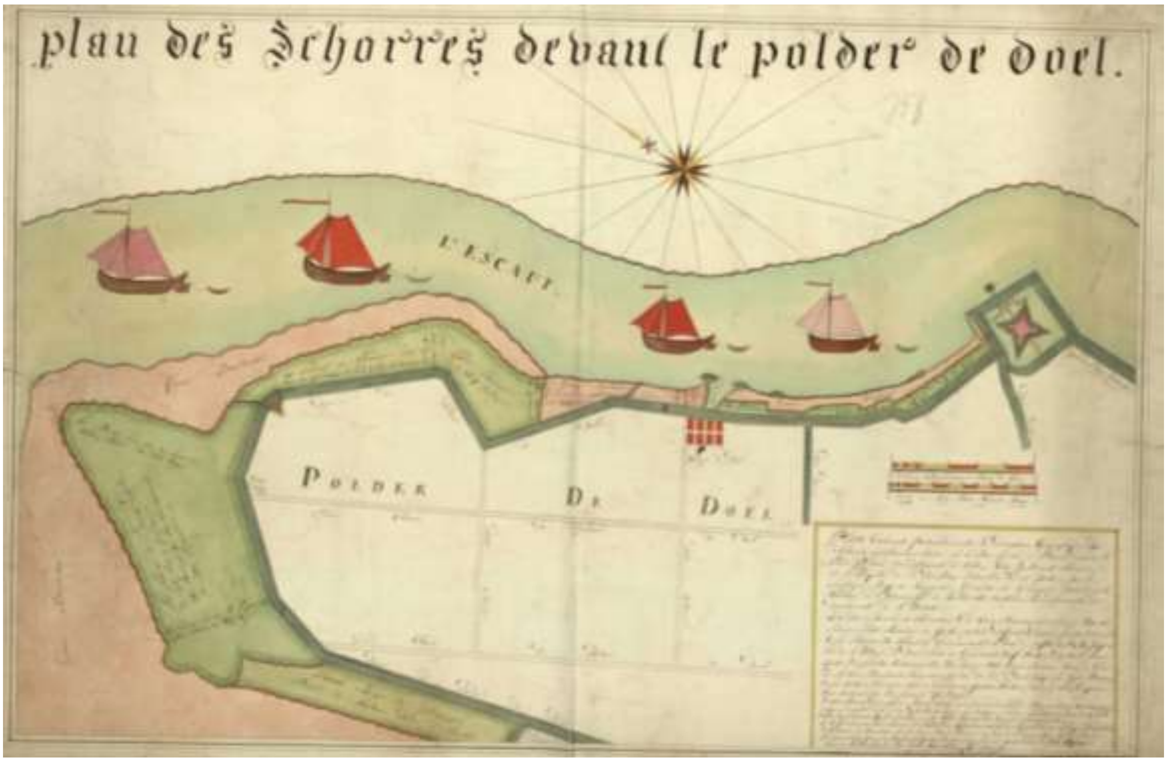

Figure 3M31: Tidal marsh surrounding the Doelpolder, 1813 (ARA, Arenberg, n°842).

The GIS reconstruction of 1790 (Figure 3M32) shows large differences compared to the previous period (1700). Apart from the embankment of the *Nieuw-Arenberg polder* also on the left bank of the river Scheldt the *Nieuw-Kieldrechtpolder* was embanked, just north of the border. In the area north of the Western Scheldt, however large embankment works west of *Bath* were conducted, converting the former higher tidal marsh to embankments streching to the older embankments surrounding *Waarde*. Looking at the unembanked area it is clear that another 90 years of sedimentation has allowed the tidal marsh to be heightened in the *Drowned land of Saeftinghe*. The tidal channel *Saeftingher Gat* is still present but it is much less wide, and especially the area of lower tidal marsh has extended. Furthermore, higher tidal marsh developed against the sea-dikes of most of the embankments.

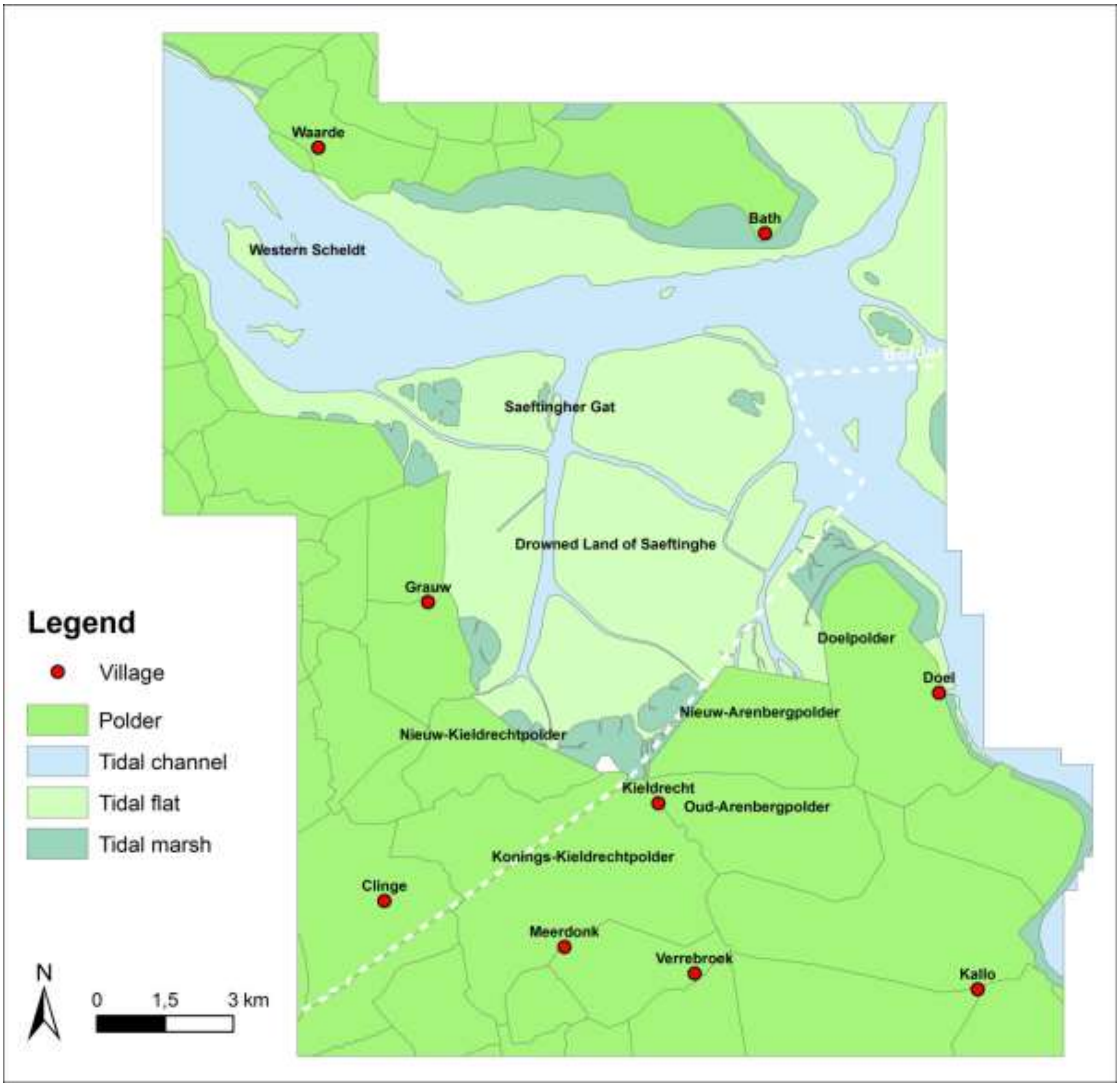

Figure 3M32: GIS-landscape reconstruction of the Waasland polder area for 1790.

<u>*1850 AD*</u>

The last landscape reconstruction dates to around 1850 and is based on two series of maps: the topographic military map (*Topografisch Militaire Kaart*) (TMK) for the part of the reconstruction on Dutch territory, and the maps of *P. Vandermaelen* for the Belgian part of the reconstruction. The maps of the TMK (Figure 3M33, left) are based on a large-scale field survey and accompanying field minutes, carried out between 1836 and 1856. The field minutes were drawn at a scale of 1:25.000, but the resulting stone engraved black and white maps are at a scale of 1:50.000. The maps of *P. Vandermaelen* (Figure 3M33, right) are derived from a large series (250) of individual maps, drawn at scale 1:20.000 between 1850 and 1854 and entitled "Carte topographique de la Belgique".

By 1850, successive embankments in the study area (Figure 3M34) had resulted in a further decrease of the tidal marsh. Next to the *Prosperpolder*, south of the *Land of Saeftinghe* the *Van Alsteinpolder, Louisapolder* and *Saeftinghepolder* were embanked. Clear sections of higher tidal marsh at the (sea) dikes surrounding the embankments were present. The tidal channel surface diminished even further and the *Saeftingher Gat* is no longer distinguishable.

Figure 3M33: Topografische Militaire Kaart, 1850 (fragment, left) and Maps of Vandermaelen, 1854 (fragment, right).

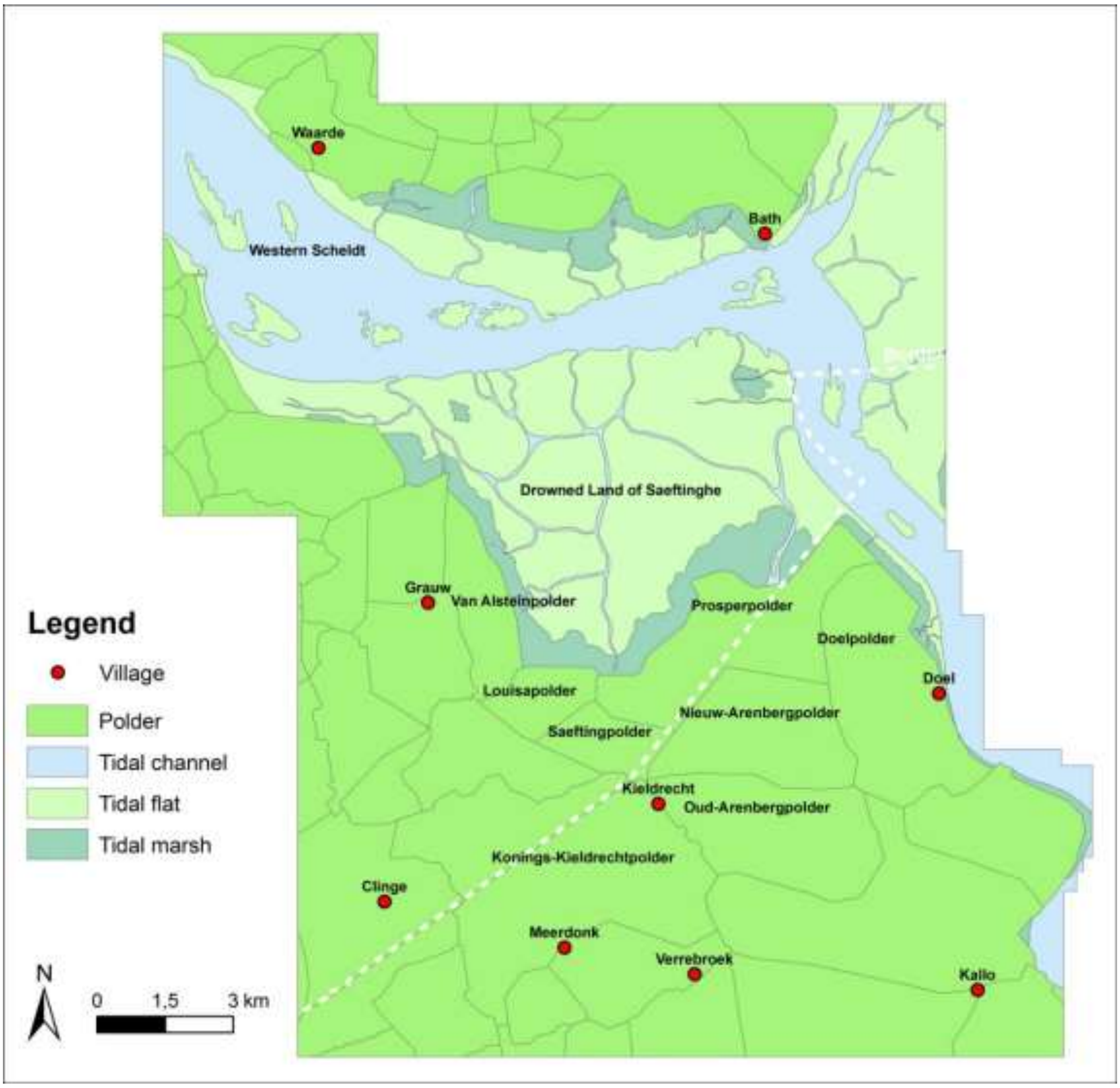

Figure 3M34: GIS-landscape reconstruction of the Waasland polder area for 1850.

3M.7 Conclusions and Recommendations

The Waasland polder area, including Doelpolder-Noord is an area under imminent “threat” of harbour extension and de-embankment. Large parts of the existing landscape might be profoundly changed over the next couple of decades, which will also have consequences for buried records of past landscapes. Hence there is an urgent need for detailed and fast archaeological and palaeoenvironmental assessment before these future changes take place, and therefore this area was chosen as one of the two Belgian case studies. The uniqueness of this study area lies in the fact that many “layers” of the past prehistoric landscape have been recorded in the soil archive: Tertiary sandy deposits, Late Glacial aeolian deposits and Holocene marine sediments and peat bogs are still retraceable in the subsoil. In the more recent period (during the late Middle Ages), the area was transformed again: deliberate inundations during wartime caused the area (which was by then embanked) to flood permanently, and an extensive tidal marsh was formed. In the following centuries this marsh was gradually re-embanked, and the present-day landscape was created.

We tried to use a combination of both geotechnical-geophysical techniques and historical-geographical methods in order to reconstruct the buried paleolandscape from the Early Holocene onwards (i.e. the last 11 000 years). This approach is quite novel but proved to be highly successful.

The prehistoric (pre-medieval) landscape was investigated using CPT (Cone Penetration Test), land seismic and marine seismics. Of these techniques the CPT seems to be the most applicable and efficient method for geoarchaeological research and palaeoenvironmental reconstruction. The CPT data must however, always be ground-truthed with sufficient sediment samples from nearby locations, and should be interpreted by experts. In this study area the obtained data led to six palaeolandscape reconstructions, ranging from roughly 11 000 BP to 1000 AD.

The post-medieval landscape was reconstructed using historical maps. These maps were evaluated according topographic, geometric and chronometric accuracy. The highest ranking maps were selected for GIS-rectification and digitalization. This resulted in five reconstruction maps that illustrate the landscape evolution from 1570 (just prior to the inundations) to 1850. Critical evaluation of the maps was crucial here. Maps made at a high accuracy level proved to be far more reliable, and therefore useful for landscape reconstruction, than those made at lower accuracy levels.

The two series of maps clearly show the benefit of the combined geotechnical-geophysical and historical-geographical approach for paleolandscape reconstruction. The use of CPTs provides many opportunities for future research, especially since this method is very time-efficient. The historical maps also provided valuable information, especially the large–scale maps. Keeping in mind the positive results of the test case, we recommend applying these methods to other (coastal) regions as well, in order to enhance our knowledge of past landscapes.

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