SOLUTIONS FOR *SMART* FLOOD CONTROL

EXCURSION REEUWIJK
9 JULY 2013

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Itinerary (excursion 9 July 2013)

16:00 hrs Deltares, Stieltjesweg, Delft (see Figure 1)

17:00 hrs stop 1; Tempeldijk-South

18:00 hrs stop 2; Tempeldijk-North

18:45 hrs stop 3; visit water & gas seepage (if time permits)

19:30 visit *"Reeuwijkse Plassen"* ("*peat excavation lakes"* at "Het Wapen van Reeuwijk")

Below a short introduction and overview of the location, geology, and research is given. More details of the research will be presented on Wednesday, 10 July 2013.

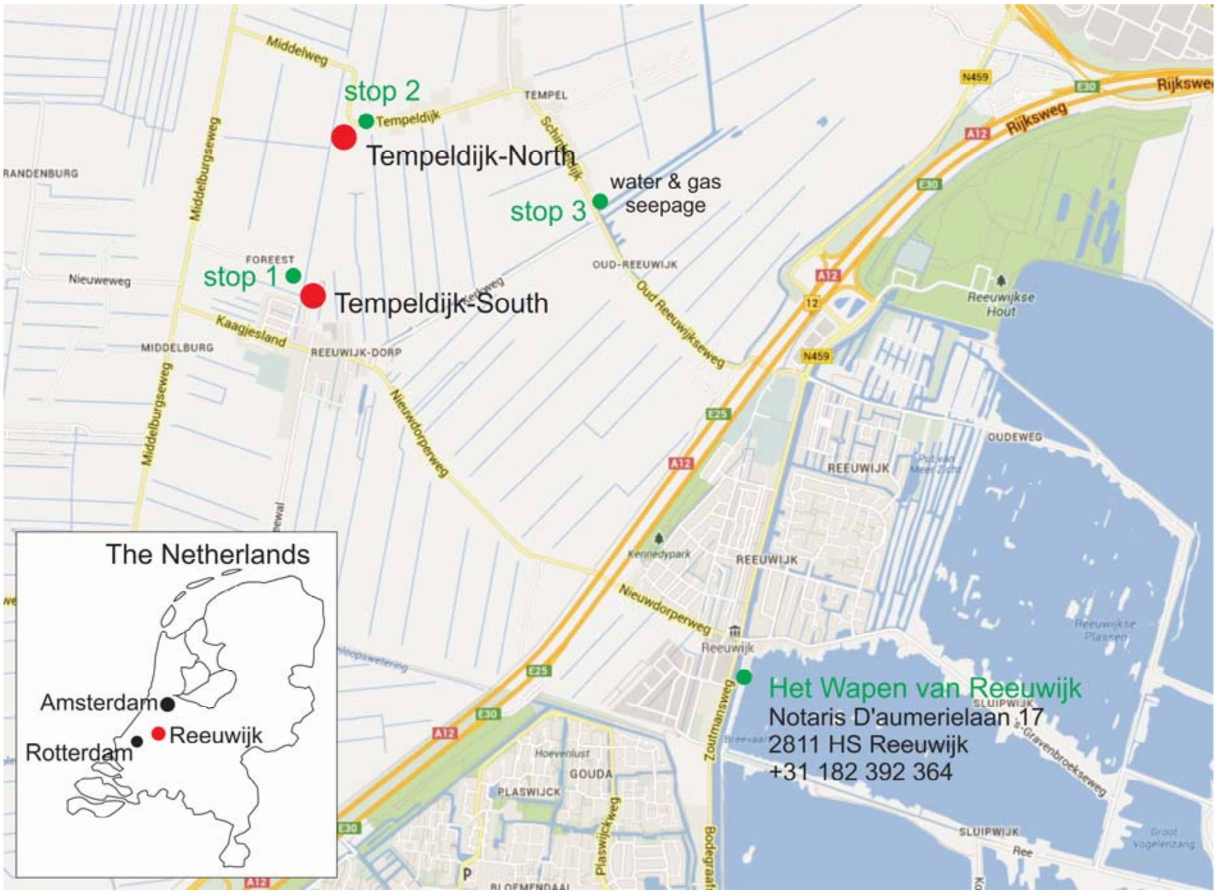

Figure 1. Test site locations Reeuwijk (Google Maps, 2012).

Contents

1 REEUWIJK LOCATION

The research for the identification of dike quality by remote sensing has concentrated on the Tempeldijk, Reeuwijk (Figure 1). The Tempeldijk is a dike located north of the village of Reeuwijk-Dorp in the province of Zuid Holland, in the central western part of The Netherlands. The dike is located in a so-called *"polder area"* (Figure 1 & Figure 5).

1.1 Peat excavation

In the area, as in large parts in the West of The Netherlands, excavation of peat for fuel has taken place since the early Middle Ages (first reported around 800 AD) and on a large and systematic scale between the 10th and mid-19th century (Nienhuis, 2008). The groundwater level in the area was near surface and excavation took mostly place underwater leaving the excavated areas inundated (Figure 2). Between the excavated areas strips were left for roads, housing, and some local farming. Wind and resulting water wave action caused the strips to erode, and increased decay by oxidation of the peat in the strips caused subsidence (section 2.4). The excavated areas became connected and formed (large) lakes, which continuously increased in size by wave erosion. This became a hazard for surrounding villages and towns. Moreover, the value of the land for agricultural use increased and starting from the 16th and especially during the 18th and 19th centuries, the land was reclaimed by pumping out the water by windmills and constructing a system of ditches and canals to drain the water to rivers and sea (Figure 3).

Figure 2. Peat-cutter (Luyken, 1694).

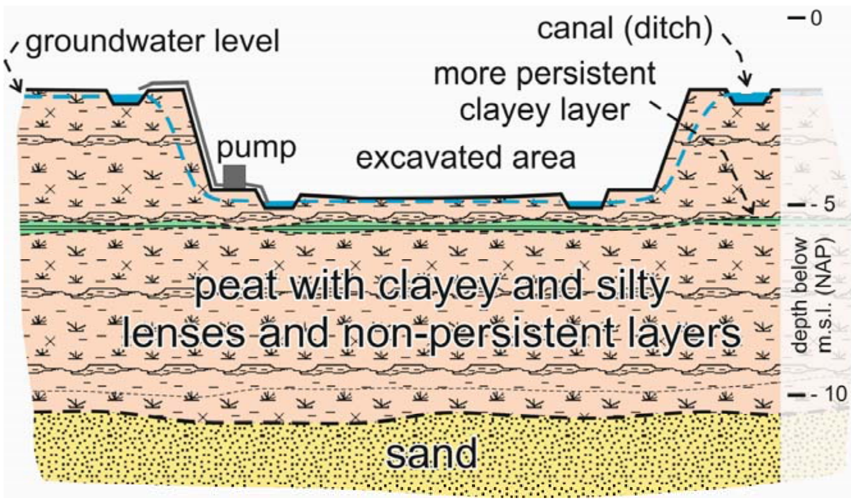

Figure 3. Sketch of peat excavation (vertical scale exaggerated) (from Cundill et al., 2012).

1.2 Tempeldijk

The Tempeldijk is the boundary between a *"high"* in-situ peat deposit area where peat has not been excavated, and a *"low"* area where peat has been excavated. The elevation of the *"high"* area (to the east of the Tempeldijk) is about 1.5 m below NAP (National Mean Sea-Level Reference – M.S.L.) and *"low"* (to the west of the Tempeldijk) is about - 5 m NAP (Figure 4). It functions as a dike (e.g. dam – in Dutch: *"boezem kade"*) for a de-watering canal (ditch) (Figure 3). Two test sites are used; one on each end, i.e. Tempeldijk-North and Tempeldijk-South (Figure 5).

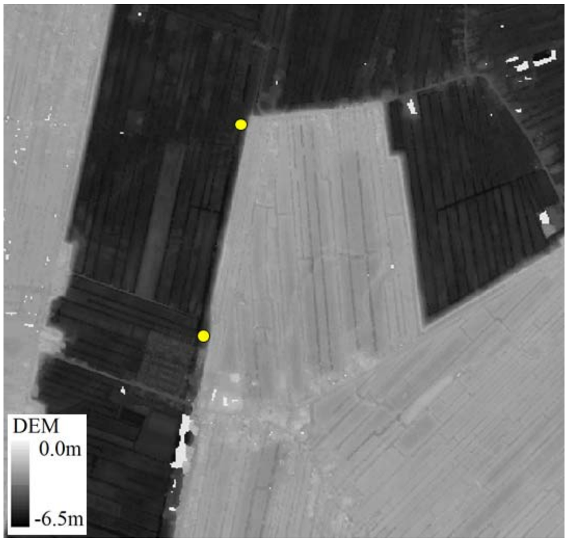

Figure 4. Digital Elevation Model (DEM) of the area of Figure 5.

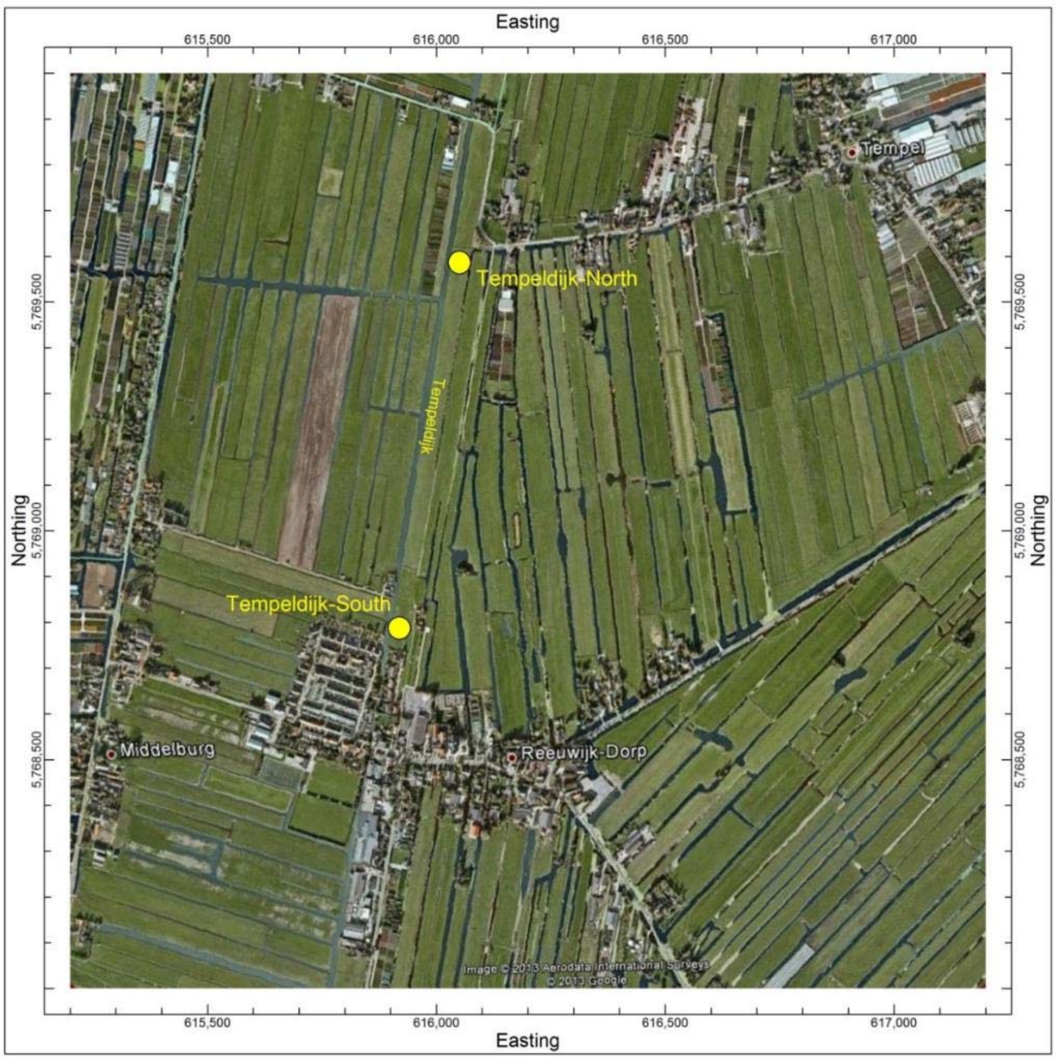

Figure 5. Location test sides. The urban area in the bottom middle is Reeuwijk-Dorp (aerial photo: Google Earth/Aerodata International Surveys; image date 2005, 2013) Grid: UTM (WGS84, zone 31 NH).

1.3 Present situation

At present, land use is mainly meadows for dairy production (milk and cheese; original *"Gouda Cheese"* – the town of Gouda is about 5 km south), and flower, shrub, and tree horticulture. Especially the horticulture has a high economic value. Both agricultural uses are very sensitive to the groundwater level. Too high groundwater level results in a too low bearing capacity of the terrain for the cows, while a too low level reduces the grass growth. The horticulture is also very sensitive for groundwater level.

Foundations of old houses and structures (> 50 years old) vary, but are mostly shallow strip foundations consisting of materials such as wood, waste, bricks, stones, or are founded on (short) mostly wooden piles into clayey or onto more sandy/silty layers. New houses and structures are founded on concrete piles down to Pleistocene sand at about 7-10 m below NAP (geology see section 2).

Most roads are on an embankment of sand, gravel, stones, or any other strong and more or less durable material available at the time of construction. The embankments are directly on in-situ peat and clay. These roads often suffer large differential settlement requiring regular maintenance. Some newer roads are made with either very light-weight embankments (polystyrene) that *"float"* on the water-saturated peat and clay, or by a (reinforced) concrete deck on concrete piles onto Pleistocene sand.

2 GEOLOGY

The Reeuwijk area is influenced by the geology mainly starting from the Tertiary (65 Ma ago) in the context of the tectonic North Sea Basin. Knowledge on the details of the deep geology is high because of the extensive investigations for oil and gas exploitation. A large part of the details in this section is based the book *"Ondergrond van Nederland"* (De Mulder et al., 2003).

2.1 Tertiary (Paleocene, Eocene, Oligocene, (Paleogene) & Miocene, Pliocene (Neogene)) (65 - 2.6 Ma ago)

The North Sea Basin developed in northwestern Europe at the end of the early Tertiary (Figure 6). The area now known as the Netherlands is located at the southern tip of the basin. During the Tertiary, the basin subsided gradually and continuously filled up with sediments (Bosch and Kok, 1994; De Mulder et al., 2003; Ten Cate, 1982). At the end of the Pliocene (end of Tertiary), the coastline was situated over the Southeastern part of the Netherlands (Figure 7).

The base of the Tertiary is at about 700 m below surface in the Reeuwijk area. The thickness of Tertiary sediments in the Reeuwijk area is about 450 m and consists of layers of originally clay, silt, and sand, and minor quantities of calcareous and organic material. The degree of consolidation and cementation varies, but generally is higher in the deeper layers. Many of the layers would be regarded geotechnically as rock rather than soil, i.e. clay-, silt-, sand-, and limestone, and coal.

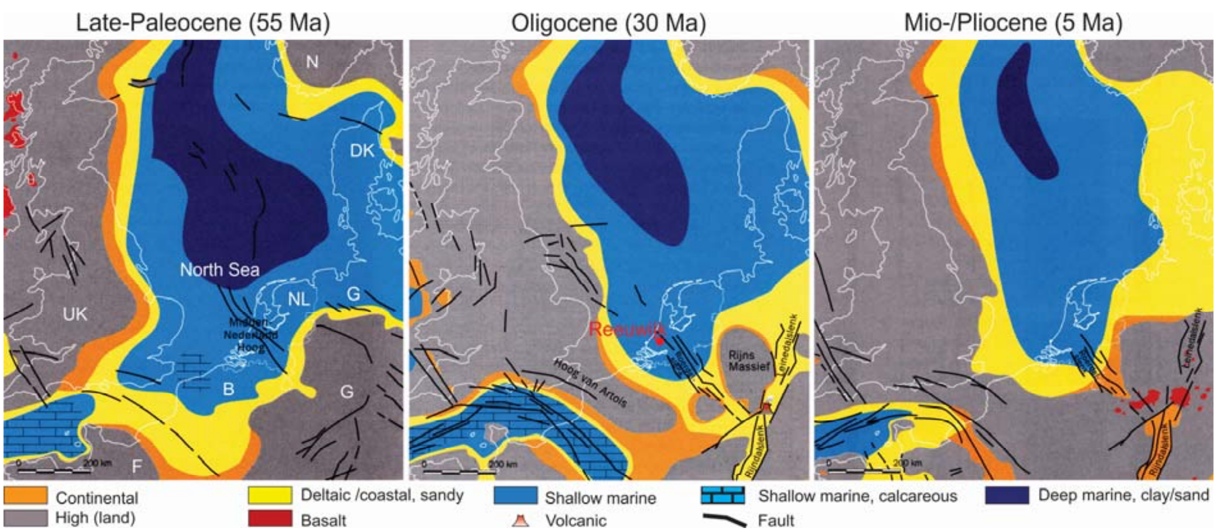

Figure 6. Development of the North Sea Basin during the Tertiary (modified from De Mulder et al., 2003).

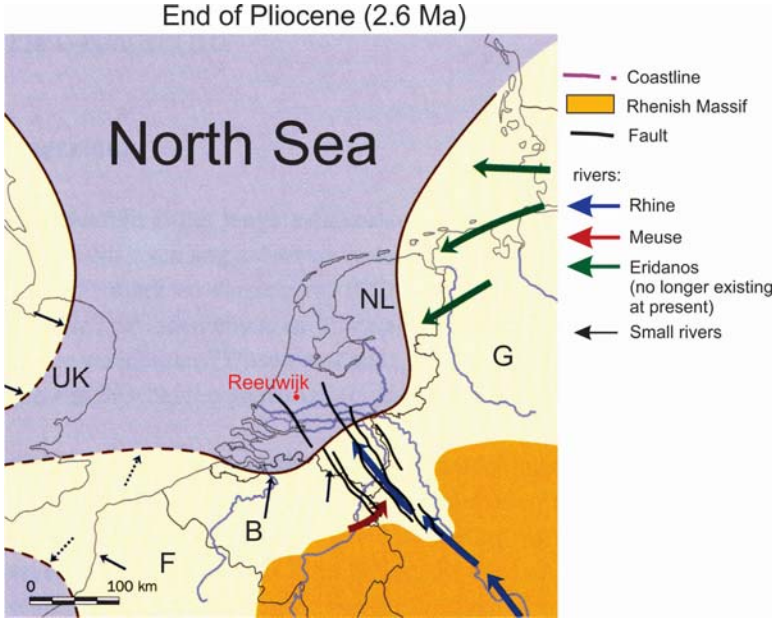

Figure 7. Coastline at end of Pliocene (end of Tertiary) (modified from De Mulder et al., 2003).

2.2 Pleistocene (Early- Quaternary) (2.6 Ma – 10,000 year ago)

During the Pleistocene (from 2.6 Ma to 10,000 year ago), multiple glaciations spread over Northern Europe. As far as known, the Reeuwijk area has never been glaciated during the Pleistocene, but the presence of the glaciations to the north and east of Reeuwijk influenced the morphology of the landscape and sedimentation pattern in the Reeuwijk area. The ice during the Saalian glaciation came nearest and the maximum extent of the ice reached to some 40 km north and northeast of the Reeuwijk area (Figure 8). The glaciations forced the rivers Rhine and Meuse into westerly courses. During the glaciations, the area of Reeuwijk remained in the peri-glacial zone and in the warmer periods in between the glaciations, the climate was more moderate.

The base of the Pleistocene in the Reeuwijk area is about 250 m below surface. The thickness of the Pleistocene is about 240 m. The Pleistocene consists mainly of marine sandy deposits with some more silty and clayey layers.

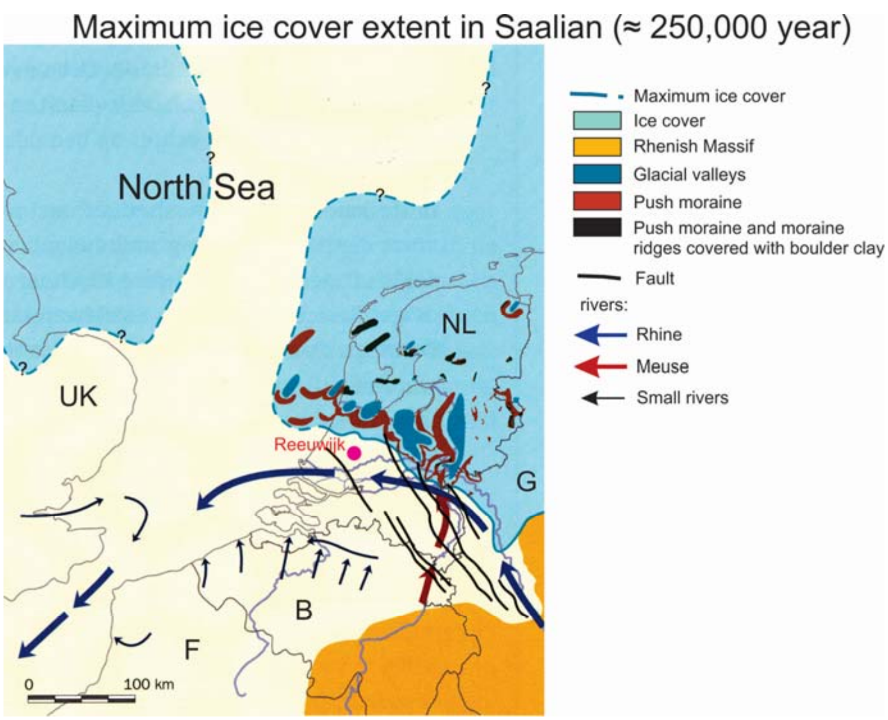

Figure 8. Maximum extent of ice cover during Saalian (modified from De Mulder et al., 2003).

2.3 Holocene (Late-Quaternary) (10,000 year to present)

At the end of the Pleistocene (10,000 year ago), i.e. at the end of the Weichselian glaciation, part of the (later) North Sea and the western Netherlands was a continental gently westward sloping plain mainly consisting of sandy deposits (Ten Cate, 1982). Climate change caused a very rapid sea level rise accompanied by a rise of regional groundwater table (Figure 9b). In this period, three zones of sedimentation can be distinguished: a littoral sandy zone of coastal barriers and dunes, a clayey zone of tidal flats, salt marshes, and brackish lagoons, and, at a greater distance from the sea, a zone of peat formation in a fresh water environment. This system of different sedimentation zones shifted towards the east as the sea gradually flooded the former dry North Sea floor (Figure 9a) (De Mulder et al., 2003; Ten Cate, 1982).

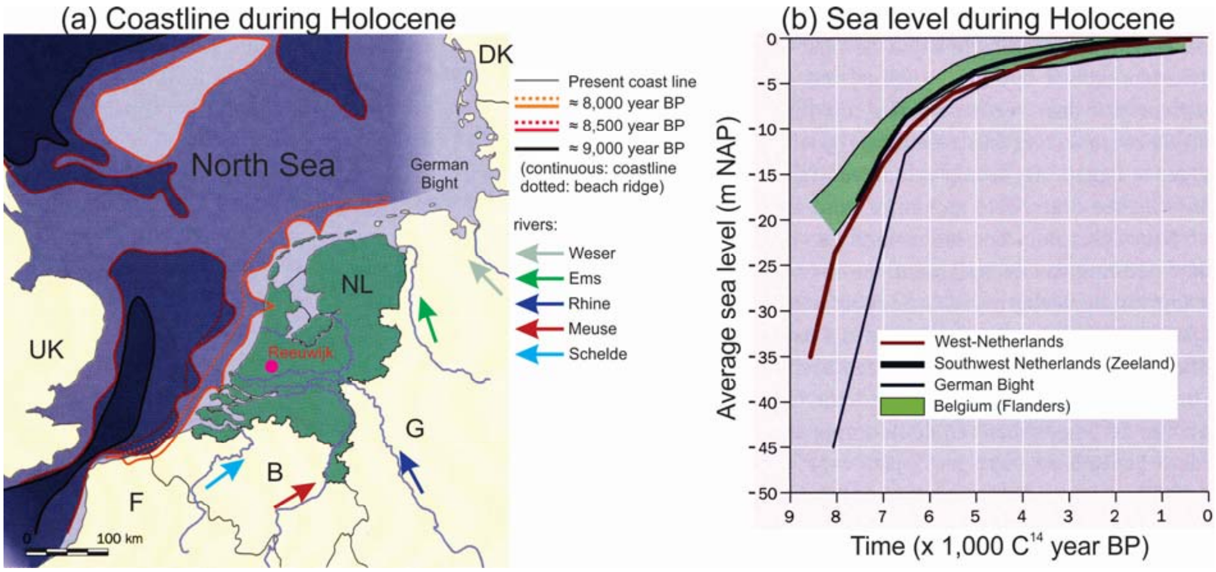

Figure 9. (a) Coastline during Holocene; (b) Sea level during Holocene (modified from De Mulder et al., 2003).

Sedimentation in the Holocene period started with the formation of peat (basal peat). The coastline moved further to the east and reached the present Netherlands in about 8000 BP. The rate of sea level rise reduced to 27 cm/100 years until 5000 BP and the extension of marine deposits reduced significantly (Bijlsma, 1982). Figure 10 shows the development of the Netherlands during the Middle and Late Holocene. The groundwater level was still high which allowed the development of a thick peat layer over the marine and fluvial deposits. This peat forming process continued until 700 BP in the central part of the Netherlands. When the peat layer was inundated and/or eroded by the water, marine or fluvial sediments were deposited over it. The base of the Holocene is about 7 – 9 m below the surface in the non-excavated areas around Reeuwijk area (- 10 NAP).

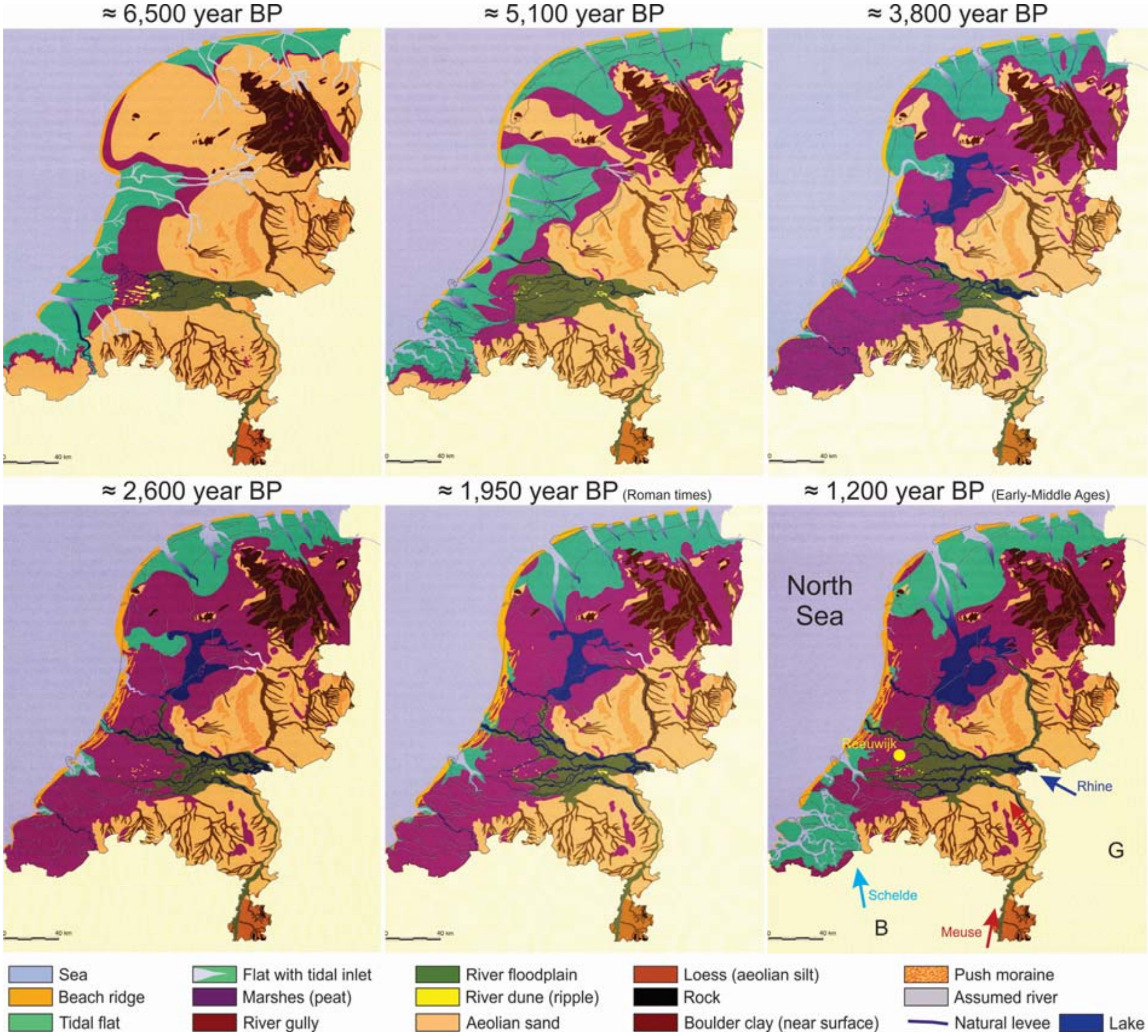

Figure 10. Paleography of The Netherlands during Middle- and Late-Holocene (modified from De Mulder et al., 2003).

2.4 Subsidence

The whole of The Netherlands is part of a subsiding tectonic sedimentary basin (North Sea Basin - see above). The subsidence during the Quaternary (i.e. up to today) is not everywhere the same and is not constant in time. The average tectonic subsidence in the Reeuwijk area over the last 2.5 Ma is 3 - 4 mm/100 year. The Netherlands is also subsiding by isostatic compensation due to increasing load of sediments, varying load by ice due to the glaciations, and varying load by seawater, which for the Reeuwijk area is around 5 - 6 mm/100 year. The sediments and in particular recent sediments undergo compaction due to overlying loads that results in a subsidence of around 1.5 - 2 mm/100 year. Water extraction by man for drinking and agricultural water in the top 10 to 200 m layers increases this last cause for subsidence. Moreover, the peat deposits decay (oxidise) rapidly and cause a substantial decrease of the terrain level when oxygen is allowed to enter. In particular, the peat excavations and lowering of groundwater level for agricultural land use cause a very fast peat decay due to oxygen entering from the air or groundwater flow with dissolved oxygen. The overall subsidence in the area of Reeuwijk is in the order of 1 cm per year but locally it maybe 4 – 10 cm/year.

2.5 Surface lithology

The resulting Holocene lithology in the Tempeldijk-Reeuwijk area follows the “new” lithological divisions with the formerly common stratigraphic names in brackets (De Mulder et al., 2003). The former common stratigraphic names were determined on borehole cores but the new layer identification is based on the descriptions in the literature only. The Holocene lithological formation of *“Nieuwkoop; layer Hollandveen”* (formerly *Hollandveen*) consisting of a fairly consistent peat layer on and partially interbedded with the formation of *“Naaldwijk; layer Wormer”* (formerly *Calais III*) consisting of mainly clay layers and marine and fluvial fine sand channel fill, and with the formation of *Echteld* (formerly *Gorkum*) consisting of sandy and silty clay with thin sand layers and lenses. The underlying Pleistocene formation of *Boxtel* consists of sand (Bosch and Kok, 1994; De Mulder et al., 2003).

3 REEUWIJK, TEMPELDIJK-SOUTH

Tempeldijk-South site (Figure 5 & Figure 11) is reported to have problems due to seepage (*"kwel"*) and possibly subsidence. For a more detailed description of Tempeldijk-South refer to the final report of the pilot project RSDYK2008 (Hack et al., 2008).

Figure 11. Tempeldijk-South panorama photo, Reeuwijk (direction ditch at the left about North-South and fence on the right about East-West).

3.1 Generalized subsurface conditions

The subsurface from the surface downwards can be generalized for the Tempeldijk-South site (see also the 3D model in Figure 12). The lithology names refer to the names used in the sections and 3D model. The generalized composition of the dike is:

- From the surface, a layer consisting of a mixture of clay and peat (*"PEAT/CLAY man-made"*) is present with a thickness of about 0.5 m in the East on top of the dike reducing in thickness towards the west, the bottom of the dike. This layer is likely a partially man-made top layer to improve the bearing capacity of the surface for the cattle and agricultural equipment (Rupke, 2008). The thickness of the layer is shown is between zero and 0.5 m.
- A sequence of peat and silty or clayey peat layers with some thin silt and clay layers (PEAT7, CLAY5, PEAT6, SILT3, and PEAT5) is present between the man-made top layer and a depth of about – 5 m. In western direction, these layers truncate against the man-made top layer.
- A fairly consistent clay and clayey peat layer (*CLAY4*) is present at -5 m.
- Between about -5 and -9.5 to -10.5 a sequence of peat and silty or clayey peat layers with some thin silt and clay layers is present.
- At about -9.5 to -10.5 m a slightly undulating boundary marks the start of a sandy sequence (*SAND2, LOAM, SAND1*).

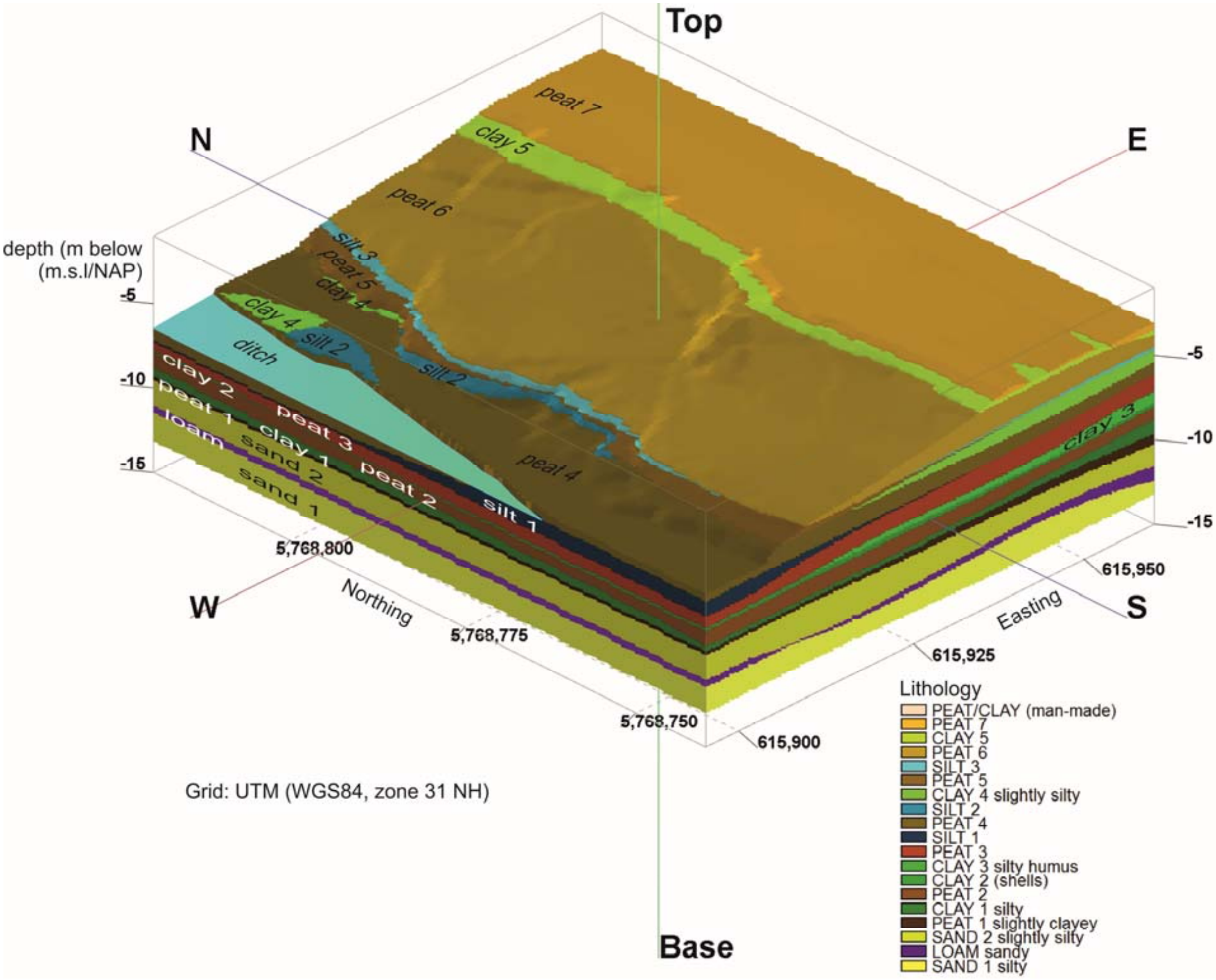

Figure 12. Tempeldijk-South, 3D subsurface model without man-made peat/clay top layer; based on boreholes and CPTs. Grid: UTM (WGS84, zone 31 NH).

3.2 Geophysics

3D-Geophysics resistivity surveys have been done on the Tempeldijk-South location (Figure 13). At the west side of the resistivity profile, resistivity values increase. This can be caused by either more fresh water or by presence of gas. The first is regarded as strange because the area in general is assumed to suffer of more brackish water seepage either from deeper layers or from the peat. For this reason, CPTs with gas measurement have been done (see section 4). These test had to be done on the Tempeldijk-North location because the bearing capacity at the south location was not enough for the CPT truck.

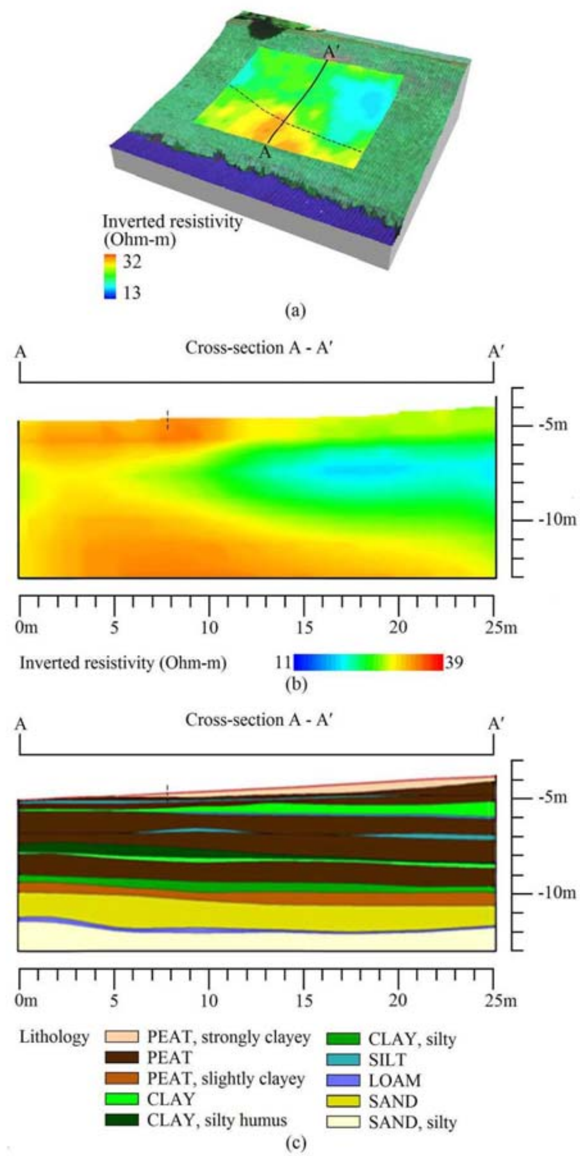

Figure 13. Tempeldijk-South, Reeuwijk, resistivity and (simplified) lithology data: (a) map of resistivity at the surface, where the dashed line indicates where the bottom part of the dike manifests differently from the rest of the dike and with the location of cross-section A-A′ indicated by the solid line; (b) resistivity cross-section A-A′ showing horizontal layering on the right and higher resistivity values on the left (bottom of the dike) with horizontal layering absent; (c) lithology cross-section A-A′ showing horizontal layering of peat, clay and silt, with sand layers starting at about −11 m NAP. Note: the lithology descriptions are simplified, indicating the most important constituents for this research. (from Cundill et al., 2013b).

4 TEMPELDIJK-NORTH

Tempeldijk-North site is chosen as reference. The dike seems to function without known problems. Also on the surface of the dike no features have been distinguished that may indicate seepage (‘kwel’), subsidence’, or otherwise features that could be an indication of “problems”.

4.1 Subsurface investigation - Dutch Cone Penetration Tests with gas measurement

At the Tempeldijk-North site, three (Dutch) Cone Penetration (CPT) tests with gas measurement (MIP) have been done (Zwang and Monden, 2012). Methane gas in the subsoil can be detected with MIP technology. The locations of the CPT measurements are shown in Figure 14 and the measurement results for MIP3 are shown in Figure 16.

Figure 14. Tempeldijk-North test site area with CPT locations (MIP1-3). (photo Google Earth/Aerodata International Surveys, 2009) (Grid: UTM (WGS84, zone 31 NH).

4.1.1 Subsurface Tempeldijk-North

The CPT measurements have been interpolated following the methodology described in Zwang and Monden (2012) and a subsurface section has been made following the methodology also used for the Tempeldijk-South site. The profile along the three CPTs (Figure 15) shows a lithology roughly similar to the Tempeldijk-South.

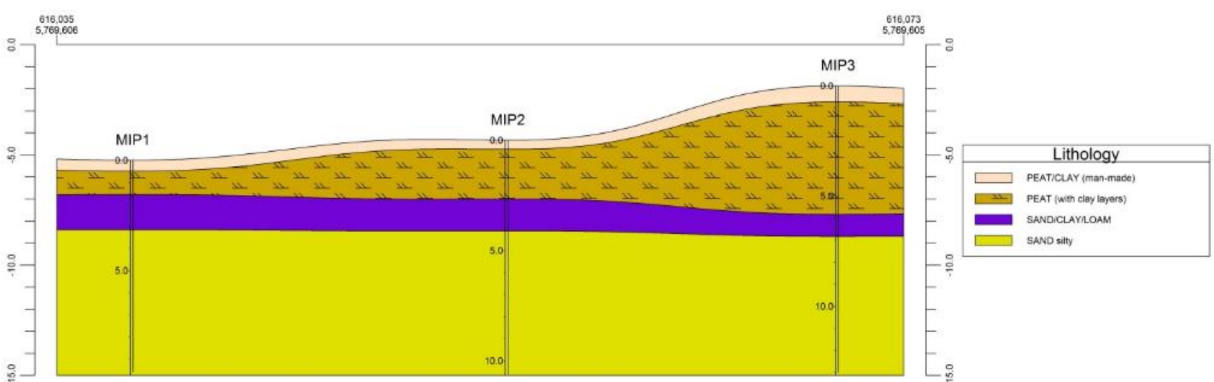

Figure 15. West-East simplified profile along CPT locations (see Figure 14 for locations; depth is in meter below NAP/m.s.l.; depth indication of CPTs is meter below surface).

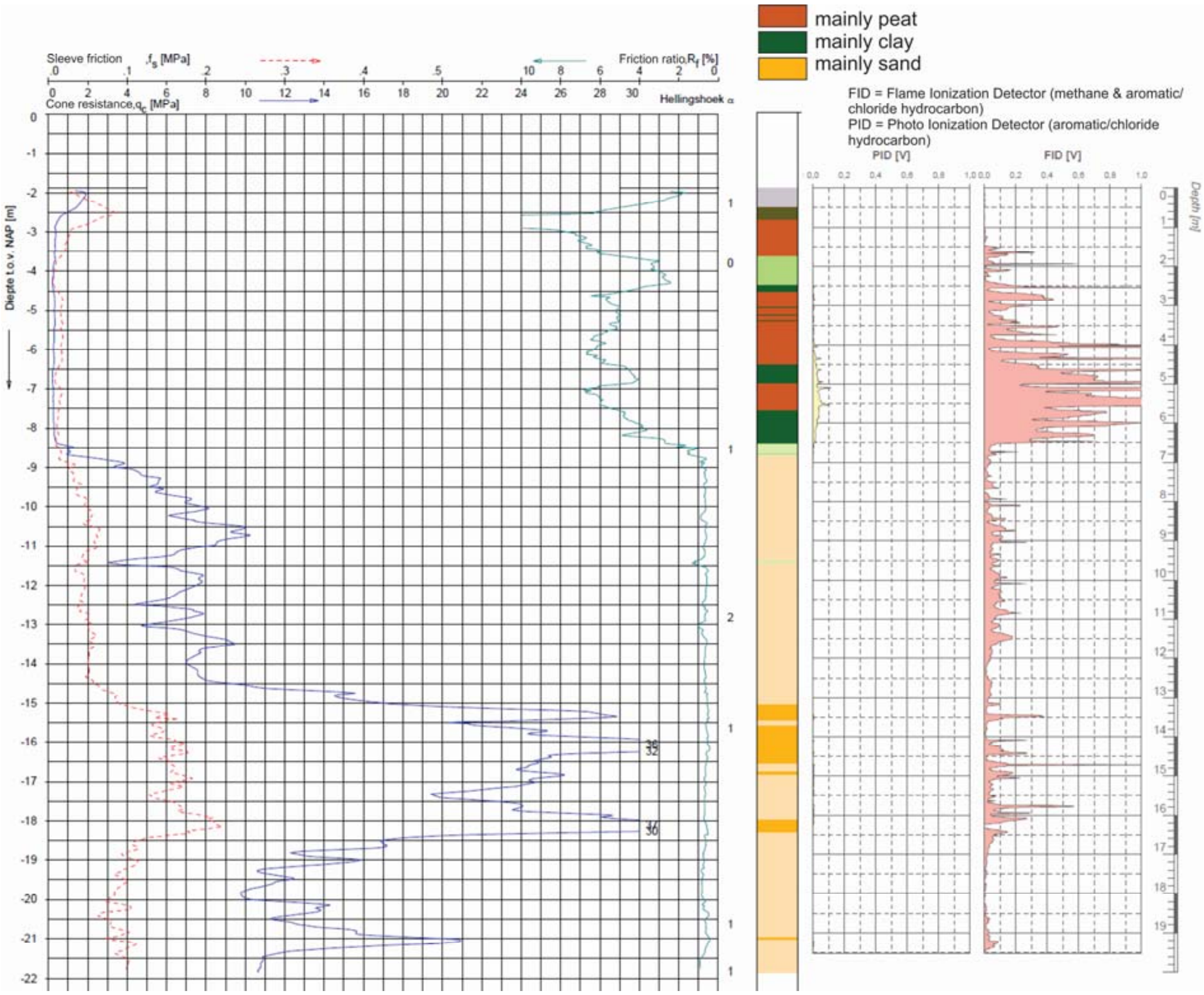

Figure 16. Gas CPT; MIP3

5 DYKE QUALITY AND REMOTE SENSING

Various topics on the relation between remote sensing and dyke quality are investigated. Nine damage parameters are evaluated by dike inspectors to establish the quality of grass covered dikes (Bakkenist et al., 2012b). Two of the damage parameters relate to the moisture content of the dike, either to wet patches or to dryness. Six of these relate, either entirely or partially, to the quality of the grass covering.

5.1 Moisture content

Soil moisture is one of the most important factors affecting surface stability in soil structures (Mukhlisin et al., 2011) of which regional dikes are an example. Soils in dikes can develop cracks and lose structural integrity if they become very dry (Van Baars and Van Kempen, 2009). Conversely, localized areas of high soil moisture content, where water is seeping through the soil, may indicate weaknesses in a dike (Moser and Zomer, 2006). If remote sensing data can be used as a proxy for soil moisture content, then a faster inspection process for this indicator is possible without limitations on accessibility.

The remote sensing technique of passive microwave radiometry (PMR) is sensitive to soil moisture and has been used for monitoring soil moisture condition in dikes (Haarbrink and Shutko, 2008; Swart, 2007). However, PMR data is usually of low spatial resolution and interpretation is complex, especially for vegetated surfaces. For these reasons, thermal remote sensing is often favored for soil moisture studies (Lillesand et al., 2008). Further, vegetation is highly responsive to changes in soil moisture (Hopkins and Hüner, 2009). Remote sensing is researched extensively for assessing vegetation water content and both thermal and hyperspectral remote sensing are actively researched for detection of water deficit stress in agricultural plants (Caccamo et al., 2011; Chen et al., 2005; Fensholt and Sandholt, 2003; Hunt and Rock, 1989; Kim et al., 2010). In addition, thermal imaging has been tested specifically for dike seepage monitoring but with mixed responses (Givehchi et al., 2002; Moser and Zomer, 2006; Swart, 2007; Van Hemert, 2004). Further research is required particularly with regards to time of observation and environmental influences.

5.2 Dike cover quality

The quality of the dike covering is important for resistance against erosion and water infiltration in the case of overtopping. In addition, a grass covering can also be influenced by processes taking place within the dike structure, such as seepage or cracking. If remote sensing data can be used as a proxy for dike covering quality, then a faster inspection process for this indicator is possible without limitations on accessibility.

The quality of the dike covering for grass-covered dikes is assessed by evaluating the health of the vegetation and the presence of standing litter (dead plant material), flotsam (floating debris), bare soil, and weeds (see Table 1 for assessment criteria). Multispectral, and more recently hyperspectral, remote sensing is widely used in vegetation studies (Blackburn, 2007; Lillesand et al., 2008; Van der Meer et al., 2006). Vegetation health can be assessed by the amount of biomass and is influenced by water availability, the presence of diseases and nutrient availability. The multispectral based Normalized Difference Vegetation Index (NDVI) is developed and is still used for biomass estimation (Broge and Leblanc, 2001; Rouse et al., 1974). Hyperspectral remote sensing is also found to be useful for the estimation of biomass (Broge and Leblanc, 2001; Darvishzadeh et al., 2009; Haboudane et al., 2004). Remote sensing is researched extensively for assessing vegetation water content and plant stress induced by water deficit (Caccamo et al., 2011; Chen et al., 2005; Fensholt and Sandholt, 2003; Hunt and Rock, 1989; Kim et al., 2010).

In this project, relationships are studied between 1) soil moisture content and 2) cover quality, and a) thermal, b) broadband multispectral and c) narrowband hyperspectral remote sensing measurements for grass-covered dikes. The study makes use of ground-based, hand-held remote sensing sensors.

Table 1. Cover quality classes and assessment criteria used for this study (modified after Bakkenist et al., 2012a).

Class	Description	Example Photo
Good	More than 90% green grass cover; little to no standing litter, weeds, etc.; no bare soil	
Medium	50% to 90% green grass cover; more than 40% dry grass or weeds; less than 5% bare soil	
Poor	Less than 50% green grass cover; 5% to 20% bare soil	
Bad	More than 20% bare soil	

5.3 Soil Moisture and Remote Sensing

The mean volumetric soil moisture values measured for the dike ranged from 19.1 to 33.5 % vol. which are low for the soil type (Kabat and Beekma, 1994; Schlotzhauer and Price, 1999) which is predominantly clayey peat (obtained from the borehole and CPT data). It is not surprising that the measurements values were low considering that they were taken during one of the driest Julys on record. Most of the dike had low soil moisture values but the bottom part of the dike had higher values.

There are significant negative correlations between the soil moisture values and the daytime thermal remote sensing, specifically the 15h00 and 19h00 datasets (Table 3). Vegetation responds to available soil moisture. When a plant suffers from a shortage of water, the stomata close which reduces evapo-transpiration (Hopkins and Hüner, 2009; Medrano et al., 2003). This causes an increase in plant temperature (Jackson et al., 1986). Thus when a plant has sufficient water available, the plant is cooler than when suffering from water deficiency.

Previous thermal remote sensing studies for dikes focused on seepage alone (Givehchi et al., 2002, Moser and Zomer, 2006, Swart, 2007, van Hemert, 2004). These previous studies were only successful when there were large contrasts in temperature between the water and the dike surface. The results from this study show that thermal remote sensing can also be used to distinguish areas of varying soil moisture and not only where water itself is present at the surface.

5.4 Cover Quality and Remote Sensing

The multispectral remote sensing shows the strongest correlations to cover quality compared to the other remote sensing datasets. This is consistent with what Broge and Leblanc (2001) found, in that broadband indices performed better than hyperspectral narrowband indices for gauging green leaf area index and canopy chlorophyll density. Both the NIR/R and the NIR/G ratios have moderate correlations to cover quality. The cover quality data is ordinal and the ratio data is continuous which may account for the relationship being only moderate. Moderate correlations between cover quality and both the thermal remote sensing data and hyperspectral remote sensing have been found. A single cover quality class is often comprised of several cover types, such as green vegetation, standing litter (dry vegetation) and bare soil, in varying proportions. These have different thermal responses and thus might account for the only moderate correlation between the thermal remote sensing and cover quality.

For the hyperspectral remote sensing data, the strongest relationship is between the WBI and cover quality (Table 2 and Table 3). This index has been developed for use as an indicator for leaf and canopy water content (Peñuelas et al., 1993) based on a water absorption feature around 970 nm, and the absence of it at 900 nm. Reflection in the 970 nm and 900 nm wavelengths is also affected by low leaf area, standing litter and bare soil (as observed by Asner, 1998), all of which increase the index value. Peñuelas et al. (1993) also state that the index does not perform well with changes in leaf area and if the vegetation does not completely cover the soil. The presence of standing litter and bare soil strongly affect values for this index and dominate over the subtler changes in absorption feature depth that result from water deficit stress in green vegetation. With the cover quality largely being medium to poor, this implies that substantial amounts of standing litter and bare soil are present. This would explain why, in this case, this index works well for cover quality but not for soil moisture.

Table 2. Hyperspectral indices (after Cundill et al., 2013b).

INDEX NAME AND ABBREV.	EQUATION	REF.
Carotenoid Reflectance Index 1 (CRI_{550})	$(1/R_{510})-(1/R_{550})$	[66]
Carotenoid Reflectance Index 2 (CRI_{700})	$(1/R_{510})-(1/R_{700})$	[66]
Green/Red Ratio (GRR)	R_{554}/R_{673}	[67],]68]
Green/Red Ratio 2 (GRR_2)	R_{550}/R_{670}	This study
Greenness Index (GI)	R_{554}/R_{677}	[69]
Near-infrared / Red Ratio (NIRRR)	R_{780}/R_{670}	This study
Ratio Vegetation Index (RVI) [a]	R_{800}/R_{673}	[68], [70]
Ratio Vegetation Index 1 (RVI_1)	R_{810}/R_{660}	[71]
Simple Ratio Water Index 2 ($SRWI_2$)	R_{1350}/R_{670}	[68]
Water Band Index (WBI)	R_{970}/R_{900}	[72]

[a] Original index is was for a broadband sensor

R = Reflectance at specified wavelength in nm

Table 3. Correlation coefficients for selected datasets (after Cundill et al., 2013b).

DATASET 1	DATASET 2	CORREL. COEF.	CORREL. TYPE
Soil moisture	Thermal (15h00)	−0.667	Pearson
Soil moisture	Thermal (19h00)	−0.619	Pearson
Soil moisture	Hyperspec. RVI_1	0.591	Pearson
Soil moisture	Hyperspec. NIRRR	0.591	Pearson
Soil moisture	Thermal (20h00)	−0.590*	Pearson
Soil moisture	Hyperspec. RVI	0.590	Pearson
Soil moisture	Visible G/R	0.589	Pearson
Cover quality	Multispec. NIR/R	−0.655	Spearman
Cover quality	Multispec. NIR/G	−0.632	Spearman
Cover quality	Hyperspec. WBI	−0.630	Spearman
Cover quality	Thermal (19h00)	0.612	Spearman
Cover quality	Hyperspec. CRI_{700}	−0.611	Spearman
Cover quality	Hyperspec.CRI_{550}	−0.610	Spearman
Cover quality	Thermal (18h00)	0.605	Spearman
Cover quality	Soil moisture	−0.460	Spearman

* Correlations are significant at $p < 0.05$ (two-tailed)
Remaining correlations are significant at $p < 0.01$ (two-tailed).

6 RESEARCH ARTICLES

Cundill, S.L., Hack, H.R.G.K., Van der Meijde, M., Van der Schrier, J.S., Ngan-Tillard, D.J.M., 2012a. Quality of Peat Dikes Evaluated by Remote Sensing. In: Klijn, F., Schweckendiek, T. (Eds), Comprehensive Flood Risk Management: Research for Policy and Practice. CRC Press, Leiden. ISBN: 978-0415621441. pp. CD-Rom. (Cundill et al., 2012)

Cundill, S.L., Hack, H.R.G.K., Van der Meijde, M., Van der Schrier, J.S., Ngan-Tillard, D.J.M., 2013. Potential of Using Remote Sensing Data for Dike Inspection. In: Huang, Y., Wu, F., Shi, Z., Ye, B. (Eds), New Frontiers in Engineering Geology and the Environment. Springer, Berlin, Heidelberg. 9. ISBN: 978-3-642-31671-5. pp. 203-206. (Cundill et al., 2013a)

Cundill, S.L., Van der Meijde, M., Hack, H.R.G.K., 2013b. Investigation of Remote Sensing for Potential Use in Dike Inspection. *Journal of Selected Topics in Applied Earth Observations and Remote Sensing (IEEE)*. p. (in review). (Cundill et al., 2013b)

7 RSDIJK - FLOODCONTROL2015

Dikes are a flooding protection structure in the Netherlands and some other counties. Remote sensing from the air allows for a far faster means of inspection. However, although it has been thought for a long time that remote sensing may be an attractive option it has never been systematically studied. Therefore, this project has been initiated to establish whether remote sensing is a possible option for dike quality assessment before and during flooding situations.

Within the context of the Flood Control 2015 (FC2015, 2013) project, the secondary peat dikes have a specific function. Secondary dikes may reduce the flooding rate in the Western part of the Netherlands when the main dikes against the sea and main rivers have failed. Important is then how long these dikes may still be able to function. Obviously, in a time of a major flooding in the Western part of the Netherlands no time will be available to start an investigation to the quality of the dikes. The quality of the dikes has therefore to be established beforehand.

The second objective of the RSDYK project is to establish the possible correlations between terrestrial remote sensing techniques, geological information of the surrounding subsurface, geophysical details of a dike and the quality of peat dikes.

7.1 Project team

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Dr. M. van der Meijde
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Organization: Royal Haskoning:
J. van der Schrier, M.Sc.

Organization: Fugro:
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Organization: Stichting IJkdijk:
W. Zomer

Organization: Delft University of Technology, Section Geo Engineering
Dr. D. J. M. Ngan-Tillard

7.2 Stakeholders involved

Organization: City of Bodegraven & Reeuwijk (formerly City of Reeuwijk):
Contact person: Dr. Jan Rupke

Organization: Hoogheemraadschap Rijnland:
Contact person: Onno van Logchem, M.Sc.

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