

5.10 New methods to analyse LIDAR-based elevation models for historical landscape studies with five time slices

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ABSTRACT

Light Detection and Ranging (LiDAR) data and derived Digital Elevation Models (DEM) have been available in the Netherlands since 2001. These models have recently become an accepted method within archaeological and historical research. Nevertheless, the use of LiDAR images for landscape characterisation by governmental organisations and institutions that deal with area management is still in its infancy.

The provincial authority of Gelderland commissioned ADC ArcheoProjecten to compile an atlas of LiDAR-based elevation models within its boundaries. Its purpose was to increase the application of the atlas within governmental organisations. To simplify the interpretation of the LiDAR-based elevation models in the atlas, a new method of time-depth was introduced by defining time slices. For each time slice, images from characteristic features were made with different visualisation techniques, depending on the character of the chosen subject. The LiDAR-based elevation images were printed next to historical and topographical maps or photographs to clarify the interpretation. To explain each image, information about the geomorphological, historical or archaeological features was added. The method was tested in four regions, each with different geomorphological and historical characteristics. The results were discussed with the potential users of the LiDAR-based atlas from different governmental organisations in the region. This new method, using the five time slices, proved to be a useful tool for analysing LiDAR-based elevation images. These images provide valuable input to (historic) landscape characterisation, which has the potential to be a substantial resource for heritage-related, archaeological and historical research as well as landscape and urban design.

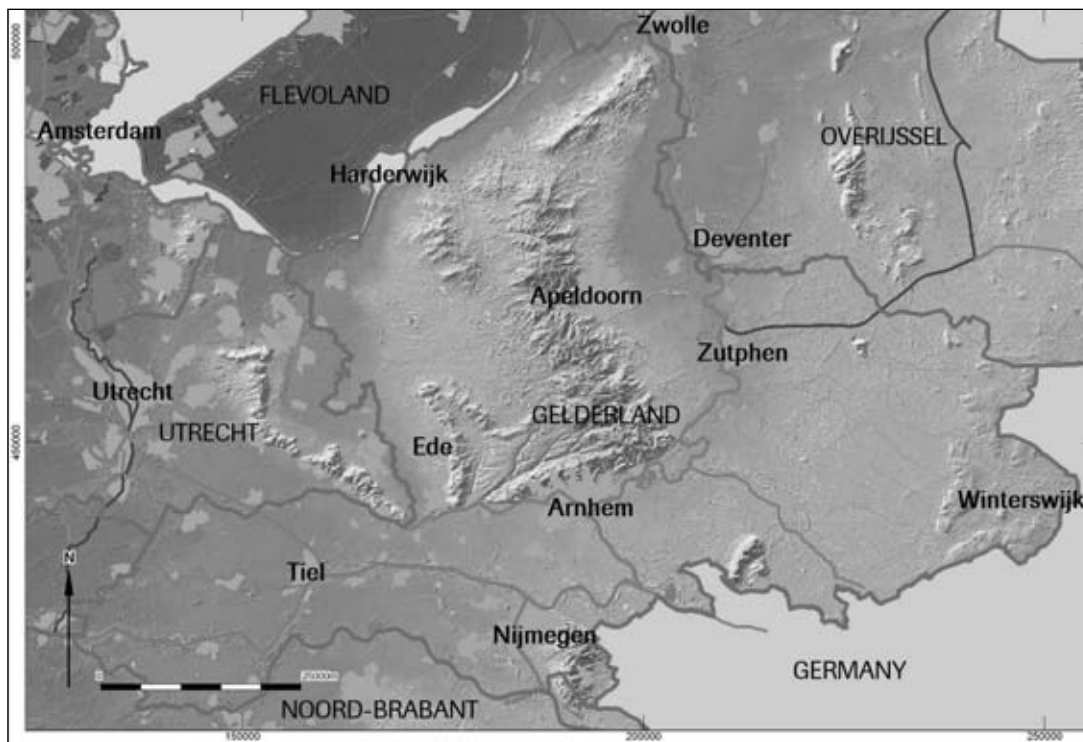
KEYWORDS

archaeology, geomorphology, historical geomorphology, digital elevation models, LiDAR, landscape characterisation, time depth

INTRODUCTION

LiDAR data and derived digital elevation models (DEM) have been available in the Netherlands since 2001. The detailed measurements of the ground surface at metre and sub-metre resolution generate spectacular images of the relief, revealing the natural landscape, archaeological and historical geographical features as well as features relating to modern human activities (Laan & Van Zijverden 2004; Waldus & Van der Velde 2006; Van Zijverden & Zuidhoff 2009). LiDAR measures with a resolution and accuracy hitherto unavailable, except through labour-intensive field survey or photogrammetry (Bewley et al. 2005). The LiDAR-based images contribute to studies based on geological and historic mapping and archaeological data, and are for example used for landscape biography studies (Van Beek 2009; Bewley et al. 2005; Lewis et al. 2008; Shell & Roughley 2004). Landscape biography or landscape characterisation takes systematic representations of the above-mentioned features and uses processes of assessment and interpretation to characterise the cultural and historical events that established the present-day landscape. It provides a comprehensive overview of the historic landscape in order to provide new, wide-ranging information for conservation, management and development decisions (Lewis et al. 2008). The landscape biography approach is less selective than conventional methods of landscape characterisation, which is the benefit of

Figure 1. A simple DEM of the province of Gelderland. Note that the relief is exaggerated by a factor 5.4 and illuminated from the northwest.



this method (Fairclough 2006a). The process does not identify one area or thing as having greater value than another. Instead it identifies what distinguishes every place (or a part of the historic environment) from others, what makes it distinctive and what gives it its character.

Despite the fact that the application of LiDAR-based DEMs within the scientific world is widely known, the use of LiDAR images for landscape characterisation by governmental organisations and institutions which deal with area management is still in its infancy. In order to improve the quality of spatial policy and to lay a solid foundation for working with surface relief within heritage management, landscape design and spatial planning, the provincial authority of Gelderland encouraged the application of LiDAR images as mentioned above. To this end, the authority commissioned ADC ArcheoProjecten to compile an atlas of LiDAR-based elevation images within the provincial boundaries (fig. 1). In order to simplify the interpretation of the images, a new method was developed with the introduction of time slicing. This method was applied in four regions. A key, containing the most characteristic natural and man-made features, was also compiled. The project's results were incorporated in a report, as well as being presented at various workshops (Van der Zee et al. 2009).

TECHNICAL BACKGROUND

LiDAR systems transmit laser pulses from an aircraft to the ground and sense the 'echo' pulses when they return. The time that it takes for a pulse to return to the sensor is a measure of the distance between the laserhead and the ground. Early airborne LiDAR systems had problems geo-referencing the laser measurements, but this has improved considerably in recent years (De Boer et al. 2008). It is now even possible to measure surface elevations with an accuracy of ca. 15cm. Between 1996 and 2004, Dutch governmental institutions measured the entire country's surface elevation with LiDAR, at a minimum density of one measurement per 16m². Except in areas with large water surfaces and forest cover, the average density was one measurement per 36m².

From 2007 onwards, an improved version of the LiDAR system has been developed, which will be available in 2012. For this purpose, every 0.25m² of the Dutch surface elevation will be measured with an accuracy of 5cm.

LiDAR-based atlas

In order to construct the LiDAR-based atlas, the provincial authority provided ADC ArcheoProjecten with files containing the raw data. These data consist of elevation points, which are subdivided in sheets. One sheet corresponds to one half map sheet of the arrangement of the Dutch Topographical Service and covers an area of 5,000 x 6,250m (3,125 ha). At the borders the sheets have different dimensions. The entire province contains 212 sheets. In order to diminish the number of sheets and to clarify the atlas, four sheets were consolidated into one new one.

For each sheet, a frame for the raw data was made by using the technique of kriging. Kriging is a geo-statistical technique used to interpolate a parameter using geostatistical characteristics of the complete data. In this study the parameter interpolated was the elevation of the landscape as a function of the geographic location. The elevation at an unobserved location was obtained from observations of its value at a nearby location. The interpolation was done with predefined adjustments and a cell dimension of 2.5 x

2.5 m. Subsequently, black-and-white maps and colour-shade relief maps were generated. The same colour pallet was used in all of the maps so that differences between adjacent maps were avoided.

Time Slices and Legend for the LiDAR-based atlas

In order to support the application of the LiDAR atlas for governmental organisations and the interpretation of the LiDAR-based elevation images, the data was simplified in two ways. To begin with, a time-depth method was introduced by defining time slices. A legend for the LiDAR-based atlas was subsequently drawn up.

Nowadays, the landforms and patterns that characterise the landscape of the densely populated area of the Netherlands, including the province of Gelderland, are mostly man-made. Seemingly ancient natural landscapes, for example heathland, are often shaped by human influence (Roymans et al. 2009). Heathland is in fact an unstable phase in the succession of vegetation; one which has been created through human land-use activity. Many different landscapes were presumably created in order to serve the needs of the society (or some part of it) at certain points of time and they have been constantly used and reused (Quigley 2010). To this end the term 'recycled landscape' is used. Within the concept of the biography of the landscape or *landscape characterisation*, the transformation of landscapes from prehistory up to the present are explored (Roymans et al. 2009). In this way the concept of *time depth* is introduced: at each point in time, the landscape is an outcome of the complex interplay between physical constraints, social and economic developments and institutional and political changes. An assumption underlying this approach is that it is not possible to understand the modern landscape without understanding the story of its past development. The introduction of *time depth* allows people to appreciate the trajectory of past change in ways that are useful for guiding future change (Herring 2009).

Within the context of this study a *time slice* can be defined as a predetermined period of time. In each period of time natural and/or human processes continuously modify the relief. They create new features, landforms and patterns, or change existing ones. Based on dominant processes and changes in the landscape, five separate *time slices* were distinguished. It is, of course, possible to distinguish an almost infinite number of *time slices*. However, within the scope of this project the number was restricted, to avoid unnecessary complications. Furthermore, the time slices are not strictly defined periods. Some processes and changes may have taken place in more than one time slice.

The notion of 'landscape' can be defined as an area whose character is the result of the interaction of natural and/or human factors, processes and changes (Fairclough 2006a; Fairclough & Møller 2008). This notion is not exclusively reserved for 'natural' and rural environments, but also for urban and peri-urban areas (Quigley & Shaw 2010). Evidence for change and for the existence of earlier landscapes exists in the present landscape; the process of landscape characterisation enables us to recognise these former patterns (Herring 2009). Each parcel of land has a current use and one or more previous uses recorded in a LiDAR-based elevation image. The variation in the number of previous uses is, in a sense, a measure of the amount of change the environment has undergone (Quigley 2010). Therefore, a LiDAR-based elevation image is composed of several time slices.

The first time slice consists of features representing the natural landscape. Aeolian river dunes are an example of such a time slice. These dunes are recognised as small, isolated heights in a rather flat, low-lying area. Some of these features are not entirely 'natural', considering the fact that people have had an increasing influence on the processes which change the landscape. Palaeochannels, for example, can be

the result of a changing pattern of sediment deposit caused by reclamation of the upstream area. Such features will be considered as representing the natural landscape, however, so as not to unnecessarily complicate this research.

The second time slice consists of features representing the prehistoric landscape. It consists of landforms and patterns, which were used during the initial occupation and reclamation of the area, from prehistoric times up until the Early Medieval period. In this time period people settled on elevated areas with easy access to water. They rarely impacted on the landscape, and man-made features belonging to this period are scarce. Furthermore, the meaning or date of their remains is not always unambiguous. Examples of this are for instance prehistoric cart tracks, which display a pattern of nearly unidirectional lines. These tracks are almost always found on ancient trading routes that were used for long periods of time. Therefore, the tracks that survive in the present-day landscape are much more recent than the original tracks that they have largely obliterated.

The third time slice includes features of the pre-industrial landscape, which evolved from the prehistoric landscape. These features originate from the Late and Post Medieval period. This period is characterised by an increase in the population, new land reclamations and the intensification of agricultural activities. These developments led to the emergence of towns and to the reallocation of rural settlements. An example of this time slice are the open field complexes found on the Late Pleistocene cover sand of the eastern Netherlands. These complexes were developed over a long period of time as a result of fertilisation whereby sods, made up of a mixture of grass, peat and dung, were regularly distributed on the land. These open fields, commonly known as *esdek* fields, appear as egg-shaped hummocks as a result of this practice.

The fourth time slice consists of features representing the industrial landscape. They were influenced by the Industrial Revolution, which took place during the 18th and 19th century. This time slice not only deals with the physical remains of industry itself, but with the concept of 'industrialisation' as a shorthand term for a package of social, economic and technological changes that impacted on the rest of society and on the agricultural landscape (Fairclough & Møller 2008). The Industrial Revolution corresponded with major changes in the agricultural sphere, through improvements in farming techniques and changes in land ownership and land division. The increasing demand for arable land and raw materials influenced the landscape too. Some features are comparable to those of the pre-industrial landscape – the third time slice – but they appear on a larger scale. An example is the reclamation of peat land, which can be recognised in the LiDAR images as elongated high and low-lying strips of land.

The fifth time slice comprises features representing the modern landscape. They appear on a very large scale and have been influenced by mechanisation, industrialisation, urbanisation and mobility, e.g. reallocation by enlargement of fields which can be recognised on LiDAR-based elevation images as a pattern of extended blocks. Later, from about the 1960s onwards, a growing concern arose as to the practice of intensive high agricultural production, usually dressed in 'green' and environmental rhetoric (Fairclough & Møller 2008). The process of improving the environment, and the tendency towards 're-wilding' it creates new landscapes (woodland, heath, green infrastructure) just as much as the intensification period did. In some areas, in more recent years, post-industrial agriculture might be recognised, for instance in 'part-time' and 'hobby' farming.

The second way of simplifying the interpretation of the LiDAR-images was to construct a legend for the LiDAR-based atlas. Although the number of distinguishing features seemed to be infinite, the problem was overcome with the use of the 'time-slice' framework. For every time slice five characteristic land-

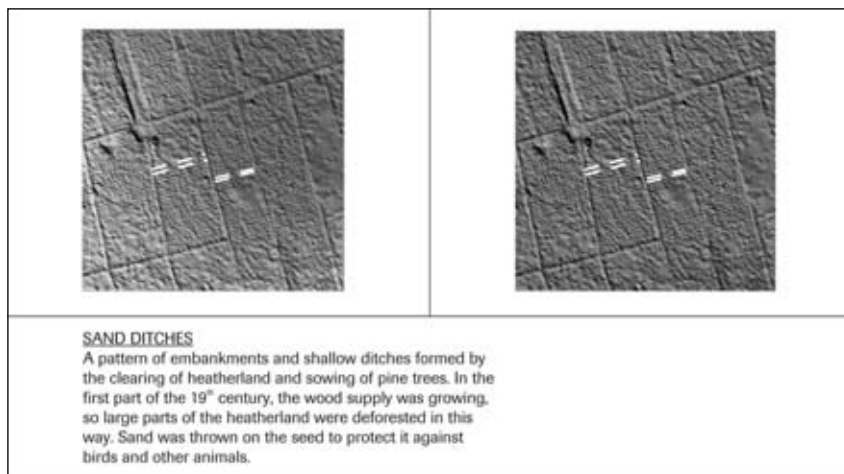


Figure 2. Example of a legend unit.

forms were selected. The legend is made up of three columns (fig. 2). The first contains a colour image of the landform, the second is a black-and-white image and the third a definition or a short description.

ANALYSIS OF THE DIFFERENT REGIONS

In order to exemplify the LiDAR-based atlas, four regions with different geomorphological, archaeological and historical-geographical characteristics were chosen (fig. 3). The four different regions were as follows:

- the area surrounding *Aalten – Lichtenvoorde*
- the *Bommelerwaard*
- the lateral moraine of *Nijmegen* and the eastern part of the *Land van Maas en Waal*
- the area surrounding *Vaassen*

All four regions were analysed systematically using the time-slice method. For each time slice three to five images were produced with different visualisation techniques, depending on the characteristics of the chosen subject. Since even the finest grained and most elegantly designed maps are only partial, two-dimensional representations of the landscape (Herring 2009), the LiDAR-based elevation images were printed alongside historical and topographical maps or photographs. These added illustrations helped to clarify the interpretation of the features identified on the images.

To explain each image, information about the geomorphological, historical or archaeological feature was added. The results were discussed with the potential users of the LiDAR-based atlas from different governmental organisations in the region.

CASE STUDY

One of the regions analysed was the landscape surrounding the village of *Vaassen*. This region is situated in the north of the province *Gelderland* (figs. 3, 4). The landscape of this region is defined by the sloping border of the *Veluwe* moraine on the western edge, a plain of melt water deposits on the central part, and

Figure 3. The location of the study areas.

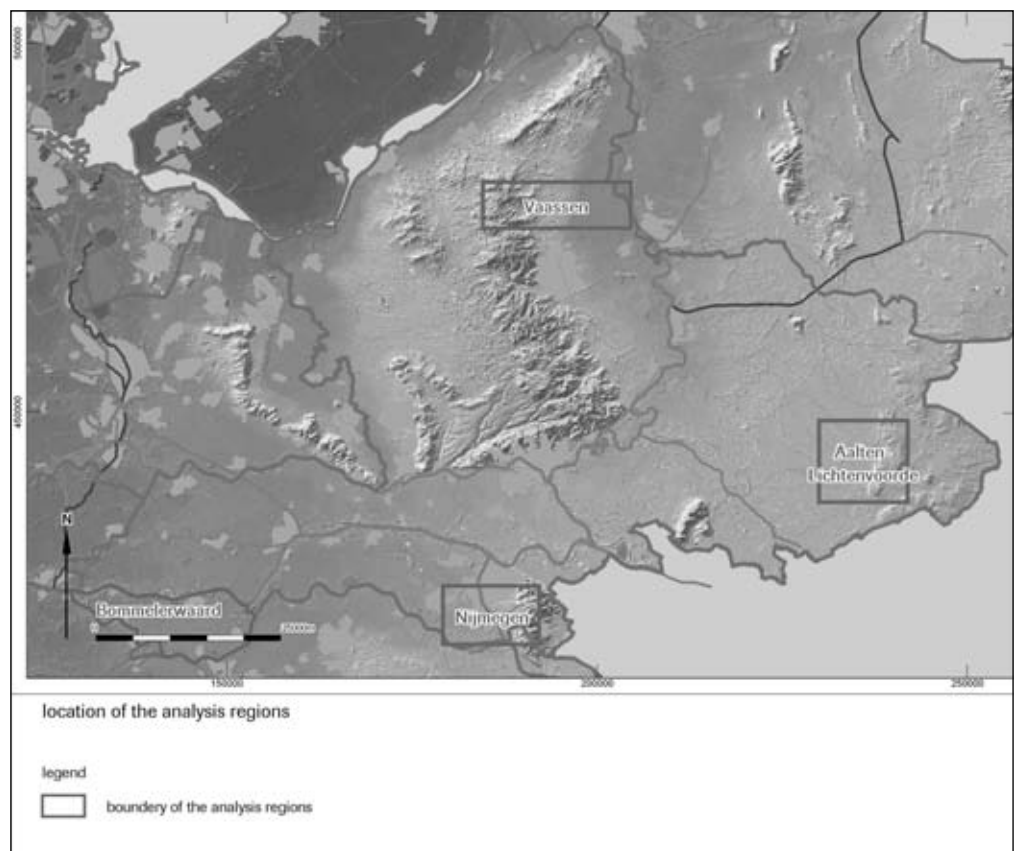
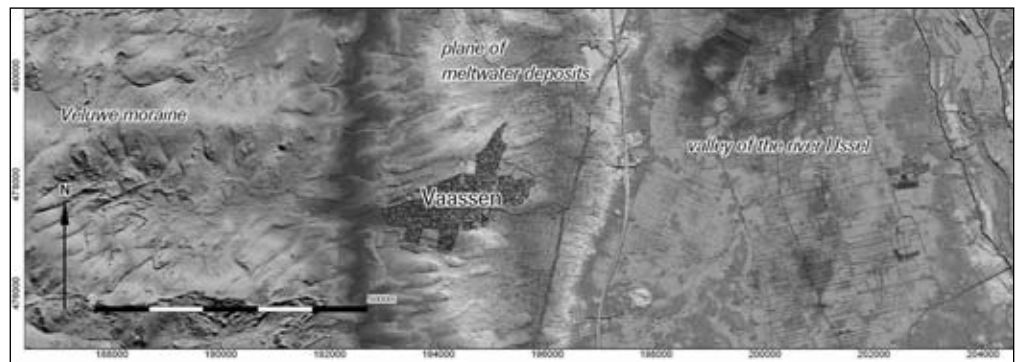


Figure 4. A DEM of the region of Vaassen. Note that the relief is exaggerated by a factor 5.4 and illuminated from the north-west.



the low-lying valley of the river IJssel on the eastern edge. The region has a varied land usage. The Veluwe moraine is, to a large extent, forested, but there is also some heathland. The plain of meltwater deposits and the valley of the river IJssel are used as farmland. Occupation is concentrated in villages on the plain.

Time slice 1: Natural landscape (figs. 5, 6)

During the cold periods of the Late Glacial, sand dunes were formed from the vast quantities of sand that were blown over the barren landscape of the Netherlands. Nowadays the dunes are vegetated, but they still stand out clearly on the LiDAR-based elevation images.



Figure 5. A DEM of a dunefield in the valley of the river IJssel. Note that the relief is exaggerated by a factor 5.4 and illuminated from the north-west. See also the full colour section in this book

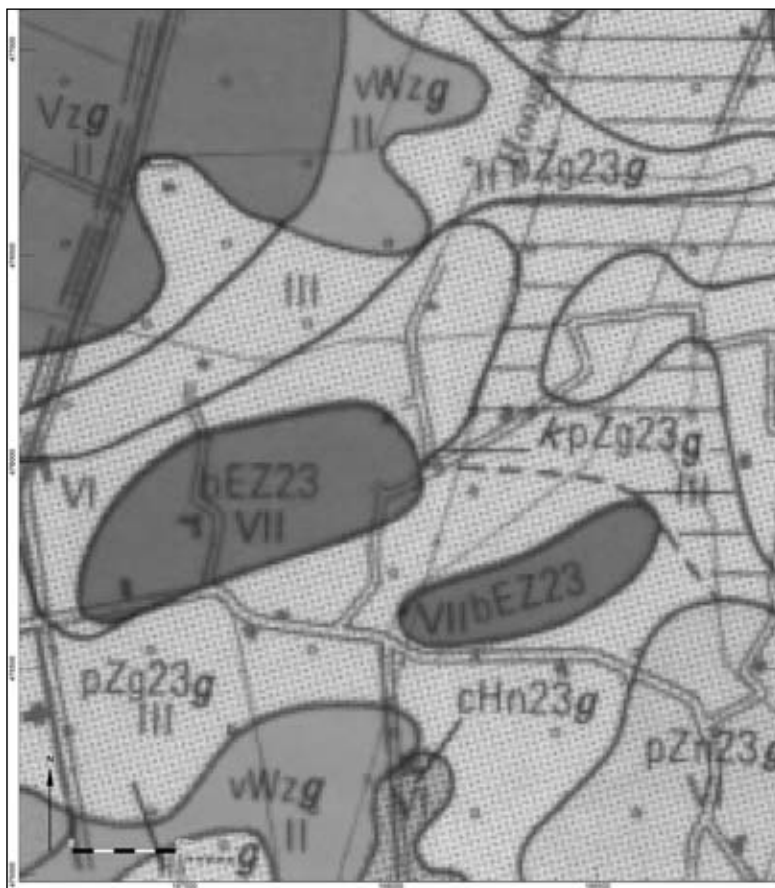


Figure 6. Comparing the soil map of the same area with a DEM, a strong relationship between topographical height and soil type can be recognised. The brown areas represent soils heightened by sods, which are characteristic for cultivated cover sand dunes. See also the full colour section in this book

Time slice 2: Pre-historic landscape (figs. 7, 8)

Celtic fields are a characteristic archaeological feature dating to the Iron Age. A Celtic field is an agricultural field system found in north-west Europe, which can be identified by the banks surrounding the parcels of arable land. These banks were formed by systematically dumping crop waste, soil and stones on the edges of each field. In the LiDAR-based elevation images the Celtic fields are clearly visible, even in wooded areas, where they cannot be identified on aerial photographs. The Celtic field system in Vaassen has a surface area of 76 ha (31 acres).

Figure 7. A DEM of a Celtic fields near Vaassen. A black-and-white colour pallet is used to emphasise the characteristic pattern of parcels and banks.

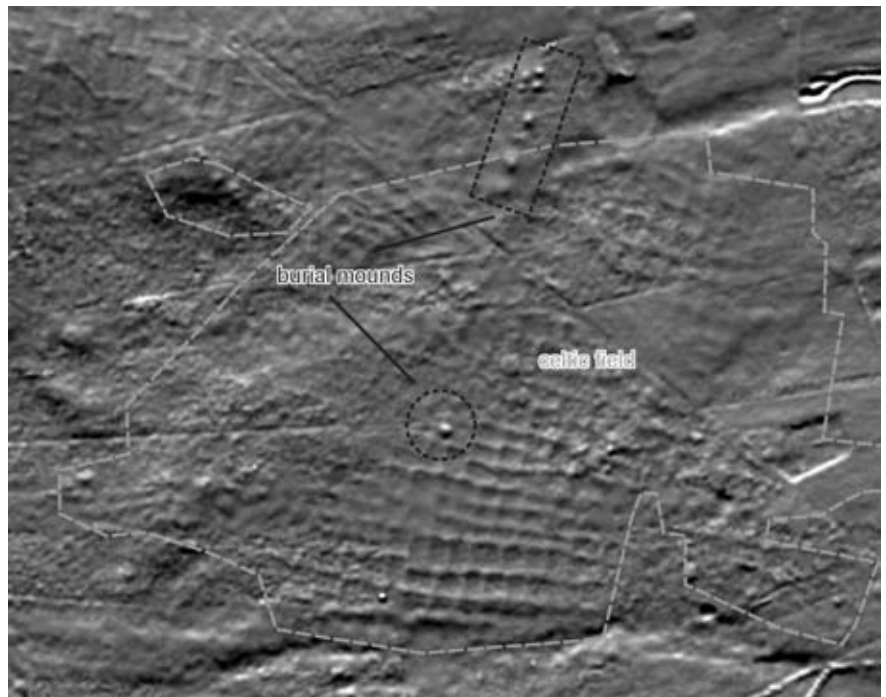


Figure 8. Height difference in the path reveal the presence of Celtic fields, but the vegetation made an overview impossible.



Time slice 3: Pre-industrial landscape (figs. 9, 10)

In the 14th century, count Reinoud van Gelre commissioned the cultivation of an extensive peat bog near the village of Nijbroek. The agreement with the owners was called a 'Cope'. A system of canals – 'weteringen' – was designed for drainage of the bog. Numerous ditches, perpendicular to the weteringen, produced long and narrow parcels of ca. 60 x 2,325m. A total of 95 farms were established in the area. The canal system is clearly visible on the LiDAR-based images.



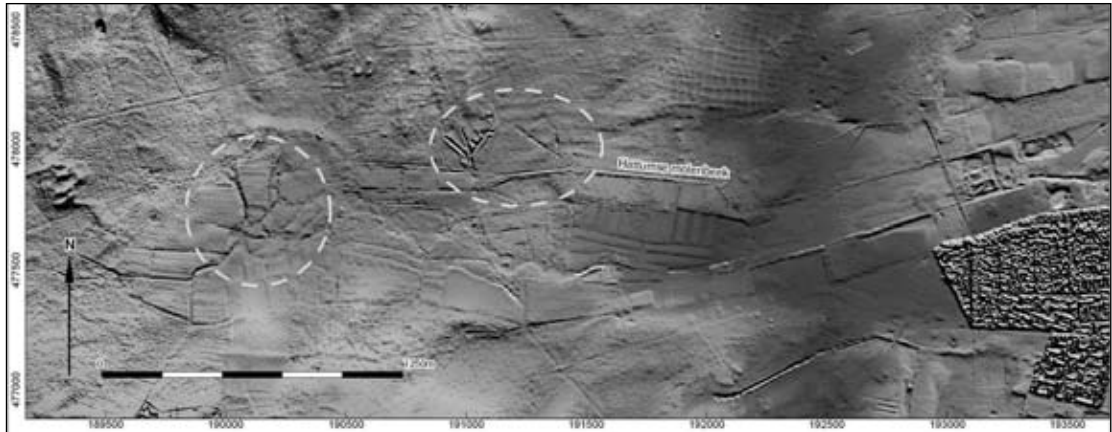
Figure 9. A DEM of the 'cope' cultivation east of Vaassen is represented as a flat and low-lying area. Note that the relief is exaggerated by a factor 5.4 and illuminated from the north-west.



Figure 10. Topographical map of the 'cope' cultivation east of Vaassen.

Time slice 4: Industrial landscape (figs. 11, 12)

To the west of Vaassen lies a network of man-made brooks; 'Sprengenbeken', which is a good example of the stream systems of the Veluwe. These were dug between the 14th and the 18th century to obtain groundwater for watermills. In Vaassen there are four of these man-made brooks with three cross-connections, some of which were constructed as aqueducts. Along the brooks as many as seventeen watermills were built.

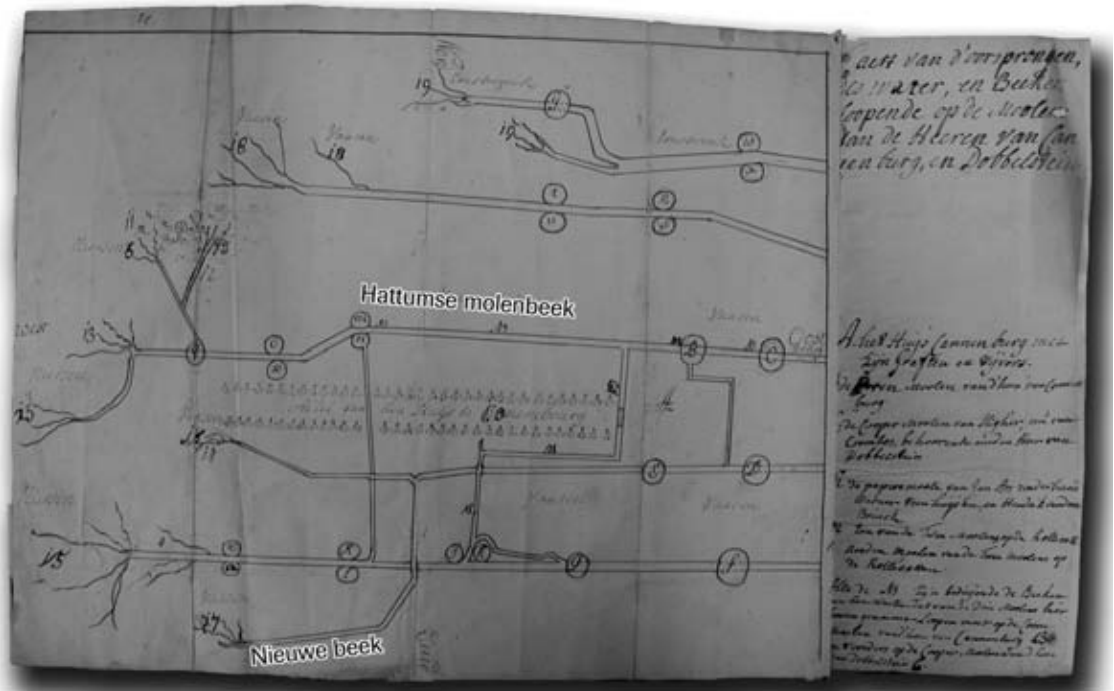


Top

Figure 11. A DEM of the stream systems near Vaassen. Note that the relief is exaggerated by a factor 5.4 and illuminated from the northwest.

Bottom

Figure 12. A topographical map dating from the 18th century gives an overview of the stream systems near Vaassen.



Time slice 5: Modern landscape (figs. 13, 14)

In 1949, fear of an invasion by the Soviet Union led to the development of a line of defensive works along the river Rhine from Switzerland to the North Sea. In the Netherlands, defence works that could inundate an area of 120 kilometres by 10 kilometres were built along the river IJssel: the 'IJssellinie'. The illustration shows the location of a floating dam. Today only the entrances of the dam remain.

Figure 13. A DEM of the IJssellinie. Note that the relief is exaggerated by a factor 5.4 and illuminated from the north-west. See also the full colour section in this book

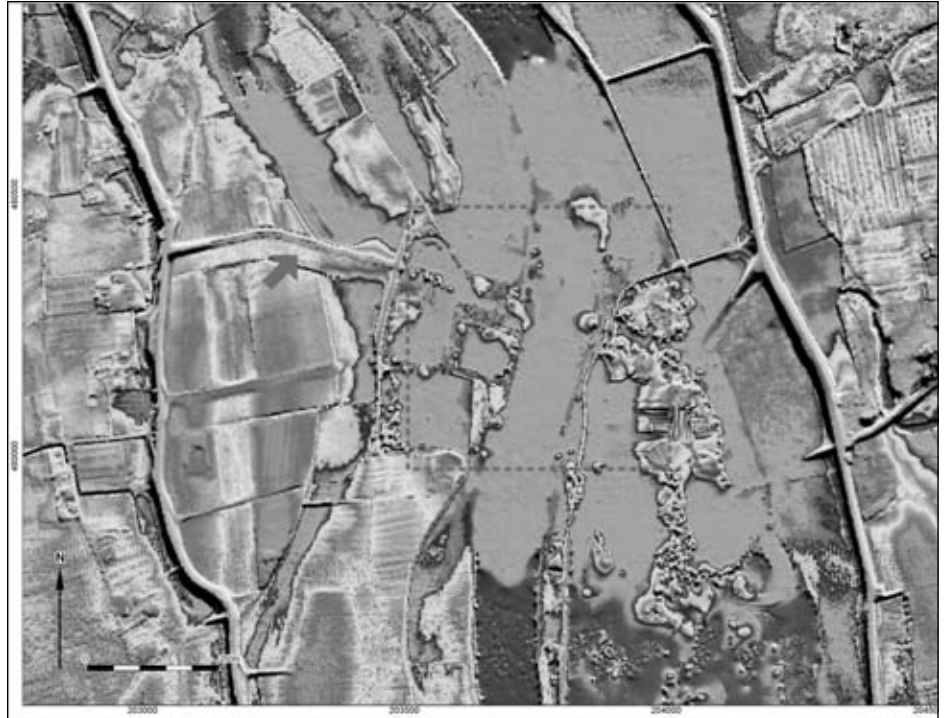


Figure 14. The IJssellinie on a topographical map from 1976. See also the full colour section in this book



Assessment of the LiDAR-based images in heritage practices

The new method of time slicing has proved to be a useful tool for time-depth analysis of LiDAR-based elevation images. During various workshops we found that these methods inspire potential users of the atlas, even those who are not very familiar with LiDAR. They discovered new landforms and patterns, which were subsequently discussed. The images can also give valuable input to (historic) landscape characterisation, which has the potential to be an immensely important resource for archaeological, historical and other heritage related research, as well as landscape and urban design. The images enhance existing input deduced from geological and historic mapping and archaeological data. An example of the use of the LiDAR-based images by urban design is the concept of a public park in a newly developed urban expansion ('VINEX wijk') to the west of the city of Utrecht: Leidsche Rijn. The park is situated at a fossil stream ridge of the river Rhine. With the help of amongst others the LiDAR-based images, the course of the channel during the Viking age, spanning the late 8th to 11th centuries, was reconstructed. The architect of the park used this reconstruction for the design of the water in the Park (www.utrecht.nl/wonenenwijken/leidscherijn/vikingrijn). By the reconstruction of the water course, a distinctive feature of the pre-industrial landscape survives in the present-day urban landscape.

Other examples whereby cultural and historic features are used in spatial development are the projects undertaken within the framework of the Belvedere Memorandum (1999). The Belvedere strategy aims to involve cultural historians early in planning processes and to provide architects, urban and rural planners and administrators with effective, usable (and understandable) information. The LiDAR-based images can be a powerful source of inspiration for spatial design within these projects.

Not only in the Netherlands, but also in other European countries, the use of the LiDAR-based images has proved a useful tool for exploring the (pre)historic landscape and landscape design. The Stonehenge LiDAR survey is a good example of this. The survey had its origin in the requirement for English Heritage to develop new approaches for investigating the historic environment (Bewley et al. 2005). As well as contributing to the archaeological record itself, there was also a need to provide an archaeological context to the proposed roadworks around the Stonehenge monument, and to the design and location of a new visitor centre. Within the framework of The Loughcrew Project, LiDAR data was used as a tool for exploring the prehistoric landscape, creating images by draping aerial photography over the LiDAR digital surface model (Shell & Roughley 2004). The ability to generate detailed visualisations and to move through the digital landscape allows us to gain a more comprehensive insight into the prehistoric landscape.

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