Combining Viewshed and LiDAR analysis to search for unknown Roman Fortifications on the Nijmegen Moraine

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1. Introduction

In 19/16 BC the Roman military laid the foundations for the oldest city in the Netherlands, by constructing a fortress on the Hunnerberg at Nijmegen (Kemmers 2005, 49). This fort was the first in various Roman military building campaigns in the area. Throughout the next four centuries, the main fortification and the surrounding *Canabae* were destroyed or relocated at various points in time (Driessen 2007, 15-6), often in attempts by emperors to regain control over this part of the empire. The various fortifications were built on the peaks of Nijmegen sandr and moraine, offering various strategic and moral advantages in the Roman army's attempt to control the area. Although large parts of Nijmegen have been excavated and several fortifications are known, the same cannot be said for the higher moraine peaks to the east of the city. It was hypothesized that these higher peaks, such as the Sterrenberg or Duivelsberg, could have been ideal locations for a Roman watchtower or other small fortification, to keep watch over the river area further to the east (Driessen 2007, 37)

This thesis has originally sprung from the idea of this 'missing' watchtower. East of the Hunnerberg and Kops Plateau, no other Roman fortifications are known. While the high moraine peaks to the east are situated increasingly further south (and thus further away from the river), watchtowers such as those at Heumensoord (Holwerda 1933, 10-23) indicate that defensive fortifications were also placed along roads in the hinterland in this area. It might be assumed that if the road to the south, even further in the hinterland, was defended by a watchtower, the road to the east would also be closely guarded, especially considering the already mentioned advantages of the peaks of the moraine.

Previous research on Roman Nijmegen is often focused on the area within the modern municipality borders. Maps of the area in Roman times invariably stretch from the Waal and *Oppidum Batavorum* to the fortification on the Kops Plateau (Driessen 2007, 25; van Enckevort and Thijssen 2014, 26; van der Heijden 2016, 88; Heirbaut and van Enckevort 2009, 9).

On the other side of the research area (Fig. 1), some new camps and auxiliary forts have also been located in the past decades, along the Rhine in western Germany, just over the country border (i.e. Bödecker et al. 2006; Brüggler et al. 2010). The discovery of new camps and forts and the seeming incompleteness of the Limes system so far suggests that we can still expect to find new military stations along the lower Rhine (Brüggler and Drechsler 2012, 36).

In between these two clusters of Roman fortifications sits the research area, largely the municipality of Berg en Dal. Compared to Nijmegen in the west, the Roman archaeology of this area is relatively poorly understood. Mentions of stray finds, older literature, and a handful of excavations indicate that this part of the moraine might hold much more Roman archaeological material than is currently known.

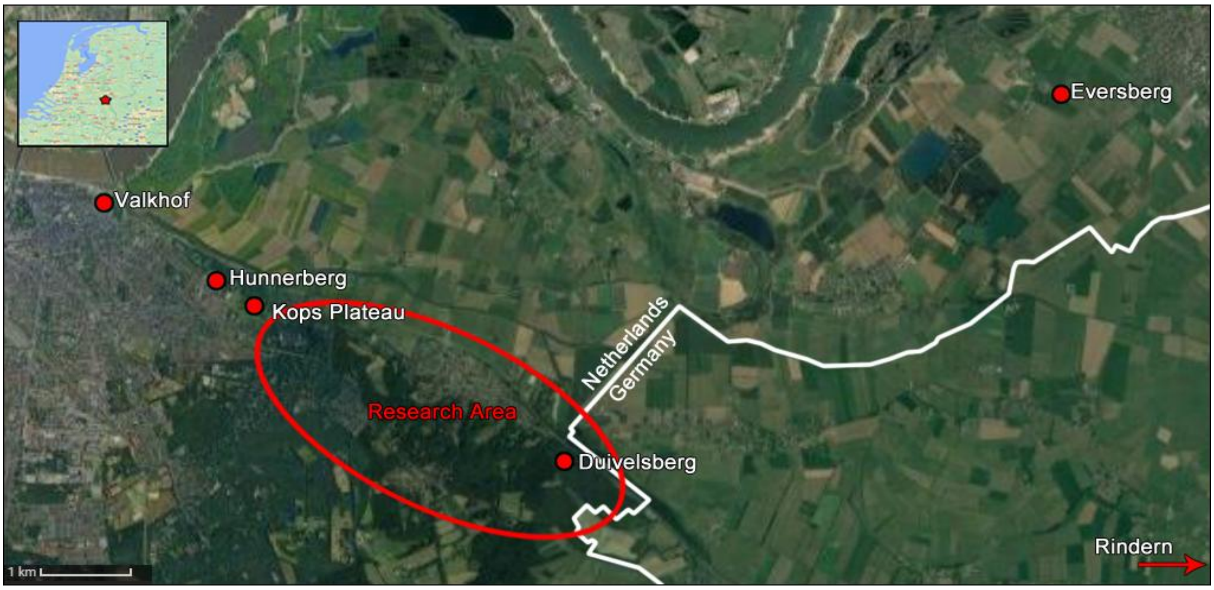


Fig. 1: Satellite image showing the research area and some of the locations mentioned in the text (edited from Google Maps).

1.2 Approach, Questions, and Methods

The overall aim of this research is thus to gain more insight into the Roman activity and its archaeological remains on the Nijmegen moraine, outside the borders of the intensively researched city.

The main objective of the thesis is to collect, compile and interpret the available data on Roman archaeological remains in the research area and predict where unknown archaeology might be located based on this. The most important data source is the available archaeological literature. Besides a review of the existing literature, a new dataset is also used. New archaeological data is usually generated through fieldwork such as excavations and surveys. A different approach is needed here to locate or identify new possible sites. For this purpose, the second dataset used is the LiDAR-based *Algemeen Hoogtebestand Nederland 3* (AHN3). The secondary objective of this research is to test the practical applicability and usefulness of this dataset and methodology in being able to locate or predict unknown archaeology.

This combination of a literature review and computational data is used to answer the main research question: *Where on the Nijmegen moraine can new, unknown Roman military structures be expected?*

To be able to meaningfully answer this question, some sub-questions first need to be answered:

> *1. How can the AHN3 dataset, using visibility analysis and visualization methods, be used to locate new archaeological sites and how applicable are these techniques to Roman military structures on the Nijmegen moraine?*
> *2. What is the nature of the evidence of Roman archaeology currently known on the Nijmegen moraine, and what are the indications that more Roman archaeological remains are to be expected?*
> *3. Where can an unknown Roman military installation be expected using visibility analysis?*
> *4. What archaeological remains are visible in the research area using LiDAR visualizations, and how are these to be interpreted?*

These questions create the backbone of the research. First, the methodological and theoretical implications of the chosen research methods, visibility analysis, and LiDAR visualization analysis, will be discussed. I will argue how these methods can be used to answer the larger research question and discuss the advantages and shortcomings. Following this is a thorough literature research of all Roman archaeology in the area. Although there are no known fortifications in the area, there are certainly indications for Roman activity. This literary evidence comes in the form of excavation reports, *Archis*, older (20th century or earlier) literature, and some amateur or stray finds. The goal of this literature research is to gain a clear overview of the current state of research. It shows not only what evidence is known so far, but perhaps more importantly what is not yet known. This includes various mentions of Roman finds without a clear origin or larger context, indications of further archaeological remains beyond the edge of excavations, and stray finds in locations where no excavation has ever taken place. It also includes speculations by other researchers about unknown Roman sites. This creates an overview of the known archaeology, but more importantly, highlights where the current knowledge could be lacking.

Next to this overview of already existing knowledge, two further methods have been chosen to detect possible new sites. Both methods are desk research based on the AHN3 dataset. The first technique is a GIS-based visibility analysis. This is used to determine the theoretically likely locations of military installations, such as watchtowers, which would have been part of a signalling system. This research method is based on a theory by Woolliscroft (2001). Woolliscroft argues that not only were Roman watchtowers part of a chain of towers and fortifications capable of sending signals (using methods such as fire or flags), but this aspect of a watchtower was also important enough that its location choice was based on it (Woolliscroft 2001, 155-7). By exploring the intervisibility from the various high peaks of the moraine, it is possible to determine which peaks are the most suitable location for a watchtower, if the goal was to visually control the surrounding area and signal to other nearby installations. A visibility analysis could thus determine or exclude locations for watchtowers, similar to what Roman engineers might have done in the field.

The final method used is a LiDAR visualization analysis. LiDAR is a relatively modern method in archaeology, which has seen increased use in locating new archaeological sites. In recent years, LiDAR data has become increasingly detailed and visualization toolboxes have been developed specifically with archaeology in mind. While the basic workflow of archaeological LiDAR research is generally the same across all research (Opitz 2017, 35), in this thesis the methods and visualization toolbox developed by Kokalj and Hesse (2017) and Kokalj and Somrak (2019) are used. The LiDAR visualizations are used to explore those areas of the moraine where further archaeology might be expected. The images are then interpreted using various secondary sources such as old topographical maps.

The combination of these three different approaches leads to an indication of where in the research area new archaeology could be expected, and what locations future excavations or other archaeological research might focus on.

2. Methodological and Theoretical Background

2.1 Visibility and Viewshed Analysis

When walking on the moraine in the present day, one can instantly imagine the value of the area from a military perspective. The high peaks provide a commanding view over the area, especially the Waal to the north. The known fortifications at the Hunnerberg, Kops Plateau, and Valkhof have this same benefit but are on a lower elevation than the peaks in the east such as the Duivelsberg. The closest known fortifications to the east of Nijmegen are a possible watchtower at the Eversberg near Millingen aan de Rijn (Heunks 2003, 29-30; Enckevort, H. van and Thijssen 2014, 32), which is situated in the lower plains at the Waal, and an auxiliary fort near Rindern, Kleve, in Germany (Bridger 2015, 960) (Fig. 1). Both are located too far away (about 11 and 16 km in a straight line respectively) from Nijmegen for direct contact and communication with the fortifications here (Kennedy 2013, 286-8 gives an average distance between two and five kilometres and gives 4400 meters as a maximum realistic viewing distance).

The concept of intervisibility and direct signalling communications between Roman fortifications was described by Woolliscroft (2010). He has demonstrated that direct communication based on intervisibility between forts, fortlets, milecastles, and watchtowers must have played an important role in the choice of location (Woolliscroft 2010, 155-7). Although it is still unsure if chains of watchtowers over long distances could ever be more effective than couriers for sending complex information, it seems the system was designed in such a way that the majority of watchtowers had a direct visibility connection with the nearest fort (Graafstal 2007, 17-8).

Woolliscroft's research was based on the known watchtowers and fortifications of Hadrian's Wall in England and the Raetian and Wetterau Limes in Germany. For the research area around Nijmegen, such a study is impossible due to a lack of known fortifications that could have played a part in such a communication system. However, considering visibility played a crucial role in the location of watchtowers, Woolliscroft's theory could be applied in reverse. Using a GIS-based visibility analysis it is possible to determine possible or likely locations of as-of-yet unknown watchtowers.

Visibility studies have a long history in archaeology before GIS-based analyses were introduced (for an overview, see Lake and Woodman 2003, 689-692). GIS-based visibility and viewshed analysis is an approach that has rapidly gained popularity in archaeology in the last decades (Wheatley and Gillings 2000, 1). A viewshed is a representation of which cells can be seen from a single specific viewpoint cell of a Digital Elevation Model (DEM) (Bourgeouis 2013, 112; see Fig. 2).

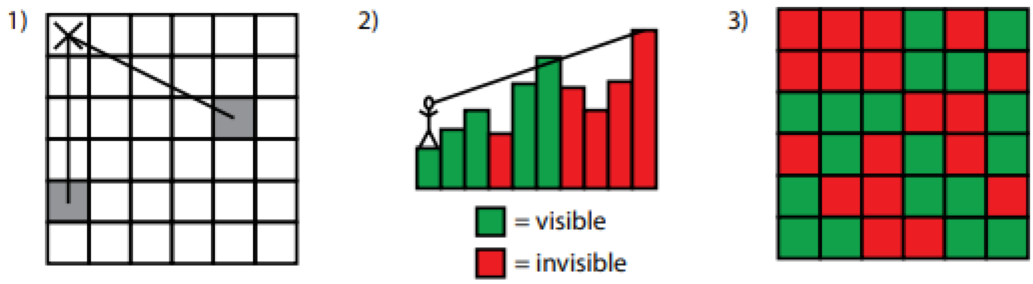


Fig. 2: A diagram of how a viewshed is calculated (Bourgeouis 2013, 112).

2.1.1 Critiques on Viewshed Analysis

As with many computer simulations, it is easy to take the result of the model for granted without understanding the underlying methodology, inherent problems, and applicability to real-life (Kennedy 2013, 281). An overview of critiques and issues on visibility analysis is given by Wheatley and Gillings (2000). The common theme for many of these points is the fact that a computer-generated model can hardly ever be compared to the real experiences of the humans we are trying to investigate. How and what a person sees is influenced by the life and experience of the individual (Kennedy 2013, 281). Changing vegetation and weather conditions or movement throughout a landscape can vastly change the perception of the viewer. A viewshed model also assumes a perfect vision 360 degrees around a point (Wheatley and Gillings 2000, 1-8).

Theoretical critiques generally revolve around the specific methodology of the analysis (Wheatley and Gillings 2000, 11-12). The standard viewshed analysis is a binary viewshed where the value of any given cell is either 1 or 0. Several other methods are commonly used to remedy the problems of a binary model and make the model more human-like, such as cumulative, fuzzy, or probable viewsheds. Binary and cumulative viewsheds generally overestimate the visibility, especially over larger distances. Methods such as fuzzy and probable viewsheds aim to counter this by effectively assigning lower visibility values to targets further away from the observer point (Murphy *et al.* 2018). Earlier methodological critiques have even called cumulative viewshed analysis a product of methodological possibilities, not rooted in any archaeological theory or real human relevance (Wansleeben and Verhart 1997, 61).

2.1.2 Applicability to Roman Defensive Systems

The question thus remains how, despite these critiques, a viewshed analysis could be used in the research of the Roman defensive system. The more practical problems are negated by the inherent nature of a system of static watchtowers:

2.1.2.1 Vegetation

Modern-day landscape and vegetation data cannot be readily used to analyze this landscape in the past (Lock and Harris 1996, 219-21) and vegetation can significantly limit the viewshed of an observer. However, watchtowers are created to tower over possible vegetation or other obstacles, or they would lose their function. Pollen analysis has shown continuous deforestation of the hills around the military structures at Nijmegen (Teunissen 1988 in Driessen 2007, 105). Vegetation was thus not an obstacle for the system of fortifications.

2.1.2.2 Mobility, Individual Perception, and Reciprocity

What a person can theoretically see from a certain point is vastly different from what they actually see. The perception of an individual changes as they move through a landscape or simply turn their head to a point of interest. Visibility studies reduce the viewer to a single fixed point, rotating 360 degrees around itself (Wheatley and Gillings 2000, 6). A watchtower, designed as a link in a signalling system, is perhaps the best approximation to such a simplified way of viewing. Towers are stationary and do not move throughout the landscape. Although the design of a fortification could allow for a 360-degree vision, it is in this case more relevant if one fortification can see, and thus send signals to, the next in line. It is thus possible to deduce the general direction of observation. This also counters the point of reciprocity, or the difference between view-to and view-from (Fisher 1996, 1298; Wheatley and Gillings 2000, 7), as it is critical for the system to work that the towers are intervisible.

2.1.2.3 Weather and Light

Changing weather and light conditions are another variable that can drastically influence what a person can see (Wheatley and Gillings 2000, 6-7). The entire system of towers would have been designed in such a way that neighbouring towers have an acceptable level of visibility to and from each other in most weather conditions, as the defensive systems must have been reliable throughout the year. In practical terms, this might mean the towers could be located closer to each other than the maximum viewing distance under ideal circumstances.

2.1.2.4 Theoretical Critiques

The practical problems of viewshed analysis can be countered by the nature of the watchtowers. A further important critique of viewshed analysis in particular and archaeological models in general, is that of technological determinism (Wheatley and Gillings 2000, 11). The ease with which a viewshed can be generated leads to the danger of accepting the model results as archaeological truth, without understanding exactly what the model is showing. Effectively the question is: how applicable is the computer model to the archaeological reality? For this viewshed analysis, a number of assumptions are made. Most importantly, it follows the assumption that the location of Roman watchtowers is determined by their intervisibility with other fortifications in a larger signalling system (Woolliscroft 2001, 155-7). The Roman military perfected its methods and strategies over the years, improving the doctrine based on military theory and the experience of past commanders and other nations (i.e. Kennedy 2013, 288; Driessen and Abudanah 2019, 457). Analysis from ancient writings shows that the location choice of Roman fortifications was relatively standardised and followed certain doctrines, as a result of military education or written manuals (Driessen 2007, 15). Within such a standardized system of fortifications determined by military doctrine, the individual soldier and the ‘human experience’ becomes less relevant. These factors make the Roman fortifications perhaps the best candidate for analysis using computer simulations. It is my opinion that a defensive watchtower, which is intended to be a part of a chain of other (intervisible) towers, is perhaps the most suitable object for GIS-based visibility analyses.

Several other case studies of viewshed analysis for Roman watchtowers have done exactly this. Bell (1998, 303-22) uses viewshed analysis to determine the probable location of a 'missing link' in a chain of watchtowers in Northern England. The technique has also been used to determine the likelihood of a hilltop in Scotland being part of a Roman signalling system (Murphy *et al*. 2018). A very early GIS study similarly suggested that the location of Roman watchtowers on the island of Hvar, Croatia, may have been chosen for their intervisibility (Gaffney and Stančič 1991). Further similar research includes Kay and Sly, 2001; Kennedy 2013 and Topouzi *et al.*2000.

2.1.3 Selected Viewshed Methods

For this research a standard, binary viewshed has been chosen. Although this technique is considered less than ideal in some cases (i.e. Murphy 2018, 122-3) compared to others such as fuzzy or probable viewsheds, the goal of this analysis makes it an acceptable choice for several reasons. The research area is relatively small compared to other visibility studies. The distance from the Hunnerberg to the German border is roughly 5km. Kennedy (2013, 286-8) gives 4400m as a maximum realistic viewing distance, while the study by Murphy (*et al.* 2018) uses 20km as a cut-off point where vision starts to become worse.

Second and perhaps most importantly, this research is not trying to establish intervisibility between known forts and towers (as these are not present in the area) but rather attempts to determine one or more probable locations, which are used as a starting point for further research. Some overestimation of visiblity does not hinder the conclusions.

2.2 LiDAR Analysis

Creating a map of archaeological expectation using indirect indicators such as geology (i.e. the IKAW in the Netherlands (cultureelerfgoed.nl)) or in this case, a viewshed analysis, often remains a theoretical application. Accurate archaeological information still has to be collected in the field, traditionally through excavations and surveys. In the past century, aerial photography has been added to this list as a valuable method of mapping archaeological evidence (Schindling and Gibbes 2014, 412). Aerial photos however are highly dependant on being collected in ‘ideal’ weather and light circumstances. Another limitation is of course modern vegetation, as tree covers completely hide the view from above (Devereux *et al.* 2005, 648-9).

Both of these limitations of aerial photography can be remedied using (airborne) LiDAR (Light Detection And Ranging), which was introduced to the archaeological community by Holden *et al.* (2002). LiDAR is an active remote sensing technology that works by creating a highly detailed point cloud of laser measurements from the air, combined with precise GPS to create a digital elevation model (DEM). The large amount of measurements taken results in highly accurate data which can be used to detect even very subtle earthworks (Devereux *et al.* 2005, 651; Schindling and Gibbes 2014, 412). Although it is sometimes claimed that LiDAR can see through vegetation, the large frequency of the scanner allows it to see *next to* vegetation and fill in the gaps in subsequent processing, which is why these measurement flights are performed in leaf-off season, to get the best possible dataset (van der Schriek and Beex 2018, 4-5). These benefits have made LiDAR an exceedingly useful tool in areas that are hard to access or difficult to survey, such as areas with dense vegetation (Schindling and Gibbes 2014, 411). Coincidentally, these areas have the advantage that they are usually undeveloped and under-researched, which gives a higher potential for new sites to be discovered (Kenzler and Lambers 2015, 73-5). Forests are also a generally stable ecosystem, with roots holding the ground together and protecting against erosion, effectively saving the archaeological record from heavy disturbances. The forests that were considered a hindrance to archaeology in the past can now be seen as beneficial (Schindling and Gibbes 2014, 413). In the Netherlands however, many forests were only planted in the 19th and 20th century AD, sometimes causing heavy disturbances themselves (Bourgeouis 2013, 46).

LiDAR is a relatively new technique that is becoming rapidly widespread in archaeology, especially in large-scale surveys, settlement patterns, or landscape research. As the technique is especially beneficial in forested areas, it has been of great use in the largely (archaeologically) unexplored (sub)tropical regions of Mesoamerica and Southeast Asia (Chase *et al.* 2017, 89-90).

In Roman contexts, airborne LiDAR has been used to locate and analyze water supply systems (Fernández-Lozano *et al.* 2015), gold mines (Matías and Llamas 2019), forts (Bernardini *et al.* 2013; Horaţiu Opreanu *et al.* 2014), temporary camps (Bödecker 2013 ;

Costa-García 2017; Costa-García and Fonte 2017), *Centuriation* (Bernardini and Vinci, 2020), roads and defensive systems (Roman *et al.* 2016).

In the Netherlands, LiDAR has been used extensively in archaeology, partially due to the easy availability of the data. Among others it has been used to locate conflict sites from World War Two (van der Schriek and Beex, 2018), prehistoric landscapes (Lambers *et al.* 2019; Amkreutz *et al.*2017; Verschoof-van der Vaart *et al.* 2020), and recently a possible Roman marching camp (Verschoof-van der Vaart and Driessen, in prep). A recent overview of more LiDAR-based research worldwide can be found in Chase *et al.* (2017).

Although the creation of LiDAR data and the development of software is a highly specialized technological field, the trend towards open access data allows the method to be incorporated into any research. Various countries have made LiDAR data freely available for anyone (Kokalj and Hesse 2017, 13) and several free online toolboxes exist which allow any interested amateur to perform the same work, using only free open access tools. This development makes it an excellent method even for researchers not specialized in digital archaeology.

2.2.1 Drawbacks of LiDAR: Interpreting the Images

"Lidar doesn't give you time. It just gives you space. Unless you have the archaeology, you cannot fully interpret it." (Arlen Chase in Daukantas 2014, 39).

This quote sums up the most prominent drawback of LiDAR visualizations. Despite the constant development in computational techniques and visualization methods, the result is always a visual representation of the palimpsest of features that cover the earth's surface (Chase *et al. 2017, 97).* The conversion of raw raster datasets to human-readable imagines through different visualization techniques always leads to a certain loss of information (Verschoof-van der Vaart and Landauer 2021, 151). LiDAR is thus best used as one element of an archaeological toolkit. To gain a meaningful understanding of any archaeological landscape, LiDAR works best when combined with data from fieldwork, laboratories, and archival sources (Harmon *et al.* 2006, 668).

Another practical issue of using LiDAR data for archaeological detection in the Netherlands that becomes immediately apparent when scrolling through any visualization is the fact that there is very little truly untouched nature left in the

Netherlands. Even the forested areas which look completely untouched on satellite images are scattered with paths, fences, small buildings, fields or other structures. Depending on the visualization used, sudden changes in heights or forest edges can also appear as straight lines which might initially be mistaken for archaeological features. These modern features can make it increasingly difficult to accurately detect archaeological remains.

2.2.1.1 Using Maps for Interpretation

I have partly remedied this issue by constantly cross-referencing the areas viewed in QGIS with maps such as Google Maps and the topographical map by *Staatsbosbeheer* (kaart.staatsbosbeheer.nl). By comparing maps like these with the LiDAR data, it becomes possible to detect which features are not part of the modern infrastructure and thus deserve extra attention.

For every noteworthy area visible in LiDAR, I have consulted archaeological reports, Archis, internet searches, and a collection of older topographical maps. These old maps have been collected, geo-referenced, and compiled into a user-friendly timeline by the Dutch government (*Kadaster),* published on topotijdreis.nl. The maps on the site cover the years from 1815 until the present day and consist of various editions of the following maps: Postroutekaart 1810, Algemene Kaart Nederland, Gemeentekaart, Kraijenhoffkaart, Topografische Militaire Kaart, RD050, Bonnebladen and, RD025 (topotijdreis.nl). The specific years and maps used have been added to the interpretations wherever relevant.

These maps are especially helpful in interpreting relatively modern remains or land use in the past two centuries, which are no longer identifiable in the field or on modern maps. It should be noted that all these tools of interpretation are best suited for relatively modern remains of which a clear origin is known. Without archaeology, interpretations of seemingly older features often remain at best a well-argued guess.

2.2.1.2 Visual Inspection in the Field

"LiDAR cannot be seen as a replacement for hands-on site surveys" (Schindling and Gibbes 2014, 422). Although new archaeological fieldwork is far beyond the scope of this research, I have inspected many of the more promising areas in the field wherever possible. This allows for interpretation of some elements in LiDAR images that are not otherwise clear on a map or photograph but might be very obvious in the field, such as pathways or stairs in a forest. These surveys however run into one of the problems which LiDAR, and aerial imaging before it, was meant to counter in the first place. Some remains are nearly impossible to detect from the ground, especially in dense forests in seasons when the ground is covered with smaller vegetation, fallen leaves, or snow. These field trips were done on sunny days between May and July 2020. While the weather and lightning conditions were optimal, the dense lower vegetation and remaining fallen leaves from the previous season could make locating the exact position of the elements on LiDAR images especially difficult. Besides this, many terrains on the Nijmegen moraine are simply inaccessible to the public, and thus could not be inspected. Exact locations and photos from these field trips have been added to the LiDAR results to the results chapter where relevant to the interpretation.

2.2.2 Different LiDAR Visualization Techniques

Visualization techniques form an important part of the current debate on the applications of LiDAR in archaeology. There are a large variety of computational techniques that can be used to visualize the raw data of the DTM. Each technique has its own strengths and weaknesses, depending on the type of terrain under investigation and the nature of the archaeological remains (Kokalj and Hesse 2017, 14-27, see Fig. 3).

	mining pits	former field boundaries	burial mounds	terraces	hollow ways	ridge and furrow
shaded relief	-	-	+	o	o	-
slope	-	o	o	+	+	++
principal components analysis	-	-	+	o	+	++
trend removal and LRM	++	+	++	+	+	++
sky-view factor	++	+	o	++	++	++
openness	++	+	+	+	++	++
local dominance	++	++	++	+	++	++
cumulative visibility	-	-	+	o	+	o
accessibility	-	o	-	o	o	-
multi-scale integral invariants	+	+	o	+	+	+
Laplacian-of-Gaussian	+	+	++	+	+	++

- not suitable; o indistinct; + suitable; ++ very suitable

Fig. 3: Suitability of visualization techniques for representing selected archaeological topographical features (Kokalj and Hesse 2017, 35).

Hillshading (also known as relief shading or shaded relief) is the most common visualization method used in archaeology because of its straightforwardness and ease of interpretation (Chase *et al.* 2017, 92). A hillshade calculates the angle between the surface area and a fictive light source from a single direction and inclination. A simple hillshade from a single direction is usually the first step when looking at LiDAR data because it represents the most natural and familiar overview of an area (Kokalj and Hesse 2017, 34). Although this technique can be used even by an untrained eye to detect structures, there are some drawbacks. Because the light comes from a single direction, areas facing towards or away from this direction will turn out extremely bright or dark, making it impossible to see any details. Linear structures lying parallel to the direction of illumination also become invisible. These problems can be partially remedied by performing a hillshade from multiple directions, either one by one (significantly increasing the time needed to analyze the results) or by combining these in a single multidirectional hillshade image (Devereux *et al.* 2008, 470-2; Kokalj and Hesse 2017, 14).

New visualization techniques have been developed specifically with archaeology in mind, such as principal component analysis of hillshades (Devereux *et al.* 2008, 471-2), slope analysis (McCoy *et al.* 2011, 2148-9), local relief model (Hesse 2010, 68-71) or Sky-

View Factor (Zakšek *et al.* 2011, 401-7). The choice of visualization method is dependent on the type of landscape, the shape and size of archaeological features being sought after, and personal choices by the researcher (Kokalj and Hesse 2017, 34-7). Of all new visualization techniques, Sky-View Factor has generally become the method of choice in archaeology (Chase *et al.* 2017, 93). It calculates the percentage of the sky visible from every pixel (Fig. 4) and assigns a greyscale value on a range between 0 and 1. Thus, a high peak will have a result close to 1 and is brightly illuminated in the image, while deep valleys are close to 0 and are coloured dark (Zakšek *et al.* 2011, 401-3).

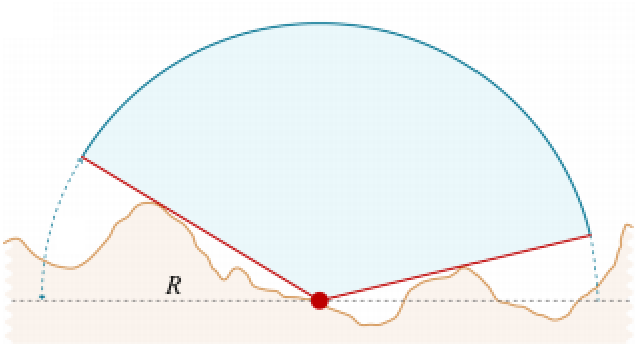


Fig. 4. Diagram illustrating the calculation of Sky-View Factor (edited from Zakšek *et al.* 2011, 403).

2.2.3 Selected Visualization Methods

To determine the best visualization choice, the most important considerations are the characteristics of the archaeological features being sought after, such as size, shape, and convexity vs. concavity (Kokalj and Hesse 2017, 32). It is thus essential to determine what archaeological features could be expected in the research area.

For the purpose of locating unknown Roman structures using LiDAR, there are several types of features that could be expected in the research area: watchtowers or similar small fortifications, roads, or marching camps. All three of these have been found with LiDAR in other parts of the world (Bödecker 2013; Horaţiu Opreanu *et al*. 2014; Bernardini *et al.* 2013; Roman *et al.* 2016; Costa-García 2017). In the *Uedemer Hochwald* near Xanten, Germany, several of these camps have recently been discovered using LiDAR and aerial photography (Bödecker 2013). As Nijmegen and Xanten share a similar development and function, it seems unlikely that these marching or training camps did not exist at all in the Nijmegen area. One of these camps, the second in the Netherlands, has also recently been discovered using LiDAR near Ermelo in the Netherlands (Verschoof-van der Vaart and Driessen, in prep).

The remains of these various features which could still exist in the current landscape, have been undiscovered so far and are visible in LiDAR, are the ditches and earthworks around the fortifications and the roads. Fig. 3, using former field boundaries and hollow ways as comparable shapes, suggests sky-view factor, openness and local dominance are the preferred visualizations.

A second consideration is the landscape itself. Different terrains and research questions require different types of visualizations (Kokalj and Hesse 2017, 35). The moraine of Nijmegen and its surroundings can be considered a mixed landscape or complex topography, consisting of both flat peaks and plains and steep slopes and elevations. As seen in Fig. 5 below, it is recommended to always start with a hillshade (shaded relief) for a 'natural' overview of the area, followed by Sky View Factor (SKF) and Local Dominance for complex topography. These two methods are thus the most suited for locating Roman ditches and roads in the research area.

flat terrain	Shaded relief (sun elevation < 10°)	Trend removal / LRM (filter radius ~ 20 m)	Local dominance (radius 10-20 m)	Openness or MSII (radius 10 m)	
gentle slopes	Shaded relief (sun elevation ~ 30°)	Sky-view factor (radius ~ 10 m)	Trend removal / LRM (filter radius ~ 20 m)	Local dominance (radius 10-20 m)	Openness or MSII (radius 10 m)
moderate slopes	Shaded relief (sun elevation ~ 45°)	SVF (& LoG) (radius ~ 10 m)	Trend removal / LRM (filter radius ~ 20 m)	LD (&LoG) (radius 10-20 m)	Openness or MSII (radius 10 m)
complex topography	Shaded relief (sun elevation > 45°)	SVF (& LoG) (radius ~ 10 m)	LD (&LoG) (radius 10-20 m)	Openness or MSII (radius 10 m)	

Fig. 5: Matrix for the suitability of visualization techniques for selected archaeological relief features in different topographic settings. Recommended methods from left to right (Kokalj and Hesse 2017, 34).

3. Research Area Background

Fig. 6: Topographical map of the research area (Edited from Google Maps).

This study focuses on the moraine on the eastern side of Nijmegen, which is currently the municipality of Berg and Dal. The research area stretches from the most eastern known Roman fortification on the *Kops Plateau*, to the Dutch-German border (Fig. 6).

3.1 Geology and Landscape

The area comprises the peaks and valleys of the moraine of Nijmegen, which was formed in the Saalien glacial. After the ice retreated, the Rhine and Meuse rivers cut through it, creating an isolated moraine. In the later Weichselien, the rain and meltwater eroded the frozen ground, creating the current landscape with high variation between peaks and valleys (Berendsen 1997, 45-7).

The (former) municipality of Ubbergen created a map (Fig. 7) of archaeological expectations largely based on geological units. It shows the highest archaeological expectations (orange) are on the relatively flat moraine peaks and the lower areas north of the moraine.

The forests on the moraine are a climatic climax community. The deep roots act as a stabiliser for the soil, which explains the lack of stray finds on the peaks and platforms.

Surface finds should most likely be expected at the bottom of the slopes after heavy rainfall or other disturbances. This point is further exemplified by the roman building remains found at the bottom of the Musschenberg after a part of the hill collapsed (Archis3 nr. 2784581100), or a large amount of Roman pottery found by amateur archaeologists at the bottom of the Hunnerberg, after trees were cut for a building project (Hendriks 2019).

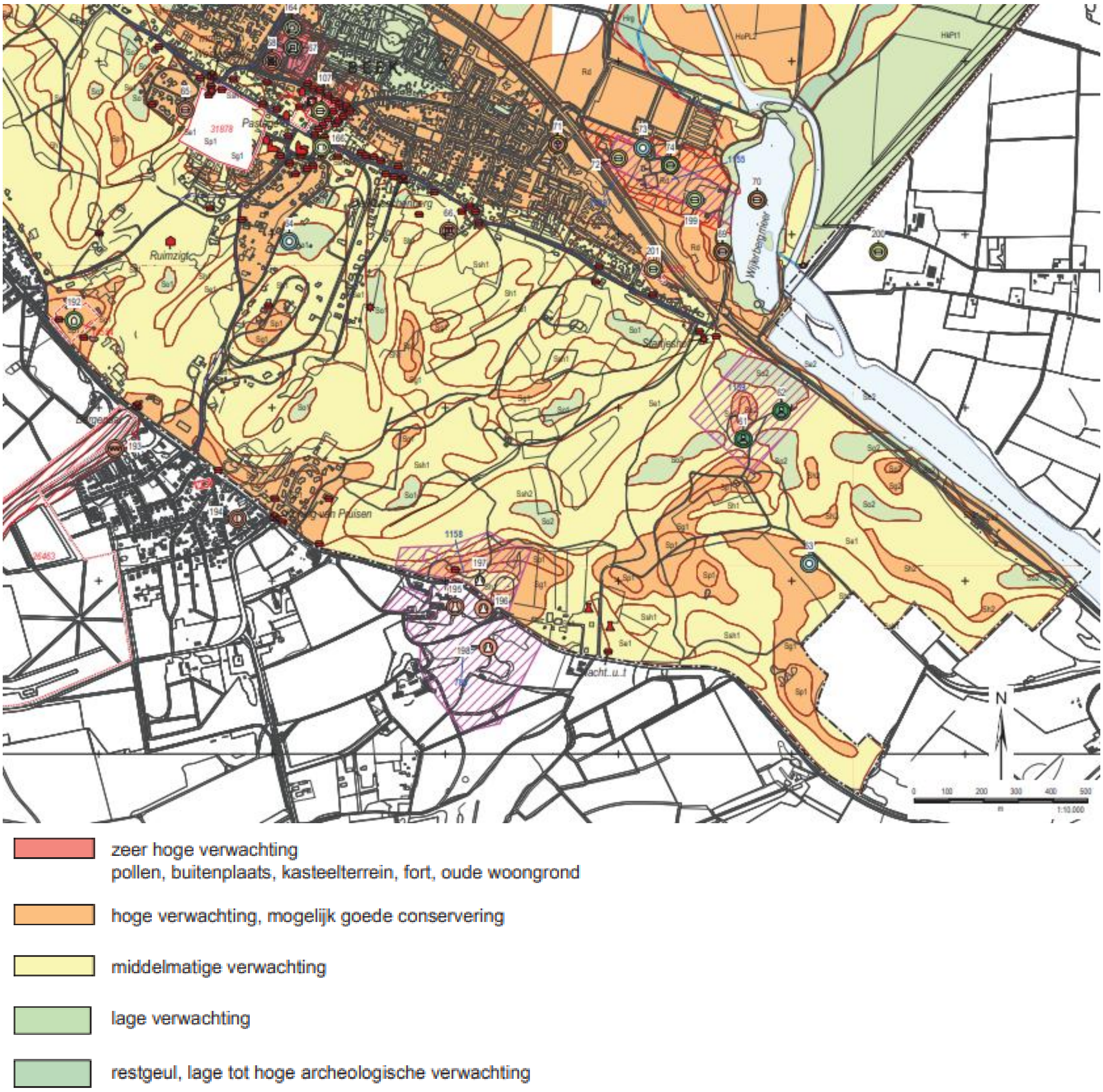


Fig. 7: Cut-out of the Archeologische Beleidsadvieskaart 2010. The full sized map can be found on the website of the municipality Berg en Dal (Bergendal.nl).

3.2 Land Use

In the research area are the towns of Ubbergen, Beek, and Berg en Dal. The rest of the research area consists largely of forests and some agricultural lands. Parts of the less densley populated areas on the moraine consist of villa or manor estates built in the late 19th or early 20th century. The publicly accessible areas are forests, protected by Staatsbosbeheer. As archaeological research in the Netherlands is often done before building projects or other ground-disturbing projects, these areas have been largely ignored archaeologically in the last century.

3.3 Historical Context of Roman Nijmegen

The Roman army first settled in Nijmegen in 19/16 BC, in a fortress on the Hunnerberg (Kemmers 2005, 49), which was abandoned soon after in 12 BC, in favour of a much smaller but monumental *Castellum* on the Kops Plateau, 400 meters to the east (Driessen 2007, 28; van der Heijden 2016, 87-8; Heirbaut and van Enckevort 2009, 8-9).

Around 10 AD the fort on the Kops Plateau was enlarged to 4.5ha with a single ditch, but the ditch and wall at the northern side are removed. Finds outside the fort indicate the presence of cavalry auxiliary units during this time. In 35/40AD the fort is made smaller again. In this last phase, cavalry units were stationed inside the fort (Driessen 2007, 64-6).

From 10 AD (possibly in the same building program as the enlargement of the Kops Plateau) until the first half of the 1st century AD, a wood and earth fortification was located on the Trajanusplein. This is one of several smaller fortifications that existed in the first century surrounding the fort on the Kops Plateau and the still-occupied north-eastern corner of the Hunnerberg (van Enckevort and Thijssen 2014, 26). Other fortifications might be located on the Oranjesingel and the Koningsplein (van Enckevort *et al.* 2011, 68). There are multiple interpretations for the function of this fortification. The units stationed here could have been used in a protecting and controlling role for *Oppidum Batavorum* or used during Germanicus' invasions across the river. It seems likely that after Germanicus' campaigns and new policies by *Tiberius*, the lowered threat level made the fort obsolete (Driessen 2007, 81; van Enckevort *et al.* 2011, 68), coinciding with the smaller third phase of the Kops Plateau.

The Kops Plateau was abandoned after the Batavian revolt in 69 AD and replaced by a new 16ha *Castra* on the Hunnerberg. Originally a wood and earth fortification, around 100 AD parts of this fort have been rebuilt in stone. Throughout the 2nd century AD, the fort was manned by only a smaller garrison for maintenance and repairs. The Hunnerberg was completely abandoned in 170-180 AD (Heirbaut and van Enckevort 2009, 9-10 ; van Enckevort and Thijssen 2014, 31).

Near the end of the 3rd century AD, a new fortification was built on the Valkhof plateau to the west, possibly as part of an attempt to reconsolidate Roman power in the area. The stone building phase of this fort is closely linked to similar building activities at the fort and bridge near Cuijk to the south (van Enckevort and Thijssen 2014, 34-5). The new defences in the surrounding area at the end of the 3rd and start of the 4th century also include a watchtower along the road at Heumensoord (Holwerda 1933, 10-23), a *villa* terrain repurposed as a watchtower at the Tienakker in Wijchen (Heirbaut and van Enckevort 2011, 49-54, 150-3) and a possible Roman fortification at Eversberg, Millingen (Enckevort, van and Thijssen 2014, 32), although the exact function of this building is unclear (Heunks 2003, 29-30). In the 4th and 5th centuries, the Roman territory along the Rhine came increasingly under the control of various Germanic armies until the eventual formal collapse of Roman influence in the area in 457 AD (van Enckevort and Thijssen 2014, 33-5).

The Roman military history of Nijmegen thus consists of several phases of building, abandonment, and rebuilding. A possible new watchtower on the moraine could be linked to any of these building phases. While there is evidence for multiple new watchtowers in the late 3rd and early 4th century AD, it is likely the Roman army already set up some system of control over roads and rivers during the earliest occupation period. Driessen (2007, 37) suggests an Augustean date for these hypothetical watchtowers, which also coincides with Woolliscroft's conclusion that lines of visibility were already an important consideration in the location forts along the early 1st century *Raetian Limes* (Woolliscroft 2001, 155-7).

4. Archaeological Evidence

The following chapter is a collection of the known Roman archaeology in the research area. This data has been collected first through a literature study of excavation reports, Archis, and various older publications which mention stray finds in the area. I have also contacted the local group of amateur archaeologists (AWN Regio Nijmegen), who have published various stray finds in yearly reports, as well as a number of larger publications and overviews of existing literature. Finally, I have contacted the local foresters (*Staatsbosbeheer)* and had impromptu meetings with various local residents about possible stray finds which might have never made it into the archaeological literature or databases such as Archis and Numis. These interviews have however not lead to new data.

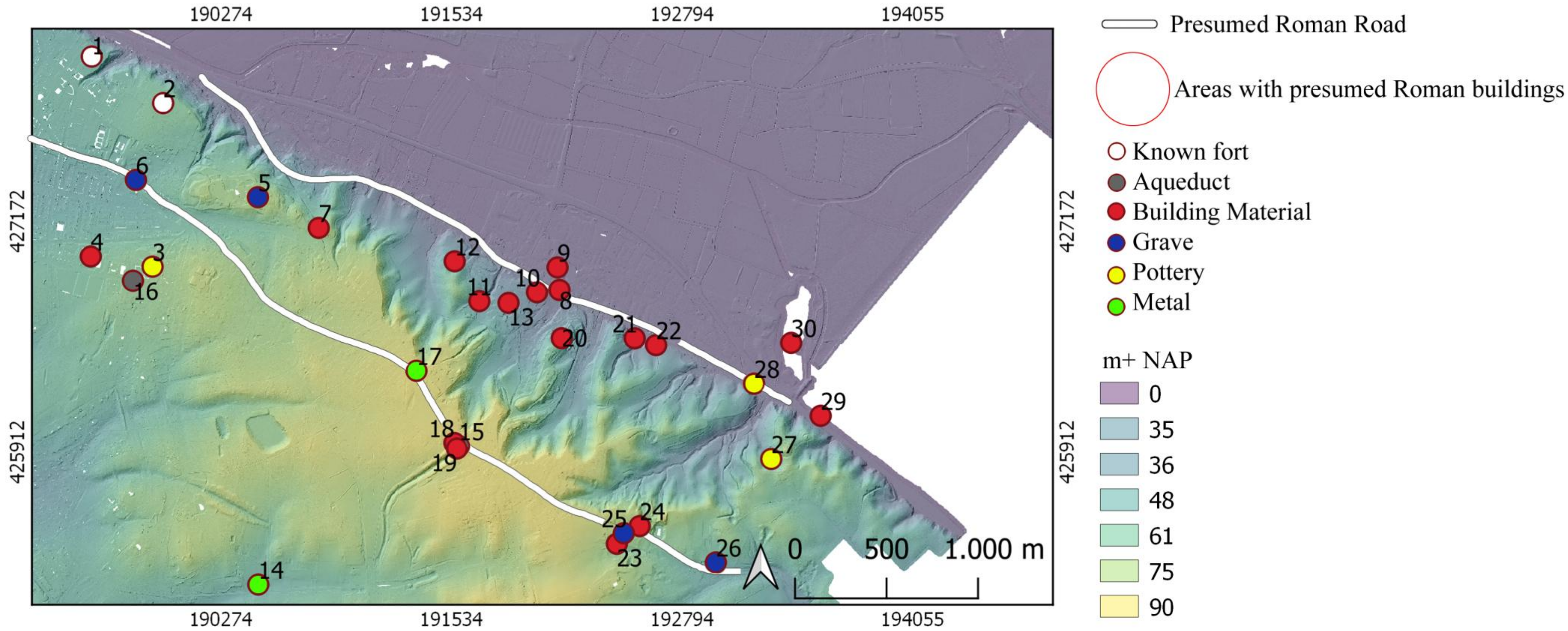
The result is an overview of all locations with known Roman archaeology, sorted topographically from west to east. This overview shows the current state of research and possible gaps in our knowledge, showing not only what is known but also giving an indication of where unknown Roman archaeology could be expected. Furthermore, the locations determined in this part of the research are used as a starting point for the viewshed and LiDAR analysis in the next chapters.

4.1 Overview

Many of the finds mentioned are at best a handful of pottery or roof tiles. Only in some areas where more extensive research has taken place, such as the Kwakkenbergweg or De Geest, there is more direct evidence of building activity. All buildings and pottery are located along the Rijksstraatweg and Oudekleefsebaan, which are suspected to follow the same route as the Roman roads. The presumed *villae* are largely located on the lower northern peaks, along the Rijksstraatweg. The building materials are fairly evenly spread from west to east, although a large concentration is found in the town of Beek (nrs. 8-13 and 20-22, Fig. 8).

All building material is usually interpreted in the literature as belonging to a *villa*. A possibility is that one or more of these buildings could have a military nature instead. A single stamped *tegula* at De Geest (van Enckevort and Tunker 2013, 25-6) shows the 10th legion was in some capacity involved in the building projects. Another possibility is that buildings, which were originally created as *villae*, have been repurposed into military buildings. This seems to be the case at the Tienakker in Wijchen, to the north-east of Nijmegen, in the fourth century AD (Heirbaut and van Enckevort 2011, 49-54, 150-3). In the case of the Tienakker, the claim by the excavators for the military use of the terrain is a new ditch surrounding the building, traces of similar ditches could possibly be located around other known *villa* terrains using LiDAR. The finds, especially the tuff stone, in the waters of the Wylermeer and Wylerbergmeer are reminiscent of those dredged up at De Bijland, which has been interpreted as the location of a small fortification (Heunks 2010, 6-7). The building remains on the higher areas of the moraine are related to a temple and the military pottery factory.

The exact location of the original buildings can be difficult to determine. While some of the older literature simply has no accurate location written down, even at modern excavations with clear documentation, many finds appear to have eroded from the moraine. For example at the Ubbergseveldweg 162, near the Hengstberg and Kops Plateau; "*the fragmented nature of the pottery finds, the slope of the ground and the significant differences in the thickness of the layers suggests that the soil was eroded from another area, possibly from the higher moraine peaks*" (Daniël and Diepeveen 2010, 13). The Building remains near the Ravenberg, Musschenberg, and Sterrenberg are all mentioned to have originated from the higher peaks. The building material found in the Wylermeer and Wylerbergmeer could have similarly have originated from the nearby Duivelsberg area.



1: Hunerberg
2: Kops Plateau
3: Sophiaweg
4: Kwakkenbergweg
5: Hengstberg
6: Berg en Dalseweg
7: Jan Dommer van Poldersveldtweg
8: Rijksstraatweg 191
9: Waterstraat
10: Kerkberg
11: Kastanjedal
12: Ravenberg
13: De Geest
14: Meerwijkselaan
15: Kerstendal
16: Kwakkenbergweg
17: Stollenbergweg
18-19: Kerstendal
20: Sterrenberg
21: Musschenberg, Rijksstraatweg 154
22: Rijksstraatweg 166
23: De Holdeurn (Factory)
24: De Holdeurn (Oudekleefsebaan)
25: De Holdeurn (Grave)
26: Minicamping Wylerberg
27: Duivelsberg motte
28: Hermelijnstraat
29: Wylermeer
30: Wylerbergmeer

Fig. 8: Map of the research area showing all locations of archaeological remains mentioned in the following chapter (Image by author).

4.2 Roman Archaeological remains per Region

Kwakkenberg

Near villa Westerhelling, on the Kwakkenberg (Sophiaweg 4), several Roman pottery sherds and large pots (including an amphora) were found, but the area was not excavated (Daniëls 1955, 289-91). Recent excavations along the Kwakkenbergweg have found no Roman features but several sherds of Roman pottery, some building material such as tegulae and two Roman coins dating to the 1st century AD (Diepeveen 2011 6-9 ; Oosterbaan et al. 2010, 7-18 ; Harmsen and Reijnen 2013, 10-2 ; Tunker et al. 2012, 9-15). The majority of these finds are located on the eastern side of the terrain, towards the aforementioned villa Westerhelling (Tunker et al. 2012, 16).

Hengstberg

Several stone coffins and other roman finds are known from the forest on the Hengstberg (Daniëls 1955, 287-9). The area on and around the Hengstberg has been used as a graveyard by *Legio X* from 70 – 110 AD (Magnée-Nentjes *et al.* 2010 17-48). This graveyard extended further to the south and west, as other graves have been found near the Berg en Dalseweg 333 – 338 (Daniël and Smits 2010, 6-14; De Roode 2014, 11-7).

Near the Jan Dommer van Poldersveldtweg (In between the Hengstberg and Boterberg) Roman *tegulae* have been found which are interpreted to have belonged to a *villa* (van Enckevort and Tunker 2013, 6 ; Archis3 nr. 2758986100).

Ravenberg & De Geest

Roman building material between the Rijksstraatweg 189 and 191 indicates a Roman building from one of the nearby peaks at the southern side of the road, likely from De Geest or the Ravenberg (Harmsen and Kuppens 2011, 15). Building materials have been found in several areas surrounding this terrain, such as at the Waterstraat (Zee 2009, 51), Kerkberg (Flokstra and Hesseling 2014, 3) the Kastanjedal (van Enckevort and

Tunker 2013, 3) and on the former camping site on the Ravenberg (Archis3 nr. 2705249100). All these finds point to a Roman *villa* on De Geest and/or the Ravenberg.

Excavations at De Geest have revealed a building with a cellar seemingly belonging to a *villa* complex. One *tegula* fragment with a stamp from *Legio X* shows the army was involved in this building. It is assumed more Roman remains can be found to the south along the Kastanjedal. These *villae* were presumably (secondary) homes of the elites from *Ulpia Noviamagus*, instead of large agricultural locations like other known *villae* (van Enckevort and Tunker 2013, 25-6).

Meerwijk

A bronze neck ring and carry bag were excavated near Meerwijk on the higher forested plains (Daniëls 1955, 286).

Kerstendal

The large earthworks in the area such as the Kerstendal and Louisedal were likely intended to be used for a Roman aqueduct to supply water to the Castra on the Hunnerberg (Schut 2005, 58-61). There is however only very limited archaeological evidence to prove this function. It is even questionable if the aqueduct was ever finished before the 10th legion left the area (Schut 2005, 76). An excavation at the Kwakkenbergweg 52 unearthed a ditch which could be linked to the water supply (Magnée-Nentjes and Wildenberg 2010, 9).

In 1806, Near the crossing of the Stollenbergweg and Oude Beekse Holleweg some Roman silverware with pictures of the goddess Cybele was found. Several authors (i.e. Ten Hoet 1826, 45; in de Betouw 1804, 6) mention the remains of a temple to Mercurius, still visible in the 17^{th} century, on the nearby *Vestal hill*, (incorrectly) named after these depictions. The location of this hill is described as being near the top of what is now known as the Kerstendal and the location of the Roman Aqueduct, north of De Meerwijk and next to the Kleefschen weg (Daniëls 1955, 291). Coring research in 2011 has attempted to locate this temple on several areas around the Kerstendal. No clear indications of buildings were found in these corings, but the authors acknowledge that these could have been eroded into the valley over time. Several roof tiles could indicate a building in the direct area, but the nearby pottery factory at the Holdeurn means that these could also have ended up 'randomly' in this area (Schut *et al.* 2011, 15; 38).

Sterrenberg

At the bottom of the 'Donderberg', a large amount of tuff stone was found. Daniëls considers that this Donderberg is probably the current Sterrenberg (Daniëls 1955, 294). Modern monument *huis de Donderberg* is located north of the Sterrenberg, on the Rijksstraatweg 132.

Musschenberg

The corner of a Roman building was uncovered on the *Musschenberg* in 1926. Parts of the wall, a repaired floor, and roof tiles were found. The location is given as just south of the German border post, on the location of a fruit tree orchard. Another description of the location is roughly 400 meters from the Dutch-German border, in a hill along the road from Nijmegen to Kranenburg, 8 meters above the street level (Gerhard Pauli in ten Hag *et al.*2020, 44-5). In 1938, a mention was made of Roman building material found near the German border post, after a part of the moraine collapsed, interpreted as belonging to a villa from the north-eastern side of the hill (Kersten 1940, 343).

The two mentions of the building remains are, based on an archival reconstruction of the locations mentioned, the hills just north of the Sterrenberg and Vossenberg, or south of Rijksstraatweg 154 – 166. (Ten Hag *et al.* 2020, 46). These are perhaps the same building remains mentioned by Daniëls (1955, 294) at the bottom of the Donderberg. These are also known in Archis3 under nr. 2784581100, which mentions Roman building materials found after a part of the hill collapses. It is also mentioned in Archis that no known archaeological research has been done on the hill. Perhaps the German finds from 1926 were not known by Dutch authorities, or the building corner was found in a different part of the terrain.

De Holdeurn

Areas of the Holdeurn pottery factory have been excavated (Holwerda and Braat 1946), but recent research has shown that the area in use by the Romans was larger than what was excavated, and more buildings or Roman material should be expected, especially towards the west and on the northern side of the road(de Groot *et al.* 2010 ; van Diepen and Polak 2009, 24-30). Unknown buildings (including fortifications) are thus still a possibility here. Archis3 nr. 3185174100 shows some Roman material north of the road. Near the Holdeurn, a roof-tile tomb grave was found in 1958 (van Agt 1958, *103), perhaps belonging to the same graveyard as mentioned by Rosenkranz (1939, see below).

Duivelsberg

Several finds are mentioned around the Duivelsberg. Near the Theunissen pottery factory (not to be confused with the Roman factory in the same area), a walled Roman grave or graveyard was found around 1900. In 1910 several urns were found around the Duivelsberg, but no further information about these is given. Cover stones from urn graves have also been found on a terrain near the Medieval mounds (Rosenkranz 1939, 447-8, see also Fig. 9A-B). This graveyard seems entirely unknown in Dutch sources. These terrains are between what is now *Minicamping Wylerberg* and restaurant *De Duivelsberg*. A medieval castle was built on the artificial mounds on the Duivelsberg. Although only Medieval finds are known on this location in Archis, it is not altogether unlikely that the mound was built over older Roman fortifications. Defenders of the area in both periods would have noticed the strategic advantages of this location. Some *Terra Sigilata* sherds have also been found in the forests around the Duivelsberg by Mark Driessen in the late 1970s – early 80s (Driessen, Pers. Comm.). North of the road, two Roman pottery sherds dated between 70 – 270 AD have been found near the Rijksstraatweg / Hermelijnstraat (Wildenberg 2008, 6-8).

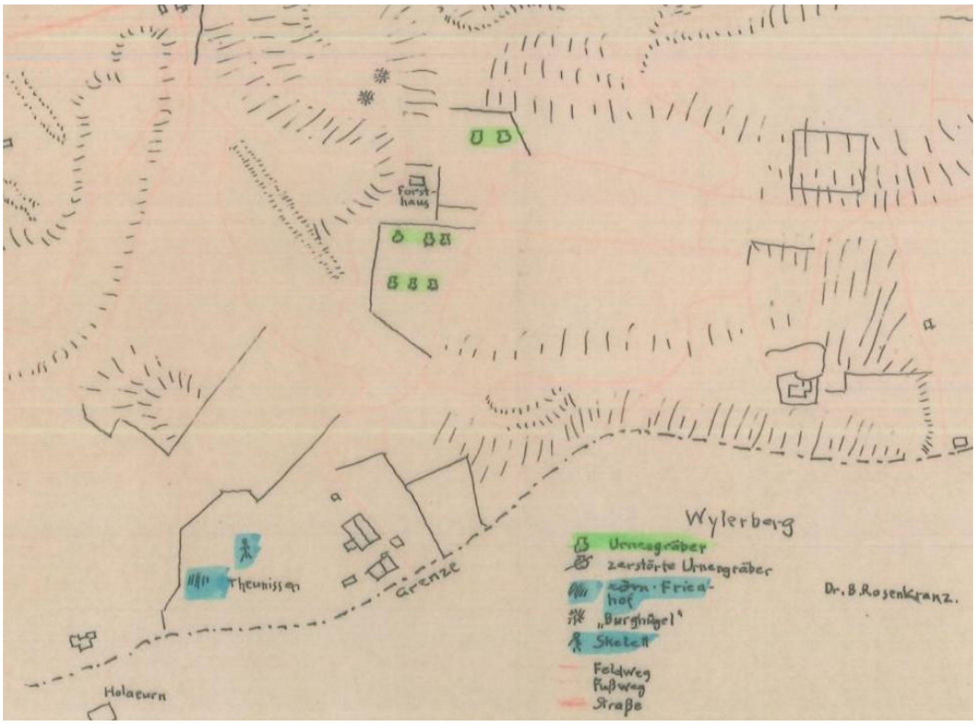


Fig. 9A: Drawing, made by Dr. B. Rosenkranz in 1939, showing the location of (urn) graves found in the Duivelsberg area (Ten Hag 2020, 48).

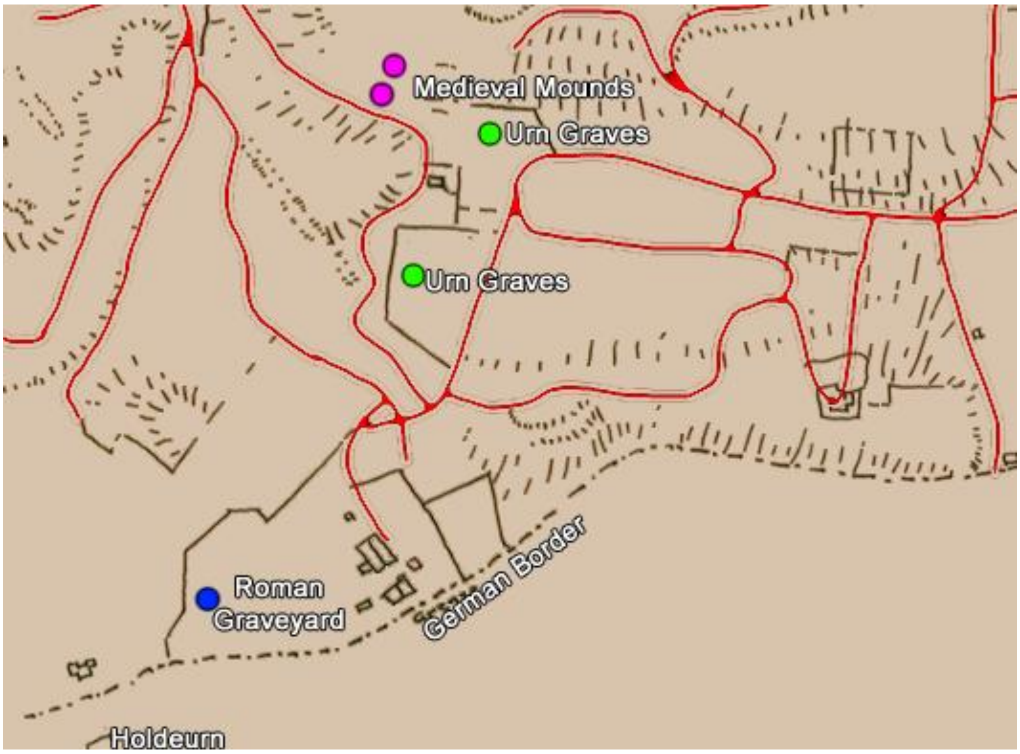


Fig. 9B: Digitally touched up version of Fig. 9A for improved readability.

Wylermeer

A selection of roman finds is known from the Wylermeer, including *Terra Sigilata* and glass dated to the 1st century AD, as well as building materials such as tuff stone and roof tiles (Den Hartog 1986, 17). 1st to 3rd-century Roman pottery and features are also known in and around the Wylerbergmeer, to the west of the Wylermeer (Archis3 nrs. 2705127100; 2706691100).

Roman features have also been found on the hilltops just over the border, in the German town of Zyfflich. More Roman buildings were expected in and around the Ooijpolder, but likely not found due to the limited depth of the coring research (Pons and Modderman 1951, 191-55). Although Zyfflich is outside the borders of the defined research area, these finds hint at a continuation of Roman activity to the east, further hinting the peaks of the research area might hold more Roman archaeology.

Roman Roads

A complex road network existed around the fortifications and civilian settlements in Roman Nijmegen and its surroundings. Parts of the roads have been discovered in excavations in and around the city, most notably a milestone found in Beek in 1621 (Diepeveen and Zee 2010, 4). The modern roads in the area still follow the same route as the original Roman roads (Franzen and van Roode 2019, 67-9). To the east of Nijmegen, the road followed what is currently the Berg en Dalseweg and Oudekleefsebaan towards the industrial complex on the Holdeurn, following the higher parts of the moraine. A part of this road was found in an excavation at the Maartenskliniek (Magnée-Nentjes *et al.* 2010, 21). Another road likely existed at the lower end of the moraine as well, giving access to the river and possible docks and harbours. The high and low roads were connected via what is now the Beekmandalseweg (Franzen and van Roode 2019, 75), and possibly other valleys. The Rijksstraatweg is a strong contender for the route of the lower road, although there is no direct evidence for this (Diepeveen and Zee 2010, 4). Daniëls (1955, 284) also produced a map (Fig. 10) of roads in the area between Nijmegen and Cuijk which he believed to have Roman origins, based on archival mentions and some excavations.

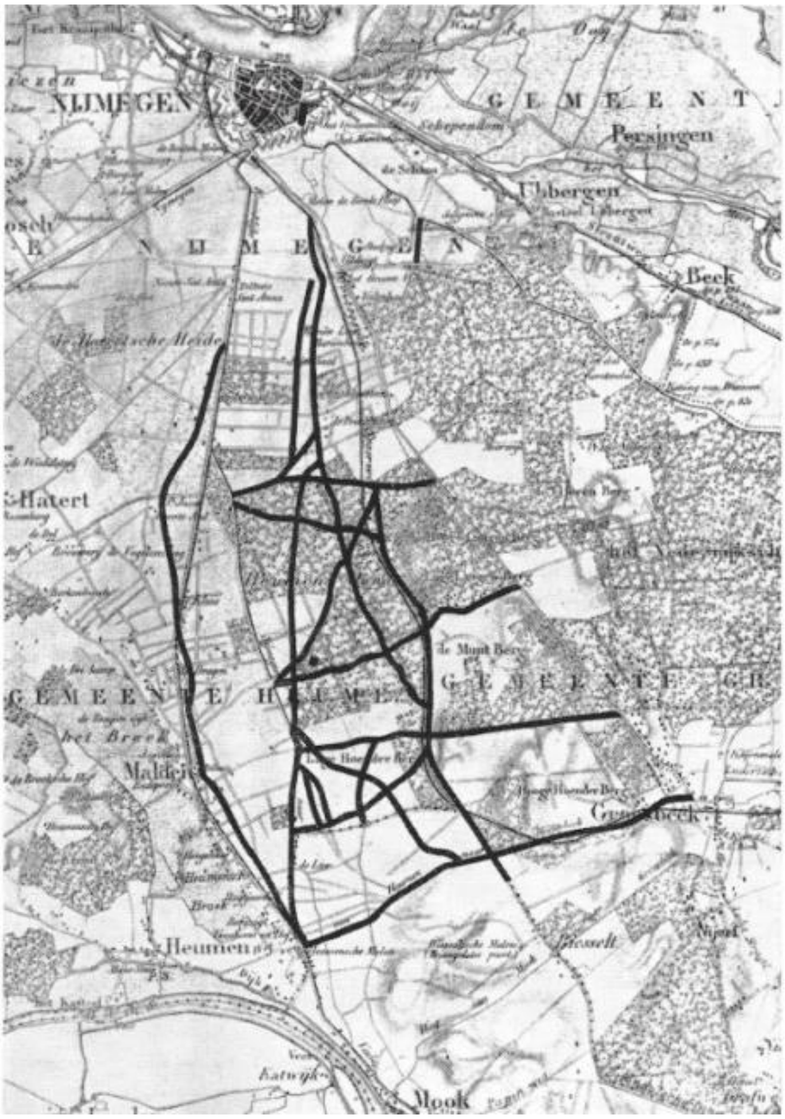


Fig. 10: Map of roads with a presumed Roman origin (Daniëls 1955, 284).

5. Viewshed Analysis

5.1 Data Collection and Selected Methods

The data used for the GIS-based analyses in this research has been generated by the Directorate-General for Public Works and Water Management / *Rijkswaterstaat* (ahn.nl). The resulting data in the form of Digital Terrain Models (DTM) or Digital Elevation Models (DEM) is freely available online in the form of the *Actueel Hoogtebestand Nederland*, currently in its third edition (AHN3). The data has been processed using the free open-source QGIS 3.12.0 software, using a 3rd party open source Visibility Analysis plugin (Cuckovic 2016). Before processing the data, the empty pixels were filled using the "fill no_data" raster processing tool in QGIS to avoid empty spaces.

5.1.1 Viewpoint Locations

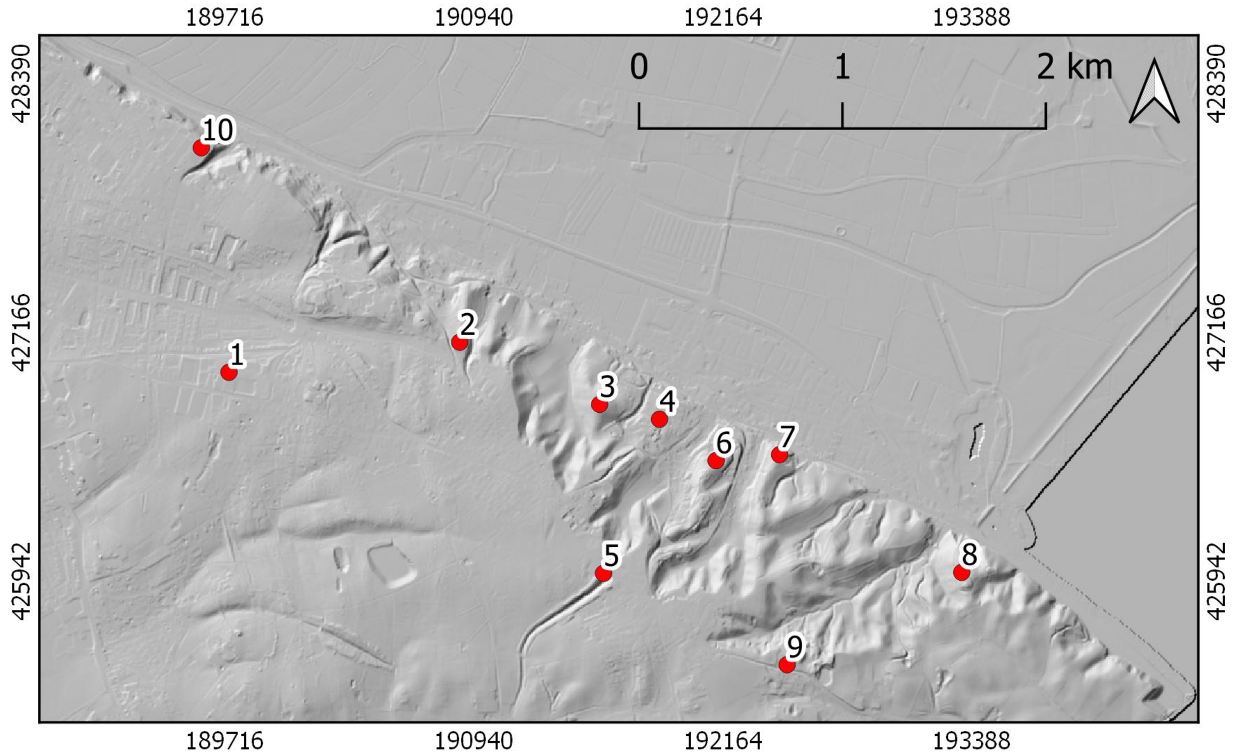


Fig. 11: Viewpoint locations plotted on a height map of the research area. 1: Kwakkenberg, 2: Boterberg, 3: Ravenberg, 4: De Geest, 5: Kerstendal, 6: Sterrenberg, 7: Musschenberg, 8: Duivelsberg, 9: De Holdeurn, 10: Hunnerberg.

The locations used in this viewshed analysis were selected based on the archaeological remains of building material, as described in Fig. 8. As many of these finds likely originated from the nearby peaks, the chosen locations are on these peaks where the buildings most likely have stood. Next to these possible new locations, the Hunnerberg has been chosen as a reference point. This was the location of the fort during the first occupation when the entire line of defences might have been created, as well as during the 2nd century AD, concurrent with the dating of many of the building remains found. As the dataset ends at the border between the Netherlands and Germany, the locations of the fortifications recently found in Germany have not been used in the calculations.The locations are shown in Fig. 11. From all these points a regular binary viewshed has been calculated in QGIS.

5.1.2 Observer Height and Calculation Parameters

The height of the watchtowers at Nijmegen is not known. Driessen (2007, 247) assumes a tower height of 6 m for the *Castra* on the Hunnerberg. Woolliscroft (2001, 16) gives an estimated height of 7 to 10 m, which is also used by Murphy (2018, 113) in a viewshed analysis of Roman towers. A visibility analysis for Roman fortifications in Portugal uses 7.75 m as an average estimate for tower heights, with 10 m used for the towers on city walls (Williams 2017, 111-2). For this analysis, an observer height (Fig. 12) of 10 m was chosen. This assumes a tower height of over 8 m plus the height of a person. The target height was also set at 10 m, again assuming an 8 m watchtower plus a person possibly holding a flag or torch. This is near the higher ends of the height estimates. However, considering the purpose of the visibility study in this thesis is to identify possible unknown fortifications, a slightly larger result area does not hinder the outcome, similar to the choice for a binary viewshed. Finally, a plugin-default atmospheric refraction value of 0,13 was used, to simulate the curvature of the earth in the calculation. No further calculations or limits were selected.

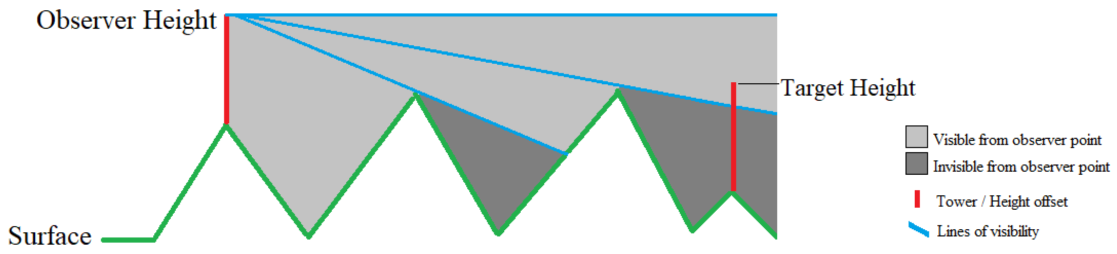


Fig. 12: Simple diagram showing observer and target height. In this example, the top of the target tower is visible from the observer while the surface of the tower is not (image by author).

5.2 Viewshed Results

Hunnerberg

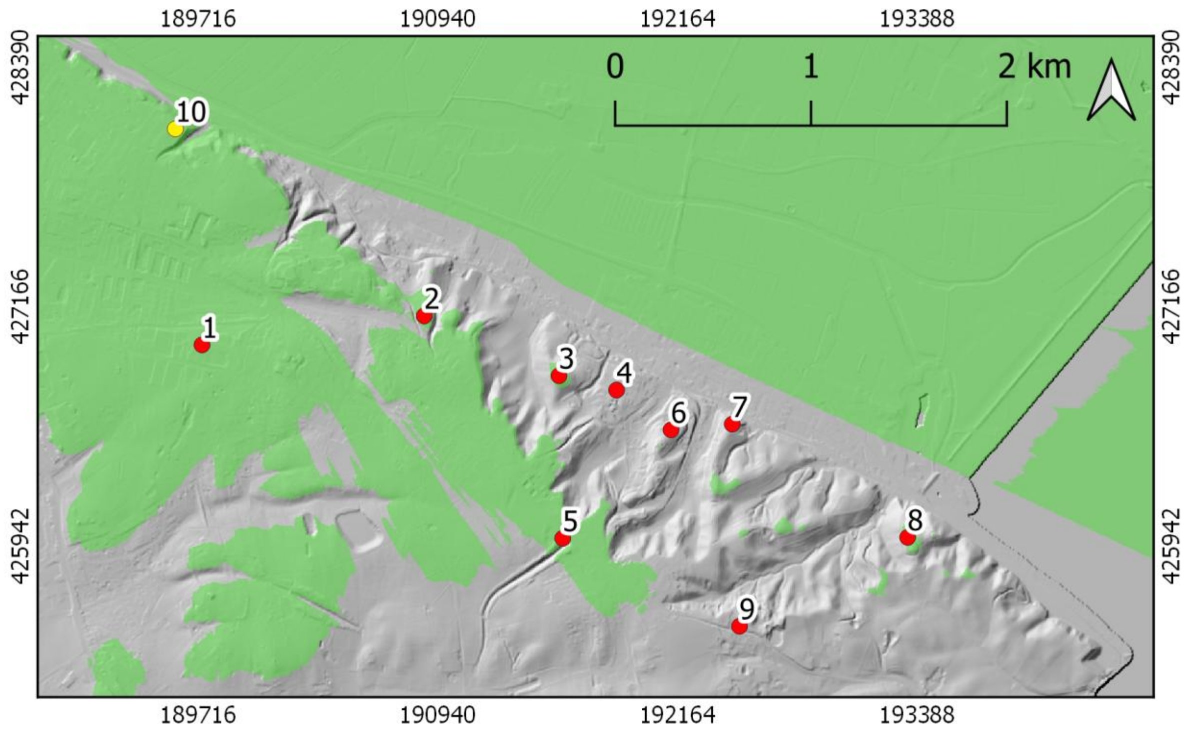


Fig. 13: Visibility (green) from the Hunnerberg (10) at a viewer height and target height of 10 m.

The first viewshed (Fig. 13) from the Hunnerberg (10) exemplifies one of the problems discussed in the introduction. From the fort, a large area over the Waal river and beyond is visible. The sight to the southeast, however, gets obscured by some of the higher peaks of the moraine such as the Boterberg (2), Ravenberg (3), or Duivelsberg (8), meaning a large part of the area cannot be observed or controlled. It might be expected that the Roman army created a watchtower, fortlet, or similar on one of the higher eastern peaks of the moraine, to ensure total visibility and control over the area.

Kwakkenberg and Boterberg

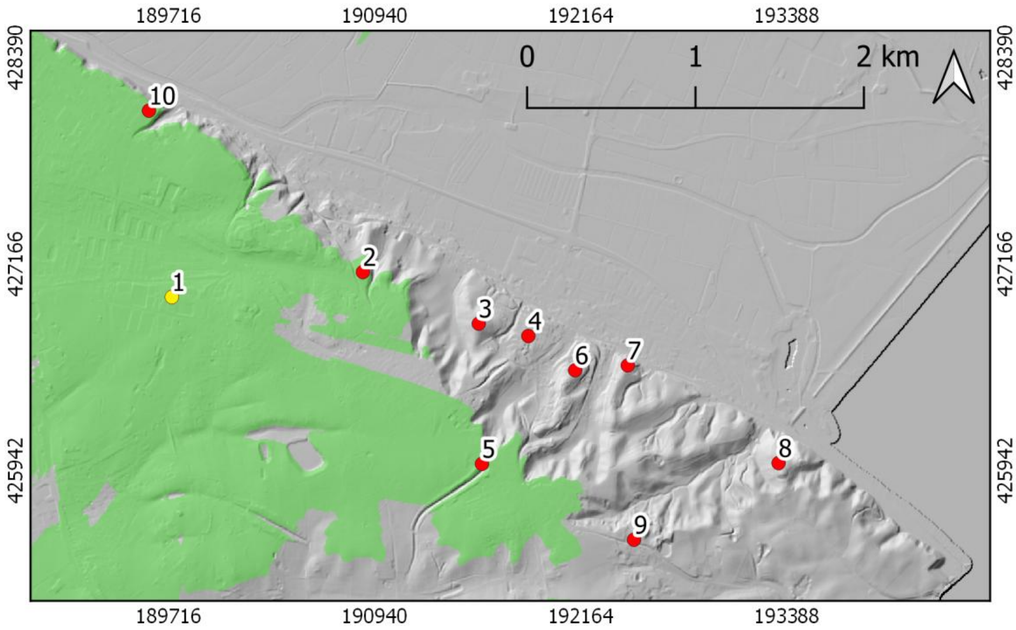


Fig. 14: Visibility (green) from the Kwakkenberg (1) at a viewer height and target height of 10 m.

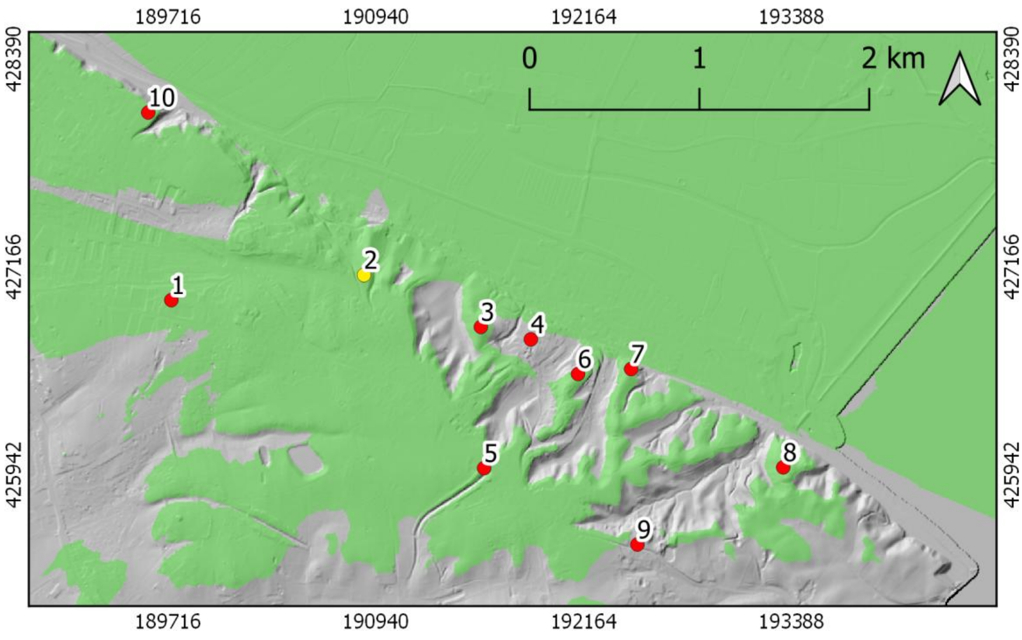


Fig. 15: Visibility (green) from the Boterberg (2) at a viewer height and target height of 10 m.

The second viewshed (Fig. 14) shows the visibility from the Kwakkenberg (1), located on the lower western sandr. The visibility here is largely limited to the west and south, making it an unlikely location for a fortification. The Boterberg (2, Fig. 15) is a much more likely location by comparison. A significant part of both the higher moraine and lower plains are visible.

Ravenberg and De Geest

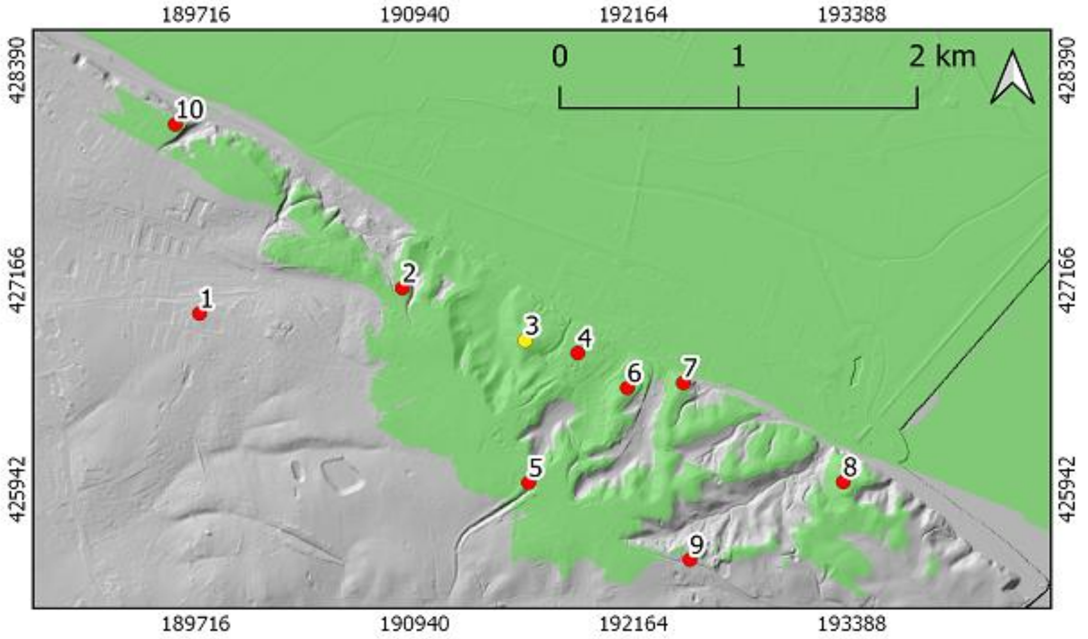


Fig. 16: Visibility (green) from the Ravenberg (3) at a viewer height and target height of 10 m.

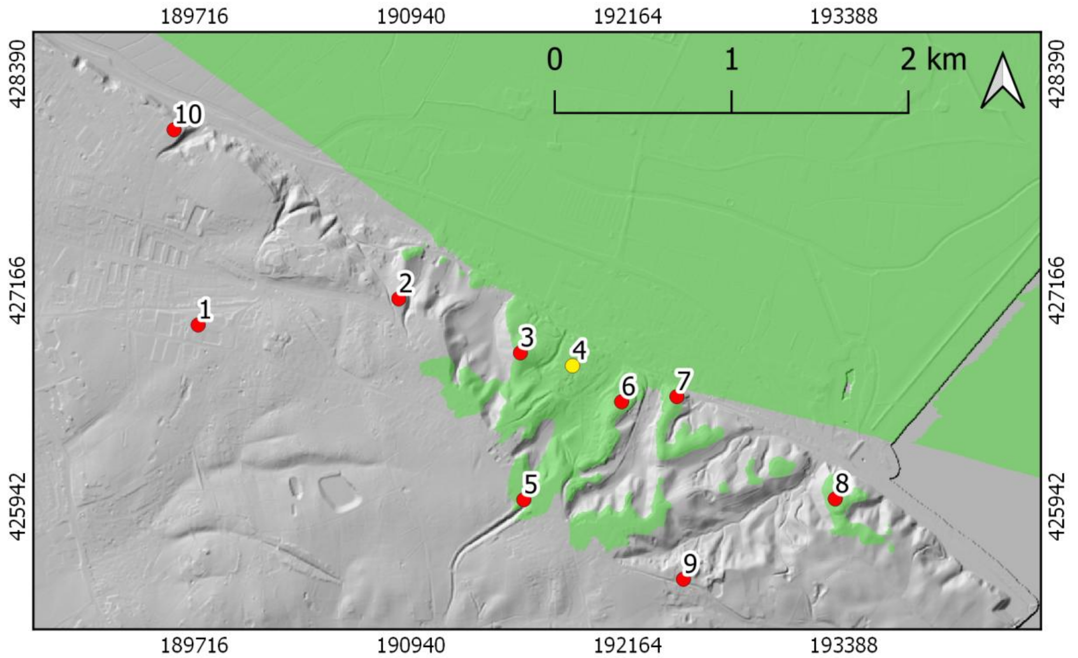


Fig. 17: Visibility (green) from De Geest (4) at a viewer height and target height of 10 m.

From the Ravenberg (3, Fig. 16), all other northern peaks are still visible. The area to the southwest is less visible than from the Boterberg (2), but this is not necessarily a detriment, as this area is already visually controlled by the fort on the Hunnerberg (10). De Geest (4, Fig. 17) is a relatively lower area surrounded by higher peaks such as the Ravenberg (3) and Sterrenberg (6). As a result, the visibility here is largely limited to its own area of the moraine and the plains to the north, although some of the peaks to the east are still visible.

Kerstendal

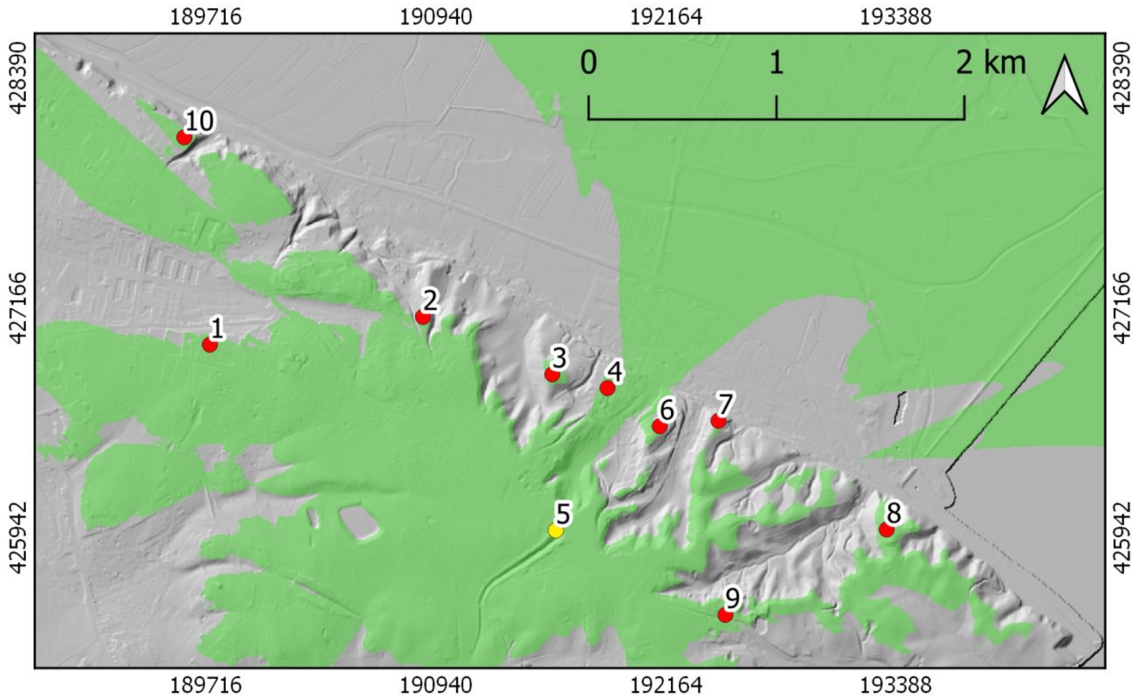


Fig. 18: Visibility (green) from the Kerstendal (5) at a viewer height and target height of 10 m.

The Kerstendal (5, Fig. 18), the starting point of the Roman aqueduct, is situated further towards the south on the highest parts of the moraine. From here, most of the higher moraine is visible, but the view over the lower plains, especially in the direction of the German fortifications such as Kleve towards the southeast, is lacking.

Sterrenberg and Musschenberg

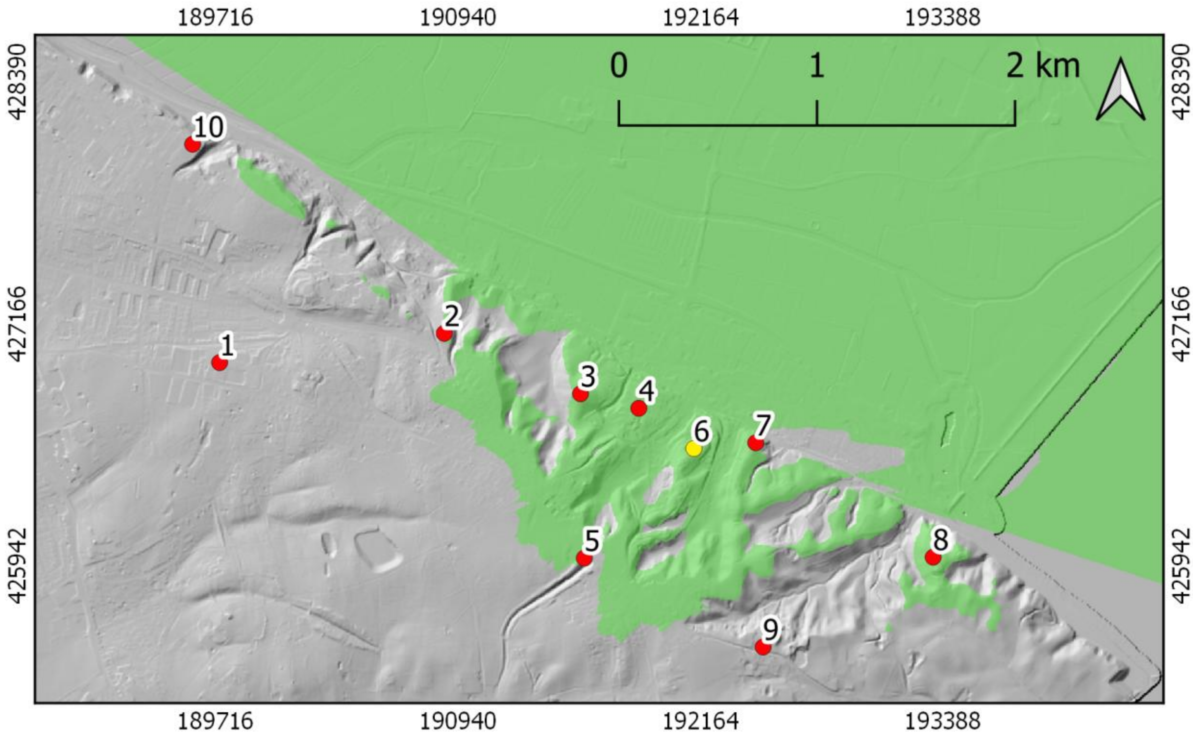


Fig. 19: Visibility (green) from the Sterrenberg (6) at a viewer height and target height of 10 m.

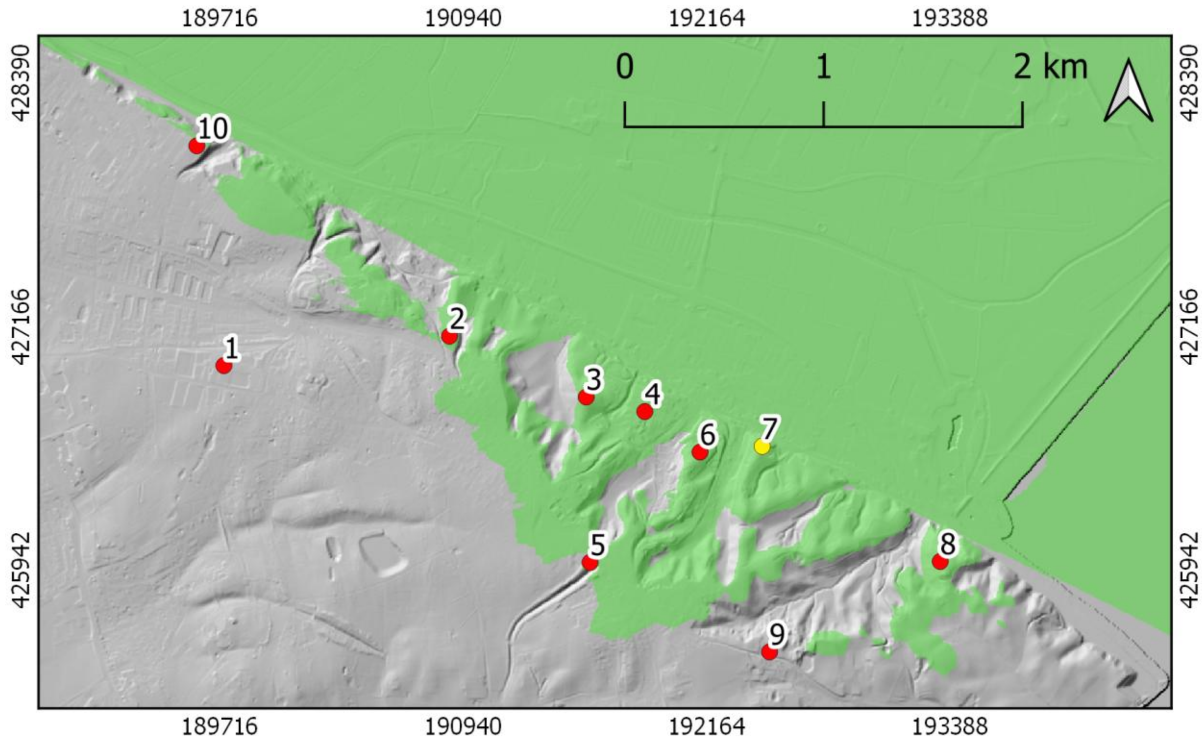


Fig. 20: Visibility (green) from the Musschenberg (7) at a viewer height and target height of 10 m.

The Sterrenberg (6, Fig. 19) and Musschenberg (7, Fig. 20) share a very similar viewshed. They offer visibility over the peaks and the plains. From the Sterrenberg there is no visual connection with the Hunnerberg, and from the Musschenberg only a small strip of the northern side of the Hunnerberg is visible.

Duivelsberg and Holdeurn

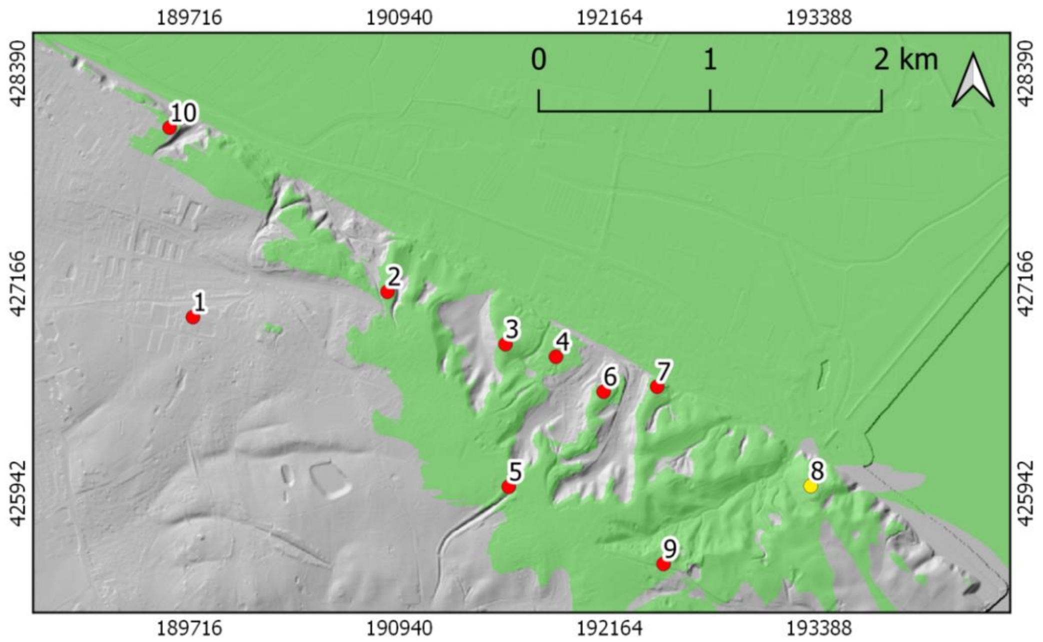


Fig. 21: Visibility (green) from the Duivelsberg (8) at a viewer height and target height of 10 m.

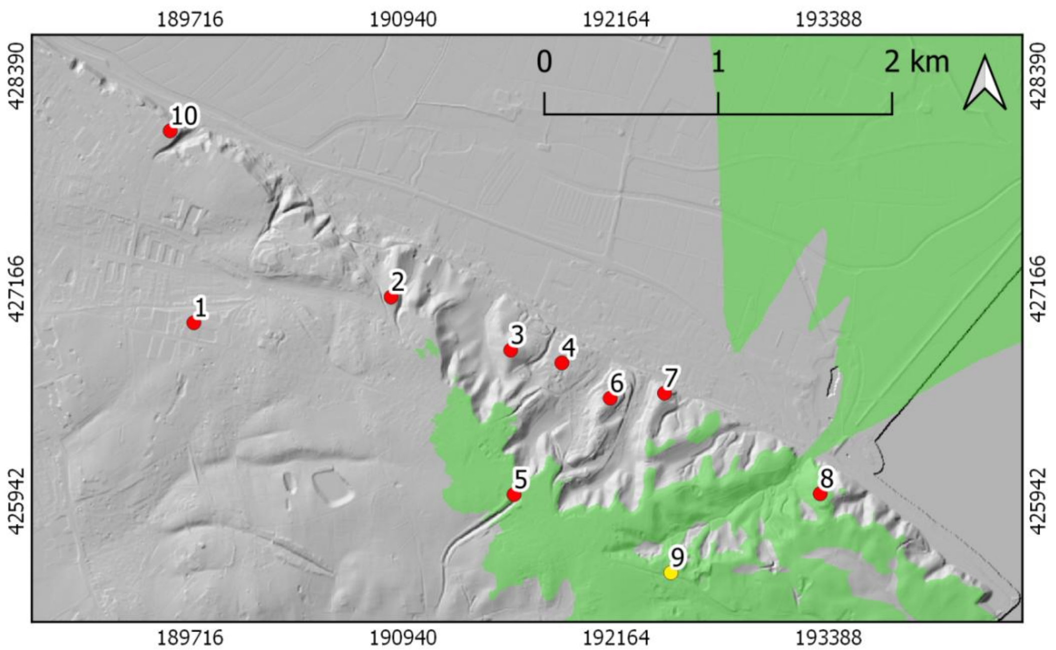


Fig. 22: Visibility (green) from De Holdeurn (9) at a viewer height and target height of 10 m.

The Duivelsberg (8, Fig. 21) is one of the higher peaks. A visual connection with the Hunnerberg (10) is again possible, while also covering the southern and eastern areas. The Duivelsberg and Hunnerberg thus control largely separate areas of the moraine, while still having a visual link to each other, making it an attractive candidate for a fortification. The final viewshed from de Holdeurn (9, Fig. 22) shows the visibility from this location is largely confined to its own southeastern area of the moraine, as it is located in a valley, relative to the higher areas in the west.

5.3 Overview

The Kwakkenberg (1), Boterberg (2), Ravenberg (3), Kerstendal (5) and Duivelsberg (8) have a visual connection with the fort on the Hunnerberg (10), while de Geest (4), Sterrenberg (6), Musschenberg (7) and de Holdeurn (9) do not. From these locations which could be part of a signalling system with the Hunnerbeg, the Boterberg and Duivelsberg offer the best view over the general moraine area. The Duivelsberg offers slightly better visibility over the southwestern part of the research area, which is not visible from the Hunnerberg, and leads toward the next known fortifications in Germany to the east. The exact visibility over the German border has not been calculated in this research.

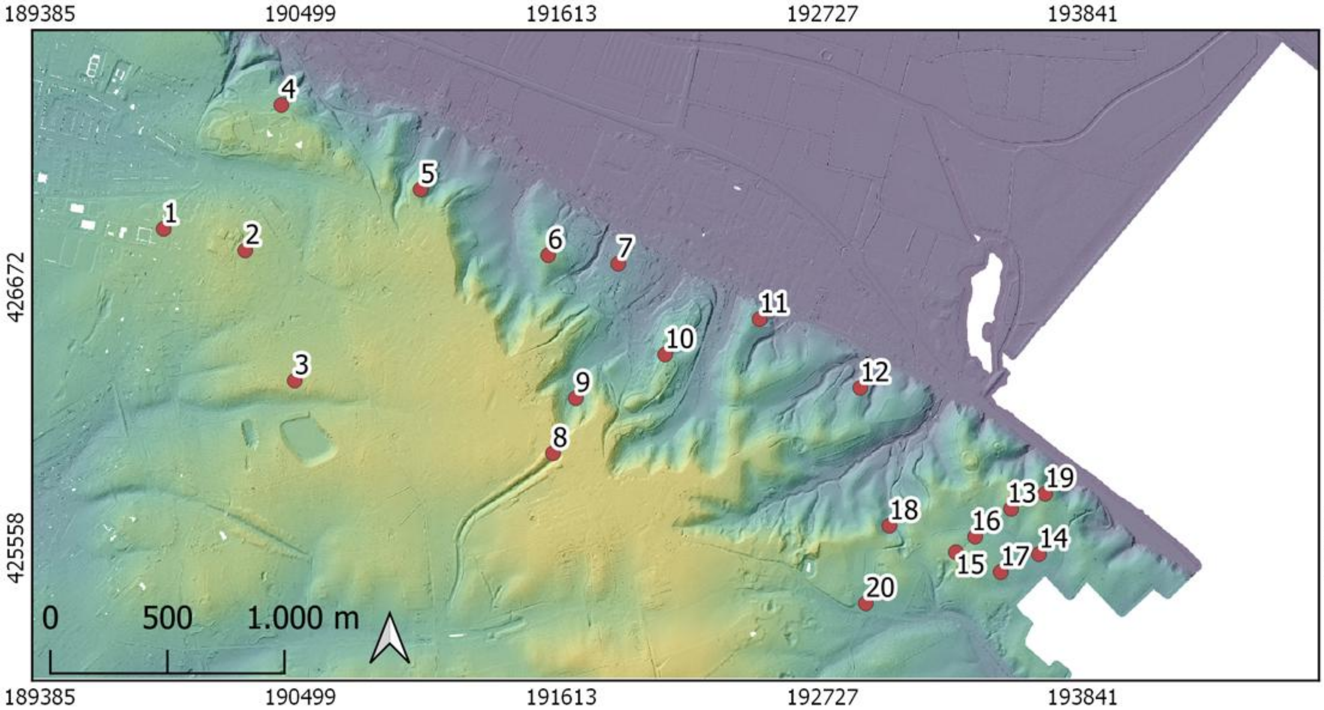
These results would imply the Duivelsberg is the ideal location for a watchtower in this scenario, because it could be part of a signalling system and offers control over an area not controlled by the fortifications in the west. We should, however, be wary to apply this conclusion to the Roman army directly. Besides the fact that many other factors could influence the location of a fortification, the Roman army might value visibility over certain areas more than larger overall visibility. For example, visibility and control along the two roads or over the Waal river could be more important than visibility over various *villa* terrains on the moraine.

6. LiDAR Visualization Analysis

6.1 Selected Tools and Methods

The standard workflow of LiDAR research in archaeology consists of data acquisition, classification, surface (DSM) and bare earth terrain model (DTM) creation, visualization, and interpretation (Opitz 2017, 35). For research in the Netherlands, data acquisition, classification, and model creation has been performed by Rijkswaterstaat in the form of the AHN3, the same data that has been used for the visibility analysis. This data is freely available online (www.ahn.nl).

Before processing the data, the empty pixels in the AHN3 data were filled using the "Fill no_data" raster processing option in the free open-source QGIS 3.12.0 software, to avoid empty spaces and anomalies in the visualization. Visualizations of this data were created using the Relief Visualization Toolbox (RVT) (version 2.2.1) developed by Kokalj *et al.*(2019). This software was specifically designed with archaeological research in mind and consists of 11 different visualization methods that have been proven to be effective for the identification of small-scale structures (https://iaps.zrc-sazu.si/). As discussed in chapter 2, the analysis starts with a hillshade visualization, followed by a Sky-View Factor visualization. The resulting images were visually inspected using QGIS, no further modifications to the data were made. The visualizations were inspected from west to east, with a specific focus on all areas with a high archaeological expectation (chapter 4.1.2, Fig. 8). For every location, a visualization method and scale was chosen which, in my opinion, best shows the discussed objects. Features that appear to be out of place and thus possible archaeological remains are mentioned and interpreted where possible.



6.2 LiDAR Results

Fig. 23: The location of the LiDAR structures mentioned in the text. 1: Villa Westerhelling, 2: Kwakkenberg, 3: De Vier Perken, 4: Path near Hengstberg, 5: Boterberg, 6: Ravenberg, 7: De Geest, 8: Kerstendal, 9: Wijchert Valley, 10: Sterrenberg, 11: Musschenberg, 12: Huis Wylerberg, 13: Duivelsberg (structure 1), 14: Duivelsberg (structure 2), 15: Duivelsberg (structure 3), 16: Duivelsberg (structure 4), 17: Duivelsberg (structure 5), 18: Duivelsberg (structure 6), 19: Duivelsberg (structure 7), 20: Camping Wylerberg

Kwakkenberg

The Kwakkenberg (Fig. 24) is a relatively urbanized area on the eastern edge of Nijmegen, where LiDAR is of little use. At villa Westerhelling, around which Roman building remains are known, only modern features are visible. To the south, the earthworks on the Mariënboom terrain are visible, which are presumed to be part of the Roman aqueduct (Schut 2005, 58-75).

The forest to the south of the Kwakkenberg is a terrain known as *De Vier Perken*. This terrain was the location of World War 2 activities in September 1944 (Theunissen and de Kort 2010, 13). Various foxholes and bomb craters are still visible using LiDAR.

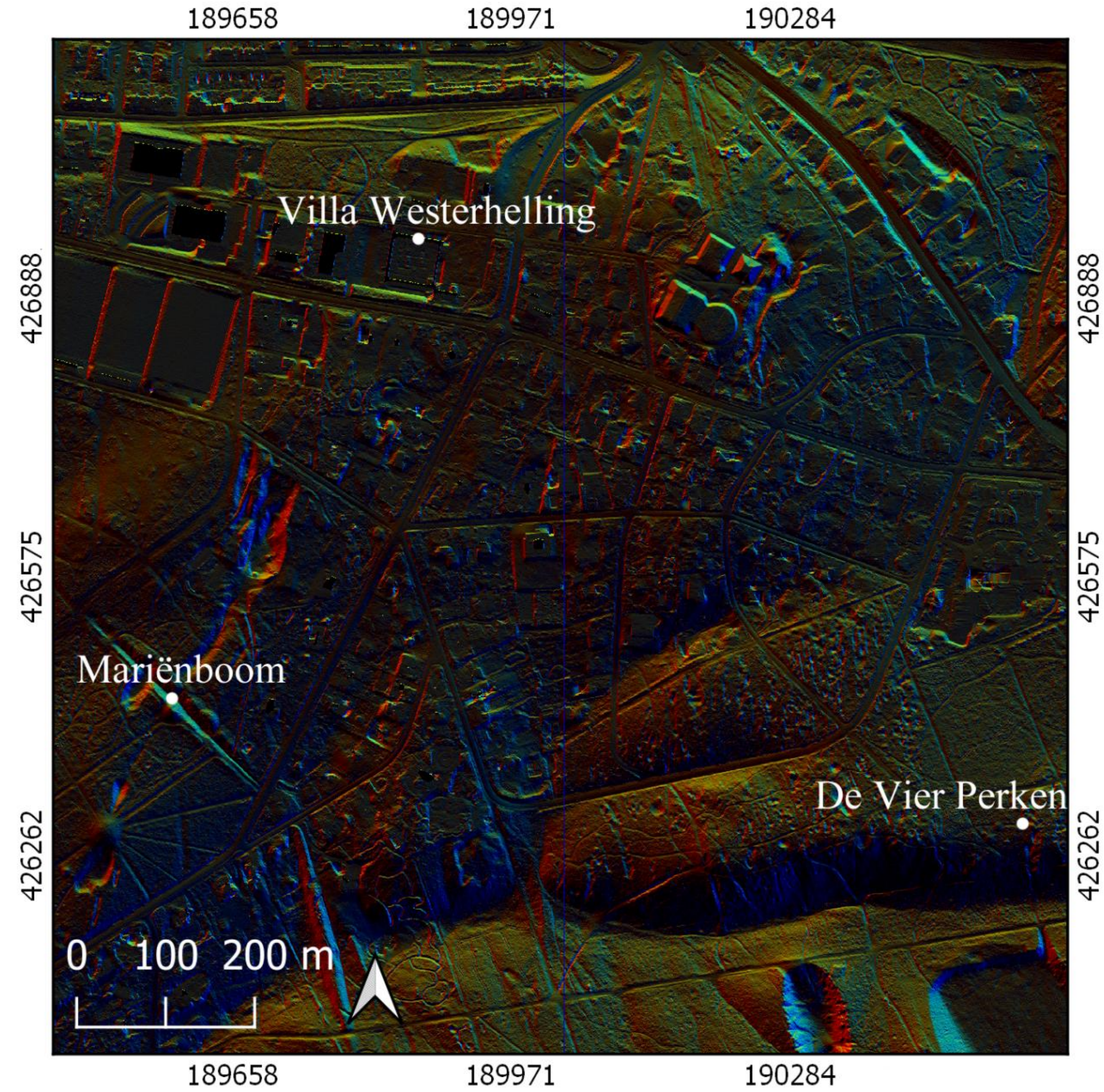


Fig. 24: Multidirectional hillshade of the area around the Kwakkenberg.

Besides these remains, some prehistoric barrows are known (Theunissen and de Kort 2010, 10-3). The researchers already mention there are likely more barrows to be found in this area, but they are nearly impossible to detect with current vegetation (Theunissen and de Kort 2010, 25). In LiDAR indeed several more hills are visible (Fig. 25). The grave field seems to be relatively untouched by the disturbances of World War 2 and clay digging, compared to the terrains further to the west.

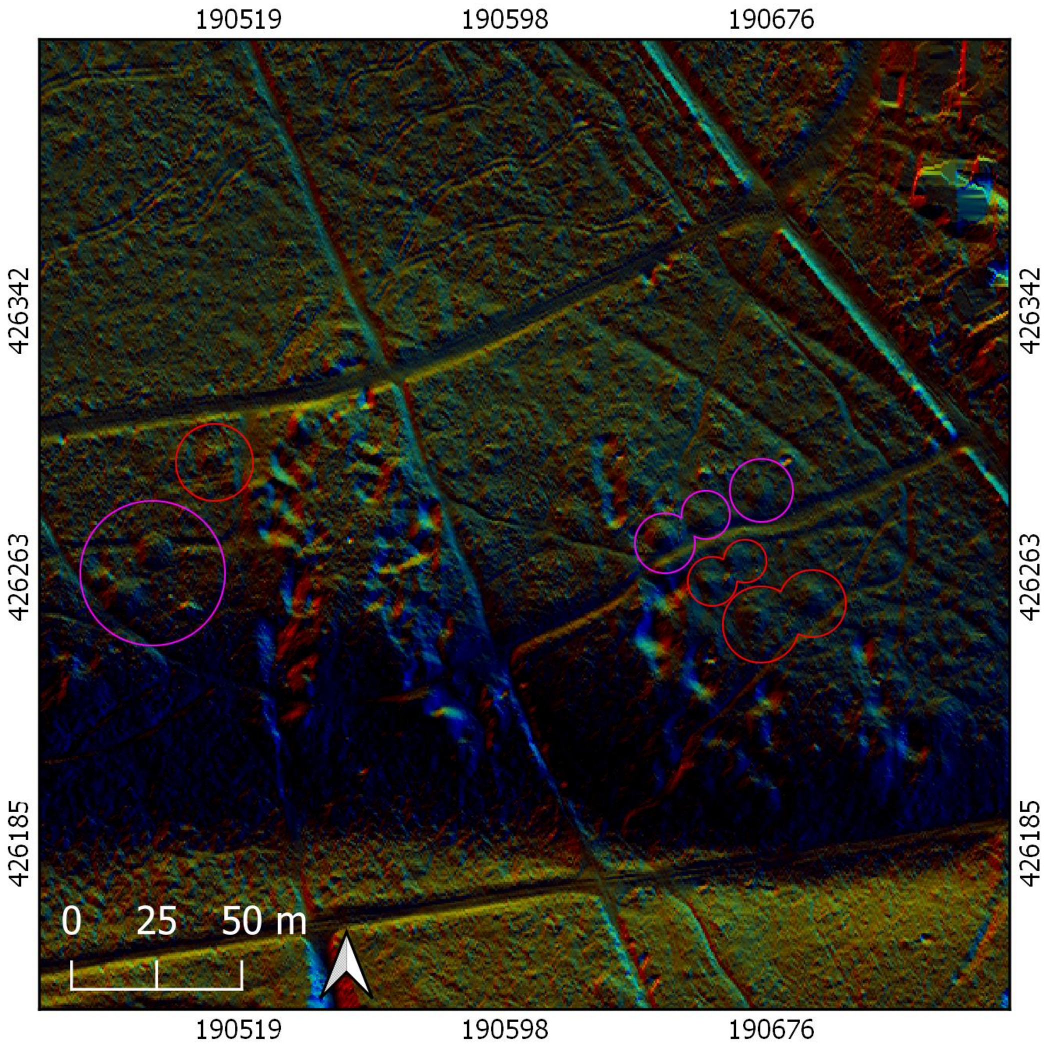


Fig. 25: Multidirectional hillshade of the terrain known as *De Vier Perken*. Highlighted in pink are barrows that are known from Theunissen and de Kort 2010, highlighted in red are other hills visible in LiDAR which could possibly be more prehistoric barrows.

Hengstberg

The Hengstberg is currently almost completely covered by the St. Maartenskliniek hospital. The only visible oddity is a path cutting straight through the forest, down the slope of the moraine (Fig. 26). This path is now overgrown and inaccessible, but it was already visible on the map in 1850 (Fig. 27). From the 1937 map onwards it is no longer visible. Although impossible to determine without an excavation, this road could very well have a Medieval or Roman predecessor, connecting the riverbanks to the higher moraine.

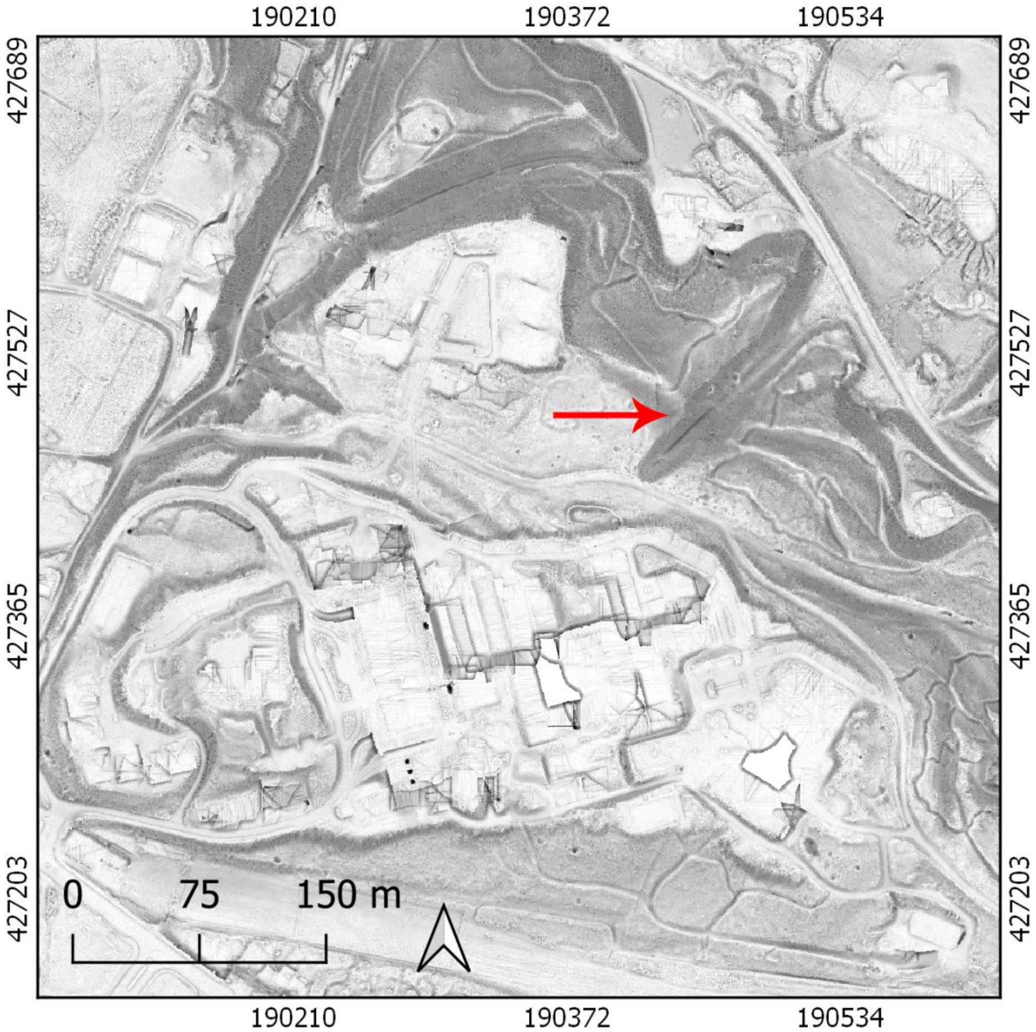


Fig. 26: SVF of the Hengstberg: The red arrow indicates a path through the forest which is now overgrown.

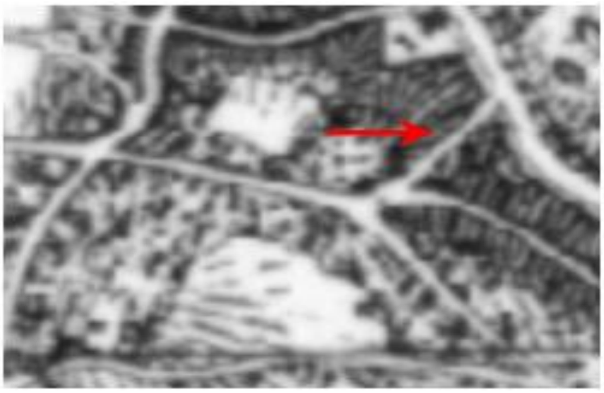


Fig. 27: The Hengstberg on an 1850 topographical map, the red arrow indicates the same path marked in Fig. 26 (edited from topotijdreis.nl).

Boterberg

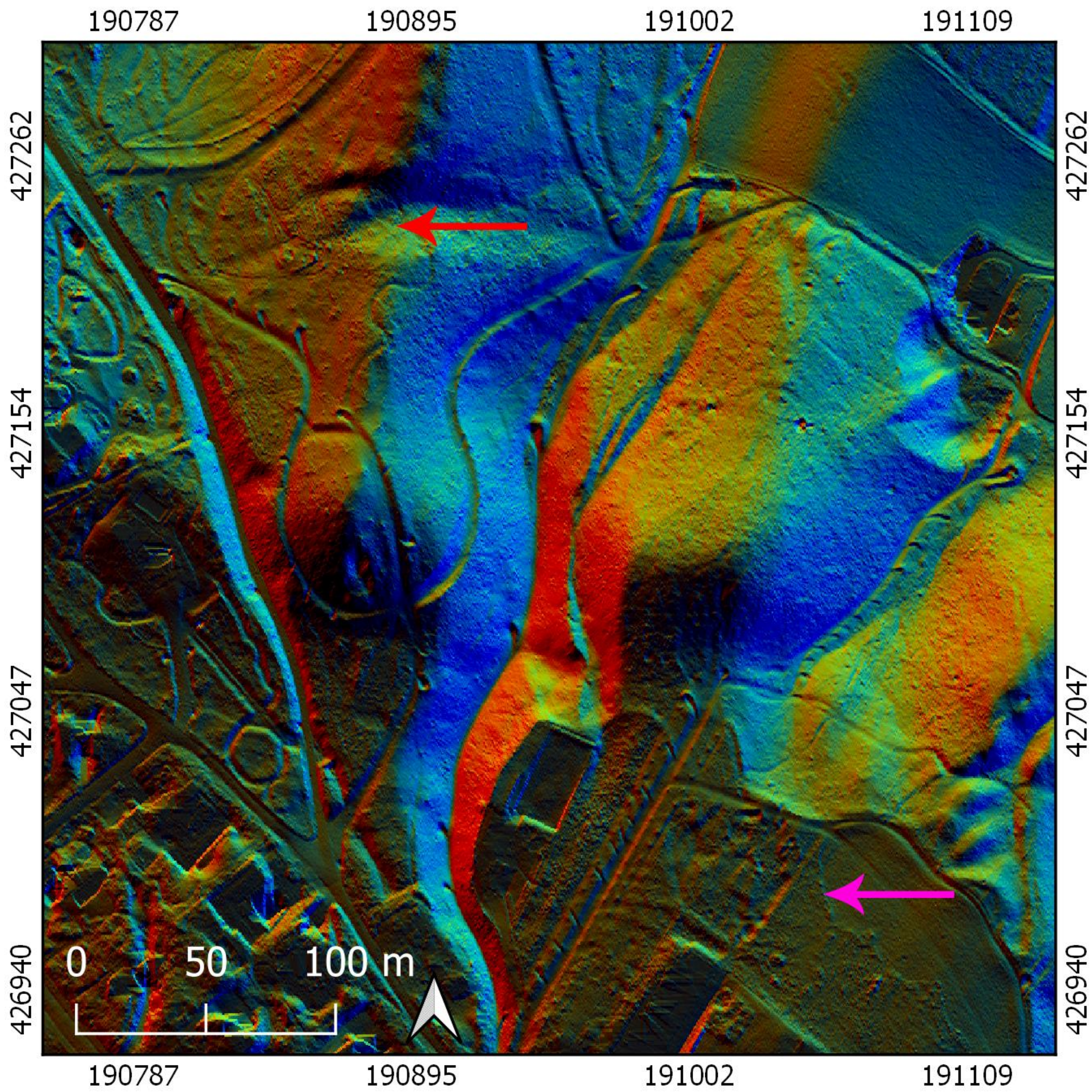


Fig. 28: Multidirectional Hillshade of the Boterberg. Marked with a red arrow are possible WW2 traces, shown with a pink arrow is an undefined angular shape in the forest.

On the Boterberg itself, no building traces are visible (Fig. 28). A small amount of craters towards the northwest indicates possible combat activity during the second world war. An angular shape can be seen in the forests to the south of the Boterberg. On this exact terrain, some Late Medieval pottery and an undetermined building feature are mentioned in Archis3 (nr. 2705184100). Maps indicate the terrain appears to have been in use (or at the very least not forested) from at least the middle of the 19th century until the middle of the 20th century. The LiDAR shape is possibly a remnant from this time, but a more precise interpretation is uncertain.

Ravenberg & De Geest

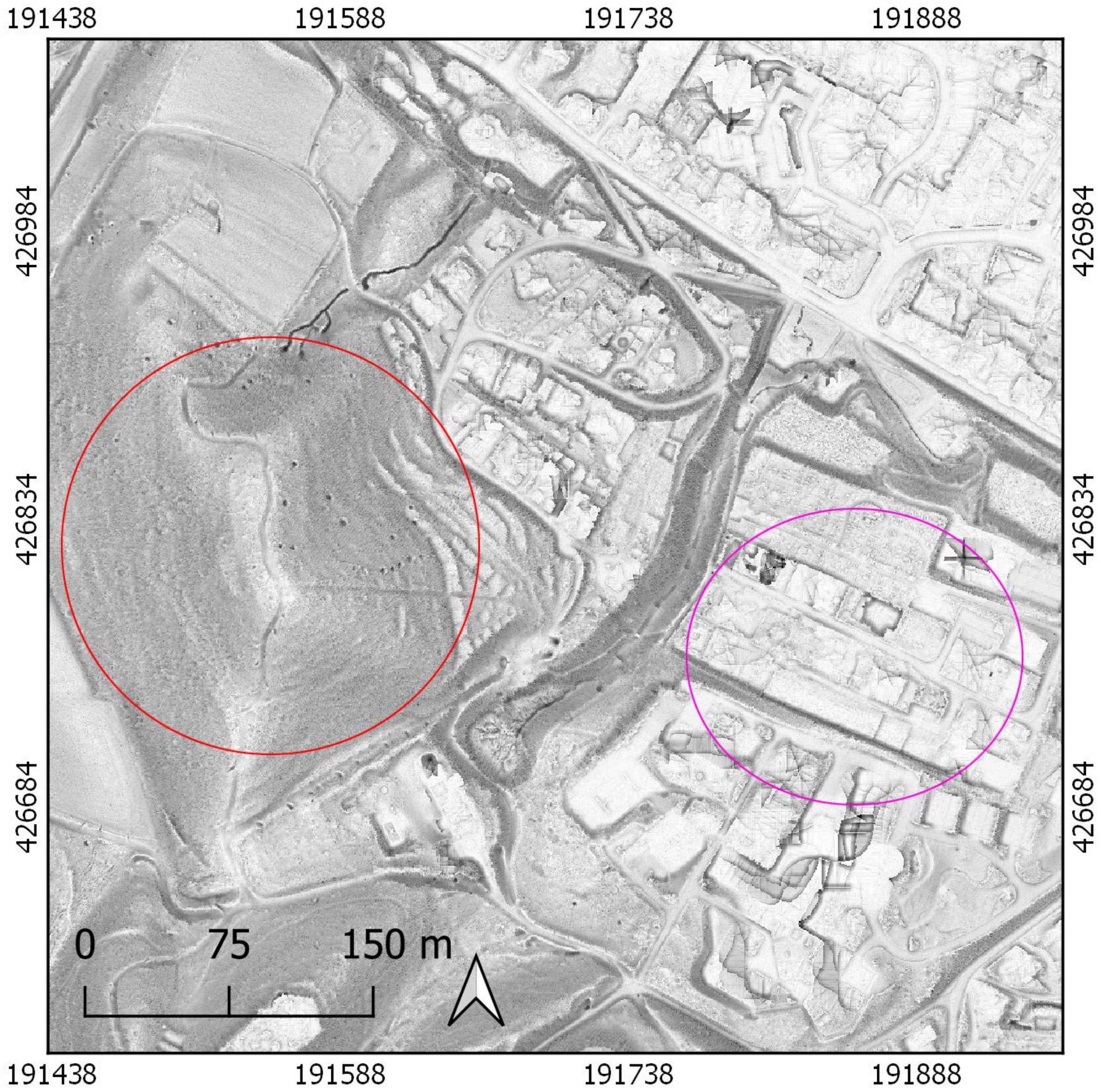


Fig. 29: SVF of the Ravenberg (Red circle) and De Geest (pink circle).

Large parts of the Ravenberg and De Geest, where *villa* remains are known, are modern residential areas. Possible traces of the older Roman buildings are thus not visible (Fig.

29). On the forested peak of the Ravenberg, no obvious anomalies can be seen. The rest of the Roman building remains is likely to be expected under the modern houses.

Kerstendal

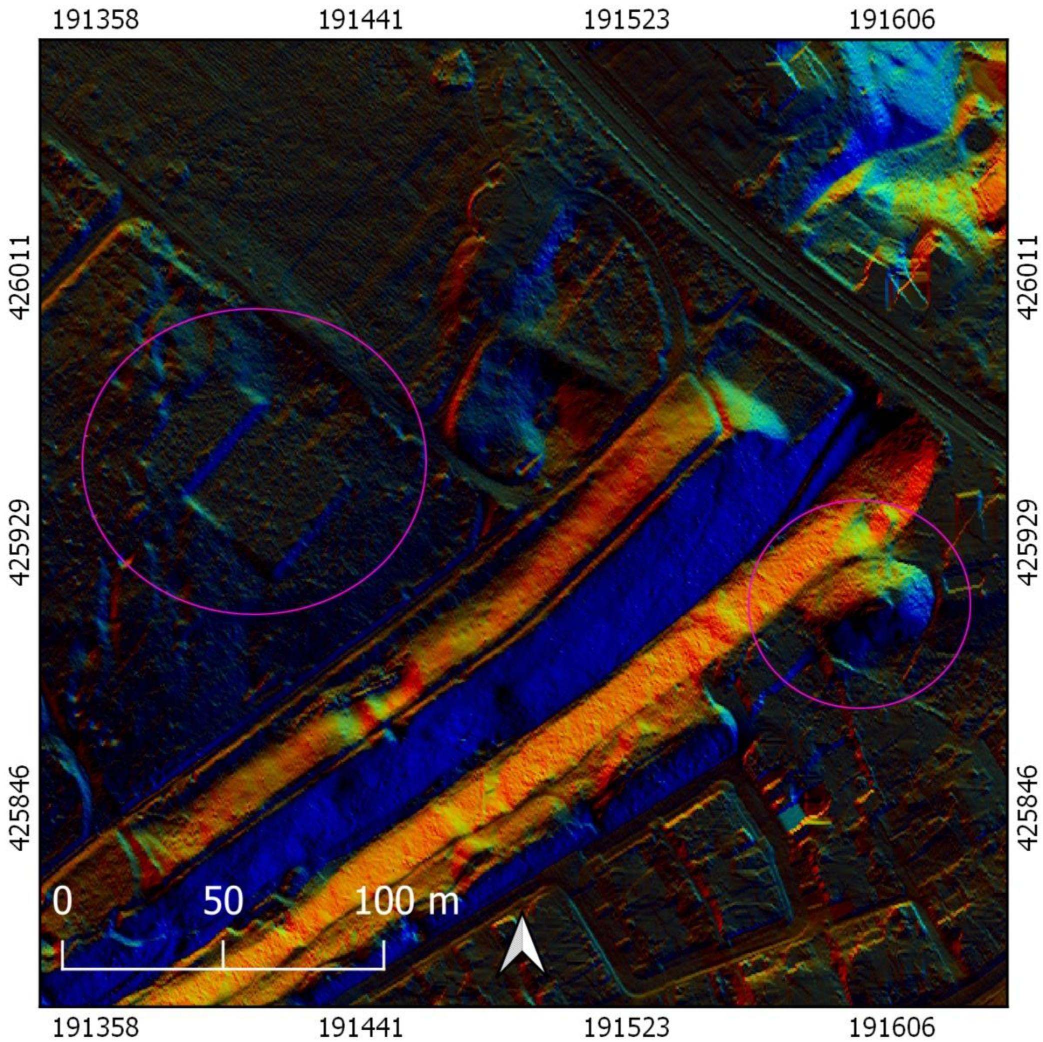


Fig. 30: Multidirectional Hillshade of the Kerstendal aqueduct.

Next to the Kerstendal, on the terrain called Watermeerwijk, a square shape of roughly 30x50m can be found (Fig. 30, left circle). The area is very close to where the *Mercurius* temple has been mentioned, albeit not on an actual hill.

On a map from 1938 (Fig. 31), a similar rectangular shape can be seen on this area. The Watermeerwijk was used in the second world war by German troops and subsequently bombed by the allied forces, after which the house was not rebuilt (Maas 2018). This rectangular shape is thus a relatively modern building or a terrain related to it.

Fig. 31: 1938 map from the area around the Kerstendal. The encircled areas correspond to the pink circles in Fig. 30 (edited from topotijdreis.nl).

The presumed location of the Mercurius temple reminds more of a small shrine at the start of the aqueduct (Schut 2005, 20), which could be significantly smaller than a temple. When looking at the LiDAR image, one lone hill stands out on the north-eastern side of the Kerstendal (Fig. 30, right circle). It is unclear when this hill was cut off from the rest of the earthworks, but no archaeological report exists for any building project here. This hill is much more reminiscent of a lone hill than the elongated earthworks of the aqueduct, which could both explain the location of a shrine and the name of 'Vestal Hill' in the past. More importantly, no corings were placed on this hill in the 2011 research (Schut *et al.* 2011). Some corings were performed in the gap between the hill and the rest of the earthworks (Merelweg 24), which concluded the soil at the north side of the terrain, the bottom of this hill, is still mostly undisturbed, and no building activity should be performed here before archaeological research is done (Emaus *et al.* 2004). If any follow-up research is to be performed, it seems worthwhile to place a coring on top of this lone hill.

Wijchert Valley

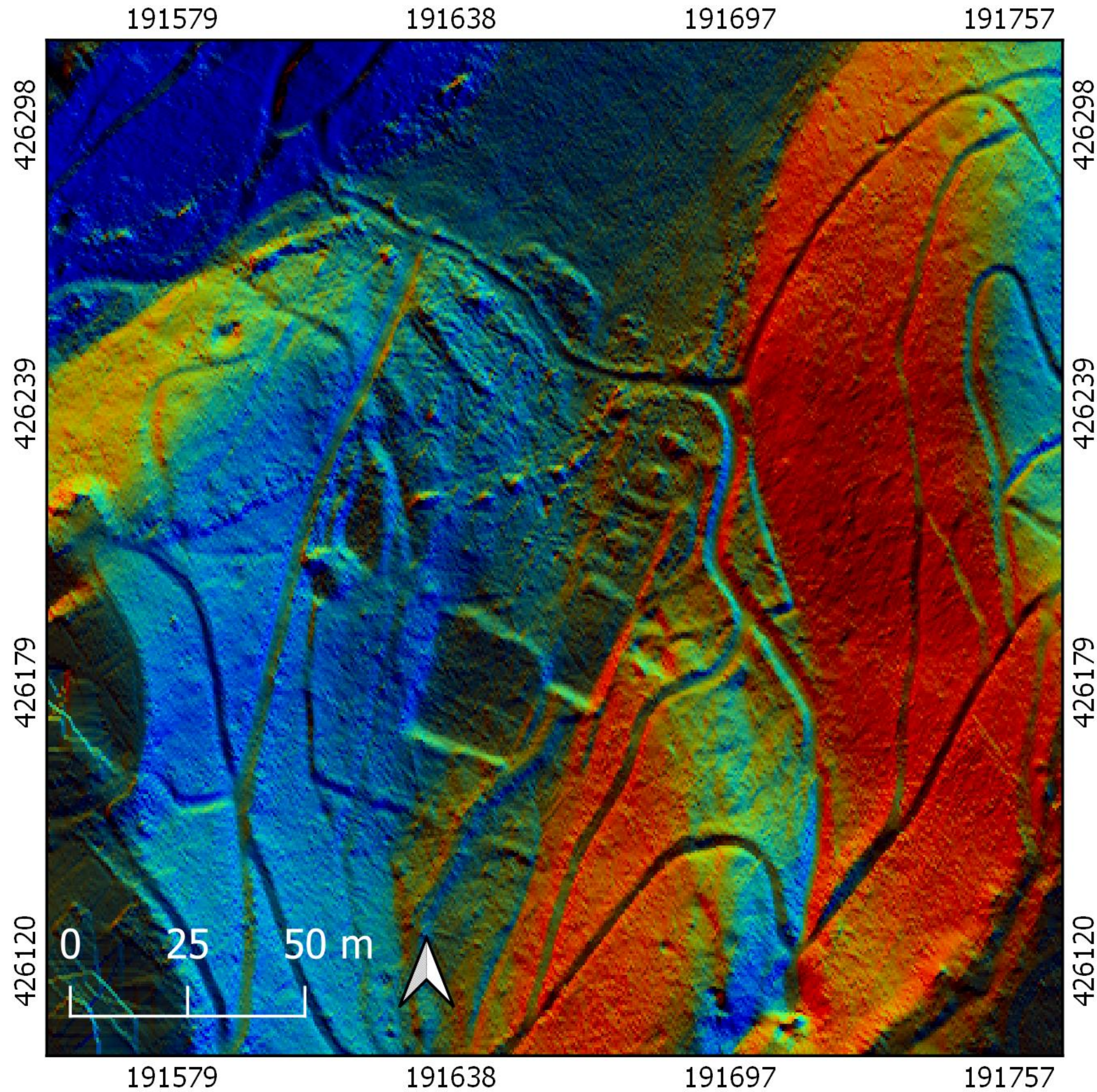


Fig. 32. Multidirectional hillshade of De Wijchert valley.

Just north of the Kerstendal, an interesting combination of shapes is visible (Fig. 32), in the valley known as De Wijchert. This area belongs to the terrain of *Villa de Wychert,* a monumental house built in 1907. This shape is situated at the bottom of the valley. It consists of various rectangles with paths or ditches going through and around it. Its location at the lower part of a valley already makes it very unlikely to be a larger building (such as a Roman *villa*).

The area is currently completely forested and inaccessible, however in the late 50s and early 60s of last century, there was an open part in the forest (Fig. 33). Considering this, and the clearness of the shape in LiDAR, this appears to be relatively modern, perhaps in some way linked to the nearby monument, although the exact purpose is unclear.

Fig. 33: 1950 map of De Wijchert, the valley in which the shape in LiDAR are visible is marked in red (edited from topotijdreis.nl).

Sterrenberg

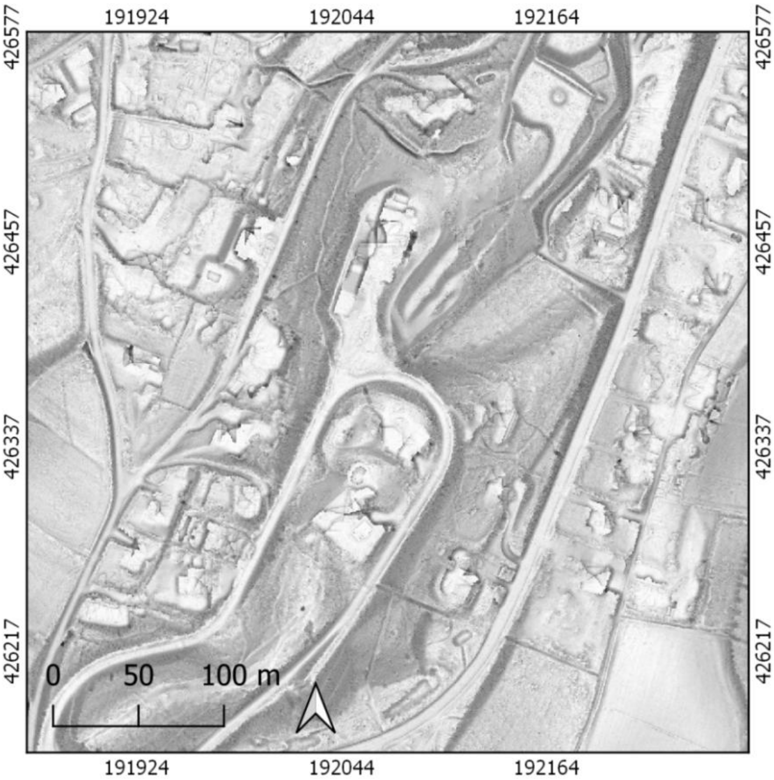


Fig. 34: SVF of the Sterrenberg.

On the Sterrenberg, there appear to be no features visible other than modern buildings and infrastructure (Fig. 34).

Musschenberg

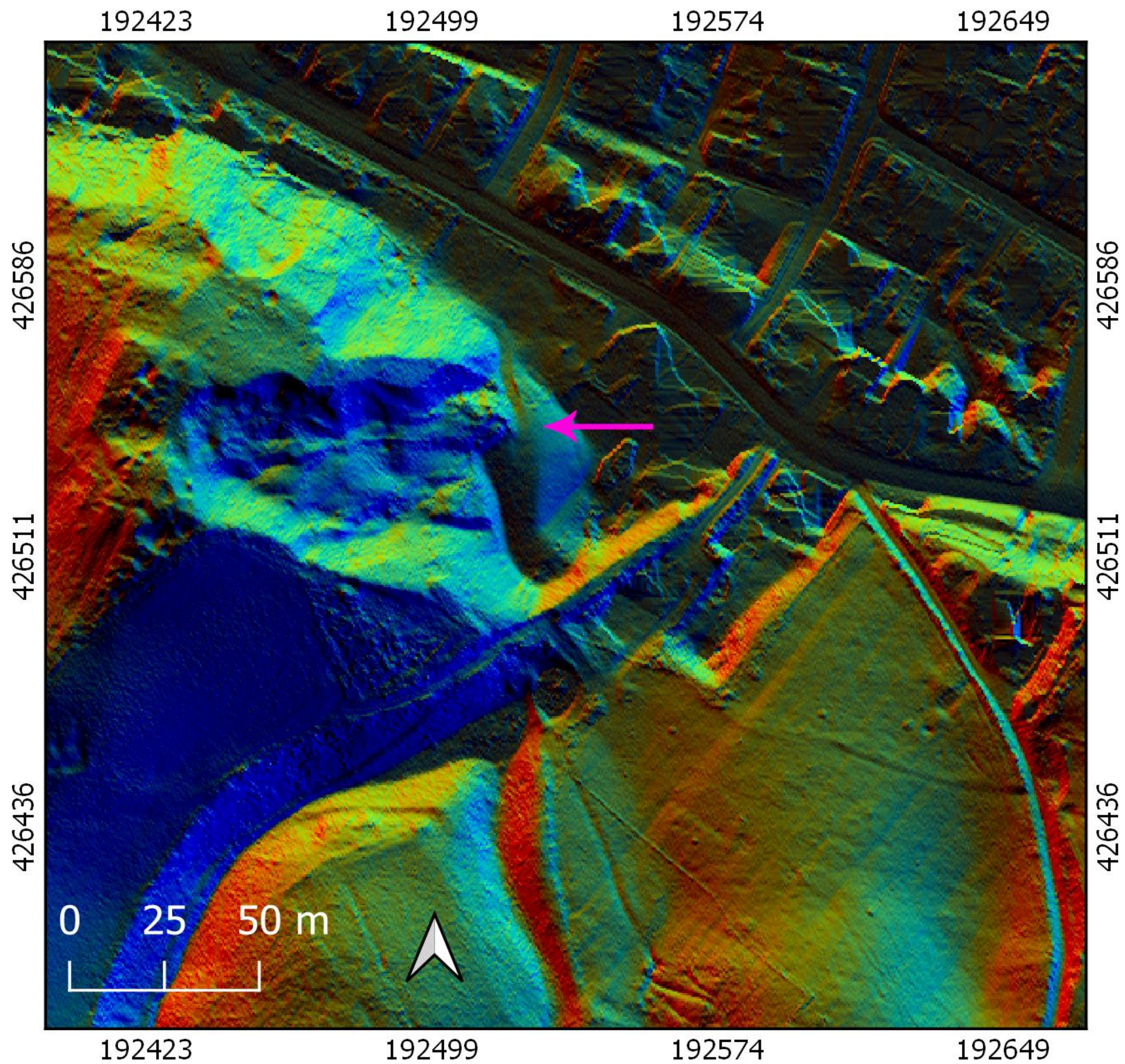


Fig. 35: Multidirectional Hillshade of the Musschenberg.

At the Musschenberg (Fig. 35), the part of the moraine which has collapsed is easily visible. There are no clear indications of any building remains around this area, although it is possible that the entire building was lost in the collapse.

The terrain to the east is likely the location where the corner of a Roman building was uncovered in 1926 (Ten Hag *et al*. 2020, 45-6). On this terrain too, no clear traces of this building are visible in LiDAR. This terrain has been used as a fruit tree orchard for the larger part of the last century, so it is not surprising that any possible remains on the surface are no longer visible.

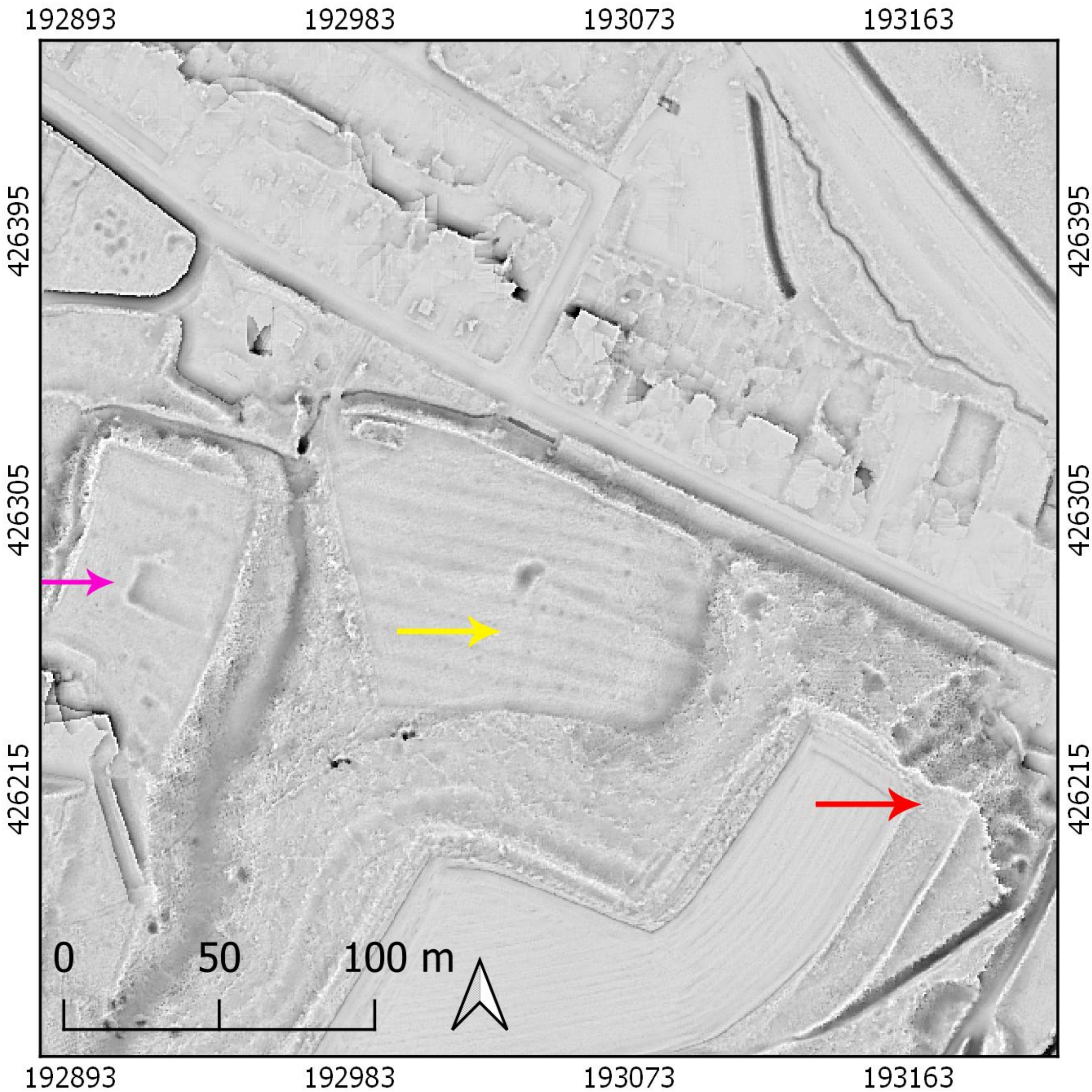


Fig. 36: Openness visualization of a terrain to the east of the Musschenberg.

Further to the east of the Musschenberg, on the terrain of *Huis Wylerberg*, a rectangular shape with circles on both ends is visible (Fig. 36, pink arrow). The origin or function of this is not visible on any map. It could be related to activities in the second world war, such as a storage or command post overlooking the Ooijpolder. On the terrain to the east (Fig. 36, yellow arrow), two ditches forming a corner, with a depression on the outside of the corner, are visible. These are perhaps the remains of older field boundaries of the terrain.

To the northwest of the Duivelsberg, at Rijksstraatweg 186, another part of the moraine, which has collapsed, is visible (Fig. 36, red arrow). Although this location is further to the east than the Musschenberg, some of the older mentions of building remains found after a collapse could refer to this area. There are, however, no other visible indications on top of the moraine here.

Duivelsberg

Around the Duivelsberg, especially in the forests to the south, several structures can be identified. One of the more obvious structures are the ditches, pits and trenches (Fig. 37, 1) from the Second World War. The Duivelsberg was a heavily contested area between the allied and German forces during Operation Market Garden. These WW2 remains have been extensively mapped and documented by volunteers over the last few years (Ten Hag *et al.* 2020). During this research, a rectangular earthen wall with a ditch, roughly 20 by 30 meters, was also found (Fig. 37, 2). This construction is said to date from before the Second World War, although the function is unclear. Two suggestions that are given are an enclosed area for sheep or growing trees (Maas 2018). The relative clarity and its location directly parallel to the current path and adjacent field suggest this enclosure should indeed be linked to relatively modern activity. The long, straight ditch (fig 37, 3) is what remains of a shooting range, built in the 1920s by occupational Belgian and French forces (Ten Hag *et al.* 2020, 55). Perhaps enclosure 2 could also be linked to this period of activity in the area.

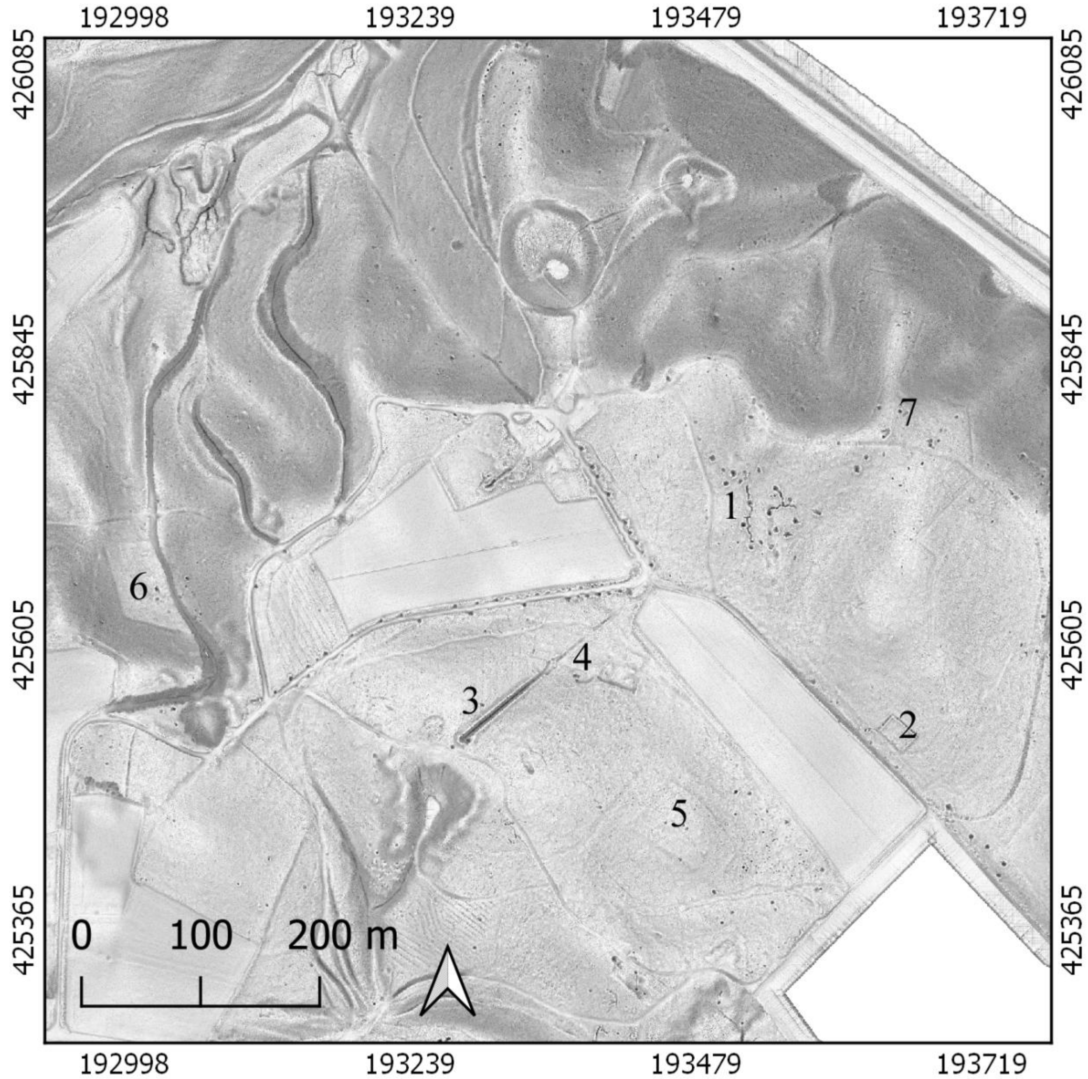


Fig. 37: SVF of the area to the south of the Duivelsberg. 1: WW2 pits and Trenches. 2: Walls and ditch. 3: Shooting range. 4-5: Unclear rectangle shapes. 6-7: Possible urnfield locations.

Structures 4 and 5 are less clear. Structure 4 is a rectangular shape, roughly 100m long, with an outcrop in the southern edge, directly next to the shooting range (Fig. 38). Initially, the outcrop is somewhat reminiscent of a quarter-circle *Clavicula* gate, however, the rest of the structure does not remind of a Roman fortification. The structure appears to be dug through the path of the shooting range, indicating it was created later than 1920. It is not drawn on older maps that depict the shooting range itself (Fig. 39).

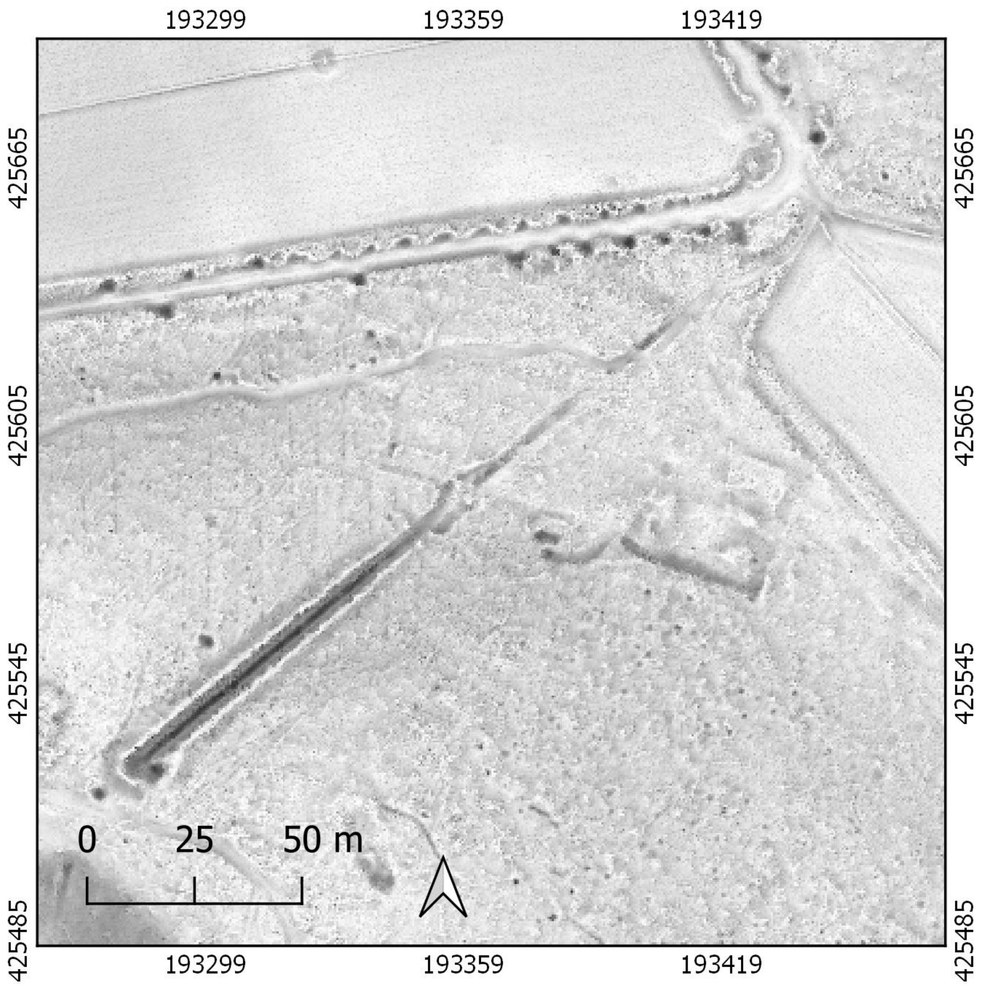


Fig. 38: SVF of structures 3 and 4 near the Duivelsberg.

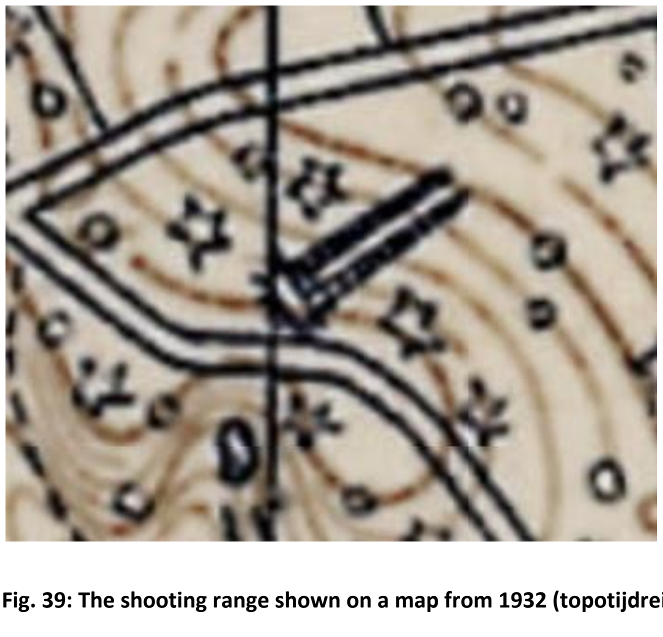


Fig. 39: The shooting range shown on a map from 1932 (topotijdreis.nl).

Slightly to the southeast, on the very edge of the Dutch–German border, there is a structure (5) consisting of an inner and an outer rectangle (Fig. 40). The inner shape is 60 by 170 m while the outer rectangle is 90 by 130 m. The rectangles appear to be slightly elevated earthworks, located on a relatively steep slope.

Two Archis records are known around this area. In the field to the north several late Neolithic flint tools were found (Archis 3 nr. 2709267100), to the south archaeological research has been done during the dredging of the ponds. This research concluded the ponds were dug in the Late Medieval period or later, and no Roman material was found (den Braven 2012). If either structure 4 or 5 had a Roman military origin, it is likely at least some stray finds would be known from the surrounding fields. The shape looks unlike other World War Two remains from this area, while maps from the early 19th to 21st century offer no further insight in this area. The structure is thus perhaps a (Late) Medieval land division or field system. A map from 1570 indicates this terrain belonged to the *Drost van Cranenburgh* during this period (den Braven 2012, 13). No Medieval finds are known either, however.

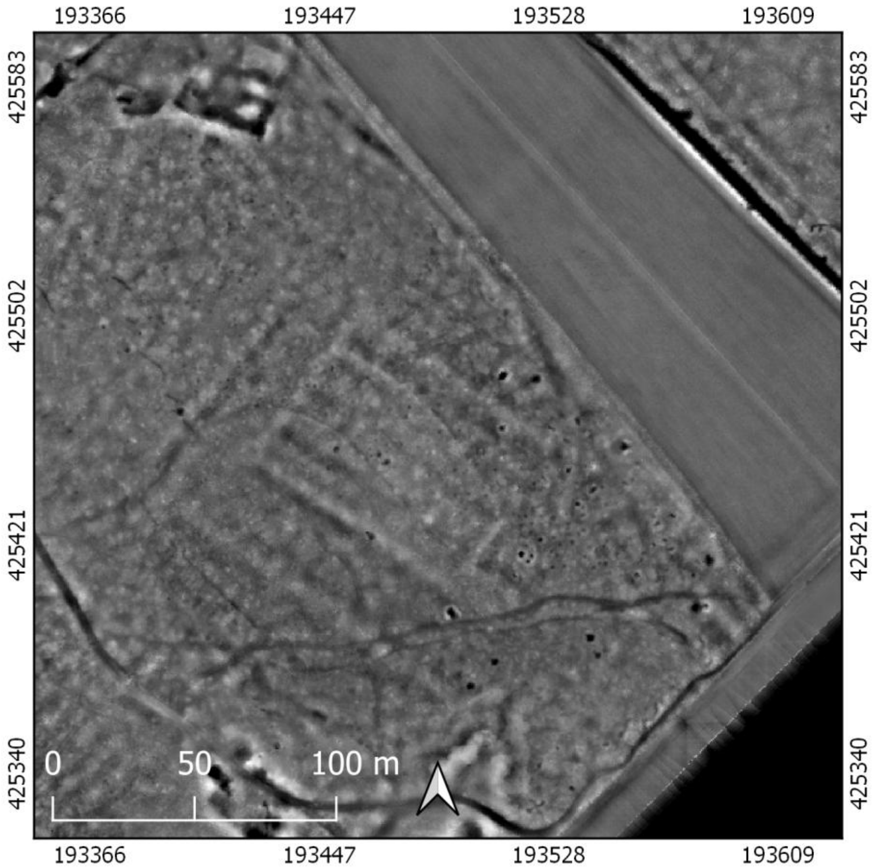


Fig. 40: Local Dominance Visualization of structure 5 near the Duivelsberg, consisting of an inner and outer rectangular shape.

North of camping Wylerberg, a distinct angular shape (Fig. 37 structure 6; Fig. 41) is visible. This shape and location correspond with the 1939 drawing by Rosenkranz (Ten Hag *et al.* 2020, 48) (Fig. 9). This is very likely the area where urn graves have been found in the early 20th century. This terrain appears to be completely unknown in Dutch archaeological literature, which makes it worthwhile to investigate in the field.

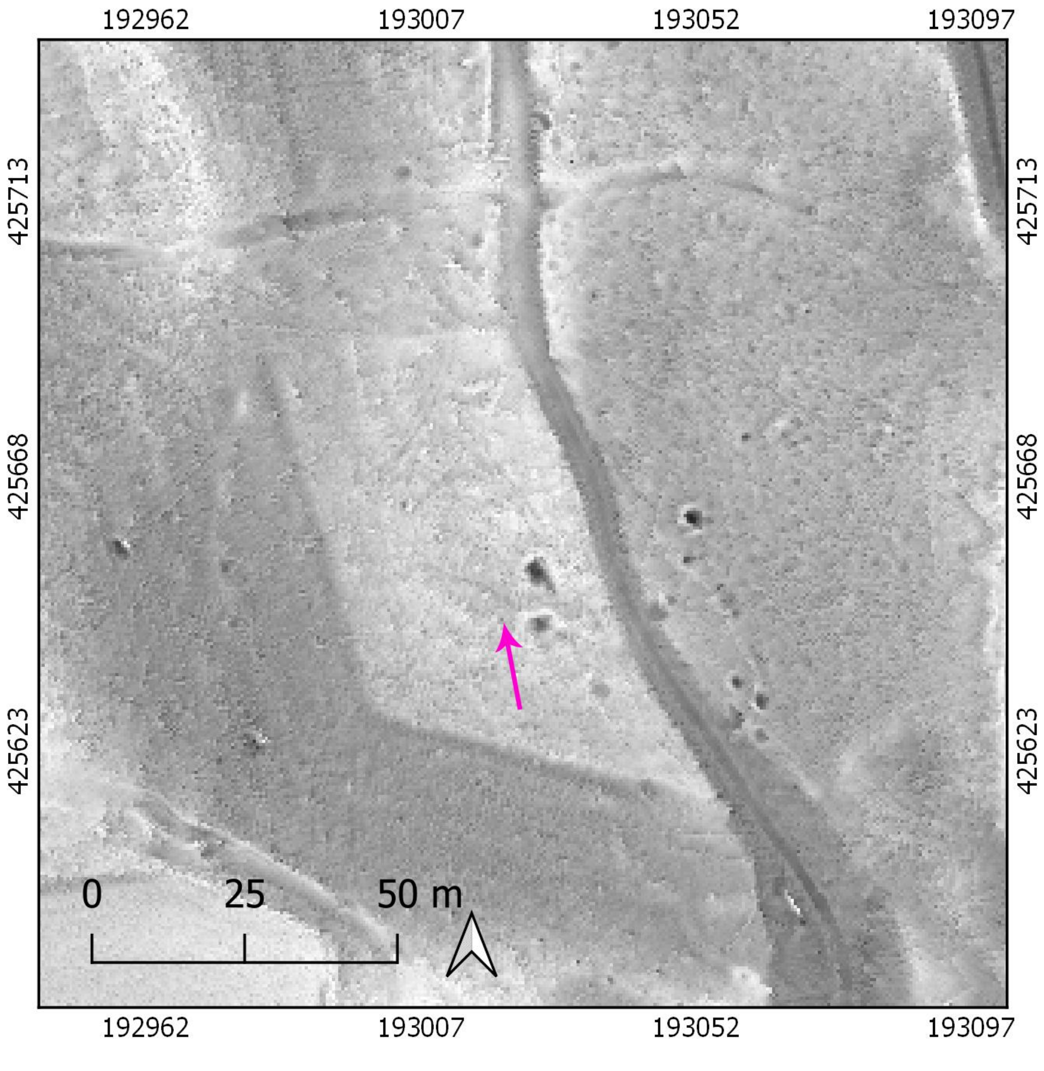


Fig. 41: SVF close-up of structure 6 near camping Wylerberg. The pink arrow indicates the location and direction of the photo in Fig. 42.

Fig. 42: The modern-day forest on the location of structure 6 (photo by author).

Currently, the area is a relatively open part of the forest (Fig. 42). The angular shape appears to simply be the bottom edge of the hill. Although hard to detect in current forest conditions, considering the unnatural straight lines visible in LiDAR and on the drawing, it is likely this corner was more easily visible in the past under different vegetation circumstances. The distinct angular corner hints at human involvement. On LiDAR and in the field, there appear to be no traces of barrows or mounds. This could indicate that the entire terrain was excavated when the urns were found, destroying any visible remains, or suggest a date of at least Iron Age or later when urns were buried without mounds (Hessing en Kooi 2009, 631). Other similar gravefields are known from around the larger Nijmegen area (I.e. van den Broeke *et al.*2011 ; Eimermann and van den Broeke 2017)

Rosenkranz has also drawn another location with urn graves to the north or northeast. The upper two green urns are drawn east of the *Burghügel*, referring to the two Medieval castle mounds. The corner extends out north from a path. East of the hills a similar shape is visible in LiDAR (Fig. 43), possibly locating the upper corner of the drawing. This is the area in which various World War Two remains can be found, so any older remains may have been lost. The area is currently in a relatively inaccessible part of the forest.

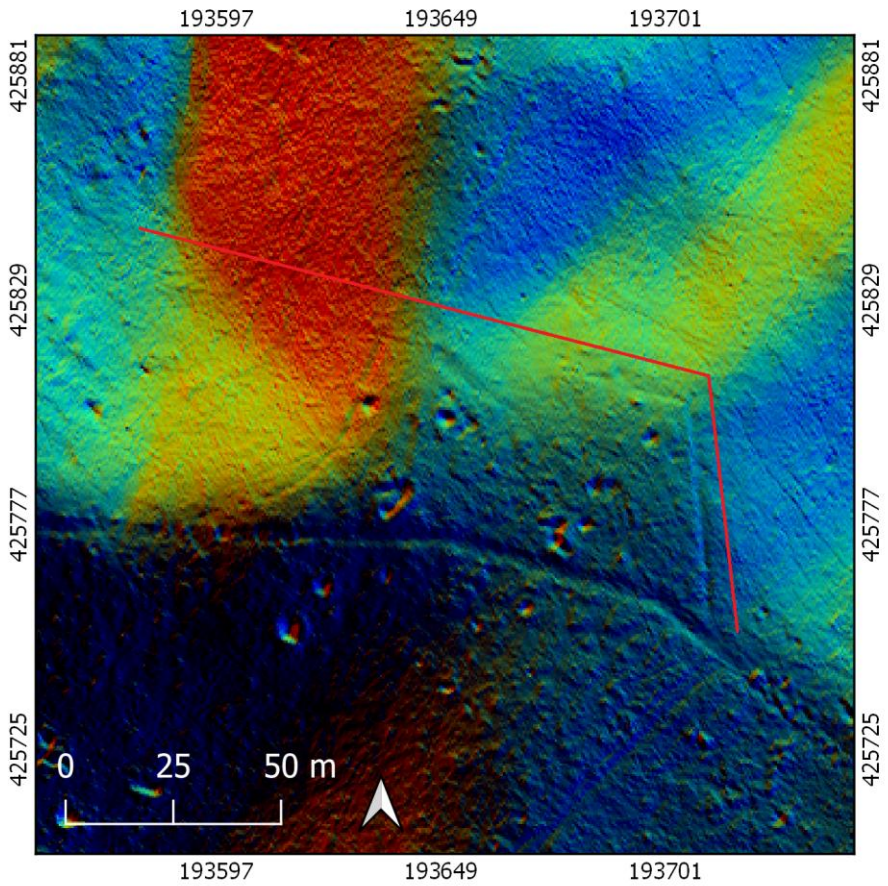


Fig. 43: Multidirectional hillshade of structure 7, the possible location of urn graves mentioned by Rosenkranz.

Furthermore, on the terrain marked with Theunissen (Fig. 9A), referring to the area around camping Wylerberg, the walled Roman graveyard and inhumation are drawn. It is unclear if this refers to a wall around the entire graveyard or a single large grave monument.

The terrain of 'Theunissen' refers to the Berg and Dal pottery factory from the late 19th century AD, known locally as the Pottery of Theunissen. A large part of this terrain is currently grassland. To the south terrain are a number of long ditches with no immediately clear purpose (Fig. 44). The ditches are still visible in the terrain (Fig. 45) but are not related to any modern paths.

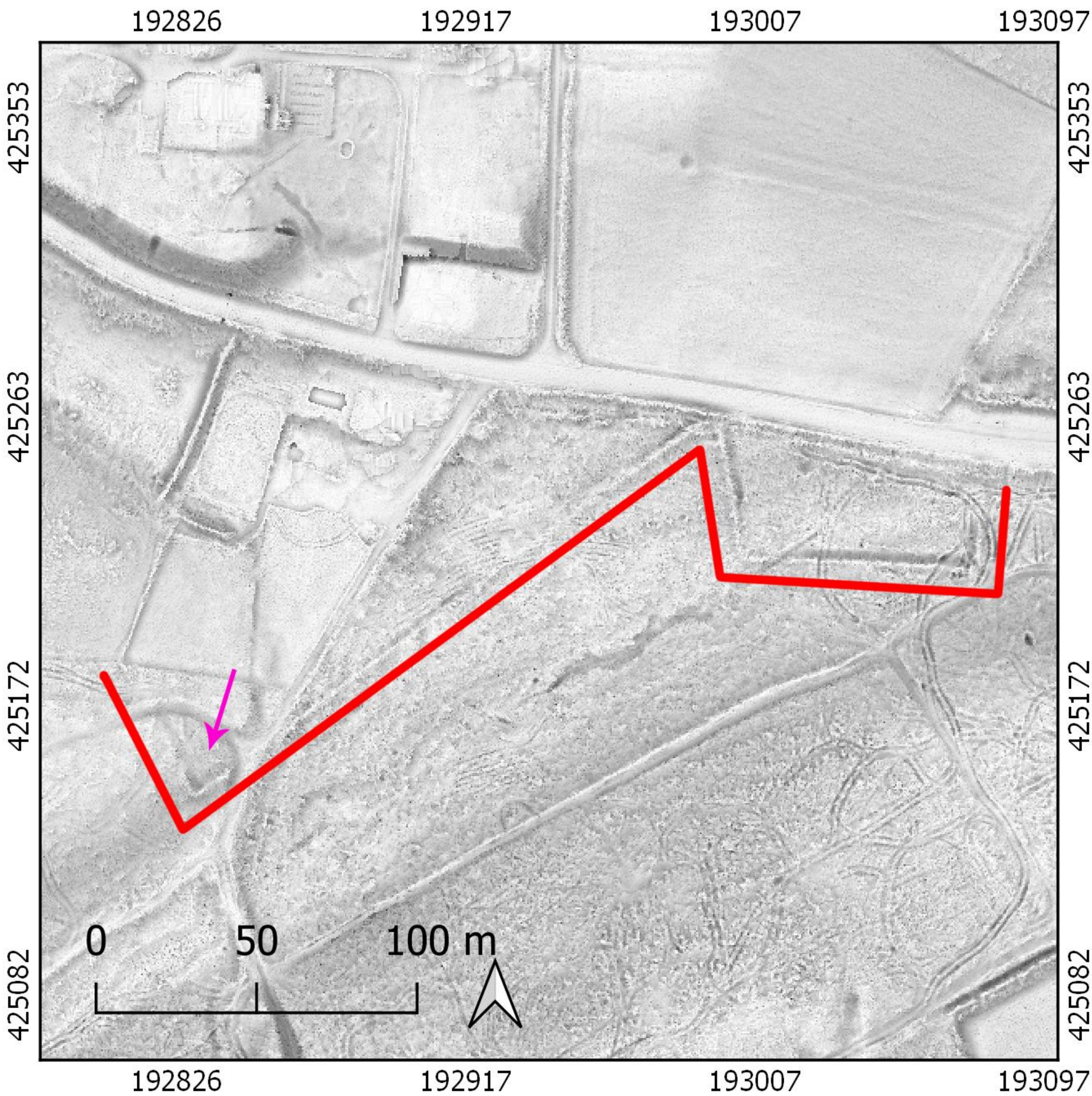


Fig. 44: SVF of the area around camping Wylerberg. The red line shows the trace of ditches or roads which are unrelated to the modern paths. The pink arrow indicates the location and direction of the photo in Fig. 45.

While it would be appealing to connect long ditches such as these with a possible fortification or temporary Roman camp, without further information or (archaeological) evidence, it is impossible to relate these ditches to any specific activity or period. The part of the area to the south of the main road shows on the map as a grassland between 1997 and 2005, indicating these could be the remains of paths, drainage, or similar. Judging by the rather abrupt corners and the absence of other pits or trenches nearby, this interpretation appears far more likely than World War Two trenches or ditches around a Roman graveyard.

Fig. 45: The corner of the southern ditch on Fig. 33, still visible in the field (photo by author).

Roman Roads

The main Roman roads to the east are now covered by the modern Oude Kleefsebaan and Rijksstraatweg, so they are no longer visible in LiDAR. Further to the southwest, near the watchtower at Heumensoord, a trace of the old road which presumably led from Cuijk to Nijmegen can still be seen (Fig. 46), however, this road cannot be traced further to the north or south in LiDAR. Next to this stretch of road are what appear to be the remains of (post)medieval hollow roads or cart tracks (Verschoof-van der Vaart and Landauer 2021, 143-4)

All other possible Roman roads mentioned by Daniëls (1955) or Franzen and van Roode (2019) are suggestions of modern roads and paths, which could follow the same route. On LiDAR imagery, there is no visible evidence of these predecessors.

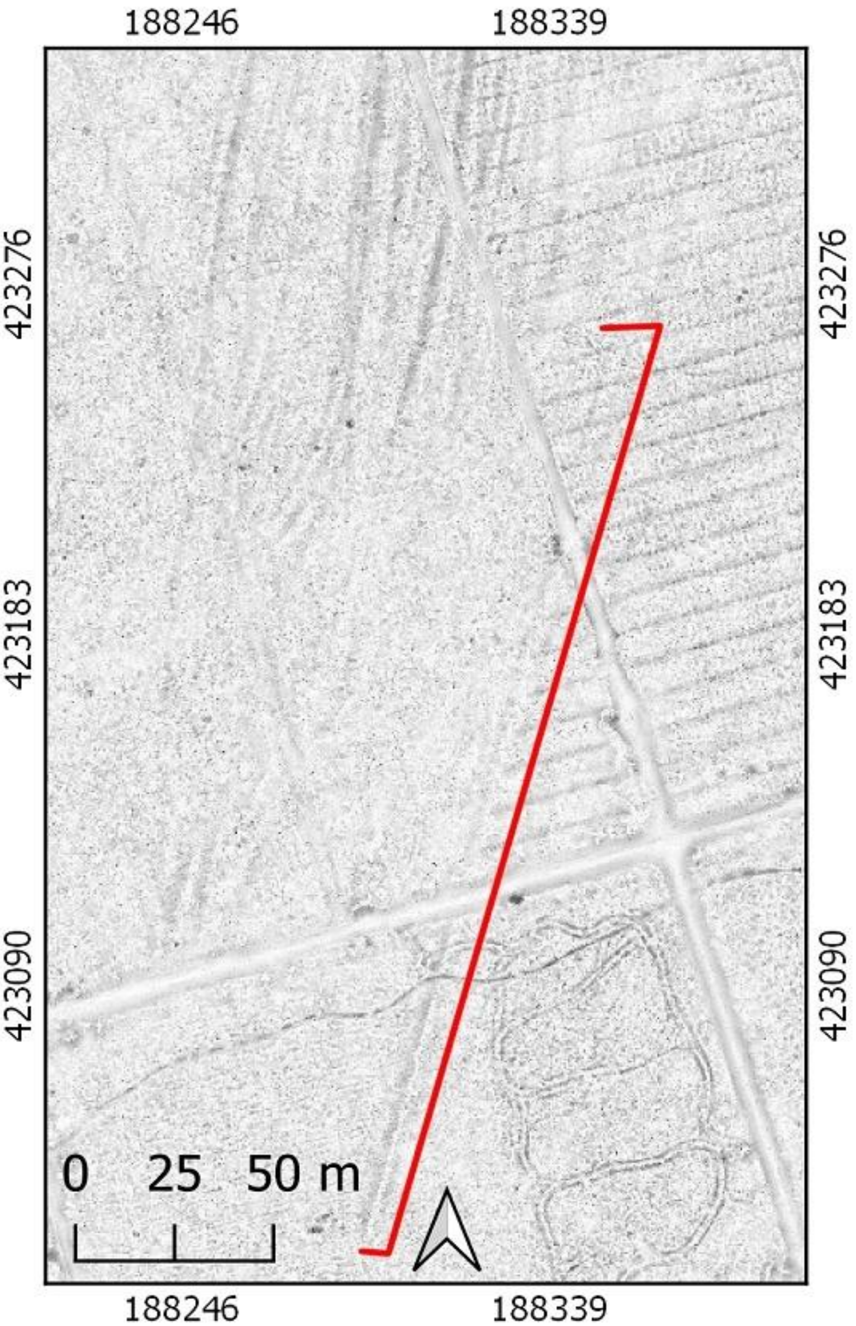


Fig. 46: SVF of the known Roman road near the watchtower at Heumensoord.

7. Conclusions

This research aimed to gain insight into the Roman archaeological remains on the Nijmegen moraine. The objective was to collect, compile and interpret the available data and predict possible new sites. This research has generally succeeded in creating an overview of the available data and identifying locations that could be the focus of future research and fieldwork. This chapter discusses the results to answer the original research questions posed in the first chapter and discusses the merits and shortcomings of this research based on these answers.

> *1. How can the AHN3 dataset, using visibility analysis and visualization methods, be used to locate new archaeological sites and how applicable are these techniques to Roman military structures on the Nijmegen moraine?*

This research has shown the AHN3 to be a promising dataset for archaeological research in the Netherlands. The techniques applied to this dataset can be used to locate and predict new archaeological sites if the theoretical and practical applications and limitations are properly understood.

7.1 Visibility Analysis

Out of the three methods in this thesis, the visibility analysis appears to be the least effective in producing quantifiable results. An important factor is the limited amount of fortifications in the research area that could be used. Similar visibility research on Roman watchtowers generally consists of large stretches of the *Limes*, spanning across countries. In the Netherlands it could perhaps be used to analyze all known fortifications in the country as one system, or focus on a smaller area in which more fortifications are known closer together. Although visibility and viewshed analysis should be implemented carefully in archaeological research, military watchtowers, which are part of a signalling system are some of the most suitable subjects for such an analysis.

7.2 LiDAR Visualization Analysis

LiDAR has been proven as a useful addition to archaeological research and has been used to find various sites all over the world. Data is rapidly becoming available for research through various open access sources, such as the AHN in the Netherlands. The last two decades have seen an ongoing discussion in archaeological literature on the possibilities, benefits and pitfalls of using LiDAR in archaeology. Much like other types of digital research, it is important to ensure the tool does not replace other archaeological research. It should be a well-designed part of a larger research for useful results and archaeological fieldwork needs to be performed for any conclusive interpretation of a possible site.

In the Netherlands, very little land is truly untouched by human activity. Various shapes and features, which are visible on LiDAR, in the forest can be difficult to determine. Even the grasslands or forests can be littered with traces of human activity. Comparing these areas with maps, old news articles or archaeological reports is a very time-intensive process, especially as the size of the research area increases. Even then, it is often not possible to give a definitive interpretation. Despite this, LiDAR is a relatively easy and accessible tool to study large areas of land. The technique is especially beneficial to locate earthworks such as barrows, trenches, and larger constructions such as hill forts or marching camps.

2. What is the nature of the evidence of Roman archaeology currently known on the Nijmegen moraine, and what are the indications that more Roman archaeological remains are to be expected?

The evidence from the research area is marked by a notable absence of larger excavations. Generally, the western part of the research area, within the municipality borders of Nijmegen, is more intensively researched than the eastern part near the Dutch-German border. The notable exception to this is the area of the Holdeurn pottery factory. The rest of the fieldwork consists of coring-research and archaeological guidance at construction work or dredging, occasionally revealing indications of Roman activity.

The evidence from older literature follows a similar geographical spread. Many of the finds from the early 20th and 19th century can be related to sites that are now well-known, such as the *Castra* on the Hunnerberg or the Roman grave field on the Hengstberg.

Further east from Nijmegen, most of the notable archaeological evidence are those found in *Archis*. These are generally stray finds with an unclear or forgotten context, in areas where no proper excavation has taken place.

It appears that most evidence of Roman archaeological remains is in those areas, which have been extensively researched already, but there is reason to assume the rest of the Nijmegen moraine is equally rich in Roman archaeology. The most notable of these are:

- Several finds indicate the existence of several 2nd-century *villae* on the northern peaks of the moraine such as at the Ravenberg and Musschenberg (Enckevort and Tunker 2013; Daniëls 1955).
- In the 17th century, a temple dedicated to Mercurius was still visible near the Kerstendal, possibly located on a hill at the beginning of the aqueduct (Ten Hoet 1826, 45; in de Betouw 1804, 6).
- Multiple Roman graves and urnfields located in between the area of the Holdeurn and the Duivelsberg (van Agt 1958, 103; Rosenkranz 1939, 447-8).
- Dredge finds from the Wylermeer, north of the Duivelsberg, which could indicate a fortification or other stone building (Den Hartog 1986, 17).

3. Where can an unknown Roman military installation be expected using visibility analysis?

The results of the visibility analysis in this research are rather straightforward. The visibility analysis has shown the Hengstberg and Duivelsberg to be the most ideal locations for a watchtower or other fortification in a signalling system. The Duivelsberg especially seems suitable for acting as a link between the fortifications of Nijmegen and those to the east in Germany.
It should be noted that these results remain highly theoretical and, at best, indicate locations that might have been attractive to the Roman military.

Until such a fortification is archaeologically proven, the existence of one or more extra watchtowers on the moraine peaks will always remain speculation. Chains of watchtowers and fortifications are known across various stretches of the Limes, so the idea of such a system existing around Nijmegen is not unlikely.

4. What archaeological remains are visible in the research area using LiDAR visualizations,and how are these to be interpreted?

Although no Roman buildings were located, the investigation of the LiDAR images of the Nijmegen moraine has revealed several interesting locations. Most obvious is a large amount of traces from the second World War. Remains of the battles are relatively recent, leave very visible traces in the soil and cover large areas, making them easily identifiable using LiDAR. Although many of these remains have already been identified and documented in this area, the technique itself is highly applicable to other such conflict locations worldwide. South of the Kwakkenberg, some possible prehistoric mounds have been located.

Other LiDAR traces in the research can be linked to relatively modern times using maps and archival sources, while some remains appear to be modern but cannot be definitively interpreted by LiDAR and maps alone.

The area around the Duivelsberg seems to be overall the most promising. It is the least densely populated and urbanized part of the research area, offering the best visibility in LiDAR and increasing the chances of undisturbed and unknown archaeological remains. Various structures can be seen which date to the early 20th century or earlier.

Two terrains in between the Duivelsberg and Holdeurn have been located which correspond very clearly with a map made in 1939, showing the location of urn graves. This location is not known in any archaeological report or the Archis database. It is however unmistakable when viewed using LiDAR. There is no other information on the urns, but the absence of mounds and barrows could hint at an Iron Age date.

7.3 Absence of Visible *Villae* and Watchtowers

The original hypothesis of this research was an unknown Roman watchtower, while the literature points toward several *villa* terrains. Neither of these have been located using LiDAR, however, this does not necessarily come as a big surprise. The absence of visible remains in LiDAR can be explained with a variety of reasons. Most importantly, the remains of buildings or their foundations could simply be too deep to leave any visible traces in the DEM. The Roman layer has been found at up to 6m below ground level at the bottom of the moraine. This theory seems especially likely considering the LiDAR images do not show any traces in areas of the Holdeurn where radar research has conclusively proven them to exist.

Another reason is the nature of the remains; LiDAR is especially useful in detecting subtle changes in the soil. These can be caused by earthworks such as roads, ditches, or other defences. A *villa* building does not necessarily leave such traces. The various Roman roads likely followed the same paths as the modern roads, obscuring them from view.

Most of the archaeological remains that hint at a *villa* are tuff stone blocks. While some of the fortifications in the area have had stone building phases, others such as the Heumensoord watchtower were only ever built in wood, which would have been lost over time. A small fortification would have been surrounded by ditches. The remains of these could also have been lost by later land use. An interesting hypothesis is that the Medieval mound castle on the Duivelsberg was built on top of the location of older Roman fortifications, as this location clearly had military value to people in the past.

7.4 Final Remarks and Implications for Future Research

The combination of the results of the three methods used in this thesis can create an overview that allows answering of the main research questions and predict where new Roman archaeology might be expected.

The hypothesis of the high moraine peaks such as the Kwakkenberg and Duivelsberg being ideal locations for military fortifications can be accepted. Other moraine peaks, which are less likely candidates for such watchtowers, such as the Ravenberg and Musschenberg, are favourable locations for *villa* terrains. The lower areas should however not be discarded. Many of the archaeological remains are found on the slopes after erosion, but the relatively lower flat areas are also the location of Roman roads, graves and the Holdeurn factory.

Perhaps our entire perception of Roman Nijmegen should expand further towards the east. Previous research has largely focused on the modern urbanized area from the fortifications on the Valkhof in the west to the Kops Plateau in the east and the surrounding. The (military) Holdeurn factory, several *villae*, multiple possible gravefields and two major roads towards the east are often excluded from maps of Roman Nijmegen. All these must have caused a sizable part of the population to spend their days on this side of the moraine, leaving behind archaeological traces.

If anything, this research has exemplified that the unexplored parts of the Nijmegen moraine still have a high archaeological value ranging from Bronze Age barrows to World War 2 battle remains. Interestingly, the areas marked here as possibly interesting terrains roughly correspond with the map of archaeological values on based on geology (Fig. 7), perhaps a small victory for processual archaeologists.

For further research into Roman Nijmegen, especially during the years of *Legio X* in the 2^{nd} century, a focus shift away from the city centre towards the moraine could be worth considering. The moraine was home to a large pottery factory, at least several *villae* and multiple possible grave fields. This area could yield valuable information regarding the development of the Roman settlements along the river.

Considering large parts of the moraine are protected either as archaeological monuments or as nature that should remain undisturbed, a next step might involve non-destructive research methods such as ground radar geomagnetic research. At the northern side of the Holdeurn pottery factory, this technique already indicated traces of unknown Roman buildings, and could be a helpful tool in detecting these on the other moraine peaks, where LiDAR could not.

Abstract

This thesis explores the evidence for Roman archaeology on the Nijmegen moraine east of the city. This area is poorly researched compared to the city of Nijmegen in the west and the newly discovered auxiliary forts in Germany to the east. Roman fortifications were hypothesized to have existed on the higher peaks of the moraine, offering a commanding view over the wider area and connecting west to east. An analysis of the available literature indicates this part of the moraine might hold more Roman archaeological remains than is currently known, including *villae* and fortifications on the high peaks. In an attempt to predict and locate these, the AHN3 height map of the Netherlands is used for a visibility analysis and LiDAR visualization analysis of the area. The visibility analysis shows that several high peaks, most notably the Duivelsberg, are ideal locations for a watchtower which could act as a missing link in a signalling system between the fortifications in Nijmegen and those in Germany. LiDAR analysis indicates that several areas on the moraine likely contain undiscovered archaeological remains, including World War Two battle remains, prehistoric barrows, and urnfields. The research also demonstrates the strengths and shortcomings of using these digital methods to locate new archaeological remains. It is concluded that the moraine is a highly attractive area for future archaeological research into Roman Nijmegen or other periods.

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