Survey report

Ground Penetrating Radar survey for Archaeological Prospection at Wijk bij Duurstede 2007

Methodology, data acquisition, results, interpretation

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Photo title-page: Georadar survey at Wijk bij Duurstede (The Netherlands). Photo: Immo Trinks
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1 Introduction

During six days in January/February 2007 the Archaeological Excavation Department of the Swedish National Heritage Board conducted Ground Penetrating Radar (GPR) measurements in the town of Wijk bij Duurstede in The Netherlands. The survey was commissioned by Archeologisch Diensten Centrum (ADC) in order to probe the presence and location of historic and archaeological structures in the subsurface at the development site Veilingterrein southwest of the crossing Frankenweg/Zandweg (Figure 1.1).

Figure 1.1: Satellite image of the survey area. The site is the open area south of the road Frankenweg and west of the road Zandweg. Three archaeological excavation trenches (see as well Figure 1.4) made earlier by ADC can be seen after refilling. Image source: Google Earth.

Recently the site had been used as a parking space. Until few years ago modern market hall buildings for the trading of fruit had occupied the site (Figure 1.2). The concrete foundations of the market hall buildings have been removed prior to the archaeological prospection survey according to information provided by ADC. In the beginning of February 2007 only a former electric transformer building was still standing at the site (Figure 1.3). In earlier times the site had been used by bone diggers who dug for human or animal bones that then were used in the production of soap.

The objective of the georadar survey at the site was the prospection for historical and archaeological remains which could be attributed to the bone digging activities as well as to traces of the city of Dorestad from Carolingian times (751 AD to 899 AD). During the Early Medieval Ages Dorestad was one of the most important and flourishing cities of The Netherlands, located on the banks of the river Rhine near the location of the modern town of Wijk bij Duurstede. Dorestad was several times raided by Vikings. In the second half of the 9th century Dorestad lost its importance due to Viking raids and displacements of the river Rhine.
ADC ArcheoProjecten conducted in 2004/2005 an archaeological investigation\(^1\) by excavating four trenches at the site Veilingterrein (Figure 1.4). The drawn profile sections of these trenches are shown in Figures 1.5 and 1.6. It can be seen that the profile in east-west orientation (911 & 912) shows a thick surface layer of recent material. The trenches dug in north-south orientation (913 & 914) show less recent disturbances and a thick agricultural plough layer. In both cases do archaeological remains exist only in small pockets and surrounding a well.

Section 2 of this report describes the georadar survey. The georadar data is presented and discussed in Section 3. An archaeological and antiquarian analysis and interpretation is provided in Section 4. The Appendix contains a general description of the georadar method, data depth-slice images and a comparison of the survey results with findings of the subsequent excavation.

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Figure 1.3: View of the survey site from the East. The former electric transformer building can be seen on the site. The ground in the south-eastern part of the survey area (left part of photograph) was darker and richer in humus than the northern part (far right in photograph), which was very sandy. Several bones were visible on the ground in the south-eastern part of the survey area.

Figure 1.4: Map showing the locations of the archaeological excavation trenches made by ADC prior to the georadar survey. Image source: ADC ArcheoProjecten Report 421, J. Dijkstra & J. van Renswoude, 2005.
Figure 1.5: Profile sections of the archaeological excavations trenches 911 and 912. Recent structures are shown in purple, the natural underground in green, archaeological culture layers in red and an agricultural layer in pink. Image source: Figure 6 in ADC ArcheoProjecten Report 421, J. Dijkstra & J. van Renswoude, 2005.

Figure 1.6: Profile sections of the archaeological excavations trenches in 913 and 914. Recent structures are shown in purple, the natural underground in green, archaeological culture layers in red and an agricultural layer in pink. Image source: Figure 7 in ADC ArcheoProjecten Report 421, J. Dijkstra & J. van Renswoude, 2005.
2 Description of the georadar survey

The georadar archaeological prospection survey at the site Veilingterrein in Wijk bij Duurstede had been conducted over the course of five days. The weather conditions remained predominately cold and dry, with the occasional drizzle. A total area of approximately 13,750 square metres (55,000 m profile length) had been surveyed using a Sensors & Software Noggin Plus 500 MHz Ground Penetrating Radar antenna system. The extent of the survey site is shown in Figure 2.1. An aerial photograph of the site prior to the survey can be seen in Figure 2.2.

The high-resolution georadar survey was conducted in zig-zag mode using a cross-line profile spacing of 25 cm and an in-line trace spacing of 5 cm. A 4-fold georadar trace stacking was chosen for signal-to-noise enhancement. The recording time window was set to 80 ns, corresponding to a maximum penetration depth of 4.0 m under the assumption of an average signal velocity of 10 cm/ns in the subsurface. The maximum profile length of individual GPR profiles was 50 m. For orientation and positioning 50 m long profile lines were placed at 1 m intervals on the ground (Figure 2.3). Prior to the measurements the system odometer was calibrated along a 50 m distance.

The light vegetation and rubble present at the site prior to the survey had been removed by a kind of ploughing procedure. Subsequently the ground had been flattened, presumably by pulling large rubber tyres that were cut in half behind a tractor across the surface. This process left deep tractor tyre marks on the surface and resulted in an inhomogeneous, very soft top layer (Figure 2.4), hampering the survey and causing minor positioning errors. The removal of the first 30-40 cm of topsoil would have resulted in a harder surface and less rubble in the top layer, which would have permitted more exact positioning and higher data quality.

The survey area was geo-referenced using a Trimble Totalstation and fix-points in the vicinity of the survey area. The coordinate information for the fix-points was provided by ADC. Quality control of the data was performed on site using the ReflexW software package. The final processing of the GPR data was performed by Alois Eder-Hinterleitner (Central Institute for Meteorology and Geodynamics, Vienna) using purpose written software for special processing of archaeological prospection GPR data. The analysis and interpretation of the geo-referenced GPR data was conducted within the Geographical Information System (GIS) ArcMap.

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2 A general introduction to the georadar method can be found in Appendix 5.1.

3 The data recording of the georadar system is triggered by an odometer wheel attached to the left rear wheel of the cart. On a soft sand surface the zig-zag survey mode at 25 cm cross-line spacing causes a higher friction for the cart wheel when the wheel is rolling through new, untouched sand, while on the return trip the left rear wheel is running with reduced friction in the track of the right wheel of the previous profile line. The unequal friction on the cart wheel causes directionally depending variable system triggering and therefore different recorded profile lengths. The variable profile length was corrected by interpolation during data processing.
Figure 2.1: Map of the survey site Veilingterrein in Wijk bij Duurstede showing the extent of the area covered with georadar measurements in blue. The whole in the area (TB) indicates where the transformer building obstructed the survey. The gap in the southern part of the area (G) is displayed inaccurately. This gap had actually been filled with georadar measurements.
Figure 2.2: Aerial photograph of the same area as shown in Figure 2.1. The photo shows the site prior to the survey. The refilled archaeological excavation trenches dug by ADC are visible.
**Figure 2.3:** Photo of the central part of the survey area. Two survey lines spaced at one meter distance can be seen on the ground. The georadar antenna cart is pushed along straight, parallel, 50 m long lines with 25 cm cross-line spacing.

**Figure 2.4:** Photo of the northern-most part of the survey area. The soft sand surface covered with deep tractor tyre marks hampered the exact positioning of the cart along the survey lines, causing minor positioning errors.
3 Presentation and discussion of the survey results

This section presents the georadar data in form of depth-slices\(^4\) and corresponding interpretation images. Depth-slices of 10 cm thickness have been generated for the entire data set. They are listed from 0 to 3.5 m depth in Appendix 5.2.

In the following depth-slice images interpretations for structures visible in the data are suggested wherever possible.

The depth information of each depth-slice is approximate, since an approximate constant velocity of 10 cm/ns was used in the time-to-depth conversion of the data. The actual depth of structures contained in depth-slices can vary by up to 50\% relative to the depth-slice label. However, the relative depth of structures is correctly imaged in subsequent depth-slices.

Figure 3.1.1 shows a georadar depth-slice in which the archaeological excavation trenches made by ADC ArcheoProjecten are clearly visible. These trenches are marked in Figure 3.1.2.

Figure 3.2.1 shows exemplary the large number and great extent of disturbances caused by the foundations of the modern buildings that had been built at the site. The many foundation pillars and connecting walls in-between can be seen. Several long, linear structures are caused by modern utilities, such as pipes, cables and the corresponding trenches. Massive basement constructions can be seen in the northern part of the survey area. The most prominent structures are marked in Figure 3.2.2.

Figure 3.3.1 shows a dark reflector in the northern part of the survey area which appears to have been intersected by the more recent foundation structures. Therefore, the dark reflector as well as the anomalies with similar orientation to its south-west (Figures 3.3.2 and 5.2.17) are presumably of older age than the recent disturbances. Possibly these structures are larger pits or ground disturbances caused by bone digging activity, or structures of even greater age.

Figures 3.4.1 and 3.4.2 show exemplary anomalies at 170-180 cm depth, indicating the great depth of disturbances caused by the foundations of the modern buildings.

Figures 3.5.1 and 3.5.2 show moderately deep structures in an exemplary depth-slice at 110-120 cm depth.

These Figures (3.4.1, 3.4.2, 3.5.1 and 3.5.2) indicate the degree of disturbance of possible archaeological structures in the area. Based on this information it is possible to prioritise areas according to their potential to contain preserved cultural layers and archaeological structures. Deep going modern structures render the likelihood to find preserved archaeological structures low. Likewise it is possible to identify areas that appear to have been left widely undisturbed and which therefore bear a greater chance to find intact archaeological structures during excavation.

Figures 3.6.1 and 3.6.2 show deep linear structures which may have geological causes, such as the bedding of alluvial sediments. Their length and number makes it unlikely that these are archaeological structures.

Figures 3.7 to 3.13 show interpretation maps with stepwise added structures.

It has not been possible to clearly identify anomalies contained in the data as archaeological structures.

\(^4\) For an explanation of the generation of georadar depth-slices see Appendix 5.1.
Figure 3.1.1: Georadar depth-slice showing the trenches that had earlier been excavated and then refilled by ADC ArcheoProjecten. The interpretation of these trenches is shown in Figure 3.1.2. See also Figure 1.4.
Figure 3.1.2: Georadar depth-slice with the trenches that had earlier been excavated and then refilled by ADC ArcheoProjecten marked. See as well Figure 1.4.
Figure 3.2.1: Georadar depth-slice showing exemplary the foundations of the recent market hall buildings. The ground disturbances where the concrete pillars and walls supporting the building have been located can clearly be seen. Even several subdivisions of buildings are visible. Some corresponding utilities (pipes, cables) are shown as thin, long linear anomalies. In the northern part spacious basement structures can be seen. The interpretation of these structures is shown in Figure 3.2.2.
Figure 3.2.2: Georadar depth-slice with the remains of modern buildings (the foundations and utilities of the recent market halls) marked.
Figure 3.3.1: Georadar depth-slice showing in the northern part large, dark reflective structures that appear to be intersected by the anomalies caused by modern foundation walls, indicating and older age. The interpretation of these structures is shown in Figure 3.3.2.
Figure 3.3.2: Georadar depth-slice with the dark reflecting structure visible in Figure 3.3.1 marked. Another with similar orientation is located to the south-west of the northern structure. This second, weaker expressed structure is best visible in Figures 3.4.1 and 5.2.17.
Figure 3.4.1: Georadar depth-slice showing reflective structures caused by recent buildings in a depth of about 170-180 cm. The interpretation of these structures is shown in Figure 3.4.2.
Figure 3.4.2: Georadar depth-slice with the deep ground disturbances caused by the foundations of the recent buildings marked.
Figure 3.5.1: Georadar depth-slice showing reflections of recent structures at the depth of 110-120 cm depth. The interpretation of these structures is shown in Figure 3.5.2.
Figure 3.5.2: Georadar depth-slice with moderately deep recent structures marked.
Figure 3.6.1: Georadar depth-slice showing from 340-350 cm depth showing linear structures dipping east-north-east to west-south-west. It is likely that these anomalies are caused by geological structures. The interpretation of these structures is shown in Figure 3.6.2. In the southern part vehicle tracks are visible as dark double lines in north-south orientation. Even though these anomalies are caused by structures at the surface, their disturbing effect is still visible at great depth. In shallower depth-slices this effect is overshadowed by stronger reflection events.
Figure 3.6.2: Georadar depth-slice with deep, long linear structures marked.
Figure 3.7: Map showing the georadar survey area.
Figure 3.8: Map showing the georadar survey area and the trenches that had earlier been excavated by ADC ArcheoProjecten.
Figure 3.9: Map showing the georadar survey area, the trenches that had earlier been excavated by ADC ArcheoProjecten and the structures caused by recent buildings and corresponding utilities.
Figure 3.10: Map showing the georadar survey area, the trenches that had earlier been excavated by ADC ArcheoProjecten, the structures caused by recent buildings and corresponding utilities and further reflective structures which appear to be of greater age than the recent buildings.
Figure 3.11: The same map as shown in Figure 3.10 with deep ground disturbances caused by recent structures marked.
Figure 3.12: The same map as shown in Figure 3.10 with deep and moderately deep ground disturbances caused by recent structures marked.
Figure 3.13: The same map as shown in Figure 3.12 with possible geological structures at greater depth marked.
4 Archaeological analysis and interpretation

Under the right conditions the georadar method is an efficient tool to gain information about structures hidden in the subsurface. Georadar prospection makes no difference between archaeological, historical or modern structures in the ground. If a contrast between specific physical properties of a structure of interest and the surrounding subsoil exists, if the measuring device is sensible enough to detect this contrast and if the anomaly is not overshadowed by stronger interfering signals it is possible to detect and map the location and shape of buried objects.

At the survey site Veilingterrein in Wijk bij Duurstede the soil conditions for the georadar method were good in regard to soil humidity and soil resistance. Sandy top-soil with low clay content resulted in a signal penetration depth of more than 3 m. The freshly worked soft sand surface however resulted in reduced antenna position accuracy and more strenuous survey work.

It is likely that the here presented work presents to date the largest high-resolution georadar survey for archaeological prospection ever conducted in The Netherlands.

The analysis of the georadar data shows indicates that

- almost the entire site is strongly disturbed,
- large areas are occupied by deep modern structures caused by foundation walls and pillars and corresponding utilities in form of cables and water/waste water pipes,
- only few, small scale intact archaeological structures are to be expected.

As a result, the information gained from the georadar survey should be used to determine areas that are most likely to contain undisturbed archaeological structures. To this purpose those areas that have been deeply affected by modern structures have been marked in the interpretation (Figures 3.4.2, 3.5.2, 3.11, 3.12). Thus it is possible to focus time and efforts of the planned excavation onto the most promising areas.

The lack of clearly interpretable archaeological structures present in the data can be explained with the strong, large scale ground disturbances caused by the foundations of the modern market hall buildings, as well as by the reported bone digging activity in the area, which is likely to have destroyed older coherent archaeological structures. As it can be seen in the profile sections of the earlier excavated trenches do archaeological structures appear in small pockets rather than in the form of a continuous cultural layer (Figures 1.5 & 1.6). The high resolution of the measurements is demonstrated in the clear mapping of the more recent structures. Vertical recent structures that are shown in the profile section in Figure 1.5 can clearly be identified to belong to the shafts of the foundation pillars of the large east-west oriented market hall which were cut by the excavation trenches 911 and 912 (see Figures 3.2.1 & 3.2.2). The lack of archaeologically interpretable structures in the geophysical prospection data can not be used as evidence for the absence of any archaeological structures.

A region of higher reflectivity in the northern part of the survey area may be attributed to structures of archaeological or historical interest (Figures 3.3.1, 3.3.2, 5.2.17). It is possible that this region is related to the bone digging activity.

During the planned excavation it is advisable to cross-check all discovered structures against the georadar data. The data images in printed and digital form contain considerably more detailed information than a simplified, subjective interpretation.
5 Appendix

5.1 Description of the Ground Penetrating Radar method

Ground Penetrating Radar, Ground Probing Radar (GPR) or Georadar is a geophysical measurement method that allows the investigation of the shallow subsurface. A GPR antenna is used to send electro-magnetic waves into the subsurface. These waves are reflected from structures such as large stones, old foundations of buildings, pits, ditches or interfaces of geological layers. The reflected radar waves that are returning to the surface like an echo are recorded with the GPR antenna and used to generate an image of the subsurface.

The GPR technique

GPR antennas used for archaeological prospection typically emit an electro-magnetic signal with an average frequency between 100 and 1000 Megahertz (MHz), similar to radio stations. In general, it can be said that the higher the frequency, the shorter the wave-length of the electro-magnetic wave. The wave-length is defining how well we can resolve structures in the subsurface: a shorter wave-length of higher frequency is able to “see” smaller objects. On the other hand, high frequency electro-magnetic waves suffer more from damping of the signal, compared to electro-magnetic waves with longer-wave lengths and lower frequency.

![Figure 5.1.1: Sketch, showing a low frequency signal of long wave-length (top), and a high frequency signal of short wave-length (bottom). Similar to acoustic waves, the low frequency range has less attenuation and travels further. It is a well known phenomenon that the low frequency bass of music penetrates walls and ceilings in buildings while the high frequency tones are filtered out.](image)

The frequency dependent damping has the effect that the amplitude of the electro-magnetic signal decreases, the further the signal travels through the ground. Low frequency signals are better suited to look deeper into the ground than high frequency signals. Thus, for the selection of the antenna with the right frequency for our survey we need to make a compromise between penetration depth and desired resolution. Antennas with different frequencies are available (e.g. 100, 200, 250, 300, 500, 800, 900, 1000 MHz), and a 500 MHz antenna is often a good choice for archaeological investigations down to a depth of about 2 to 3 metres with 15cm to 20cm resolution.

The penetration depth and resolution of the georadar method does not only depend on the frequency of the antenna used, but as well on the soil properties at the measurement location. The physical properties of the ground determine the velocity and attenuation of the electro-magnetic waves. In particular, the electrical conductivity of the soil can have a great effect on the radar waves.

Soils with high clay content, or soils that contain a large amount of conductive water, are difficult to investigate with georadar. The uppermost layers of such soils soak up the energy of the electro-magnetic waves and prevent the energy to travel deeper. Sandy soils allow much better depth penetration. Fresh-water in itself poses no problem to GPR investigations. It is...
possible to conduct a radar survey from a boat, by suspending the antennas into the water of a lake or by placing them on the floor of a rubber-boat. In that case the electro-magnetic waves penetrate through the water into the sediment underneath. Similarly, it would be possible to measure on the frozen surface of lakes in winter time, for example to search for harbour constructions or wrecks in shallow water regions, that are inaccessible during summer due to reeds or other seasonal plants.

**How is a GPR survey conducted?**
Before a georadar survey is undertaken it is important to determine the specific conditions of the measurements site. Each project is different and requires the use of an antenna of suitable frequency and a carefully designed measurement grid. If linear structures, such as walls or ditches, are the target, it is best to measure perpendicular to the expected structure. Regular survey areas with equally long profiles allow faster, cheaper measurements, while survey areas that contain obstacles, such as trees, bushes, walls or fences, cause delays.

![Image](image_url)

**Figure 5.1.2:** Pär Karlsson operating the Sensors & Software Noggin Plus 500 MHz antenna mounted in the SmartCart. The data logger with integrated monitor is fastened in a carrier frame in front of the operator. Profile lines with 1m separation distance are visible on the ground. The antenna is pushed along these lines and in between them with a GPR profile spacing of 25cm. Every 5cm along the profile a GPR trace is recorded.

While the GPR antenna is pulled over the surface an electromagnetic source signal is emitted into the ground. The antenna will then “listen” for fractions of a second and record the returning signal which has been reflected or refracted in the subsurface. For each measurement position along the profile line a *time-series* of amplitude values ("GPR trace") is recorded. It is important that the data is measured with very dense trace spacing (5cm in profile direction; 25 cm profile spacing).

**How does GPR data look like?**
Each GPR trace is a time-series of amplitude values of the reflections of the electromagnetic GPR signal, recorded with the receiver antenna, some time after emittance of the source signal from the source antenna, at a specific antenna location.

Each GPR profile consists of a large number of GPR traces. These traces can be plotted as an image with the profile distance as horizontal axis and the recording ("listening") time as vertical axis (Figures 5.1.3, 5.1.4). Such an image is called a "GPR section" or "GPR profile".
It is common to record many parallel GPR sections by measuring with the GPR antenna in zig-zag mode along parallel profiles across the survey area. The cross-line distance between the sections should be 25 cm. The inline distance of traces in direction of the profile should be 3 cm.

The individual GPR sections are merged into a three-dimensional (3D) data volume (Figure 5.1.5). Data values between the profile sections are interpolated in order to obtain a comparable sample density in inline and cross-line directions.

Such a 3D data volume can be cut like a cake in all directions. Slices of equal recording time, so called time-slices, can be generated by cutting the 3D data volume horizontally (Figures 5.1.6, 5.1.7).
If the velocity of the electromagnetic waves in the subsurface is known, the 3D data volume can be converted into a 3D block with depth as the vertical axis. Then it is possible to generate depth-slices, which show the reflecting structures at a certain depth or within a certain depth range. Often an average velocity is used for the time-to-depth-conversion (e.g. 10cm/ns). It should be noted that in the case of an average velocity used, depth variations of up to 50%, compared to the real depth, can remain present in the data.

Structures in depth are best recognizable by analyzing a series of depth-slices. From a series of depth-slice images an animation (simple movie) can be generated. Then the viewer can observe the emergence and change of different structures with increasing, or decreasing depth.
Other common GPR data processing steps are the removal of the average trace, or background removal. This process removes signal-ringing in the data and allows to image the uppermost region of the data, which otherwise would be hidden by the high amplitudes of the direct-wave. The direct-wave is the wave that travels directly from the source antenna to the receiver antenna, which are often located both inside the same GPR antenna box. The direct-wave is the first signal that is recorded by the receiver antenna. Since the direct-wave is of several ns length, it covers the reflections that occur in the uppermost layers of the subsurface.

**What objects can GPR detect?**
Under the right conditions georadar can be used to detect the foundations of buildings, canalisation pipes, pits, ditches, graves, cavities and geological structures such as layer interfaces and faults.

It is important to realize that the GPR method cannot guarantee the detection of objects or structures, particularly if they are small in size (relative to the wave-length used), if their physical properties do not differentiate them from the surrounding material or if the soil conditions are adverse (e.g. in case of limited signal penetration depth caused by a highly conductive soil).

GPR measurements can allow the archaeologist to obtain an image of structures that are hidden in the subsurface without digging. GPR surveying, similar to magnetic prospection, is a non-destructive method.

GPR measurements provide information about the relative depth of structures. If the velocity of the radar waves in the subsurface is known, the absolute depth of structures seen in the GPR data can be determined.

The results of georadar measurements can be used to plan excavation activities efficiently in regard of costs and time. GPR measurements make it possible to target interesting structures and to excavate selectively with the benefit of prior knowledge.

**Suggested reading**


5.2 Georadar depth-slices
Figure 5.2.1: Depth-slice of 10cm thickness covering the depth range 0.00 to 0.10m.
Figure 5.2.2: Depth-slice of 10cm thickness covering the depth range 0.10 to 0.20m.
Figure 5.2.3: Depth-slice of 10cm thickness covering the depth range 0.20 to 0.30m.
Figure 5.2.4: Depth-slice of 10cm thickness covering the depth range 0.30 to 0.40m.
Figure 5.2.5: Depth-slice of 10cm thickness covering the depth range 0.40 to 0.50m.
Figure 5.2.6: Depth-slice of 10cm thickness covering the depth range 0.50 to 0.60m.
Figure 5.2.7: Depth-slice of 10cm thickness covering the depth range 0.60 to 0.70m.
Figure 5.2.8: Depth-slice of 10cm thickness covering the depth range 0.70 to 0.80m.
Figure 5.2.9: Depth-slice of 10cm thickness covering the depth range 0.80 to 0.90m.
Figure 5.2.10: Depth-slice of 10cm thickness covering the depth range 0.90 to 1.00m.
Figure 5.2.11: Depth-slice of 10cm thickness covering the depth range 1.00 to 1.10m.
Figure 5.2.12: Depth-slice of 10cm thickness covering the depth range 1.10 to 1.20m.
Figure 5.2.13: Depth-slice of 10cm thickness covering the depth range 1.20 to 1.30m.
Figure 5.2.14: Depth-slice of 10cm thickness covering the depth range 1.30 to 1.40m.
Figure 5.2.15: Depth-slice of 10cm thickness covering the depth range 1.40 to 1.50m.
Figure 5.2.16: Depth-slice of 10cm thickness covering the depth range 1.50 to 1.60m.
Figure 5.2.17: Depth-slice of 10cm thickness covering the depth range 1.60 to 1.70m.
Figure 5.2.18: Depth-slice of 10cm thickness covering the depth range 1.70 to 0.80m.
Figure 5.2.19: Depth-slice of 10cm thickness covering the depth range 1.80 to 1.90m.
Figure 5.2.20: Depth-slice of 10cm thickness covering the depth range 1.90 to 2.00m.
Figure 5.2.21: Depth-slice of 10cm thickness covering the depth range 2.00 to 2.10m.
Figure 5.2.22: Depth-slice of 10cm thickness covering the depth range 2.10 to 2.20m.
Figure 5.2.23: Depth-slice of 10cm thickness covering the depth range 2.20 to 2.30m.
**Figure 5.2.24:** Depth-slice of 10cm thickness covering the depth range 2.30 to 2.40m.
Figure 5.2.25: Depth-slice of 10cm thickness covering the depth range 2.40 to 2.50m.
Figure 5.2.26: Depth-slice of 10cm thickness covering the depth range 2.50 to 2.60m.
Figure 5.2.27: Depth-slice of 10cm thickness covering the depth range 2.60 to 2.70m.
Figure 5.2.28: Depth-slice of 10cm thickness covering the depth range 2.70 to 2.80m.
Figure 5.2.29: Depth-slice of 10cm thickness covering the depth range 2.80 to 2.90m.
Figure 5.2.30: Depth-slice of 10cm thickness covering the depth range 2.90 to 3.00m.
Figure 5.2.31: Depth-slice of 10cm thickness covering the depth range 3.00 to 3.10m.
Figure 5.2.32: Depth-slice of 10cm thickness covering the depth range 3.10 to 3.20m.
Figure 5.2.33: Depth-slice of 10cm thickness covering the depth range 3.20 to 3.30m.
Figure 5.2.34: Depth-slice of 10cm thickness covering the depth range 3.30 to 3.40m.
Figure 5.2.35: Depth-slice of 10cm thickness covering the depth range 3.40 to 3.50m.
5.3 Comparison of the georadar data with results from the subsequent excavation

Soon after the georadar survey had been conducted the archaeological excavation of the site started. The archaeologists had been provided with the georadar data and its interpretation in digital form.

Archaeological structures that came to light during the excavation were documented digitally in form of geo-referenced shape files (MapView). It is possible to superimpose these shapes onto the georadar data in a GIS (e.g. ArcMap) in order to try to identify matching anomalies in the georadar data.

Several shape files have been provided by ADC for such a comparison. Several water wells were documented digitally. The comparison with the georadar data showed that these water wells do not show as anomalies in the georadar data. The most plausible explanation is that there is insufficient or no physical contrast in the dielectric permittivity of the material filled into the wells compared to the surrounding ground. It is possible that a weak contrast exists, however, due to the depth of the structures and due to an inhomogeneous layer on top it is likely that this effect is too small to be detectable. Due to the depth of these structures and the high ground water level it is likely that the soil humidity and electrical soil resistance is very similar for the well filling and the surrounding soil. According to the georadar data did the wells have no surrounding casing made of stones or clay bricks. Well casings made of organic material (e.g. wood) are not likely to cause sufficiently large reflections of the radar signal, unless the wood constructions are massive and well preserved.

Nevertheless it is possible to match other, shallower archaeological structures to anomalies visible in the georadar data (Figures 5.3.1 & 5.3.2). However, due to the incoherency, complexity and weak expression of these archaeological structures their recognition and identification in the georadar data alone is impossible.
Figure 5.3.1: Depth-slice of 130-140cm with archaeological structures found during excavation superimposed. The coloured shapes correspond to the outline of archaeological structures from three different depth-levels. Agreement between several of the polygonal shapes with anomalies in the data can be observed.

Figure 5.3.2: The same depth-slice as shown in Figure 5.3.1 without the superimposed shapes.
6 Survey Documentation

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Wijk bij Duurstede, Veilingterrein, January 2007</th>
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<tbody>
<tr>
<td>Survey purpose</td>
<td>Detection of historical and archaeological structures in the ground</td>
</tr>
<tr>
<td>Bibliographic references</td>
<td></td>
</tr>
<tr>
<td>Survey keywords</td>
<td>GPR</td>
</tr>
<tr>
<td>Administrative area</td>
<td>Wijk bij Duurstede, The Netherlands</td>
</tr>
<tr>
<td>Country</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>Drift geology</td>
<td>Sand, clay, silt</td>
</tr>
<tr>
<td>Duration</td>
<td>Monday 29th January 2007 until Saturday 3rd February 2007</td>
</tr>
<tr>
<td>Weather</td>
<td>Cold, humid. The occasional drizzle.</td>
</tr>
<tr>
<td>Soil condition</td>
<td>Humid to wet. Over large areas soft sand surface. Tractor tracks.</td>
</tr>
<tr>
<td>Land-use</td>
<td>Sand and soil covered area. The site had formerly housed market halls. Prior to the survey the topsoil of the site had been worked to remove vegetation. Subsequently the surface had been leveled.</td>
</tr>
<tr>
<td>Monument type</td>
<td>Early medieval, Karolingian settlement; expected pits due to bone digging activities in the last centuries</td>
</tr>
<tr>
<td>Monument period</td>
<td>Karolingian until recent</td>
</tr>
<tr>
<td>Surveyor</td>
<td>Pär Karlsson, Immo Trinks</td>
</tr>
<tr>
<td>Depositor</td>
<td>Immo Trinks</td>
</tr>
<tr>
<td>Primary archive</td>
<td>Swedish National Heritage Board, UV Teknik, Box 5404, 114 84 Stockholm, Sweden</td>
</tr>
<tr>
<td>Copyright</td>
<td>Riksantikvarieämbetet, UV Teknik</td>
</tr>
<tr>
<td>Geophysical coordinate system</td>
<td>Up to 50m profile lines. The site was subdivided into squares of 50m by 50m size. One single coordinate system was used.</td>
</tr>
<tr>
<td>Georeferencing</td>
<td>All survey areas were geo-referenced using fix-points provided by ADC.</td>
</tr>
<tr>
<td>Survey type</td>
<td>Ground Penetrating Radar</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>One manually pushed Sensors &amp; Software Noggin Plus 500MHz antenna mounted in Noggin SmartCart with included odometer wheel and DVLIII/ data monitor and logger.</td>
</tr>
<tr>
<td>Method of coverage</td>
<td>Regular grid of parallel profile lines, Zigzag; All profiles were run approximately in east-west / west-east direction.</td>
</tr>
<tr>
<td>Traverse separation</td>
<td>25cm</td>
</tr>
<tr>
<td>Reading interval</td>
<td>5cm inline</td>
</tr>
<tr>
<td>Grid size</td>
<td>Maximum profile length: 50m</td>
</tr>
<tr>
<td></td>
<td>Covered area: 13 750m²</td>
</tr>
<tr>
<td></td>
<td>Total profile length: 55 000m</td>
</tr>
</tbody>
</table>

This documentation is based on the guide: Geophysical Data in Archaeology: Guide to Good Practice by Armin Schmidt, Arts and Humanities Data Service (http://ads.ahds.ac.uk/project/goodguides/geophys/).