4.2.6 GPR Data Collection

GPR data were collected with the SIR3000 GPR system using a shielded 400 MHz antenna antenna. Data collection was regulated with a survey wheel ensuring a regular and measured record. Basic high pass and low pass vertical filters were set according to each survey area. Because of potential gain issues encountered in the Phase 1 survey (see Watters, *forthcoming*) a 2 point linear gain was set to ensure consistent data across the site.

Figure 23. The SIR3000 GPR unit was used with a shielded 400 MHz antenna.

GPR data were collected along a uni-directional survey grid to an approximate depth of 2m (targeted between 1.5m and 2m in order to complement the vertical aspect of the resistivity survey). The data sampling rate was 512 samples per scan and 100 scans per metre with 0.25m transect spacing. GPR data were collected in orthogonal grids with the first oriented east-west and the second oriented north-south. There was, however, some variation west-east and south-north from area to area. Depth conversion was conducted for each survey area based on velocity data collected in each area.

4.2.7 2m x 5m Sub-area Dielectric Permittivity Data Collection

The Adek Pyrometer v.6 with a surface probe was used to collect dielectric permittivity, conductivity and temperature. Data were recorded at 0.2m sample intervals across the 2m x 5m sub-areas. Data were manually collected with a data logger.

Figure 24. The Adek Pyrometer v.6 was used to collect dielectric permittivity data in the 2m x 5m sub-areas.

4.3 Geophysical Techniques and Methodology

4.3.1 Magnetometry

Magnetic survey measures the variation of the magnetic fields of the Earth and buried features across a site. Different soils and features can be mapped through their contrasting magnetic values. Examples of features that can be detected through this process include ferrous materials, soil affected by human occupation (rubbish pits and middens with organic materials), fired materials such as kilns and hearths, tiles, bricks, and concentrations of ceramics. Differences in soil type or soil perturbation are also detected through magnetic survey enabling identification of ditches, pits, foundations, graves and other excavated features (Clark 1996).

When interpreting data for archaeological purposes we look at the gradient of the magnetic field that best reveals archaeological features. Magnetometry collects two total fields from two separate magnetometer sensors. These sensors measure the total magnetic field at their respective distance above the earth. The gradient is calculated from the two total fields and effectively removes broader scale background noise. This background noise includes larger geological trends and diurnal effects and acts as an edge filter (Breiner, 1973).

The Geometrics G858 cesium vapor gradiometer collects the magnetic total field (uncorrected for diurnal influence) at a height above the ground from which the magnetic gradient can be derived. The G858 was used in the vertical gradient mode with the two sensors mounted on a vertical staff. The sensors were arranged so that the center of the lower sensor was 0.3m from the survey surface and the top sensor was 1m from the lower sensor. An additional remote station was set to collect continuous readings on a single sensor in order to record a steady record of diurnal variations. Data were collected by a two person team, one person moving the sensor array and the second person with the computer/batter pack collecting data as discrete stations. The sensors and computer and battery pack were kept as far apart as possible to regulate and reduce any effect of the iron in the computer/battery pack array.

4.3.2 Magnetic Susceptibility

Magnetic Susceptibility measures the effect of sediment magnetisation when subjected to a magnetic field. The more magnetised the material becomes the higher its susceptibility but it is a temporary response and only possible when a magnetizing field is present. Archaeological sites may have enhanced susceptibility due to the disturbance of underlying archaeological features through ploughing or other activities (Gaffney *et al* 2003).

4.3.3 Resistivity

Resistivity survey measures the change in the resistance of the earth. The twin probe array was used in the WRM project where current and potential probes are paired on a mobile frame that measures the variation in resistance across a grid. A second pair of current and potential probes is fixed at a great distance from the area being surveyed (approximately 100m in the case of this project). With a fixed separation distance of

0.5 m, the roving probes map an effective volume of resistivity to a depth of approximately 0.75 m, measured in Ohms/m. In the case of this research data were collected at a variety of depths with different probe separation readings controlled through the multi-plexer.

Resistance effectively looks at the saturation level of the materials in the survey area, thus is sensitive to soil compaction, soil type, geological features and objects that may be buried with in the soil. Resistance survey can map features that include pits, trenches, foundations, compacted or disturbed surfaces, and changes in soil type (Clark 1996).

Resistivity data were collected with the multi-plexer in order collect information across the site at different depths. Resistivity survey samples at each position across the site and at each depth are influenced by the surrounding soils. This method sends an electrical current into the earth and records the resistivity value for a volume of earth controlled by the probe separation distance. For example, if the twin probe spacing is 0.50 m, a resistivity value for a volume of earth measuring approximately 0.50m from the central point of the frame is recorded.

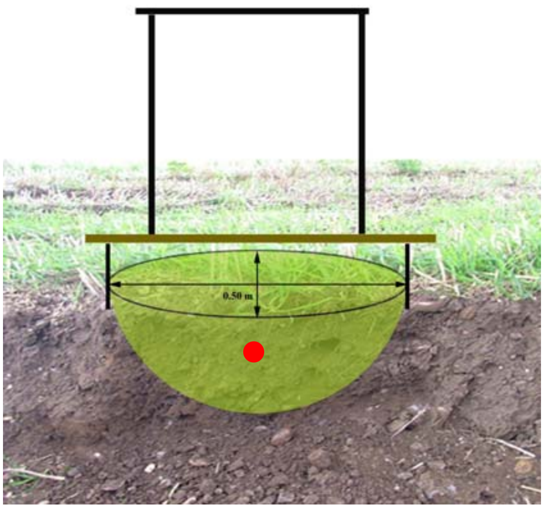

Figure 25. Resistivity data samples a volume of earth dependent upon probe separation distance.

The wider the probe spacing the deeper the penetration with a larger volume of earth sampled. The deeper the sampling, the more interference is potentially introduced to the resistivity record because the sampling is recording the resistivity representative of the entire volume of earth. Features closer to the surface have an effect on the deeper readings. This is important to keep in mind while interpreting deeper resistivity anomalies.

A good example of this effect can be seen in the resistivity data interpretation section of this report for area A1. Data collected at different depths with the multi-plexer can be assembled into vertical profiles called pseudosections that are graphic plots of measured resistivity. In order to assess the true resistivity at each depth, pseudosections must be inverted to remove artefacts introduced by the data collection method.

Due to time constraints all resistivity data are presented in this report as plan views. Preliminary pseudosection inversions have been tested over area A1 in order to prove the necessity for more effective data assessment.

4.3.4 GPR

GPR maps the form of contrasting electrical properties (dielectric permittivity and conductivity) of a soil or other materials below the ground surface. The stronger the difference between the electrical properties of two materials, the stronger the reflected signal in the GPR profile. The conductivity of soils and buried features causes the attenuation, or loss, of the GPR signal that impacts the effectiveness of GPR survey. Though a highly conductive material will attenuate the GPR signal, it can also be an effective mapping tool contributing information to the nature of the subsurface and features within it. (Daniels 1996, Conyers and Goodman 1997)

GPR records information on the amplitude, phase and time related to the capture and induction properties of the antenna in addition to the energy propagation, scattering and reflection off of subsurface features. Unlike resistivity or other archaeological-based geophysical methods, GPR data are collected as 2D vertical profiles into the earth. The 2D profiles are made up of a number of traces (or scans) at a particular location (x, y) that record the response of sub-surface properties to the radar's electromagnetic wave at discrete points at a particular time (or depth) in the earth. The horizontal axis represents surface distance along a transect with the vertical axis recording time (often referred to as two-way travel time.) The time is recorded in nanoseconds (ns). Time can be easily converted to depth in two ways: the first is by having a known dielectric permittivity value for the material in the survey area, the second through having a known depth to a feature that appears in the radar profile. The more accurate of these two methods is the latter but this requires digging or coring. It must be kept in mind that earth properties are not constant and can change drastically over an area. Depth conversion should be checked at intervals across a site if possible.

When considering feature resolution, differences are best viewed based on a relative scale. The outline of features may be identified at the lowest resolution and individual features such as bones and artefacts within for example, a grave, may be imaged at the highest resolution (to date, no conclusive research has been conducted that has positively imaged bones within a grave, although Watters and Hunter *in press* propose a method through which this may be possible). GPR is easily adaptable to these different scales because of its range of antenna frequencies. These frequencies range between 10 MHz and 1.5 GHz with the lowest frequencies used to map geological and environmental targets with a typical penetration of approximately 30m. The highest frequency, 1.5 GHz, will effectively penetrate to about 1.5 – 2m in basic, dry loamy soils but often much less, particularly in wet, clay-rich material. The deeper penetration achieved with lower frequency antennas provides a coarser resolution while the finest feature resolution is achieved with higher frequency antennas (but with a limited depth penetration). The most suitable antennas for archaeological feature location and detailed imaging are the 200, 400, 900, and 1500 MHz antennas. This group provides a range of depth and resolution flexibility.

GPR Data Viewing and Imaging:
GPR data are collected along a grid as vertical slices into the ground. Grid lines (transects) are collected in parallel lines typically spaced 0.5 to 1m apart. Due to the form of the beam of radar wave propagation into the earth, survey transects are most effective if oriented perpendicular to known archaeology. To record the most information on buried features, data can be collected orthogonally, or on a grid with perpendicular transects.

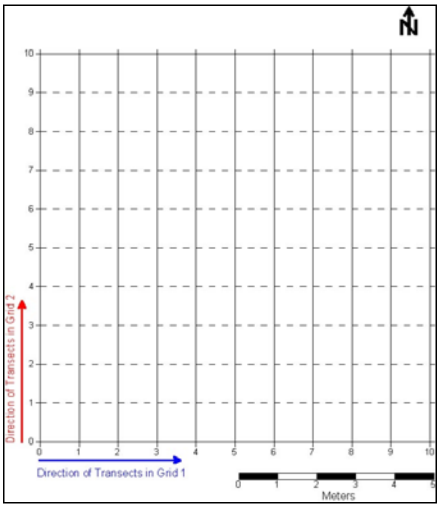

Figure 26. Orthogonal grid display.

Initial data review is conducted on these vertical profiles. Anomalies can be identified in individual profiles. Time slicing enables anomalies from individual profiles to be merged in order to view plan maps of the GPR data in a similar format to magnetic and resistivity data.

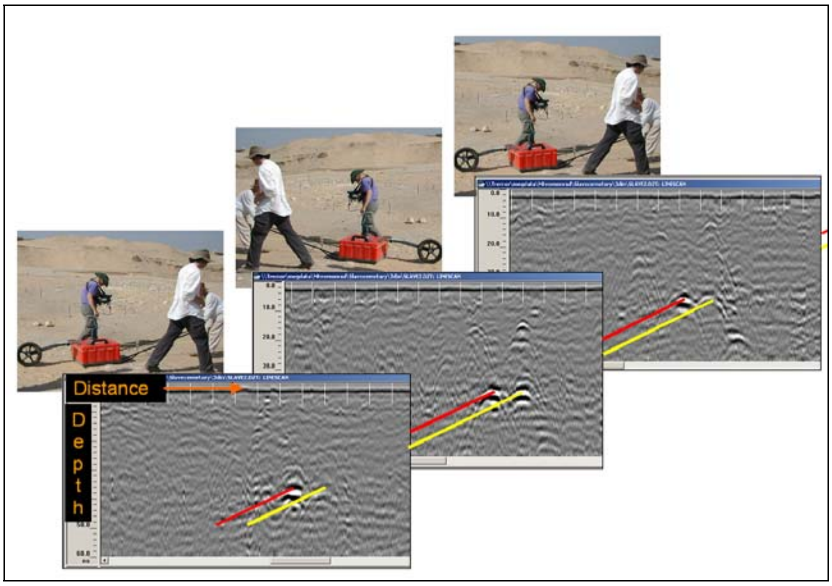

Figure 27. Vertical profiles can be stacked together to create a 3D cube of information for use in data imaging and analysis.

Time slicing is when the vertical slices are stacked next to each other and the data interpolated to form a cube. This cube is then sliced on the horizontal plane to create plan views of the area. As GPR data records the nature of the subsurface to a certain depth, a number of time slices can be created that depict the nature of the subsurface at given depths. Further assistance in feature mapping can be achieved through displaying all three axes of the GPR cube x, y, and z. This helps define feature shape and volume.

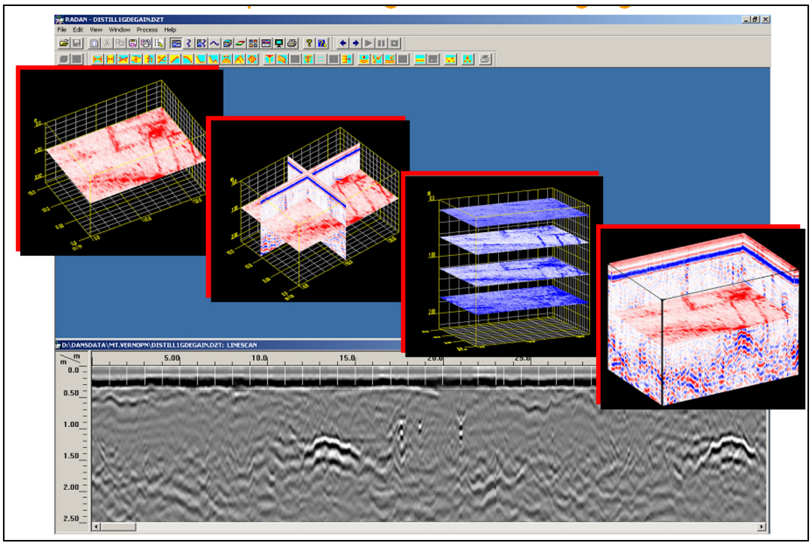

Figure 28. GPR data can be displayed as 2D vertical profiles (greyscale at the bottom of the figure), or sliced along the x, y, and z axes.

Each area surveyed with GPR during the WRM project was reviewed in both vertical profile and plan views. Each area is represented by a selection of plan views in the GIS which best represent the nature of the sub-surface. Images included in this report are time slices for each area that best represent the archaeology, whilst not depicting all features. The images with interpretations include interpretations from every time slice in the GIS for an overall depiction of identified features.

4.4 *Geophysical Data Processing and GIS Integration*

All geophysical data were processed in proprietary software. After data were processed they were converted to .tif formats for rectification into the GIS. The steps listed below for each geophysical survey method are basic techniques employed in the process of data analysis. A thorough assessment and study of the geophysical data went beyond the listed techniques to present end results of high confidence.

4.4.1 Magnetic Data Processing

1. The G858 data are adjusted for grid orientation and during data export corrected for diurnal influence with data from the base station.
2. Data are then sorted in Surfer according the field strength and the outliers clipped from the file.
3. Data are gridded and imaged as contours or images in Surfer.
4. Data are exported as .tif files for input to the GIS.

FM256 magnetic data processing:

1. FM256 data are filtered to remove any background noise, de-spiked and clipped of data outliers in Geoplot.
2. Data are then interpolated along the y axis to generate an equally spaced data sample.
3. Data are exported and imaged as contour files or images in Surfer.
4. Data are exported as .tif files for input to the GIS.

Magnetic susceptibility data processing:

1. Data are converted to digital format and gridded in Surfer.
2. Data are exported as .tif files for input to the GIS.

Post processing software for data analysis and interpretation included Magmap2000, Geoplot 3.0, Surfer 8, and ArcGIS 8.3.

4.4.2 Resistivity Data Processing

1. The RM15 data are filtered to remove any background noise, de-spiked and clipped of data outliers in Geoplot for each layer of data.
2. Data are then converted to resistivity and exported and imaged as contour files or images in Surfer.
3. Data are exported as .tif files for input to the GIS.

Post processing software for data analysis and interpretation included: Geoplot 3.0, Excel, Surfer 8, and ArcGIS 8.3.

4.4.3 GPR Data Processing

1. GPR survey transects are compiled into 3D cube format in RADAN.
2. Data are processed to adjust for the correct time zero, gain adjustment and migrated. If it was necessary, additional vertical and horizontal background removal filters were applied.

Note: the Catholme GPR data was mostly very clean and needed little data processing other than time zero adjustment and migration. A Hilbert transform function was also applied to all the GPR data and data fully investigated for the best end results.

3. Data are then viewed and exported as plan views (or time slices) from the 3D cube as .csv files.
4. The .csv files are converted to .dat files and gridded in Imagine to create .img files that are exported as .tif files for input to the GIS.

Post processing software for data analysis and interpretation included RADAN 6.0.0.1, Erdas Imagine 6.0, and ArcGIS 8.3.

4.4.4 GIS Data Integration

During Phase I of the WRM project a GIS was created to manage, analyse and present the breadth of information utilised in the study. This encompassed airborne data including aerial photography and LiDAR, ground based Ordnance Survey and geological maps and geophysical survey maps and data interpretations.

A separate geophysical data GIS has been maintained and expanded to include all of the geophysical survey results from the Phase II investigations. This GIS is the core organisational tool for the huge amount of data which was collected throughout the WRM project. The layers in this GIS include: OS base maps, the Full Area LiDAR and aerial photographic surveys, the oblique ortho-rectified photograph over the ‘Woodhenge monument, all the geophysical survey maps and interpretations from Phase I and all the geophysical survey maps and interpretations from Phase II. Not only does the GIS enable data management, it is a powerful tool for data assessment and analysis especially following the integration of the archaeological database and results from the soil sampling studies.