



global environmental solutions

**Nantwich Waterlogged Deposits
Cheshire**

**Phase 2 Interim Report No.3
English Heritage HEEP 3839 Main**



December 2013



SLR Ref: 406-00889-00005

CONTENTS

1.0 INTRODUCTION.....	1
2.0 RESULTS OF HYDROGEOLOGICAL ASSESSMENT.....	2
3.0 RESULTS OF GROUND GAS MONITORING	10
4.0 METHODOLOGICAL IMPROVEMENTS	13
5.0 CONCLUSIONS.....	16
6.0 CLOSURE.....	16

TABLES

Table 1 Geochemical Laboratory Analysis - Groundwater	8
Table 2 Ground Gas Monitoring Results.....	10
Table 3 Groundwater Monitoring Data - 2011 to 2013	23

FIGURES

Figure 1 Daily Groundwater Level and Rainfall Data Graph	2
Figure 2 Groundwater Elevations from 2011 to 2013 plotted against Borehole Logs....	3
Figure 3 Dissolved Oxygen Plot.....	4
Figure 4 Redox v. pH graph – 2011 to 2013.....	5
Figure 5 Seasonal Redox Fluctuations – West of River Weaver.....	6
Figure 6 Seasonal Redox Fluctuations – East of River Weaver.....	6
Figure 7 Contour Plot showing mean Carbon Dioxide Gas Concentrations (% vol)....	11
Figure 8 Groundwater Measurements with Datalogging Transducer v. Dip Meter.....	14
Figure 9 Gas Sampling from a Borehole using a Vacuum Canister	15
Figure 10 Preservation Zones	17

APPENDICES

Appendix A	Borehole Locations
Appendix B	Groundwater & Gas Monitoring Data
Appendix C	Laboratory Certificates
Appendix D	Transducer and Rain Gauge Data

1.0 INTRODUCTION

In November 2010, SLR Consulting Limited (SLR) was commissioned by English Heritage and Cheshire East Council to undertake Phase 2 of the Nantwich Waterlogged Deposits Project. The purpose of the project is to develop an effective methodology to monitor the condition of the urban waterlogged deposits and to monitor these archaeological deposits within Nantwich over a three year period as a case study. The results of this study will enable an update to the strategy for managing these remains effectively, within the context of the need for continuing economic development within the historic centre. In September 2013 a variation was agreed by English Heritage, extending the duration of the project for a further two years, so that in total five years of monitoring data will be gathered.

The details relating to Phase 1 of the Nantwich Waterlogged Deposits project are recorded in a separate report¹ completed in November 2009, followed by two annual interim reports²³ which summarised the works undertaken as part of Phase 2 during 2011 and 2012. These previous reports should be read in conjunction with the present report.

This report presents a summary of the fieldwork undertaken as part of the project during 2013, which comprised the following key elements:

- Collecting groundwater samples from each of the fifteen separate dipwell locations for geochemical laboratory analysis;
- Completing quarterly monitoring at all of the eighteen dipwells for depth to groundwater, water quality parameters and ground gas concentrations.

Drawings are presented in Appendix A. Appendix B presents the groundwater and gas monitoring data, Appendix C presents the analytical chemistry results and Appendix D presents the transducer and rain gauge data.

¹ SLR Consulting Limited (January 2010): *Nantwich Waterlogged Deposits Report No 2: The Character and Extent of Archaeological Preservation*

² SLR Consulting Limited (November 2011): *Nantwich Waterlogged Deposits Phase 2 Interim Report (Ref:406.008889.00005)*

³ SLR Consulting Limited (November 2012): *Nantwich Waterlogged Deposits Phase 2 Interim Report (Ref:406.008889.00005)*

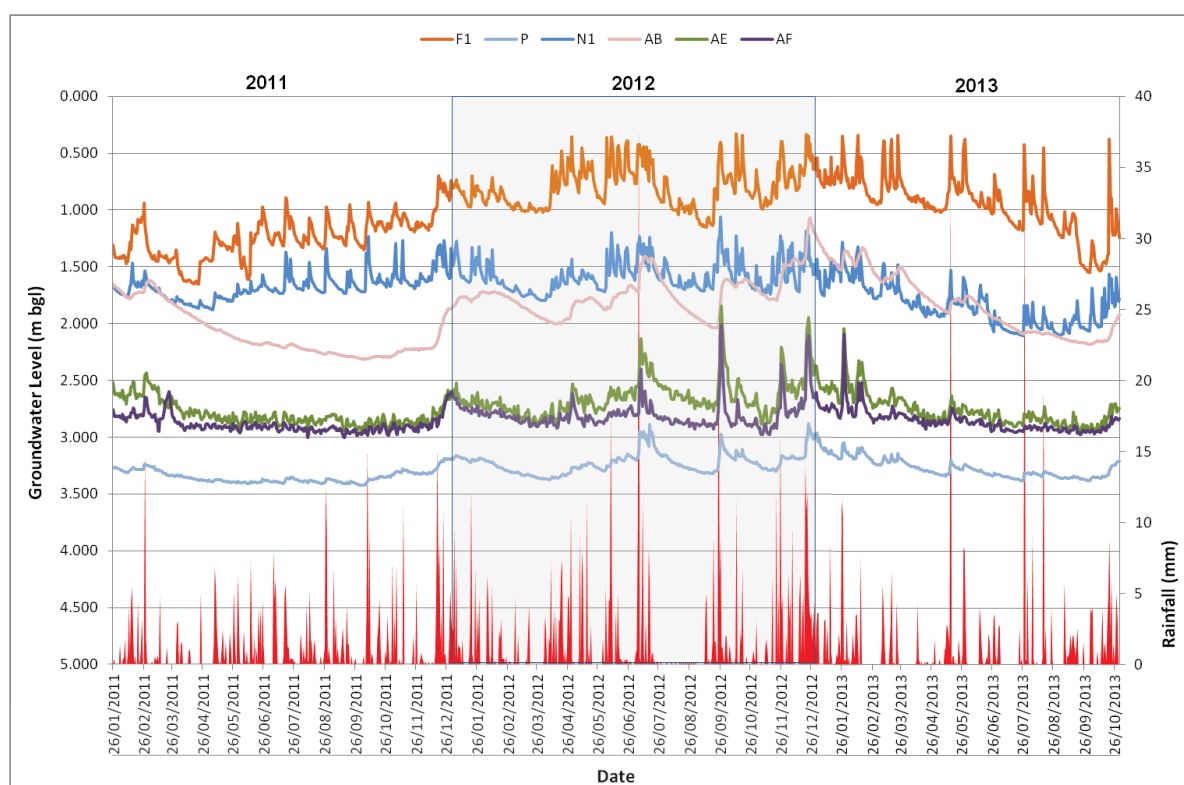
2.0 RESULTS OF HYDROGEOLOGICAL ASSESSMENT

2.1.1 Transducer Data: Rainfall and Groundwater Levels

SLR completed the installation of the transducers at six locations to monitor particularly sensitive areas within the waterlogged deposits. This provides a minimum of three transducer points on each side of the River Weaver. Therefore the six transducers were installed in dipwells F1, N1, P, AB, AE and AF. The transducer was installed in dipwell P instead of P1, because P1 contained insufficient water. The transducer that was intended for installation in dipwell AG was moved to AB because no waterlogged deposits were recorded in Bowers Row Car Park. The locations of the transducers are shown on a plan in Appendix A.

The results of water level measurement from the transducers and rainfall gauge are shown in Appendix D and summarised in Figure 1 below.

Figure 1
Daily Groundwater Level and Rainfall Data Graph



The comparison of data from the rainfall gauge and the water level data loggers confirms the direct correlation between the water table and rainfall events (see Figure 1). The results also indicate that the data loggers in BH P and BH AB show a significantly reduced level of fluctuation compared to the other transducer locations, which is potentially related to variations in the permeability of the deposits.

2.1.2 Groundwater Monitoring Data

In situ monitoring has been undertaken at seventeen dipwells at quarterly intervals since February 2011. No water has ever been recorded in dipwell P1 because the water table is located below the archaeological deposits specifically targeted by the borehole, and therefore it has been possible to complete any monitoring at this location. In addition to

groundwater depth measurements, dissolved oxygen, conductivity, pH and REDOX potential were also measured using a YSI 556™ water quality meter.

The in situ monitoring results are included in Appendix C, and are summarised in Table 1.

The groundwater monitoring results indicate that groundwater is present between 0.76m and 3.44m below ground level. As expected, the hydraulic gradient indicates that flow direction is toward the River Weaver from both sides of Nantwich, as shown on the groundwater contour plot in Appendix A.

Figure 2
Groundwater Elevations from 2011 to 2013 plotted against Borehole Logs

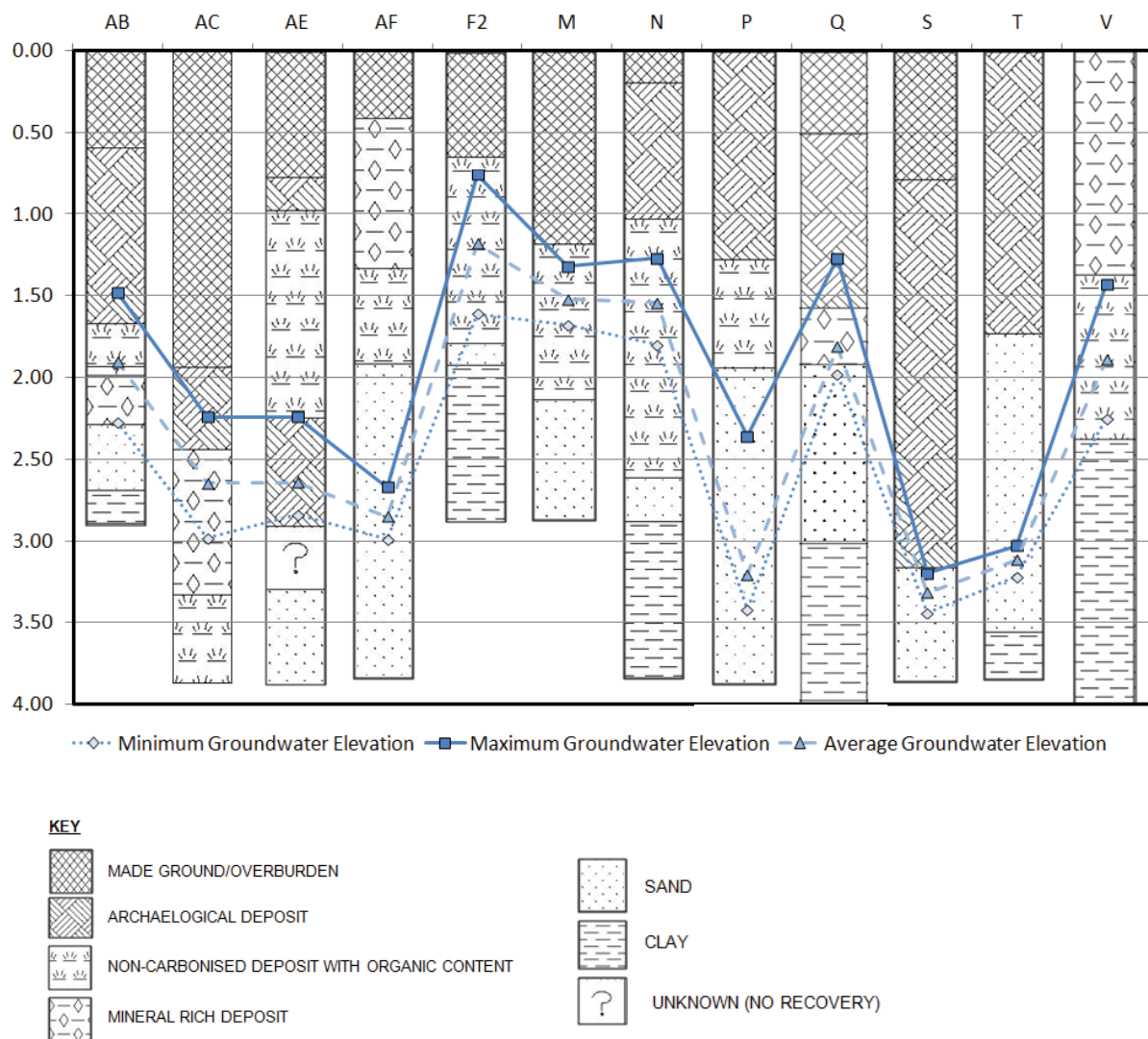


Figure 2 shows the maximum and minimum groundwater elevations plotted against ten borehole logs from the key borehole locations. This suggests that the saturation of shallow sands overlying boulder clay (e.g. locations AB, F2, Q and V) is a contributing factor to the waterlogging of deposits, whereas areas with deeper sand deposition contribute to increased drainage (e.g. locations S and P).

Therefore, the monitoring wells in the area around the memorial close to St Mary's Church (e.g. S, T and P) tend to have a lower water table and this is confirmed in the groundwater monitoring data. In general the inverse is true at other locations where less permeable

sediments are present, and the monitoring wells in these locations tend to have a water table at a shallower depth (e.g. AB, F2 and N).

The water table in boreholes AE, AF and AG within 100m of the River Weaver is generally located below the archaeological deposits due to the draining effect of the river, which lies at a lower level than the cultural horizon. This suggests that the good levels of preservation historically recorded in this area are potentially due to location of the deposits within the capillary zone, otherwise more active decay would be expected if the deposits were actively drying out.

Dissolved Oxygen

Figure 3
Dissolved Oxygen Plot



Figure 3 above indicates that the lowest concentrations of dissolved oxygen are generally recorded within 100m of the River Weaver, which is conducive with the other indications of reducing conditions generally recorded in that area.

Redox Potential

Figure 4
Redox v. pH graph – 2011 to 2013
(Calibrated to SHE)

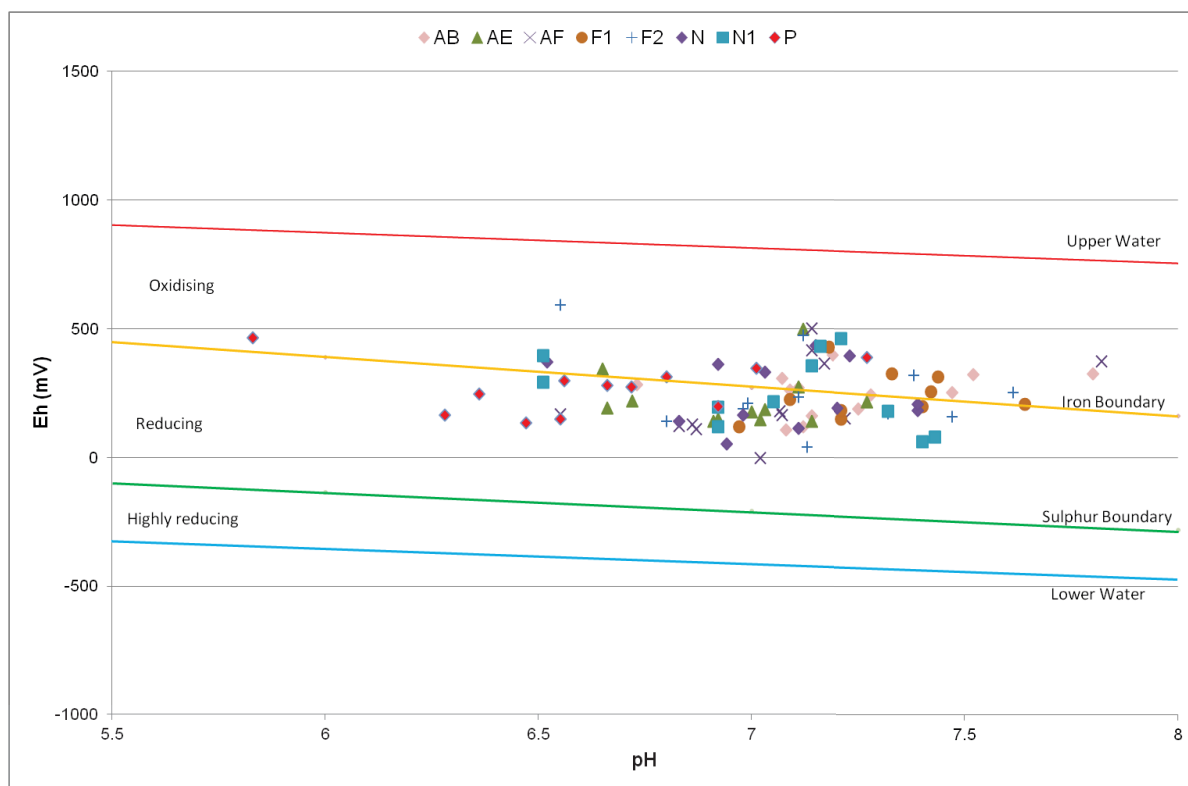


Figure 4 above shows a redox/pH diagram which indicates that the SHE calibrated redox levels are located close to the iron reduction boundary at most of the monitoring points around Nantwich, and there is evidence to suggest the reducing and oxidising conditions fluctuate with seasonal variations (see Figures 5 and 6).

Overall, the most reducing conditions correspond with the depleted levels of dissolved oxygen located close to the River Weaver, and these results are supported by indications of bacterial activity including methane generation, nitrate reduction and sulphate reduction recorded in borehole locations AE, AF and to a lesser extent AC.

Figure 5
Seasonal Redox Fluctuations – West of River Weaver

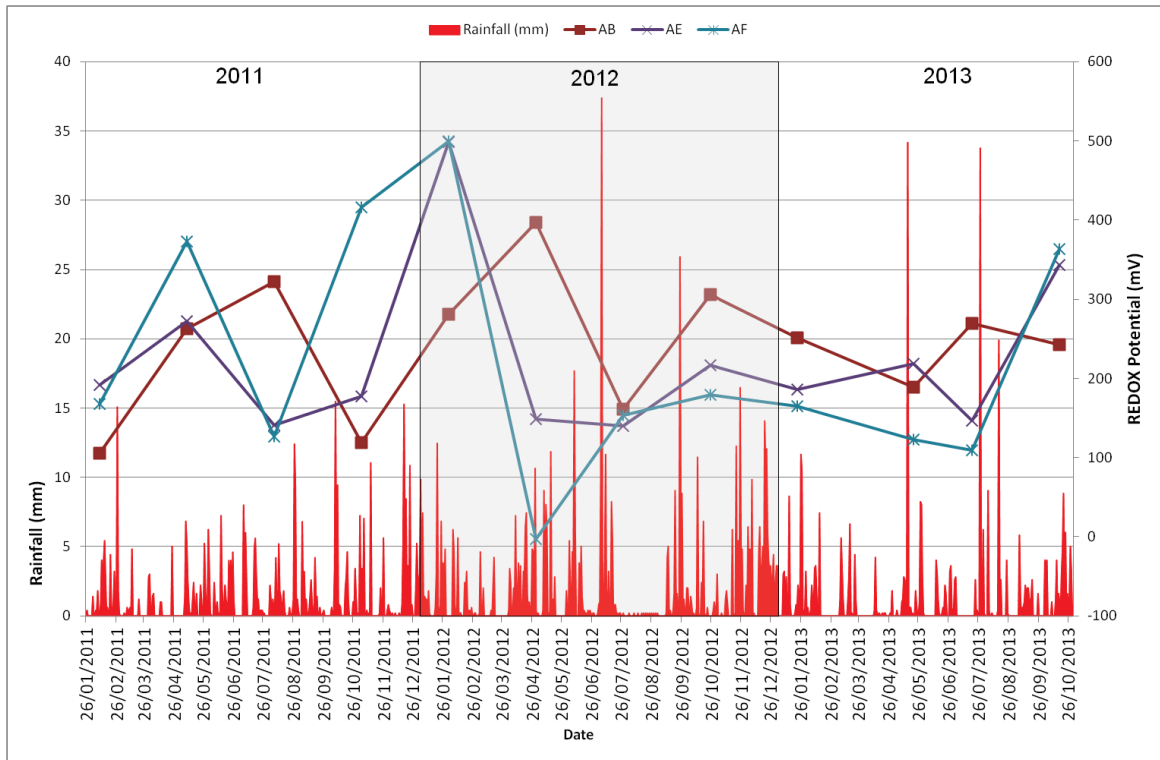
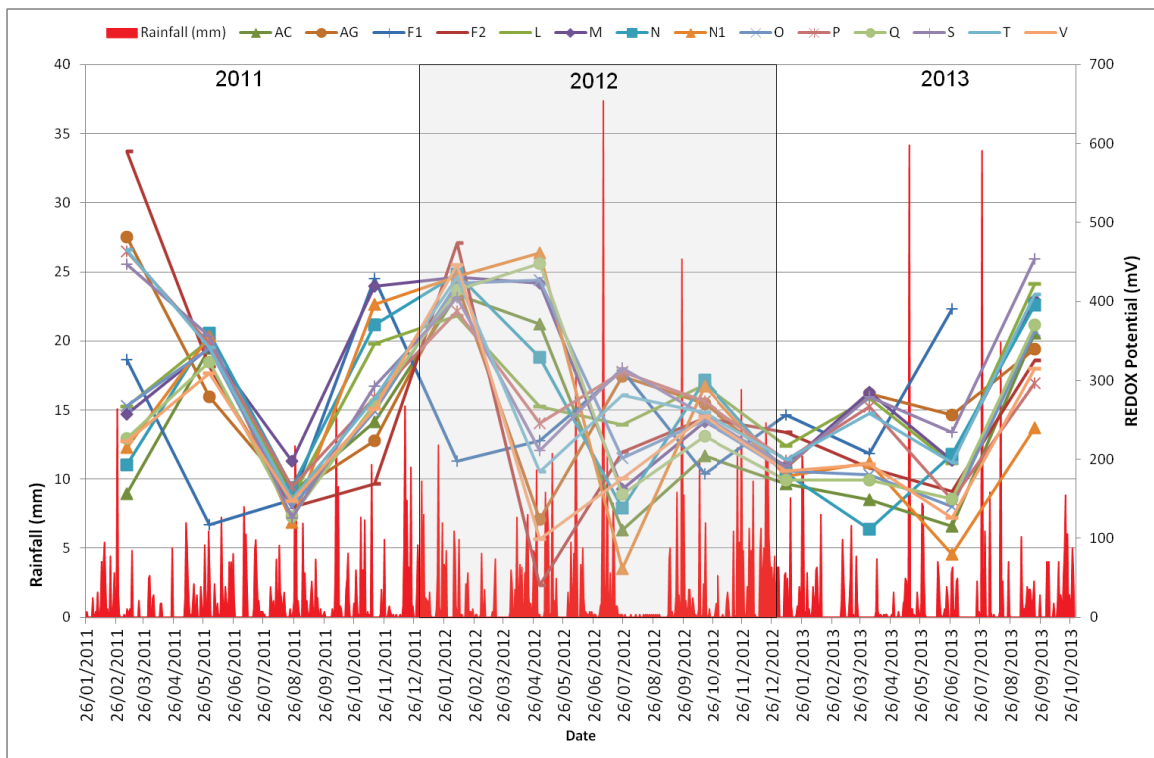


Figure 6
Seasonal Redox Fluctuations – East of River Weaver



Figures 5 and 6 above shows the seasonal fluctuations in redox values between January 2011 and October 2013. The data suggests that there is a general increase in redox values

over the winter period when effective rainfall causes an influx of oxygenated water into the ground. This theory is supported by the anomalous readings in spring/summer 2012 which coincide with the unseasonably high rainfall over that period.

Conductivity

The results of the electrical conductivity monitoring also follow the pattern of the redox and dissolved oxygen results, with the highest conductivity values also recorded boreholes AE, AF and AG in the vicinity of the River Weaver. Conductivity measurements provide a reliably accurate idea of the source of the water, suggesting that the groundwater in this area is mixed with salt-rich groundwater from natural brine runs. Rainwater probably has a negligible influence. These results complement the geochemical analyses that indicate the presence of sodium and chlorides.

pH

Overall the groundwater samples are near neutral or mildly acidic.

2.1.3 Comparison of Methodologies for Monitoring Water Quality Parameters

A comparison of the techniques for measuring water parameters including REDOX, dissolved oxygen, electrical conductivity and pH was undertaken at location N as part of a separate English Heritage funded project, but the results are still valuable to this project.

A YSI water quality meter was used to measure these parameters in situ before purging, in a flow through cell connected to a peristaltic pump, in sample collected with a passive bailer after purging and in situ after purging. The tests were repeated on a monthly basis in both monitoring wells at location N, which are screened at different depths in order to target different layers within the deposits.

The tests revealed that the different techniques had little impact on the pH or REDOX results. As expected, the bailing process was found to oxygenate the water samples. However, the bailing process also caused a reduction in water level which drew in more saline water from a deeper layer and caused a significant increase in conductivity.

2.1.4 Groundwater Geochemical Laboratory Analysis

SLR collected groundwater samples on an annual basis from the fifteen separate monitoring points located across Nantwich (5 from Preservation Zone 1 and the remainder in Zone 2) and completed a suite of laboratory tests to characterise the geochemistry of the groundwater. Sampling was undertaken during each February between 2011 and 2013 using a peristaltic low flow pump and each dipwell was purged of stagnant water until the water quality parameters stabilised. Samples were despatched to Jones Environmental Forensics of Deeside for analysis,

The results of the chemical analysis undertaken on the collected samples of groundwater are presented in Appendix D and key dissolved phase contaminants are summarised in Table 2.

Table 1
Geochemical Laboratory Analysis - Groundwater

BH	Date	Fe	Mn	CaCO ₃	NO ₃	SO ₄	PO ₄	S ²⁻	CH ₄	Na	C ⁻	N	pH
AB	20/11/07	MDL	0.028	530	26	77	10	MDL	MDL	-	-	-	-
	01/02/11	MDL	0.007	430	25	45	9.9	MDL	MDL	65	91	0.03	8.1
	16/02/12	MDL	MDL	490	8.5	56	10	MDL	0.006	66	96	MDL	8.4
	27/02/13	MDL	MDL	500	100	190	9.5	MDL	0.007	110	270	MDL	7.3
AC	20/11/07	MDL	3.4	480	MDL	180	MDL	MDL	0.051	-	-	-	-
	01/02/11	14	3.5	480	5.4	170	MDL	MDL	MDL	510	1100	1.5	7.4
	16/02/12	MDL	2.1	430	0.4	190	MDL	MDL	0.36	2100	2800	2.6	8
	27/02/13	9.4	3	530	MDL	170	MDL	MDL	MDL	580	1100	1.9	6.8
AE	01/02/11	0.25	1.7	710	MDL	62	12	MDL	2	150	230	21	7.8
	17/02/12	0.011	1.2	850	0.9	9.9	11	MDL	5.3	200	310	24	8.3
	27/02/13	MDL	2.1	830	1.4	180	9.9	MDL	MDL	180	520	12	7
AF	01/02/11	0.1	0.92	870	MDL	12	11	MDL	3.4	470	790	46	7.7
	17/02/12	0.021	0.92	940	MDL	12	8.6	MDL	3.8	410	590	50	8
	27/02/13	0.03	1.1	860	MDL	8.1	14	MDL	4	400	680	40	7.1
AG	01/02/11	0.24	0.54	550	MDL	310	MDL	MDL	0.009	600	1500	5.3	7.5
	17/02/12	0.021	0.83	560	2.5	270	0.19	MDL	0.012	1700	3000	1.5	7.6
	27/02/13	0.02	1.2	640	0.8	260	0.74	MDL	MDL	1600	3900	1.4	6.8
F2	01/02/11	MDL	1.4	480	MDL	220	0.82	MDL	MDL	180	330	4.7	7.7
	17/02/12	0.058	0.45	310	MDL	38	14	MDL	0.94	91	100	1.9	8.4
	26/02/13	MDL	0.77	300	0.3	49	9.8	MDL	MDL	140	250	2.2	7
L	20/11/07	MDL	0.3	330	66	170	0.78	MDL	0.003	-	-	-	-
	01/02/11	MDL	0.64	480	9.7	150	0.89	MDL	0.032	150	300	22	7.9
	16/02/12	0.027	0.5	460	6.4	120	1.4	MDL	MDL	140	220	21	8.3
	27/02/13	MDL	0.033	110	12	49	6.5	MDL	0.012	30	29	5.5	6.8
M	20/11/07	MDL	0.53	310	0.8	41	13	MDL	0.008	-	-	-	-
	01/02/11	MDL	0.15	350	3.1	100	7.8	MDL	MDL	200	370	0.23	7.5
	17/02/12	0.03	0.24	390	6	130	7.1	MDL	MDL	210	300	0.09	8.3
	28/02/13	MDL	0.18	310	11	97	5.7	MDL	MDL	170	290	0.04	7
N	20/11/07	MDL	0.61	320	8	58	1.3	MDL	2.9	-	-	-	-
N1	01/02/11	0.07	0.48	470	1.2	86	0.41	MDL	8.1	110	180	4.5	7.9
	17/02/12	0.17	0.6	470	1.5	75	0.12	MDL	6.8	64	79	3.5	8.3
	26/02/13	MDL	1.1	390	MDL	69	0.48	MDL	2.8	22	28	1.2	7.1
O	20/11/07	MDL	2	600	2	38	2.4	MDL	2.2	-	-	-	-
	01/02/11	MDL	1.4	590	3.4	42	1.2	MDL	MDL	140	200	10	7.8
	16/02/12	0.023	1.2	450	0.3	28	5	MDL	MDL	73	76	8.1	8.4
	28/02/13	MDL	1.3	440	MDL	30	3	MDL	MDL	120	150	9.6	7.1
P	20/11/07	MDL	6.8	270	27	560	22	MDL	0.004	-	-	-	-
	01/02/11	MDL	1.3	250	17	470	16	MDL	0.007	15	17	0.12	7
	16/02/12	MDL	2.3	240	32	880	15	MDL	MDL	23	23	0.4	8.1
	28/02/2013	0.03	3.7	250	9.6	1100	7.9	MDL	MDL	21	27	0.22	6.3
Q	20/11/07	MDL	1.4	390	9.3	26	13	MDL	0.001	-	-	-	-

BH	Date	Fe	Mn	CaCO ₃	NO ₃	SO ₄	PO ₄	S ²⁻	CH ₄	Na	C ⁻	N	pH
	01/02/11	MDL	0.15	280	6	59	6	MDL	MDL	660	1100	0.15	7.5
	16/02/12	0.013	0.034	370	24	58	11	MDL	MDL	550	750	MDL	8.3
	27/02/13	MDL	0.058	230	12	53	6.7	MDL	MDL	880	1400	0.15	6.9
	20/11/07	MDL	0.25	260	5.3	68	4.9	MDL	0.005	-	-	-	-
S	01/02/11	MDL	0.21	340	2	56	7.7	MDL	0.017	100	200	0.29	7.3
	16/02/12	0.016	0.31	310	16	72	5	MDL	0.005	310	580	0.17	8.1
	28/02/13	MDL	0.31	370	9.4	80	6.2	MDL	0.011	260	430	0.29	6.9
	20/11/07	MDL	1.6	430	MDL	15	23	MDL	2.6	-	-	-	-
T	01/02/11	MDL	0.79	300	1.8	20	12	MDL	3	31	69	4	7.4
	16/02/12	0.084	1.1	380	MDL	30	14	MDL	2	45	76	6	8.2
	28/02/13	MDL	0.5	290	6.3	110	9.8	MDL	MDL	35	52	2.7	6.9
	20/11/07	MDL	2.6	170	0.5	86	0.11	MDL	0.039	-	-	-	-
V	01/02/11	MDL	4	78	MDL	400	MDL	MDL	0.094	18	16	1.2	6.4
	16/02/12	1.9	8.6	MDL	MDL	970	MDL	MDL	0.026	38	35	1.8	3.4
	27/02/13	15	1.2	66	MDL	130	18	MDL	0.006	27	22	0.18	5.8

All concentrations are measured in mg/l rounded to 2 significant figures, except pH.
 MDL – Below minimum laboratory detection limits

The results of the geochemical groundwater analysis show that most samples were alkaline or had near-neutral pH values, apart from BHV. Assays for the principal redox reactive species proved negative for sulphides, but sulphates were present in all samples, whilst nitrates were absent from boreholes AC, AF, N1, O and V. Dissolved iron was low but appreciable concentrations of both sodium and chloride were recorded in all samples. Interestingly methane was also detected from 7 samples, with the highest concentration recorded from BH AF.

BH P which was described as being in active decay when assessed in 2007 recorded the highest concentration of sulphate (1100 mg/L).

3.0 RESULTS OF GROUND GAS MONITORING

Quarterly ground gas monitoring was undertaken in each of the installed seventeen dipwells using a Geotechnical Instruments GA2000 gas analyser. The Gas Analyser is used to measure the concentration of hydrogen sulphide, methane, oxygen, carbon monoxide and dioxide through the gas taps which have been fitted to all dipwells. Methane and hydrogen sulphide are indicators of anaerobic conditions, but methane can also be generated from the decay of organic debris. Oxygen, carbon monoxide and carbon dioxide are indicators of oxygen-rich deposits.

The results of the ground gas monitoring are shown in Table 2 below.

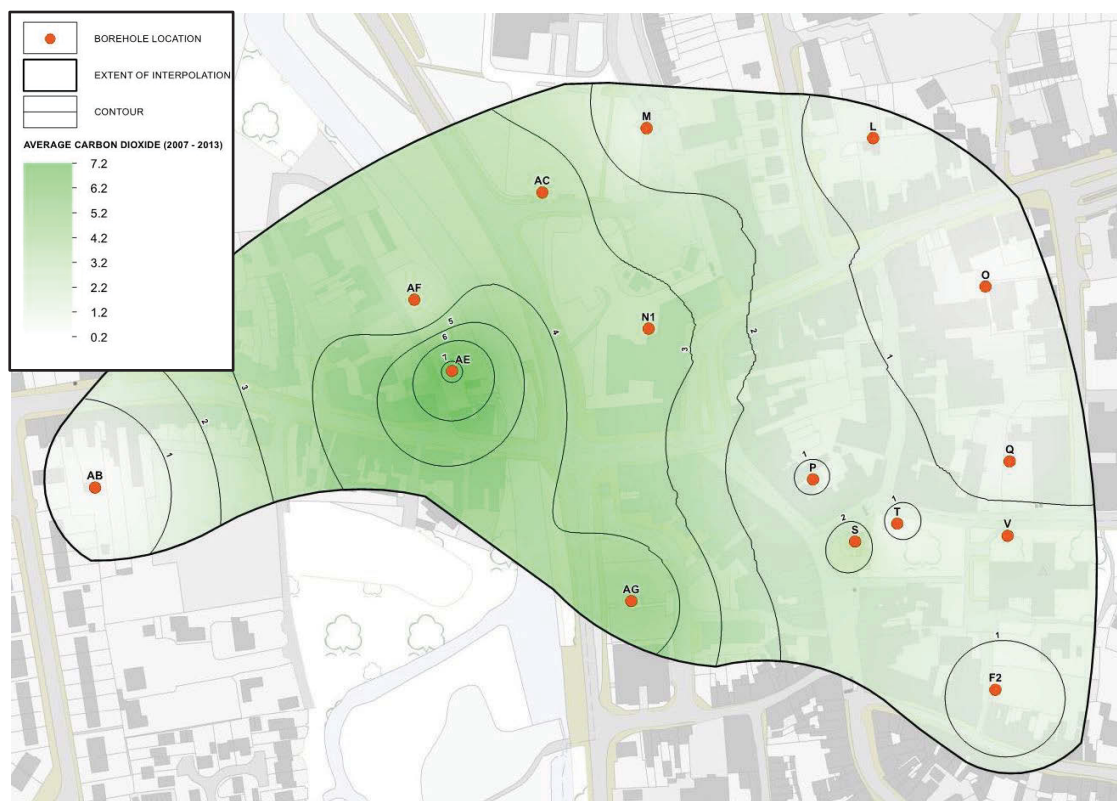
Table 2
Ground Gas Monitoring Results

BH	Value	Methane (%)	Hydrogen Sulphide (ppm)	Carbon Dioxide (%)	Oxygen (%)	Carbon Monoxide (ppm)
AB	Max	0.00	0.00	1.50	20.90	5.00
	Min	0.00	0.00	0.00	18.40	0.00
	Average	0.00	0.00	0.40	20.07	0.82
AC	Max	6.50	5.00	5.60	14.70	5.00
	Min	1.80	0.00	1.60	0.20	0.00
	Average	3.95	0.45	3.76	5.13	1.36
AE	Max	0.10	0.00	12.80	20.70	7.00
	Min	0.00	0.00	0.10	3.80	0.00
	Average	0.02	0.00	8.02	11.27	0.91
AF	Max	0.80	0.00	8.90	18.80	4.00
	Min	0.00	0.00	0.80	10.20	0.00
	Average	0.13	0.00	3.85	15.05	0.73
AG	Max	0.00	0.00	11.10	20.90	2.00
	Min	0.00	0.00	0.00	4.30	0.00
	Average	0.00	0.00	5.11	12.79	0.36
F1	Max	0.00	0.00	3.20	20.50	7.00
	Min	0.00	0.00	0.50	16.60	0.00
	Average	0.00	0.00	1.56	18.46	0.91
F2	Max	0.10	1.00	2.10	20.80	5.00
	Min	0.00	0.00	0.00	16.20	0.00
	Average	0.02	0.09	0.99	19.07	1.00
L	Max	0.00	1.00	1.80	21.20	5.00
	Min	0.00	0.00	0.00	18.30	0.00
	Average	0.00	0.09	0.85	19.82	0.64
M	Max	0.10	0.00	3.20	20.80	0.00
	Min	0.00	0.00	0.30	16.30	0.00
	Average	0.01	0.00	1.31	19.13	0.00
N	Max	0.10	0.00	7.40	20.60	5.00
	Min	0.00	0.00	0.00	10.50	0.00
	Average	0.01	0.00	3.06	15.86	1.00
N1	Max	0.10	0.00	7.60	20.90	5.00
	Min	0.00	0.00	0.00	9.30	0.00
	Average	0.02	0.00	1.67	18.13	0.82
O	Max	0.10	0.00	0.60	20.80	4.00
	Min	0.00	0.00	0.00	19.30	0.00
	Average	0.01	0.00	0.28	20.29	0.36
P	Max	0.00	0.00	4.50	20.90	6.00
	Min	0.00	0.00	0.00	16.10	0.00
	Average	0.00	0.00	1.01	19.54	0.82

BH	Value	Methane (%)	Hydrogen Sulphide (ppm)	Carbon Dioxide (%)	Oxygen (%)	Carbon Monoxide (ppm)
P1	Max	0.00	0.00	7.50	20.80	5.00
	Min	0.00	0.00	0.00	13.20	0.00
	Average	0.00	0.00	1.90	18.58	0.91
Q	Max	0.10	0.00	3.30	20.90	3.00
	Min	0.00	0.00	0.10	12.80	0.00
	Average	0.02	0.00	0.83	19.23	0.36
S	Max	0.00	0.00	5.40	20.60	4.00
	Min	0.00	0.00	0.00	14.00	0.00
	Average	0.00	0.00	2.63	17.64	0.73
T	Max	0.00	0.00	2.40	21.00	3.00
	Min	0.00	0.00	0.10	18.10	0.00
	Average	0.00	0.00	0.98	19.64	0.73
V	Max	0.10	0.00	4.30	20.60	2.00
	Min	0.00	0.00	0.00	15.70	0.00
	Average	0.01	0.00	1.65	18.82	0.18

The results of the ground gas monitoring indicate that elevated concentrations of methane and carbon dioxide exist in the areas adjacent to the river, which also correspond with depleted oxygen levels. The highest concentrations of methane were recorded in borehole AC, indicative of anaerobic processes in a reducing environment. In addition, one of only two detections of hydrogen sulphide recorded to date were detected in the well (the other location was borehole L). High levels of methane in BH AC also correspond with lower concentrations of oxygen which suggest reducing conditions exist at this location. However, methane gas can travel long distances underground following paths of less resistance and therefore the source of the gas might not be immediately adjacent to the monitoring well at AC.

Figure 7
Contour Plot showing mean Carbon Dioxide Gas Concentrations (% vol)



Furthermore as both methane and hydrogen sulphide can oxidise rapidly then an absence in detection does not necessarily imply the gas is not present within the deposits. For example, higher-than-average concentrations of carbon dioxide have been observed in borehole AE with corresponding lower-than-average levels of oxygen and zero levels of methane (Figure 7). Such high levels of carbon dioxide could have resulted from the aerobic conversion of methane gas and hence an absence of either methane or hydrogen sulphide does not indicate an absence of reducing conditions.

4.0 METHODOLOGICAL IMPROVEMENTS

Since the start of the regular monitoring programme in February 2011 several improvements have been implemented to improve the reliability and frequency of the data collection process.

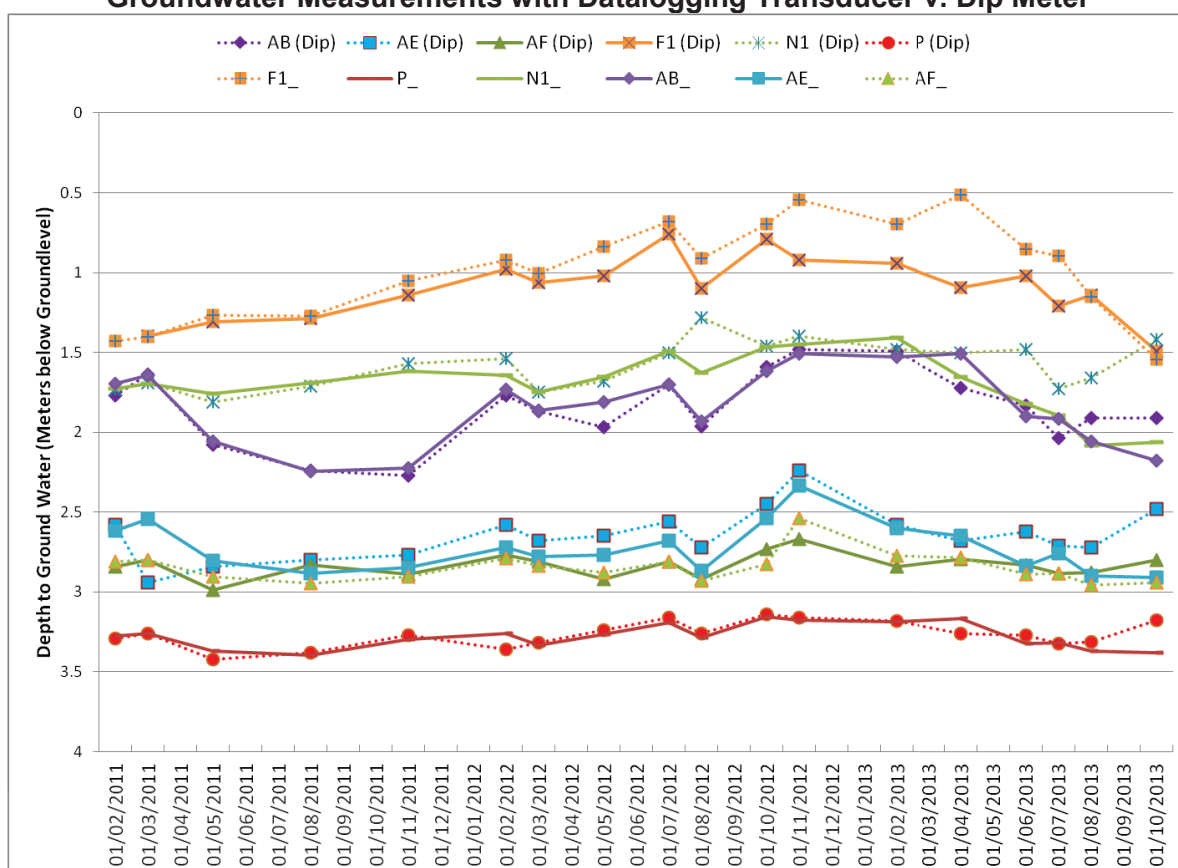
In order to prevent blockages to the rain gauge, a nylon mesh was fitted to the rain collection device in November 2011. This has been successful in preventing the build-up of leaf litter and insect larvae which caused the rain gauge to stop working that occurred between June and September 2011. A revised maintenance schedule was also put in place by separating the quarterly water quality and gas monitoring visits by a six week interval. Not only did this allow the rain gauge to be serviced more regularly, but it also enabled additional rounds of groundwater monitoring to be completed using a dip meter to supplement the daily water level data from the six transducer monitoring points.

Based on the experiences with rain gauge gained during this project, consideration should be given to installing simpler automated rain gauge systems as part of similar monitoring programs in other locations. One possible approach would be to install a water level datalogger (transducer) into an open barrel covered with a nylon mesh. This method would be more accurate, cost effective and reliable than the current system, whilst still being able to automatically record daily or hourly rainfall measurements. Although extra data processing would be required for this system, it is likely that the additional time requirements would be offset by the significant cost benefits and practical advantages.

There are also several additional techniques that could be considered to provide additional information for the Nantwich project or other similar monitoring programmes in future.

Figure 8 shows a graph comparing the results of the manual monitoring with a dip meter against the datalogging transducer. Overall the results from the two methods are very similar. Therefore, the benefits of each method are largely dependent on the desired frequency of the monitoring intervals and the data required. If groundwater monitoring data is required at daily or weekly intervals then the transducers are highly cost effective. However, if monthly groundwater level data is sufficient and can be completed in conjunction with other measurements on site then the installation of the datalogging transducers may not be necessary. Although the transducer highlights the fluctuations that occur on a daily basis, the manual monitoring is still sufficient to monitor key trends on a seasonal and annual scale which are essential for projects of this nature.

Figure 8
Groundwater Measurements with Datalogging Transducer v. Dip Meter



Another issue that would benefit further analysis would be a comparison of the results from the redox monitoring probe with the geochemical laboratory results from redox indicative species such as sulphate, nitrate and dissolved methane. Given the inherent technical issues with measuring redox in the field, the results of the geochemical analysis may give more reliable results in the long term. Measurements using redox probes in the field are significantly impacted by the concentrations of redox species present and the inevitable oxidation of the platinum probe in the natural environment. If only low concentrations of redox sensitive chemicals exist, then the probe will not be able to make an accurate reading due to the detection sensitivity limits of the probe itself. In addition, any build up of oxide on the probe will also reduce the detection sensitivity. However, the results of either method of measuring the oxidising and reducing conditions using groundwater will only remain valid if the archaeological deposits remain saturated.

It would be sensible to collect a sample of methane from borehole AC and submit the gas sample for radiocarbon analysis at an accredited laboratory. This would then enable the source of the methane to be identified, and determine if the methane is related to the decay of ancient organic remains or an alternative modern origin.

The most practical method would be to use a vacuum canister to obtain the gas sample (see Figure 9). The vacuum canister would be attached to the gas tap on the borehole using flexible silicon tubing. The gas tap on the sampling chain would then be opened to allow the vacuum canister to draw in the gas sample. The pressure gauge on the sampling chain would be monitored throughout the sampling process to ensure that sample was taken successfully. The gas tap would then be closed to seal methane sample within the canister so that the sample could then be shipped to an accredited laboratory.

Figure 9
Gas Sampling from a Borehole using a Vacuum Canister



One of the recognised limitations of using borehole investigations to characterise waterlogged deposits is the fact that the small cross-sectional area of the soil cores allows only a key-hole view of the deposits. Given the variable nature of the deposits, and the complexities in their formation processes, it would be beneficial to undertake geophysical surveys using ground penetrating radar (GPR) in areas of key interest. The sedimentary sequence revealed by the boreholes could then be used to help interpret the results of the GPR survey. The information from both the intrusive and geophysical investigations could then be combined to provide three dimensional information about the extent and distribution of the deposits over a wider area, particularly in favourable locations like car parks.

It would also be useful to install an additional datalogging transducer in various dipwells to investigate if permeability is the controlling factor that determines the flatter response to rainfall events recorded in Dipwells P and AB. The datalogger would be installed into boreholes which recorded high and low levels of permeability, and the results would be compared with the existing transducer data to establish if the higher permeability wells exhibit a similar response.

If additional borehole investigations were to be planned in the future, consideration should also be given to further geotechnical testing of the deposits. Undisturbed samples could be collected from specific horizons, as long as they contained a sufficient proportion of cohesive soils. These samples could then be sent to a geotechnical laboratory for triaxial permeability testing, porosity and density analysis which enhance our hydrogeological understanding of the deposits.

5.0 CONCLUSIONS

5.1 Summary

The results of the investigations to date suggest that preservation conditions are not ideal for continuing survival of organic remains, with redox fluctuating between reducing and oxidising conditions. However, the results from the geochemical, water quality and gas monitoring data indicate that the initial characterization from Phase 1 was reasonably accurate and two distinct preservation zones are present, with a well-preserved Zone 1 in proximity to the river, and a less well-preserved Zone 2 on the valley side prone to external influences. Location F next to Church Lane and the Lamb Hotel, however, appears to be an exception to this generalization, and requires further analysis.

In general Zone 1 has good preservation potential characterized by high methane readings, low levels of phosphate and nitrate, sulphate and ferric iron, whilst in Zone 2 (which was located uphill from Zone 1 (Figure 10)); the conditions generally suggested past and active decay. There were also isolated boreholes, however, which showed contradictory results to the general pattern in both zones, and the water table varied from between 1.4m to over 3m below existing ground surface. Conductivity and geochemical results also show that Zone 1 has relatively high levels of salinity, presumed to derive from brine sources rather than chemical content from rainwater ingress.

In Nantwich and other locations in the UK and continental Europe, preservation is occurring not only under conventional waterlogged conditions, but also in semi-saturated environments. These are often zones above full waterlogged sediments, where capillary action and permeability draw sufficient water into the pores of the sediment to restrict or prevent the ingress of oxygen, thus inhibiting the decay process. The results from Nantwich are helping to further our understanding of these tension saturated zones.

The quantity of data that the project is now producing, enhanced by an additional two years of monitoring agreed by the variation to the project, are beginning to take up substantial amounts of time in processing and presentation of the data as part of analysis. The value of these data are already becoming clear, and opportunities exist for many lines of research to be pursued using these results. The success of the project variation for an additional two years of data is becoming clear, providing a long-term research resource that will be available beyond the duration of this specific project.

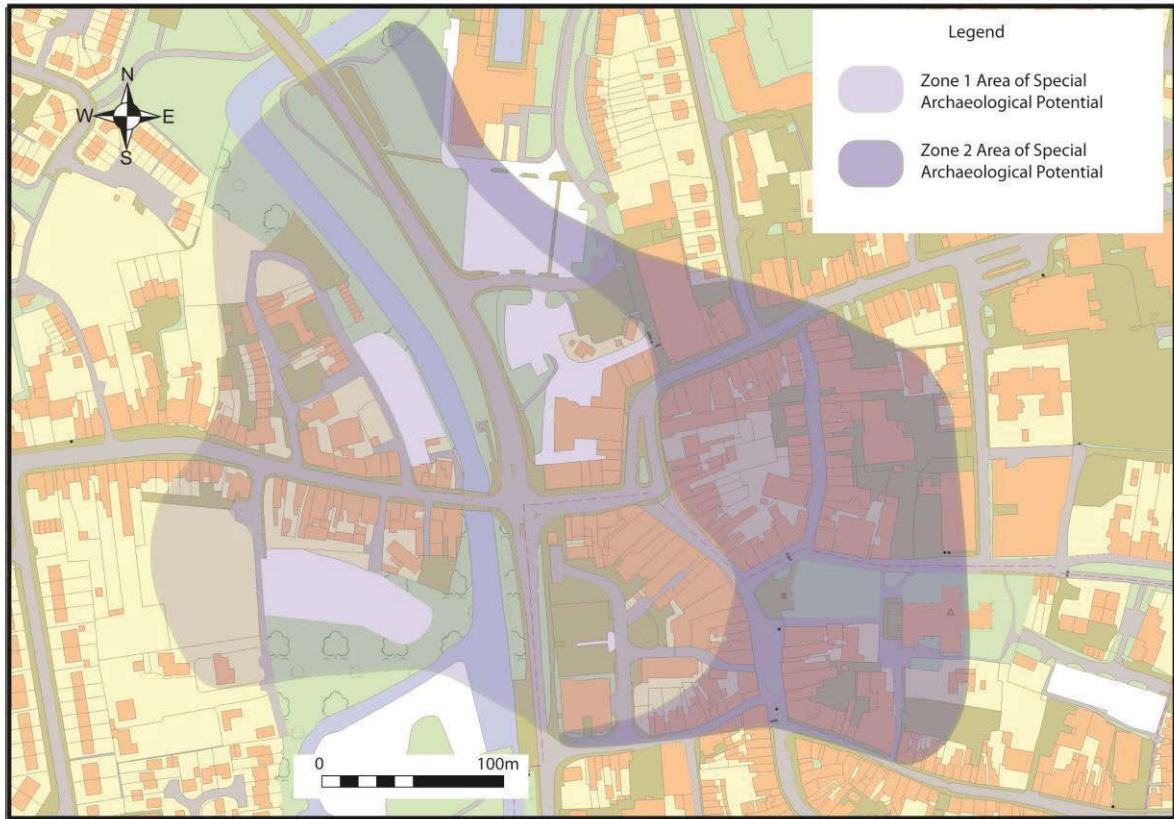
6.0 CLOSURE

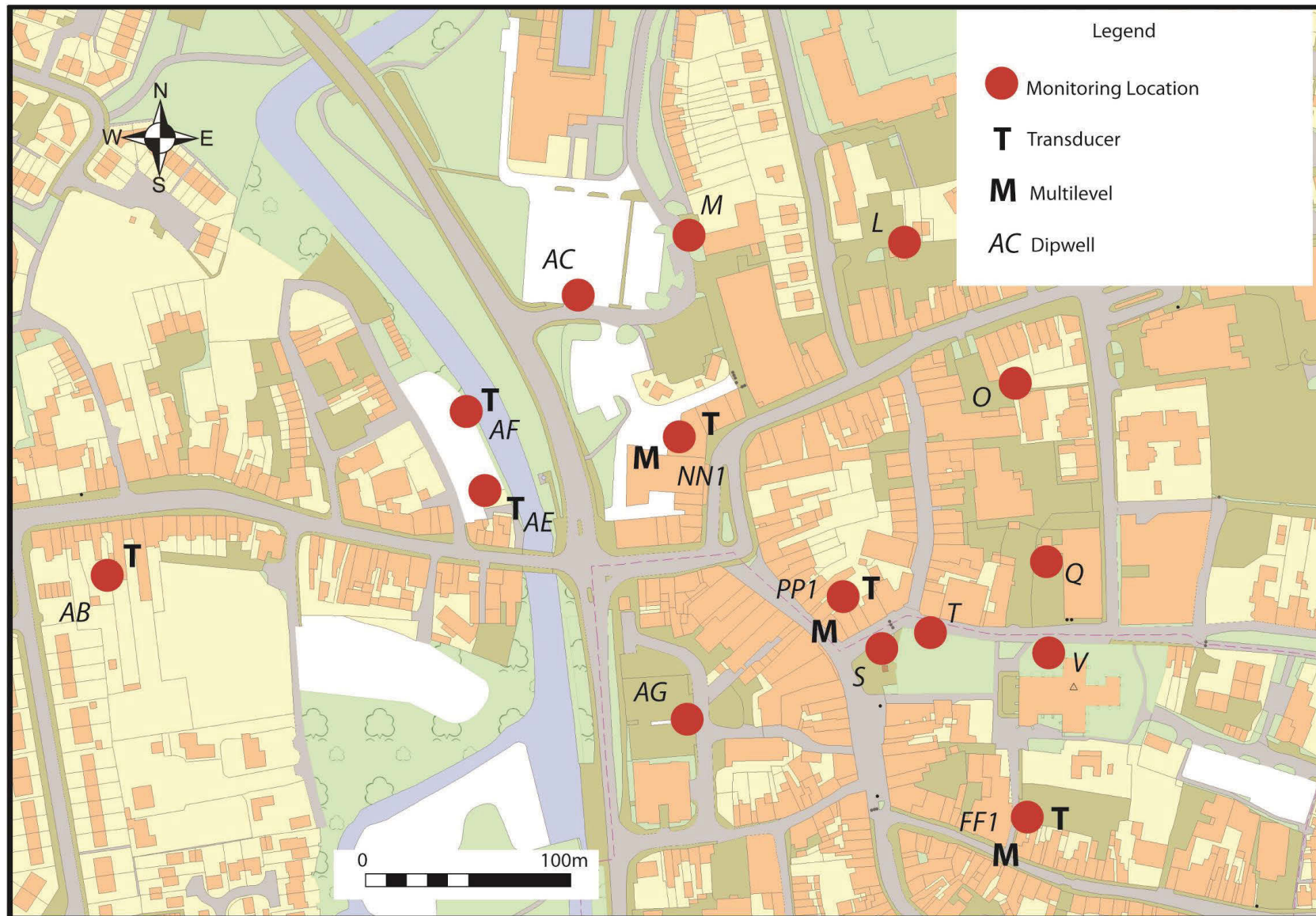
This report has been prepared by SLR Consulting Limited with all reasonable skill, care and diligence, and taking account of the manpower and resources devoted to it by agreement with the client. Information reported herein is based on the interpretation of data collected and has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of Cheshire East Council and English Heritage; no warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the client and others in respect of any matters outside the agreed scope of the work.

Figure 10
Preservation Zones





Groundwater Monitoring Data - 2011 to 2013

Well No	Screened interval (m)	Surface elevation (m AOD)	Values	Depth to water below Ground (m)	Water elevation (m AOD)	Dissolved Oxygen (mg/l)	REDOX (mV)	pH	Conductivity (µS/CM)	Temp (°C)
AB	1.0-3.0	37.93	Max	2.27	36.45	3.94	397	7.80	1253	12.41
			Min	1.48	35.66	0.00	105	6.73	344	4.92
			Average	1.90	36.03	1.51	249	7.22	787	9.34
AC	1.0-4.0	36.42	Max	2.98	34.18	1.70	409	7.20	3505	14.90
			Min	2.24	33.44	0.00	79	6.37	1343	6.42
			Average	2.65	33.77	0.90	221	6.83	2242	11.00
AE	1.0 – 4.0	35.19	Max	2.84	32.95	2.18	498	7.27	2114	14.50
			Min	2.24	32.35	0.28	140	6.65	883	7.68
			Average	2.64	32.55	1.00	223	6.96	1343	11.13
AF	1.0 – 4.0	34.89	Max	2.99	32.22	1.57	500	7.82	2337	15.20
			Min	2.67	31.90	0.36	-3	6.55	1062	7.07
			Average	2.85	32.04	0.91	223	7.06	1698	11.32
AG	1.0 – 4.0	37.03	Max	2.61	35.82	1.64	482	7.75	7274	14.30
			Min	1.21	34.42	0.46	124	6.55	2355	7.18
			Average	1.67	35.36	1.11	278	7.01	4454	11.02
F1	1.3 – 2.0	39.69	Max	1.60	38.77	3.30	429	8.44	1252	16.50
			Min	0.92	38.08	0.82	118	6.97	241	4.51
			Average	1.13	38.56	1.84	254	7.39	553	10.47
F2	1.0 – 4.0	39.69	Max	1.61	38.93	5.96	590	8.24	1918	13.82
			Min	0.76	38.08	0.24	41	6.55	3	4.27
			Average	1.18	38.51	1.45	258	7.23	817	10.03
L	1.0-4.0	38.71	Max	2.35	37.53	4.19	423	7.90	1807	13.30
			Min	1.18	36.36	0.39	87	6.52	260	4.04
			Average	2.14	36.57	1.29	269	7.16	959	9.74
M	1.0-3.0	37.81	Max	1.68	36.49	3.91	431	7.81	1577	13.20
			Min	1.32	36.13	0.00	162	6.39	590	3.55
			Average	1.52	36.29	1.51	292	6.99	991	9.89
N	1.0-4.0	39.17	Max	1.80	37.89	4.28	435	8.05	7939	14.10
			Min	1.27	37.37	0.30	53	6.52	286	5.18
			Average	1.54	37.62	1.29	249	7.13	1105	10.74
N1	1.0 – 3.0	39.16	Max	1.81	37.89	2.34	461	8.33	1183	14.90
			Min	1.28	37.35	0.28	62	6.51	307	4.69
			Average	1.58	37.59	1.12	252	7.16	655	10.36
O	1.0-4.0	39.64	Max	1.57	38.26	3.30	427	8.19	1981	14.00
			Min	1.38	38.07	0.07	77	6.60	348	7.16
			Average	1.48	38.16	1.27	251	7.15	804	10.95
P	1.0-3.8	39.93	Max	3.42	37.57	2.08	463	7.27	1401	14.40
			Min	2.36	36.51	0.00	135	5.42	565	8.23
			Average	3.21	36.72	1.05	270	6.53	903	11.48
Q	1.0-4.0	39.22	Max	1.98	37.95	2.54	448	7.79	3246	15.50
			Min	1.27	37.24	0.17	128	6.50	548	5.14
			Average	1.81	37.40	1.18	247	7.01	1770	10.90
S	1.0-4.0	39.77	Max	3.44	36.57	3.22	454	7.34	2386	14.20
			Min	3.20	36.33	0.00	126	6.21	501	7.26
			Average	3.32	36.45	1.11	290	6.84	1099	10.26
T	1.0-3.0	39.5	Max	3.22	36.47	5.43	465	8.31	853	12.56
			Min	3.03	36.28	0.04	71	6.38	285	6.25
			Average	3.11	36.38	1.67	271	7.04	472	9.33
V	1.0-3.0	39.39	Max	2.25	38.14	3.07	446	7.39	1473	12.68
			Min	1.43	37.14	0.00	99	5.68	161	3.46
			Average	1.89	37.55	1.21	219	6.57	616	9.14

