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Complete List of Authors:	Pringle, Jamie; Keele University, School of Physical Sciences & Geography Cassella, John; Staffordshire University, Department of Forensic & Crime Science Jervis, John; Keele University, School of Physical Sciences & Geography Williams, Anna; Huddersfield University, School of Applied Sciences; Cranfield University, Cranfield Forensic Institute Cross, Peter; University of Central Lancashire, School of Forensic and Investigative Science; Cassidy, Nigel; Keele University, School of Physical Sciences & Geography
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Soilwater Conductivity Analysis to Date and Locate Clandestine Graves of Homicide Victims*

Jamie K. Pringle,[1] Ph.D.; John P. Cassella,[2] Ph.D.; John R. Jervis,[1] Ph.D.; Anna Williams,[3,4] Ph.D; Peter Cross,[5] M.Sc; and Nigel J Cassidy, Ph.D[1]

[1]School of Physical Sciences & Geography, Keele University, Keele, Staffordshire, ST4 6DA, U.K.

[2]Department of Forensic & Crime Science, Staffordshire University, Leek Road, Stoke-on-Trent, Staffordshire, ST4 2DF, U.K.

[3]Cranfield Forensic Institute, Cranfield University, Shrivenham, Berkshire, SN6 8LA, U.K.

[4]now at School of Applied Sciences, University of Huddersfield, Queensgate, Huddersfield, Yorkshire, HD1 3DH, U.K.

[5]School of Forensic & Investigative Sciences, University of Central Lancashire, Preston, Lancashire, PR1 2HE, U.K.

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ABSTRACT

In homicide investigations, it is critically important that post-mortem (PMI) and post-burial interval (PBI) of buried victims is determined accurately. However, clandestine graves can be difficult to locate; and the detection rates for a variety of search methods (ranging from simple ground probing through to remote imaging and near-surface geophysics) can be very low. In this study, simulated graves of homicide victims were emplaced in three sites with contrasting soil types, bedrock and depositional environments. The long-term monthly *in situ* monitoring of grave soilwater revealed rapid increases in conductivity up to two years after burial, with the longest study evidencing declining values to background levels after 4.25 years. Results were corrected for site temperatures and rainfall to produce generic models of fluid conductivity as a function of time. The research suggest soilwater conductivity can give reliable PBI estimates for clandestine burials and therefore be used as a grave detection method.

Keywords: forensic science, forensic geophysics, conductivity, clandestine burials, PMI,

Geoscientific methods are being increasingly utilised by forensic search teams for the detection and location of clandestine burials (1-2). Clandestine graves of murder victims are usually shallow, less than 3 m and typically 0.5 m below ground level or bgl (3,4), but current detection rates are low and, without locating the victim's body, obtaining a successful conviction is more difficult (5,6). Search investigators will typically use a variety of methods, which include scenario-based, feature focused, intelligence-led and systematic Standard Operating Procedures (SOPs) (5,6). SOPs require investigators to follow sequential workflows, from reviewing case information, sourcing background / intelligence information and remote data analysis. This process occurs before determining search strategies, undergoing site reconnaissance and phased site investigations, and then intrusively investigating anomalous areas (1,5,8). Geoscientific site investigation methods vary depending upon the specific case, search site and numerous other factors that are reviewed elsewhere (1), but can include scent-trained human remains detection dogs (7-8), forensic geomorphology (9-10), forensic botany (11-12) and entomology (13-14), near-surface geophysics (15-22), intrusive probing (10,23) and soil geoscience analysis (24-26).

After a body has been found, it is natural for investigators to focus on determining time since death. There has been extensive research on estimating the post-mortem interval (PMI) of very recently deceased individuals discovered above-ground that has been reviewed elsewhere (27), commonly using body cadaver temperatures (28-29), entomology (30) and entomofauna (31) and thanatochemistry (32). For longer deceased individuals, other common PMI dating methods include tissue decomposition (33), skeletal remains (34) and tooth odontology (35).

Below-ground decomposition rates of discovered individuals has been shown to be highly variable (36), depending on organic content (37), various local environmental factors such as soil type (38-41) and organism accessibility (42), amongst other factors. These factors complicate the estimation of PMI for buried remains. Furthermore, it may useful to estimate the Post-Burial interval (PBI) as a guide to the PMI. However, the PMI and PBI may be different: a victim might not be buried immediately after death. In such cases, the PBI can be used as an estimate of the lower limit of the PMI.

The presence of a decomposing cadaver has also been shown to be detectable on the surrounding soil. For example, changes in soil chemistry (24, 25, 37), such as changes in the levels of phosphates and nitrates (44), ninhydrin reactive nitrogen (25,45), volatile organic compounds (24, 37,46) and pH (44,47) can all be detected. Changes in these soil properties can be used to estimate time since death. The decay of other items such as materials associated with a grave have also been suggested to allow a PBI to be estimated (39,48).

Although relatively poorly understood, 'grave soil' has been shown to be detectable by near-surface geophysical search methods, specifically electrical resistivity (21,18,49) and it's reciprocal, bulk ground conductivity (17). Geophysical research using simulated clandestine grave burials can provide critical information, for example, on optimal geophysical detection methods and equipment configurations (15,50-52), as well as providing continuous datasets for comparison with real cases (50,53-55). Recent research has found that electrical resistivity anomalies over burials are predominantly due to conductive fluids in grave soil that vary temporally (27,50,56) that may be due to decomposition (Fig. 1). It has been shown that it is possible to repeatedly extract *in situ* decomposition fluids from both a buried pig cadaver and background soilwater, without the need for repeated disturbance or numerous replicate samples as other authors have done. The resulting fluids can be simply analysed for conductivity using a hand-held meter, with initial results of a pilot two year monitoring study showing promise (27).

The aim of this was study was to expand the work of Pringle et al. (27). *Firstly* the aim was to obtain long-term (6 years) *in situ* grave soil water conductivity monitoring data for a U.K. simulated clandestine burial. Results were then used to generate linear regression curves to correlate measurements against PBI. *Secondly* the same experiment was conducted over a shorter time period at two other U.K. academic study sites to assess the method's robustness and variability in different soil and bedrock types. *Thirdly,* all results were corrected for local major climate variations (temperature and rainfall) to allow direct comparisons with other studies, and to allow search teams to utilise this method.. *Fourthly,* the potential for detecting clandestine burials using this method was assessed.

Methodology

Study test sites

Three U.K. University test sites in different parts of the country were employed for this study, all in temperate climates that were typical of the U.K.

The University of Central Lancashire (UCLan) test site in Lancashire was situated in a dedicated research facility off campus in a rural environment on peat moorland (Fig. 2). The site lies ~300 m above sea level. The local soil was determined onsite to be a dark brown, organic-rich hill peat with interbeds of silt and sand. Nearby records (57) indicated the Carboniferous (Westphalian) Pennine Lower Coal Measures Formation comprising a mixture of sandstone, mudstone and coal bedrock was present at least 4 m below ground level (bgl). This site has been used for several decomposition studies prior to this (58,59), albeit spatially far enough away and downslope of the area to prevent any potential contamination issues; initial 'grave' soilwater conductivity values were also the same as for the control.

The Keele University test site in Staffordshire was situated in a restricted area in grassed semi-rural ground surrounded by deciduous woodland and hedges (Fig. 2). The site lies ~200 m above sea level. The local soil was determined onsite to be a sandy loam with nearby borehole records (27) indicating the Carboniferous (Westphalian) Butterton Sandstone bedrock was present ~2.5 m bgl. This site has also been previously used for a forensic geophysical study (27) but again these were situated far enough away and downslope to avoid any potential contamination issues;

initial 'grave' soilwater conductivity values were also the same as for the control. The preliminary two years of results were published (27).

The Cranfield University test site in Wiltshire was situated in a restricted area on the Shrivenham campus in cleared semi-urban ground surrounded by deciduous woodland and hedges (Fig. 2). The site lies ~80 m above sea level. The local soil was determined to be a mixed made-ground and sandy loam with nearby records (60) indicating Jurassic Oxford Clay Formation and Corallian Limestone bedrock both present at shallow depths bgl. The site had not been used for previous decomposition studies.

Simulated graves

For consistency, the simulated graves at all three sites (Fig. 2) were created following the same method, albeit at different dates (08/12/2007 for Keele University, 12/10/2010 for UCLan and 18/08/2011 for Cranfield Universities respectively). Each ~2 m x ~0.5 m grave was hand-excavated to 0.5 m below ground level (bgl), the respective (~80 kg) pig (*Sus scrofa*) cadavers, sourced from local abattoirs and dead for less than 12 h at the time of burial, were then placed within the graves. Simulated grave depths were based on published data on average depths of discovered human clandestine burials (87 in the U.S. (4) and 29 in the U.K. (3) respectively). The use of pig cadavers as human analogues is well established in forensic science studies as they have similar chemical compositions, body sizes, tissue:body fat ratios, and skin/hair type to humans (50, 41,61). The use of pig cadavers at these sites had been approved by DEFRA and the respective University Ethics Committees.

A soilwater sample lysimeter was placed within each grave between the pig cadaver and the grave wall (Fig. 3). The porous end cap of each model 1900 (SoilMoisture Equipment Corporation™) soilwater lysimeter was vertically inserted into a mixture of water and excavated soil which ensured good hydraulic conductivity between the grave and the lysimeter following standard practice (62). The simulated graves were then back-filled using the excavated soil and the overlying grass sods were then replaced. Control site lysimeters were installed ~10 m away from each grave by digging narrow holes (~0.3 m x ~0.3 m) to ~0.5 m bgl and following the sample lysimeter emplacement procedure described above. These control lysimeters were placed far enough away and up-slope of the simulated graves to avoid any potential contamination with grave fluid (Fig. 2). Once installed, the exposed top of each lysimeter was sealed with a rubber stopper (Fig. 3) and a vacuum pump was employed to generate the established lysimeter suction of 65 KPa13, in order for the instrument to draw fluid from the surrounding soil.

Sample collection and measurements

Two days before a sample was extracted, rubber stoppers from the respective lysimeters were removed and any fluid present extracted using a plastic syringe with a narrow tube attachment. This was to ensure that the analysed fluid had an accurate post-burial date when measured. The lysimeters were then resealed and re-pressurised as previously described. On the day of sampling (usually monthly, see Tables 1-3), the extraction procedure was repeated but any fluid was placed in a labelled plastic sample bottle; a portable WTW Instrument multi-line P4 temperature-calibrated conductivity meter (6) was then immediately placed in the bottle and three conductivity values obtained; an average was therefore derived (Fig. 3). If no sample was present, this was recorded.

Climatological data

The closest weather stations run by the U.K. Meteorological Office were used to obtain average daily rainfall and air temperature readings over the respective monitoring periods (Tables 1-3). These were situated ~2.4 km (Bacup), ~0.2 km (Keele), and ~3 km (Sevenhampton) away from the UCLan, Keele and Cranfield University study sites respectively. Keele University operates the Keele meteorological weather station which is close to the study site and recorded temperate weather patterns (Fig. 4). It recorded monthly minimum, maximum and average total rainfall of 2.6 mm, 167 mm and 64 mm respectively over the 2,004 day study period. The corresponding values recorded for UCLan were 23 mm, 278 mm and 126 mm respectively over the 610 day study period. Cranfield recorded 17 mm, 138 mm and 68 mm respectively over the 475 day study period.

The daily average temperatures from each site were used to convert post-burial days to Accumulated Degree Days (ADDs) (see 37). ADDs correct for local site temperature variations by weighting each day by the average daily temperature and then giving each burial day an ADD value. Therefore, for a 2-day period, in which the average temperature of the first day was 12 ºC and the second day was 15 ºC, the ADD value for those 2 days would be 27 ADDs. Tables 1-3 summarises these datasets.

Calculated monthly total rainfall (mm) data from all three sites were also used to obtain yearly monthly rainfall averages as well as obtaining yearly monthly rainfall averages for England over the study period from the U.K. Meteorological Office. Table 4 lists these datasets. The rainfall datasets were used to correct the measured soilwater measurements for local rainfall variation; conductivity values were multiplied by a rainfall correction factor, which was calculated by dividing the average monthly rainfall for England in a given year by the average monthly rainfall for the local area in the same year. Correction for rainfall was important as relatively high rainfall rates could potentially dilute grave soil water and hence reduce the measured conductivity values, and relatively low rainfall rates would effectively concentrate grave soil water and hence increase measured conductivity values.

Results

All measured climatological data from the three field sites showed cyclical seasonal variations in temperature as would be expected in a mid-latitude Northern hemisphere climate, with winter months being colder and wetter compared to warmer and dryer summer months (Fig, 4). However, there were significant variations between monitoring years; for example, the first three summers of the Keele study were warmer than subsequent summers, with rainfall in particular being variable between years (Fig. 4).

The field soilwater measurement results from the Keele test site (Fig. 5A) evidenced consistent background conductivity values over the 2,004 day study period (averaging 411 ± 0.1 mS/cm). The grave conductivity values (see Table 1) rapidly increased from 266 ± 0.1 mS/cm (12 days) up to 28,800 ± 0.1 mS/cm (307 days) before gradually increasing to a maximum of 33,400 ± 0.1 mS/cm (671 days). Measured grave conductivity then rapidly decreased to 10,460 ± 0.1 mS/cm (840 days) before gradually decreasing to typical background values of 499 ± 0.1 mS/cm (1,621 days) until the end of the study period (2,004 days). These grave conductivity changes could be grouped into six linear regressions with good fits (R^2 values of 0.72 – 0.99 - see Fig. 5A).

The field soilwater measurement results from the UCLAN test site (Fig. 5A) evidenced consistent background conductivity values over the 511 day study period (averaging 331 ± 0.1 mS/cm). The grave conductivity values (see Table 2) rapidly increased from 570 ± 0.1 mS/cm (12 days) up to 17,300 ± 0.1 mS/cm (344 days), albeit being relatively constant at ~5,000 ± mS/cm between 181 to 287 days PBI.

Measured grave conductivity then gradually decreased to 14,000 ± 0.1 mS/cm at the end of the study period (511 days). Samples were not collected during a few months of the study period but this did not affect the overall trends.

The field soilwater measurement results from the Cranfield test site (Fig. 5A) evidenced consistent background conductivity values over the 264 day study period (averaging 829 ± 0.1 mS/cm). The grave conductivity values (see Table 3) rapidly increased from 674 ± 0.1 mS/cm (22 days) up to 24,625 ± 0.1 mS/cm (117 days), before rapidly decreasing to 10,987 ± mS/cm at the end of the study period (264 days). Again, samples were not collected during some months of the study period but this did not affect the overall trends.

At each study site, there were local temperature variations, which directly affected decomposition rates (4), and these variations were removed from raw conductivity values by converting Post-Burial (day) Interval (PBI) to Accumulated Degree Days (ADD), as detailed in the methods. Local study site rainfall variations, which effect conductivity values as relative higher rainfall rates will reduce measured conductivities, were also removed by calculating each of the respective site's monthly average rainfall during the study and then correcting these by percentage changes against the average monthly rainfall for England (Table 4). The resulting climate-corrected Keele site data showed a much improved set of five linear correlations (Fig. 5B), with the other two study sites also showing similar conductivity results with the Keele study results over the same post-burial time periods (Fig. 5B). This method also accounted for the different respective study start dates (December 2007, October 2010 and August 2011 for the Keele, UCLAN and Cranfield studies respectively) and their associated seasonal local climate variations buried at different times of the year.

Discussion

Every search for a murder victim in a clandestine burial is unique: the conditions (e.g. the local soil type, vegetation, climate and potential depositional environment) and factors relating to the burial (e.g. the victim's body size, burial depth bgl and season of deposition) will vary from case to case (1,3,4,50). These factors will affect both successful detection of a clandestine burial and the determination of the PBI; the latter has, to-date, proved difficult to estimate when a grave is discovered (37,63,64). Nevertheless, forensic search teams have an obligation "to use any means at their disposal to find [a body]" (5). When victims have been missing for a long period of time, it becomes even more of a challenge,as seen, for example, with the forensic high profile and ongoing U.K. search for Keith Bennett since his disappearance in 1964 (65).

These three studies have demonstrated that measuring 'grave' soilwater conductivity is a relatively robust geoscientific method for estimating a PBI of a discovered clandestine burial up to ~1,600 days / ~13,500 ADDs after burial. The importance of correcting measured conductivity values for local rainfall and temperature information has also been shown by this study to be critical (Fig. 4). It is difficult with current methods to estimate a PBI after an individual is skeletonised (1,3,27) and this proposed simple method may thus prove very beneficial to forensic recovery teams. Comparison of a pilot (66) and this study's preliminary (27) results has also noted that cadaver size did not have a significant effect on measured 'grave' soilwater conductivity measurements.

The potential of this PBI estimation method was demonstrated with an early simulated clandestine burial study (27), where the measured conductivity value for a 'discovered' buried pig cadaver resulted in a ~10% date discrepancy between calculated and actual PBI over the 6 monthly monitoring period. It should be noted that a measured conductivity value could potentially give two PBI burial dates (*cf.* Fig. 5); but this may still narrow down the PBI and may be more information than forensic investigators would otherwise have.

As the same experimental method was utilised at three U.K. study sites, with different local soil types, depositional environments and weather conditions over different temporal periods, and the geoscience dataset were still found to be reliable, the method findings give confidence that the methodology used is robust. Note however that there was some variability between comparable corrected results with the three study sites, which may be due to the differing depositional environments and soil types.

These studies have demonstrated that 'grave' soil water can clearly be differentiated from background soilwater by measuring soilwater conductivities and therefore this technique has the potential to also be a useful clandestine grave detection method. This dataset shows clear grave soil conductivity changes over time, with the most rapid changes occurring from burial up to ~300 days / ~3,000 ADDs after burial. This change is most likely due to decomposition changes (4,33) (Fig. 1). Forensic search teams could potentially detect clandestine graves by initially measuring conductivities in surface water downslope / downstream of identified potential burial site(s) as (5) and (2) have undertaken in their respective forensic searches. This would also require a programme of water sampling all around the identified potential burial site(s) in order to gain sufficient background conductivity readings to allow potential sites to be identified using this detection method. Whilst surface water sampling is relatively straightforward and commonly undertaken in environmental contamination surveys (1), forensic soilwater surveys would involve a significant amount of effort, from initial soil sampling of suspected burial sites and careful storage, to centrifuging to extract soilwater (25), and measuring their respective conductivity values to identify anomalous readings. This therefore would not be recommended as an initial search method; rather it should be undertaken when a search area has been narrowed down to an appropriate size. This does, however, have promise as other studies have shown decomposition fluids to be retained in the local soil environment and to be electrically detectable, even when physical remains have decayed (67).

Remaining unknown variables will be case-specific, but could include any delay between death and burial (e.g. storage), style of burial (50) and removal and reburial of the body or bodies (68). Other decomposing remains (e.g. animal cadavers) may also interfere with results. The proposed method could also be applied to determine the post-burial interval for other organic material, for example, illegal animal burials (69) or landfill leachate plumes (1).

Conclusions and further work

This long-term research project regularly extracted soilwater from three simulated clandestine burials in different soil and bedrock types and depositional environments in the UK. This has produced datasets of temporally varying conductivities over 6 years, evidencing relative rapid increasing of ‘grave’ soilwater conductivities up to 2 years post-burial, before declining to background conductivity values after 4.25 years of burial. Local climate variations of temperature and rainfall have been corrected for and comparable results have been obtained from the three sites using the same methodology which gives confidence in the method. Analysing soilwater conductivities of a discovered clandestine grave *in situ* would be relatively simple and could provide an estimate of the PBI for forensic search teams although this may be different to the PMI. Note that discovered burials plotted on the conductivity graphs may suggest two possible PBI values. The method could also potentially be used as a search tool if multiple soilwater and/or surface water samples are collected and analysed. This proposed method could also be applied to estimate the post-burial interval of other organic material, such as illegal animal burials or landfill plumes.

Further work should clearly *first* test this potential PBI method in a real forensic case of a discovered clandestine grave in order to determine its usefulness for forensic investigators. *Secondly,* it is important that the experiment is replicated in other soil types in order to quantitatively understand how this important variable affects the soilwater conductivity results. *Thirdly*, analytical chemical techniques should be utilised to examine the soilwater water samples. This would hopefully clarify the chemical changes that cause the variations in soilwater conductivity that were measured in this study. It may also determine whether individual elements, compounds or acids could be used as complimentary dating techniques. *Fourthly,* this experiment should be replicated using human cadavers as this may be a variable to consider.

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Additional information and reprint requests:

Jamie K. Pringle, Ph.D.

School of Physical Sciences & Geography

William Smith Building

Keele University

Keele

Staffordshire ST5 5BG

U.K.

E-mail: j.k.pringle@keele.ac.uk

FIGURE CAPTIONS:

FIG. 1. Four main clandestine burial decompositional stages. (A) Recent burial, surface expression is most obvious. (B) Early decomposition with search dogs and/or methane probes being optimal. (C) Late-stage decomposition with grave soil fluids. (D) Final skeletonised decomposition. Modified from (1).

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FIG. 5. Measured fluid conductivity results showing (A) Keele test site and (B) corrected for both temperature and monthly average rainfall (see text). Comparison data from Cranfield (crosses) and UCLan (squares) study sites also shown.

TABLES

Sample date	Post-burial days / interval (PBI)	Accum-ulated Degree Days (ADD)	Field-measured 'grave' conductivity (mS/cm)	Rainfall england-corrected grave conductivity	Field-measured 'control' conductivity (mS/cm)
08/12/2007	0	0			
19/12/2007	12	27	729	743	463
10/01/2008	34	114	1597	1463	422
17/01/2008	41	149	1780	1631	414
31/01/2008	55	244	2060	1888	517
14/02/2008	69	308	2680	2456	527
28/02/2008	84	364	2740	2511	no sample
13/03/2008	97	436	3520	3226	560
27/03/2008	111	498	4390	4023	587
10/04/2008	125	588	5400	4949	626
24/04/2008	139	683	5860	5370	625
08/05/2008	153	850	6610	6057	617
22/05/2008	167	1035	9130	8367	442
05/06/2008	181	1225	11610	10639	423
19/06/2008	195	1416	13810	12656	350
17/07/2008	223	1815	18640	17082	415
14/08/2008	251	2266	22100	20253	430
11/09/2008	279	2673	no sample	no sample	439
09/10/2008	307	2992	28800	26392	419
06/11/2008	335	3225	30000	27492	401
04/12/2008	363	3368	29600	27126	no sample
29/01/2009	419	3497	30800	27456	no sample
26/02/2009	447	3566	29800	26565	428
26/03/2009	475	3740	29700	26475	452
23/04/2009	503	3987	30200	26921	479
21/05/2009	531	4274	31500	28080	495
18/06/2009	559	4659	30900	27545	424
05/09/2009	638	5883	31400	27991	413
08/10/2009	671	6306	33400	29774	no sample
03/12/2009	727	6777	24600	21929	354
30/12/2009	754	6827	22500	20057	346
28/01/2010	783	6837	18940	17033	364
26/02/2010	812	6868	13030	11718	375
26/03/2010	840	7000	10460	9407	386
27/04/2010	872	7251	10480	9425	396
27/05/2010	902	7582	9400	8454	369
25/06/2010	931	7985	9350	8409	335

30/07/2010	966	8552	10200	9173	no sample
01/10/2010	1029	9421	no sample	no sample	376
29/10/2010	1057	9678	6210	5585	367
10/12/2010	1099	9794	6670	5999	357
04/01/2011	1124	9786	5610	4569	no sample
11/02/2011	1162	9940	3540	2883	335
11/03/2011	1190	10053	2370	1930	342
18/04/2011	1228	10391	2300	1873	350
23/05/2011	1263	10818	3110	2533	326
22/06/2011	1293	11202	no sample	no sample	304
03/01/2012	1487	13439	1375	1178	no sample
20/02/2012	1536	13584	855	733	330
12/03/2012	1557	13727	646	553	357
16/04/2012	1592	13985	716	613	no sample
15/05/2012	1621	14214	499	428	394
03/07/2012	1670	14872	415	356	395
03/08/2012	1701	15331	369	316	385
05/09/2012	1734	15853	no sample	no sample	394
04/10/2012	1763	16198	392	336	391
09/11/2012	1799	16454	413	354	402
07/12/2012	1827	16584	363	311	410
07/01/2013	1858	16722	335	260	372
18/02/2013	1900	16781	344	267	323
13/03/2013	1923	16823	350	272	278
18/04/2013	1959	16954	394	306	no sample
04/06/2013	2006	17423	402	313	300
30/11/2013	2185	19702	415	323	396

TABLE 1. Summary of measured conductivity values and local temperature data from Keele study site over the monitoring period. Conductivity and temperature data are from our new data and previously published data (27,50). No sample = no fluid was able to be extracted. Stated measurements are averages with a ± 0.1 mS/cm accuracy.

Date	Post-burial days / interval (PBI)	Accum-ulated Degree Days (ADD)	Field-measured 'grave' conductivity (mS/cm)	Rainfall england-corrected grave conductivity	Field-measured 'control' conductivity (mS/cm)
12/10/2010	0	0	-	-	-
28/10/2010	16	132	570	1096	250
04/11/2010	23	206	780	1500	230
11/11/2010	30	248	500	961	190
04/02/2011	115	421	2300	4877	100
04/03/2011	143	572	3500	7421	100
11/04/2011	181	866	6900	14630	460
11/05/2011	211	1220	4500	9541	400
14/06/2011	245	1605	4600	9753	370
07/07/2011	268	1936	5200	11026	310
26/07/2011	287	2204	6450	13676	250
21/09/2011	344	3008	17300	36682	850
27/10/2011	380	3449	16500	no sample	270
12/01/2012	457	4007	13220	22540	200
06/03/2012	511	4217	14000	23870	650

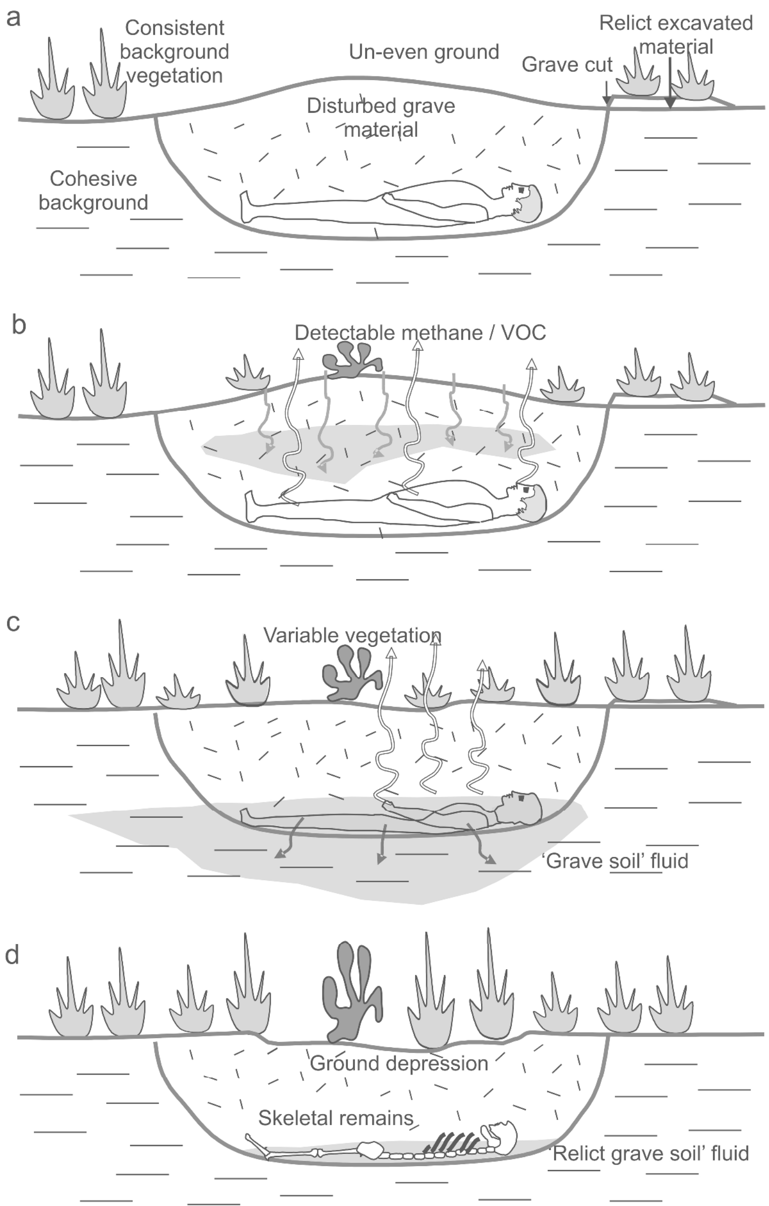
TABLE 2. Summary of measured conductivity values and local temperature data from the UCLan study site over the monitoring period. Stated measurements are averages with a ± 0.1 mS/cm accuracy.

Date	Post-burial days / interval (PBI)	Accum-ulated Degree Days (ADD)	Field-measured 'grave' conductivity (mS/cm)	Rainfall england-corrected grave conductivity	Field-measured 'control' conductivity (mS/cm)
18/08/11	0	0	-	-	-
09/09/11	22	347	1918	1646	674
15/09/11	28	434	4945	4244	330
19/09/11	32	488	5475	4699	890
26/09/11	39	589	4638	3980	1138
29/09/11	42	642	4103	3521	800
05/10/11	48	749	8113	6963	633
12/10/11	55	849	7600	6523	1094
21/10/11	64	934	8230	7063	1173
28/10/11	71	1011	9660	8290	1187
13/12/11	117	1412	24625	21134	595
22/02/12	188	1763	21805	18589	611
24/04/12	250	2261	9223	7863	725
04/05/12	260	2343	9647	8224	510
08/05/12	264	2379	10987	9366	591

TABLE 3. Summary of measured conductivity values and local temperature data from the Cranfield study sites over the monitoring period. Stated measurements are averages with a ± 0.1 mS/cm accuracy.

Year	England	Keele	UCLAN	Cranfield
2007	77.9	79.4	-	-
2008	81.8	75	-	-
2009	72.9	65	-	-
2010	60.6	54.5	116.5	-
2011	59.4	48.4	126	51
2012	93.8	80.4	160	80
2013	81.3	63.2	-	-
average	**75.4**	**66.6**	**134.2**	**66**

TABLE 4. Summary of monthly average rainfall data from the respective study sites over the monitoring period. Measurements have 1 mm accuracy.



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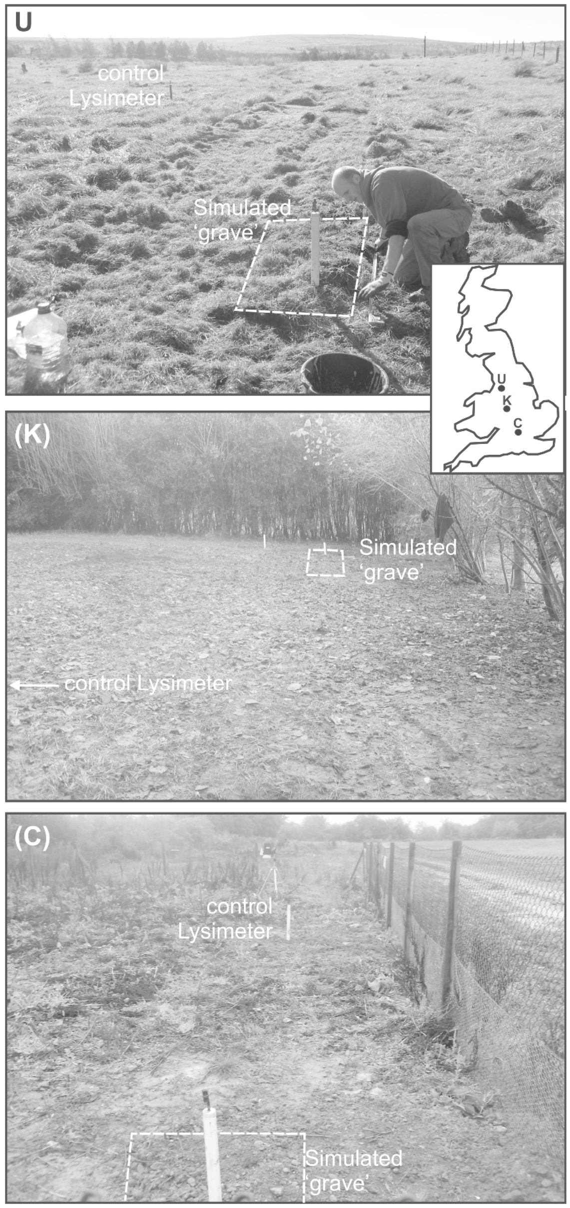

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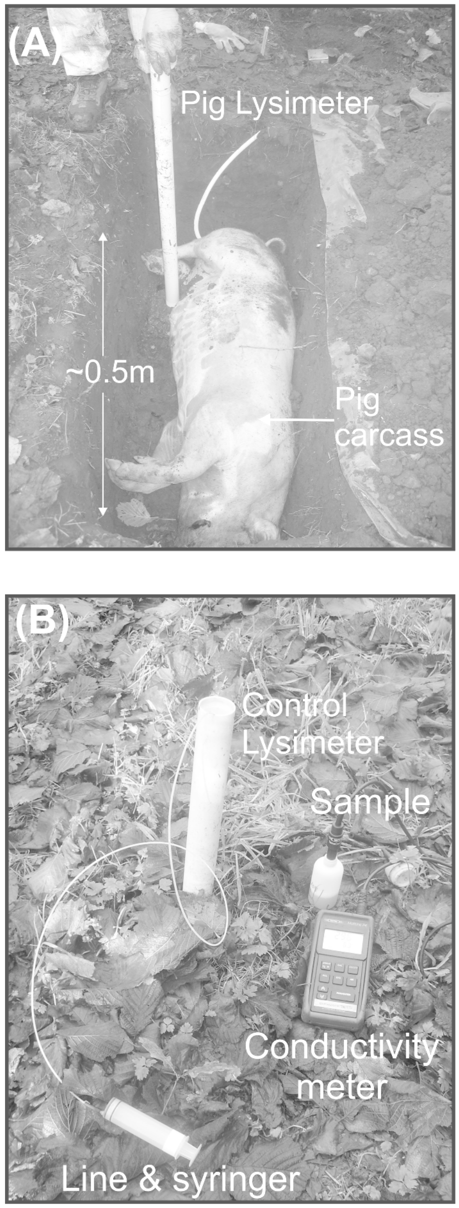

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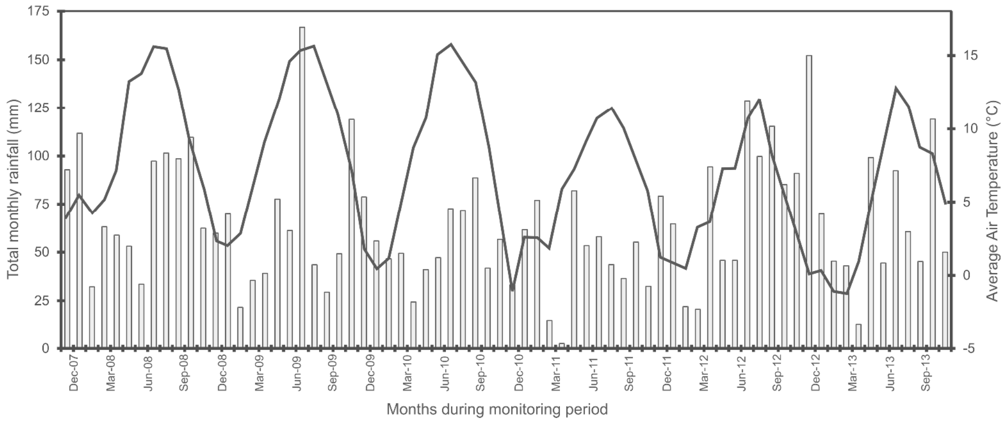

FIG. 4. Graphical climate summary of rainfall (bars) and temperature (line) data from Keele University weather station, from our data and previously published data (27,50).

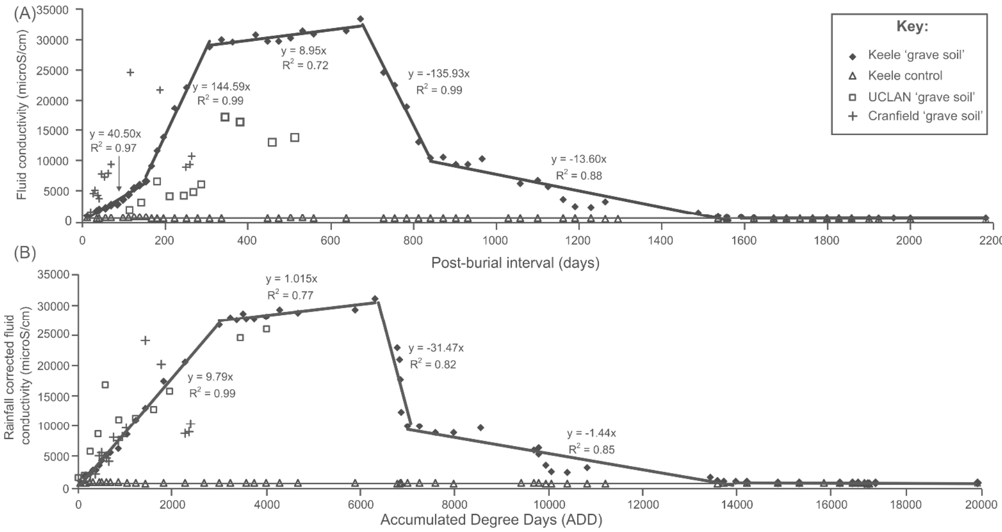

FIG. 5. Measured fluid conductivity results showing (A) Keele test site and (B) corrected for both temperature and monthly average rainfall (see text). Comparison data from Cranfield (crosses) and UCLan (squares) study sites also shown (see key).

Soilwater Conductivity Analysis to Date and Locate Clandestine Graves of Homicide Victims~~Soilwater conductivity analysis to date clandestine graves of homicide victims~~*

Jamie K. Pringle,[1] Ph.D.; John P. Cassella,[2] Ph.D.; John R. Jervis,[1] Ph.D.; Anna Williams,[3,4] Ph.D; Peter Cross,[5] M.Sc; and Nigel J Cassidy, Ph.D[1]

[1]School of Physical Sciences & Geography, Keele University, Keele, Staffordshire, ST4 6DA, U.K.

[2]Department of Forensic & Crime Science, Staffordshire University, Leek Road, Stoke-on-Trent, Staffordshire, ST4 2DF, U.K.

[3]Cranfield Forensic Institute, Cranfield University, Shrivenham, Berkshire, SN6 8LA, U.K.

[4]now at School of Applied Sciences, University of Huddersfield, Queensgate, Huddersfield, Yorkshire, HD1 3DH, U.K.

[5]School of Forensic & Investigative Sciences, University of Central Lancashire, Preston, Lancashire, PR1 2HE, U.K.

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ABSTRACT

In homicide investigations, it is critically important that ~~Accurate determination of~~ post-mortem ~~interval~~ (PMI) and~~the~~ ~~time since~~post-~~-~~burial interval (~~PMI/~~PBI) of~~ a clandestine grave of~~ buried victims is determined accurately~~ in a clandestine grave is critical~~ ~~importance to a murder investigation~~~~for forensic investigators to link suspects to a crime or eliminate~~ ~~suspect(s)~~~~them from it~~. However, clandestine graves can be difficult to locate;~~ Currently,~~ and the detection rates ~~worldwide are low using~~ for a variety of search methods ~~,~~ (ranging from simple ground probing ~~and use of scent-trained search dogs,~~through to ~~more advanced~~ remote imaging~~ery~~ ~~analysis~~ and near-surface geophysics) can be very low~~ techniques~~. ~~Here we show how long-term geoscience monitoring (6 years) of~~ In this study, simulated ~~clandestine~~ graves of homicide victims were emplaced in three sites with contrasting soil types, bedrock and depositional environments. The long-term monthly *in situ* monitoring of grave soilwater~~all~~ revealed rapid increases in conductivity up to two years after burial~~ at all sites~~, with the longest study evidencing declining values to background levels after 4.25 years. R~~econductivity of grave-soil decomposition fluids can be used to detect the presence of a buried cadaver. Measurements could also determine the post-burial interval. R~~esults were corrected for site temperatures and rainfall to ~~allow~~ produce generic models ~~s~~ of fluid conductivity as a function of time~~ time to be generated~~. The research suggest soilwater conductivity can give reliable~~, facilitating predictions of~~

~~grave location and~~ PBI ~~time since~~ estimates for ~~of PMI/date~~~~burial~~clandestine burials and therefore ~~., with~~~~It is also possible that measurements could b~~be used as a ~~also a potential~~grave detection method.~~ Comparisons with weather-corrected results from two additional sites with different soil types confirmed the reliability and effectiveness of decomposition fluid conductivity measurements for locating clandestine graves and providing an estimate of the time of burial.~~

Keywords: forensic science, forensic geophysics, conductivity, clandestine burials, PMI,

Geoscientific methods are being increasingly utilised by forensic search teams for the detection and location of clandestine burials (1-2). Clandestine graves of murder victims are usually shallow, less than 3 m and typically 0.5 m below ground level or bgl (3,4), but current detection rates are low and, without locating the victim's body, obtaining a successful conviction is more difficult (5,6). Search investigators will typically use a variety of methods, which include scenario-based, feature focused, intelligence-led and systematic Standard Operating Procedures (SOPs) (5,6). SOPs require investigators to follow sequential workflows, from reviewing case information, sourcing background / intelligence information and remote data analysis. This process occurs before determining search strategies, undergoing site reconnaissance and phased site investigations, and then intrusively investigating anomalous areas (1,5,8). Geoscientific site investigation methods vary depending upon the specific case, search site and numerous other factors that are reviewed elsewhere (1), but can include scent-trained human remains detection dogs (7-8), forensic geomorphology (9-10), forensic botany (11-12) and entomology (13-14), near-surface geophysics (15-22), intrusive probing (10,23) and soil geoscience analysis (24-26).

After a body has been found, it is natural for investigators to focus on determining time since death. There has been extensive ~~taphonomy~~ research on estimating the post-mortem interval (PMI) ~~estimation~~ of very recently deceased individuals discovered above-ground that has been reviewed elsewhere ~~is relatively well established~~ (27), commonly using body cadaver temperatures (28-29), entomology (30) and entomofauna (31) and thanatochemistry (32). For longer deceased individuals, other common PMI dating methods include tissue decomposition (33), skeletal remains (34) and tooth odontology (35). ~~but the determination of both PMI of~~

~~deceased individuals over longer time periods and importantly the post-burial interval (PBI) of below-ground individuals is at present poorly understood (1,3,6).~~

Below-ground decomposition rates of discovered individuals has been shown to be highly variable (36), depending ~~up~~on organic content (37), various local environmental factors such as soil type (38-41) and organism accessibility (42), amongst other factors~~ to name but three, and note that the PMI may be different to the Post-Burial Interval (PBI)~~. - These factors complicate the estimation of PMI for buried remains. Furthermore, it may useful to estimate the Post-Burial interval (PBI) as a guide to the PMI. However, the PMI and PBI may be different: a victim might not be buried immediately after death. In such cases, the PBI can be used as an estimate of the lower limit of the PMI.

The presence of a decomposing cadaver ~~on the surrounding soil~~ has also been shown to be detectable on the surrounding soil~~,~~. ~~f~~For example, ~~elevated levels of elements with respect to background values~~ changes in soil chemistry (24, 25, 37), such as changes in the levels of phosphates and nitrates (44), ninhydrin reactive nitrogen (25,45), volatile organic compounds (24, 37,46) and pH (44,47) can all be detected. Changes in these soil properties can be used to estimate time since death. The decay of ~~O~~other items such as materials associated with a grave have also been suggested to allow a PBI to be estimated (39,48).

Although relatively poorly understood, ‘grave soil’ has been shown to be detectable by near-surface geophysical search methods, specifically electrical resistivity (21,18,49) and it’s reciprocal, bulk ground conductivity (17). Geophysical research using simulated clandestine grave burials can provide critical information, for example, on optimal geophysical detection methods and equipment configurations (15,50-52), as well as providing continuous datasets for comparison with real cases (50,53-55). Recent research has found that electrical resistivity anomalies over burials are predominantly due to conductive fluids in grave soil that vary temporally (27,50,56) that may be due to decomposition (Fig. 1). It has been shown that it is possible to repeatedly extract *in situ* decomposition fluids from both a buried pig cadaver and background soilwater, without the need for repeated disturbance or numerous ~~replicants~~replicate samples as other authors have done. The resulting fluids can be simply analysed for conductivity using a hand-held meter, with initial results of a pilot two year monitoring study showing promise (27).

~~This~~ The aim of this was study was to expand the work of Pringle et al.~~–~~ (27). ~~f~~*Firstly* ~~aimed~~ the aim was to obtain long-term (6 years) *in situ* grave soil water conductivity monitoring data ~~of~~ for a U.K. simulated clandestine burial. Results ~~will~~were then ~~be~~ used to generate linear regression curves to correlate measurements against PBI. *Secondly* the same experiment ~~will be~~was conducted over a shorter time period at two other U.K. academic study sites to assess the method's robustness and variability in different soil and bedrock types. *Thirdly,* all results ~~will be~~were ~~verified by~~ corrected for local major climate variations (temperature and rainfall) to allow direct comparisons ~~for~~with other studies, and to allow search teams to utilise this method. ~~and then comparing datasets collected using the same methodology at two other U.K. academic study sites~~. *Fourthly,* ~~and finally~~ the potential for detecting clandestine burials using this method ~~is discussed~~was assessed.

Methodology

Study test sites

Three U.K. University test sites in different parts of the country were employed for this study, all in temperate climates that were typical of the U.K.

The University of Central Lancashire (UCLan) test site in Lancashire was situated in a dedicated research facility off campus in a rural environment on peat moorland (Fig. 2). The site lies ~300 m above sea level. The local soil was determined onsite to be a dark brown, organic-rich hill peat with interbeds of silt and sand. Nearby records (57) indicated the Carboniferous (Westphalian) Pennine Lower Coal Measures Formation comprising a mixture of sandstone, mudstone and coal bedrock was present at least 4 m below ground level (bgl). This site has been used for several decomposition studies prior to this (58,59), albeit spatially far enough away and downslope of the area to prevent any potential contamination issues; initial 'grave' soilwater conductivity values were also the same as for the control.

The Keele University test site in Staffordshire was situated in a restricted area in grassed semi-rural ground surrounded by deciduous woodland and hedges (Fig. 2). The site lies ~200 m above sea level. The local soil was determined onsite to be a sandy loam with nearby borehole records (27) indicating the Carboniferous (Westphalian) Butterton Sandstone bedrock was present ~2.5 m bgl. This site has also been previously used for ~~several~~ a forensic geophysical study (27) but again ~~earlier simulated burials~~these were situated far enough away and downslope to avoid any potential contamination issues; initial 'grave' soilwater conductivity values were also the same as for the control. The preliminary two years of results were published (27).

The Cranfield University test site in ~~Oxfordshire~~ Wiltshire was situated in a restricted area on the Shrivenham campus in cleared semi-urban ground surrounded by deciduous woodland and hedges (Fig. 2). The site lies ~80 m above sea level. The local soil was determined to be a mixed made-ground and sandy loam with nearby records (60) indicating Jurassic Oxford Clay Formation and Corallian Limestone bedrock both present at shallow depths bgl. The site had not been used for previous decomposition studies.

Simulated graves

For consistency, the simulated graves at all three sites (Fig. 2) were created following the same method, albeit at different dates (08/12/2007 for Keele University, 12/10/2010 for UCLan and 18/08/2011 for Cranfield Universities respectively). Each ~2 m x ~0.5 m grave was hand-excavated to 0.5 m below ground level (bgl), the respective (~80 ~~K~~kg) pig (*Sus scrofa*) cadavers, ~~which had been~~ sourced from local abattoirs and dead for less than 12 h at the time of burial, were then placed within the graves. Simulated grave depths were based on published data on average depths of discovered human clandestine burials (87 in the U.S. (4) and 29 in the U.K. (3) respectively). The use of pig cadavers as human analogues is well established in forensic science studies as they have similar chemical compositions, body sizes, tissue:body fat ratios, and skin/hair type to humans (50, 41,61). The use of pig cadavers at these sites had been approved by DEFRA and the respective University Ethics Committees.

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A soilwater sample lysimeter was placed within each grave between the pig cadaver and the grave wall (Fig. 3). The porous end cap of each model 1900 (SoilMoisture Equipment Corporation™) soilwater lysimeter was~~ere~~ vertically inserted into a mixture of water and excavated soil which ensured good hydraulic conductivity between the grave and the lysimeter following standard practice (62). The simulated graves were then back-filled using the excavated soil and the overlying grass sods were then replaced. Control site lysimeters were installed ~10 m away from each grave by digging narrow holes (~0.3 m x ~0.3 m) to ~0.5 m bgl and following the sample lysimeter emplacement procedure described above. These control lysimeters were placed far enough away and up-slope of the simulated graves to avoid any potential contamination with grave fluid (Fig. 2). Once installed, the exposed top of each lysimeter ~~were~~ was sealed with a rubber stopper (Fig. 3) and a vacuum pump was employed to generate the established lysimeter suction of 65 KPa13, in order for the instrument to draw fluid from the surrounding soil.

Sample collection and measurements

Two days before a sample was extracted, rubber stoppers from the respective lysimeters were removed and any fluid present extracted using a plastic syringe with a narrow tube attachment. This was to ensure that the analysed fluid had an accurate post-burial date when measured. The lysimeters were then resealed and re-pressurised as previously described. On the day of sampling (usually monthly, see Tables 1-3), the extraction procedure was repeated but any fluid was placed in a labelled plastic sample bottle; a portable WTW Instrument multi-line P4 temperature-calibrated conductivity meter (6) was then immediately placed in the bottle and three conductivity values obtained; an average was therefore derived (Fig. 3). If no sample was present, this was recorded.

Climatological data

The closest weather stations run by the U.K. Meteorological Office were used to obtain average daily rainfall and air temperature readings over the respective monitoring periods (Tables 1-3). These were situated ~2.4 km (Bacup), ~0.2 km (Keele), and ~3 km (Sevenhampton) away from the UCLan, Keele and Cranfield University study sites respectively. Keele University operates the Keele meteorological weather station which is close to the study site and recorded temperate weather patterns (Fig. 4). It recorded monthly minimum, maximum and average total rainfall of 2.6 mm, 167 mm and 64 mm respectively over the 2,004 day study period. The corresponding values recorded for UCLan were 23 mm, 278 mm and 126 mm respectively over the 610 day study period. Cranfield recorded 17 mm, 138 mm and 68 mm respectively over the 475 day study period.

The daily average temperatures from each site were used to convert post-burial days to Accumulated Degree Days (ADDs) (see 37). ADDs correct for local site temperature variations by weighting each day by the average daily temperature and then giving each burial day an ADD value. Therefore, for a 2-day period, in which the average temperature of the first day was 12 ºC and the second day was 15 ºC, the ADD value for those 2 days would be 27 ADDs. Tables 1-3 summarises these datasets.

Calculated monthly total rainfall (mm) data from all three sites were also used to obtain yearly monthly rainfall averages as well as obtaining yearly monthly rainfall averages for England over the study period from the U.K. Meteorological Office. Table 4 lists these datasets. The rainfall datasets were used to correct the measured soilwater measurements for local rainfall variation; conductivity values were multiplied by a rainfall correction factor, which was calculated by dividing the average monthly rainfall for England in a given year by the average monthly rainfall for the local area in the same year. Correction for rainfall was important as relatively high rainfall rates could potentially dilute grave soil water and hence reduce the measured conductivity values, and relatively low rainfall rates would effectively concentrate grave soil water and hence increase measured conductivity values.

Results

All measured climatological data from the three field sites showed cyclical seasonal variations in temperature as would be expected in a- mid-latitude ~~n~~Northern hemisphere climate, with winter months being colder and wetter compared to warmer and dryer summer months (Fig, 4). However, there were significant variations between monitoring years;~~,~~ for example, the first three summers of the Keele study were warmer than subsequent summers, with rainfall in particular being variable between years (Fig. 4).

The ~~main~~ field soilwater measurement results from the Keele test site (Fig. 5A) evidenced consistent background conductivity values over the 2,004 day study period (averaging 411 ± 0.1 mS/cm). The grave conductivity values (see Table 1) rapidly increased from 266 ± 0.1 mS/cm (12 days) up to 28,800 ± 0.1 mS/cm (307 days) before gradually increasing to a maximum of 33,400 ± 0.1 mS/cm (671 days). Measured grave conductivity then rapidly decreased to 10,460 ± 0.1 mS/cm (840 days) before gradually decreasing to typical background values of 499 ± 0.1 mS/cm (1,621 days) until the end of the study period (2,004 days). These grave conductivity changes could be grouped into six linear regressions with ~~a~~ good fits (R^2 values of 0.72 – 0.99 - see Fig. 5A).

The field soilwater measurement results from the UCLAN test site (Fig. 5A) evidenced consistent background conductivity values over the 511 day study period (averaging 331 ± 0.1 mS/cm). The grave conductivity values (see Table 2) rapidly increased from 570 ± 0.1 mS/cm (12 days) up to 17,300 ± 0.1 mS/cm (344 days), albeit being relatively constant at ~5,000 ± mS/cm between 181 to 287 days PBI.

Measured grave conductivity then gradually decreased to 14,000 ± 0.1 mS/cm at the end of the study period (511 days). ~~A few months~~Samples were not collected during a few months of the study period but this did not affect the overall trends.

The field soilwater measurement results from the Cranfield test site (Fig. 5A) evidenced consistent background conductivity values over the 264 day study period (averaging 829 ± 0.1 mS/cm). The grave conductivity values (see Table 3) rapidly increased from 674 ± 0.1 mS/cm (22 days) up to 24,625 ± 0.1 mS/cm (117 days), before rapidly decreasing to 10,987 ± mS/cm at the end of the study period (264 days). Again, samples~~A few months~~ were not collected during some months of the study period but this did not affect the overall trends.

At ~~E~~each ~~local~~ study site, there were local temperature variations, which directly ~~impact~~ affected decomposition rates (4), and these variations were removed from raw conductivity values by converting Post-Burial (day) Interval (PBI) to Accumulated Degree Days (ADD), as detailed in the methods. Local study site rainfall variations, ~~(~~which ~~impacts~~effect conductivity values as relative higher rainfall rates will reduce measured conductivities,~~)~~ were also removed by calculating each of the ~~the~~ respective site's monthly average rainfall during the study and then correcting these by percentage changes against the ~~of test sites from England~~ average monthly rainfall for England (Table 4). The resulting climate-corrected Keele site data showed a much improved ~~5~~ set ~~five~~ of five linear correlations (Fig. 5B), with ~~comparable results then derived from~~ the other two study sites also showing ~~a good comparison of~~similar conductivity results with the Keele study results over the same post-burial time periods (Fig. 5B). This method also accounted for the different respective study start dates (December 2007, October 2010 and August 2011 for the Keele, UCLAN and

Cranfield studies respectively) and their associated seasonal local climate variations buried at different times of the year~~buried at different times of the year (Fig. 5B)~~.

Discussion

Every search for a murder victim in a clandestine burial is unique: the conditions (e.g. the local soil type, vegetation, climate and potential depositional environment) and factors relating to the burial (e.g. the victim's body size, burial depth bgl and season of deposition) will vary from case to case (1,3,4,50). These factors will affect both successful detection of a clandestine burial and the determination of the PBI; the latter has, to-date, proved difficult to estimate when a grave is discovered (37,63,64). Nevertheless, forensic search teams have an obligation "to use any means at their disposal to find [a body]" (5). When victims have been missing for a long period of time, it becomes even more of a challenge,as seen, for example, with the forensic high profile and ongoing U.K. search for Keith Bennett since his disappearance in 1964 (65).

These three studies ha~~ves also been~~ demonstrated ~~here~~ that measuring 'grave' soilwater conductivity ~~it~~ is a relatively robust geoscientific method ~~to~~ for estimating ~~obtain~~ a PBI ~~date~~ of a discovered clandestine burial up to ~1,600 days / ~13,500 ADDs after burial~~, if local temperature and rainfall data are available to correct measured values~~. The importance of correcting measured conductivity values for local rainfall and temperature information has also been shown by -this study to be critical ~~from this study~~ (Fig. 4). It is difficult with current methods to estimate a PBI after an individual is skeletonised (1,3,27) and this proposed simple method may thus prove very beneficial to ~~analyse by~~ forensic recovery teams. Comparison of a pilot

(66) and this study's preliminary (27) results has also noted that cadaver size did not have a significant effect on measured 'grave' soilwater conductivity measurements.

~~To test whether this could be used as a dating~~The potential of this PBI estimation method~~, this~~ was demonstrated with an early simulated clandestine burial study (27), where ~~a domestic pig cadaver was 'discovered',~~ the measured conductivity value for a 'discovered' buried pig cadaver ~~resulting~~ resulted in a ~10% date discrepancy between calculated and actual PBI over the 6 monthly monitoring period. It should be noted that a measured conductivity value could potentially give two PBI burial dates (*cf.* Fig. 5); but this may ~~be~~ still narrow down the PBI and may be more information than forensic investigators would otherwise have.

As the same experimental method was utilised ~~Having conducted the same experiment in~~at three U.K. study sites, ~~on different sites~~ with different local soil types, depositional environments and ~~climates~~ weather conditions over different temporal periods, and the~~but still having obtained reliable~~ geoscience dataset were still found to be reliable, the method ~~described~~ findings give~~s~~ confidence that ~~it~~ the methodology used is robust. Note however that there was some variability between comparable corrected results with the three study sites, which may be due to the differing depositional environments and soil types.

These studies have demonstrated that 'grave' soil water ~~conductivity~~ can clearly be differentiated from background soilwater by measuring soilwater conductivities and therefore this technique has the potential to also be a useful clandestine grave detection method. This dataset shows clear grave soil conductivity changes over time, with the most rapid changes occurring from burial up to ~300 days / ~3,000 ADDs after burial. This change is most likely due to decomposition changes (4,33) (Fig. 1). Forensic search teams could potentially detect clandestine graves by ~~either~~ initially measuring conductivities in surface water downslope / downstream of identified potential burial site(s) as (5) and (2) have undertaken in their respective forensic searches. This would ~~obviously~~ also require a programme of water sampling all around the identified potential burial site(s) in order to gain sufficient background conductivity readings to allow potential sites to be ~~confirmed/not prioritised~~identified using this detection method. Whilst surface water sampling is relatively straightforward and commonly undertaken in environmental contamination surveys (1), forensic soilwater surveys would involve a significant amount of effort, from initial soil sampling of suspected burial sites and careful storage, to ~~and/or by undertaking a geoscience soil survey programme over search area(s) and, after to~~ centrifuging to extract soilwater (25), and measuring their respective conductivity values to identify anomalous readings. This therefore would not be recommended as an initial search method; rather it should be undertaken when ~~identified site(s) have been located~~ a search area has been narrowed down to an appropriate size. This does, however, have promise as other studies have shown decomposition fluids to be retained in the local soil environment and ~~are~~to be electrically detectable, even when physical remains have decayed (67).

Remaining unknown variables will be ~~case~~ case-specific, but could include any delay between death and burial (e.g. storage), style of burial (50) and removal and reburial of the body or bodies (68). Other decomposing remains (e.g. animal ~~burials~~cadavers) may also interfere with results. The proposed method could also be applied to determine the post-burial interval for other organic material, for example, illegal animal burials (69) or landfill leachate plumes (1).

Conclusions and further work

This long-term research project regularly extracted soilwater from ~~a~~ three simulated clandestine burials in different soil and bedrock types and depositional environments in the UK. This ~~and~~ has produced ~~a~~ datasets of temporally varying conductivities over ~~the~~ 6 years, ~~monitoring period~~evidencing relative rapid increasing of 'grave' soilwater conductivities up to 2 years post-burial, before declining to background conductivity values after 4.25 years of burial. Local climate variations of temperature and rainfall have been corrected for and comparable results have been obtained from the three ~~other~~ sites using the same methodology ~~in contrasting local depositional environments and soil types~~ which gives confidence in the method. Analysing soilwater conductivities of a discovered clandestine grave *in ~~the field~~situ* would be relatively simple and could provide an estimate of ~~both PMI and~~the PBI for forensic search teams although this may be different to the PMI. Note that discovered burials ~~may~~ plotted on the conductivity graphs may suggest two possible PBI value~~on two positions on the conductivity graph~~s. The method could also potentially be used as a search tool if multiple soilwater and/or surface water samples are collected and analysed. This proposed method could also be applied to estimate the post-burial interval~~time burial of~~ of other organic material, such as illegal animal burials or landfill plumes.

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Further work should clearly *first* test this potential PBI method in a real forensic case of a discovered clandestine grave in order to determine its usefulness for forensic investigators. *Secondly,* it is important that the experiment is replicated in other soil types in order to quantitatively understand how this important variable affects the soilwater conductivity results. *Thirdly*, analytical chemical techniques should be utilised to examine the soilwater water samples. This would hopefully clarify the chemical changes that cause the variations in soilwater conductivity that were measured in this study~~where there is a clearly observed temporal change in conductivity that will be related to decomposition~~. It may also determine ~~if~~ whether individual elements, compounds or acids could be used as ~~a~~ complimentary dating technique~~(s)~~. *Fourthly,* ~~and finally,~~ this experiment should be replicated using human cadavers as this may be a variable to consider.

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Additional information and reprint requests:

Jamie K. Pringle, Ph.D.

School of Physical Sciences & Geography

William Smith Building

Keele University

Keele

Staffordshire ST5 5BG

U.K.

E-mail: j.k.pringle@keele.ac.uk

FIGURE CAPTIONS:

FIG. 1. Four main clandestine burial decompositional stages. (A) Recent burial, surface expression is most obvious. (B) Early decomposition with search dogs and/or methane probes being optimal. (C) Late-stage decomposition with grave soil fluids. (D) Final skeletonised decomposition. Modified from (1).

FIG. 2. Annotated photographs of the three test sites (U = UCLan, K = Keele and C = Cranfield Universities) with respective locations on U.K. map (inset). Respective simulated clandestine grave and control lysimeter positions also shown.

FIG. 3. Simulated clandestine burial annotated photographs from Keele study site of (A) simulated grave contents and (B) fluid measuring accessories (see text). Modified from (27).

FIG. 4. Graphical climate summary of rainfall (bars) and temperature (line) data from Keele University weather station, from our data and previously published data (27,50).

FIG. 5. Measured fluid conductivity results showing (A) Keele test site and (B) corrected for both temperature and monthly average rainfall (see text). Comparison data from Cranfield (crosses) and UCLan (squares) study sites also shown.

TABLES

Sample date	Post-burial days / interval (PBI)	Accum-ulated Degree Days (ADD)	Field-measured 'grave' conductivity (mS/cm)	Rainfall england-corrected grave conductivity	Field-measured 'control' conductivity (mS/cm)
08/12/2007	0	0			
19/12/2007	12	27	729	743	463
10/01/2008	34	114	1597	1463	422
17/01/2008	41	149	1780	1631	414
31/01/2008	55	244	2060	1888	517
14/02/2008	69	308	2680	2456	527
28/02/2008	84	364	2740	2511	no sample
13/03/2008	97	436	3520	3226	560
27/03/2008	111	498	4390	4023	587
10/04/2008	125	588	5400	4949	626
24/04/2008	139	683	5860	5370	625
08/05/2008	153	850	6610	6057	617
22/05/2008	167	1035	9130	8367	442
05/06/2008	181	1225	11610	10639	423
19/06/2008	195	1416	13810	12656	350
17/07/2008	223	1815	18640	17082	415
14/08/2008	251	2266	22100	20253	430
11/09/2008	279	2673	no sample	no sample	439
09/10/2008	307	2992	28800	26392	419
06/11/2008	335	3225	30000	27492	401
04/12/2008	363	3368	29600	27126	no sample
29/01/2009	419	3497	30800	27456	no sample
26/02/2009	447	3566	29800	26565	428
26/03/2009	475	3740	29700	26475	452
23/04/2009	503	3987	30200	26921	479
21/05/2009	531	4274	31500	28080	495
18/06/2009	559	4659	30900	27545	424
05/09/2009	638	5883	31400	27991	413
08/10/2009	671	6306	33400	29774	no sample
03/12/2009	727	6777	24600	21929	354
30/12/2009	754	6827	22500	20057	346
28/01/2010	783	6837	18940	17033	364
26/02/2010	812	6868	13030	11718	375
26/03/2010	840	7000	10460	9407	386
27/04/2010	872	7251	10480	9425	396
27/05/2010	902	7582	9400	8454	369
25/06/2010	931	7985	9350	8409	335

30/07/2010	966	8552	10200	9173	no sample
01/10/2010	1029	9421	no sample	no sample	376
29/10/2010	1057	9678	6210	5585	367
10/12/2010	1099	9794	6670	5999	357
04/01/2011	1124	9786	5610	4569	no sample
11/02/2011	1162	9940	3540	2883	335
11/03/2011	1190	10053	2370	1930	342
18/04/2011	1228	10391	2300	1873	350
23/05/2011	1263	10818	3110	2533	326
22/06/2011	1293	11202	no sample	no sample	304
03/01/2012	1487	13439	1375	1178	no sample
20/02/2012	1536	13584	855	733	330
12/03/2012	1557	13727	646	553	357
16/04/2012	1592	13985	716	613	no sample
15/05/2012	1621	14214	499	428	394
03/07/2012	1670	14872	415	356	395
03/08/2012	1701	15331	369	316	385
05/09/2012	1734	15853	no sample	no sample	394
04/10/2012	1763	16198	392	336	391
09/11/2012	1799	16454	413	354	402
07/12/2012	1827	16584	363	311	410
07/01/2013	1858	16722	335	260	372
18/02/2013	1900	16781	344	267	323
13/03/2013	1923	16823	350	272	278
18/04/2013	1959	16954	394	306	no sample
04/06/2013	2006	17423	402	313	300
30/11/2013	2185	19702	415	323	396

TABLE 1. Summary of measured conductivity values and local temperature data from Keele study site over the monitoring period. Conductivity and temperature data are from our new data and previously published data (27,50). No sample = no fluid was able to be extracted. Stated measurements are averages with a ± 0.1 mS/cm accuracy.

Date	Post-burial days / interval (PBI)	Accum-ulated Degree Days (ADD)	Field-measured 'grave' conductivity (mS/cm)	Rainfall england-corrected grave conductivity	Field-measured 'control' conductivity (mS/cm)
12/10/2010	0	0	-	-	-
28/10/2010	16	132	570	1096	250
04/11/2010	23	206	780	1500	230
11/11/2010	30	248	500	961	190
04/02/2011	115	421	2300	4877	100
04/03/2011	143	572	3500	7421	100
11/04/2011	181	866	6900	14630	460
11/05/2011	211	1220	4500	9541	400
14/06/2011	245	1605	4600	9753	370
07/07/2011	268	1936	5200	11026	310
26/07/2011	287	2204	6450	13676	250
21/09/2011	344	3008	17300	36682	850
27/10/2011	380	3449	16500	no sample	270
12/01/2012	457	4007	13220	22540	200
06/03/2012	511	4217	14000	23870	650

TABLE 2. Summary of measured conductivity values and local temperature data from the UCLan study site over the monitoring period. Stated measurements are averages with a ± 0.1 mS/cm accuracy.

Date	Post-burial days / interval (PBI)	Accum-ulated Degree Days (ADD)	Field-measured 'grave' conductivity (mS/cm)	Rainfall england-corrected grave conductivity	Field-measured 'control' conductivity (mS/cm)
18/08/11	0	0	-	-	-
09/09/11	22	347	1918	1646	674
15/09/11	28	434	4945	4244	330
19/09/11	32	488	5475	4699	890
26/09/11	39	589	4638	3980	1138
29/09/11	42	642	4103	3521	800
05/10/11	48	749	8113	6963	633
12/10/11	55	849	7600	6523	1094
21/10/11	64	934	8230	7063	1173
28/10/11	71	1011	9660	8290	1187
13/12/11	117	1412	24625	21134	595
22/02/12	188	1763	21805	18589	611
24/04/12	250	2261	9223	7863	725
04/05/12	260	2343	9647	8224	510
08/05/12	264	2379	10987	9366	591

TABLE 3. Summary of measured conductivity values and local temperature data from the Cranfield study sites over the monitoring period. Stated measurements are averages with a ± 0.1 mS/cm accuracy.

Year	England	Keele	UCLAN	Cranfield
2007	77.9	79.4	-	-
2008	81.8	75	-	-
2009	72.9	65	-	-
2010	60.6	54.5	116.5	-
2011	59.4	48.4	126	51
2012	93.8	80.4	160	80
2013	81.3	63.2	-	-
average	**75.4**	**66.6**	**134.2**	**66**

TABLE 4. Summary of monthly average rainfall data from the respective study sites over the monitoring period. Measurements have 1 mm accuracy.