The use of geoscience methods for aquatic forensic searches

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ABSTRACT

There have been few publications on the forensic search of water and fewer still on the use of geoforensic techniques when exploring aqueous environments. Here we consider what the nature of the aqueous environment is, what the forensic target(s) may be, update the geoforensic search assets we may use in light of these, and provide a search strategy that includes multiple exploration assets. Some of the good practice involved in terrestrial searches has not been applied to water to-date, water being seen as homogenous and without the complexity of solid ground: this is incorrect and a full desktop study prior to searching, with prioritized areas, is recommended. Much experimental work on the decay of human remains is focused on terrestrial surface deposition or burial, with less known about the nature of this target in water, something which is expanded upon here, in order to deploy the most appropriate geoforensic method in water-based detection. We include case studies where detecting other forensic targets have been searched for; from metal (guns, knives) to those of a non-metallic nature, such as submerged barrels/packages of explosives, drugs, contraband and items that cause environmental pollution. A combination of the consideration of the environment, the target(s), and both modern and traditional search devices, leads to a preliminary aqueous search strategy for forensic targets. With further experimental research and criminal/humanitarian casework, this strategy will continue to evolve and improve our detection of forensic targets.

1. Background

Geoforensic science (also forensic geology and forensic geoscience) is an important sub-discipline of the Earth Sciences (see Ruffell and McKinley, 2005); similarly, the use of such techniques in searching the (solid) ground has recently been shown to be important (Pringle et al., 2012). With water covering approximately 2/3rds of our planet, the two articles above lead us to consider how geoforensic science may assist in the search for items (e.g. homicide victims, explosives, drugs) within the aqueous environment. Water bodies (fresh water, brackish and saline) are forensically searched for the rescue of victims of accidents (usually by trained victim recovery dogs: see Judah, 2011), to locate objects associated with criminal activity (Parker et al., 2010) and to assess environmental problems (Dalezios, 2016). Our review concentrates on the first two search targets (criminal activity and environmental issues) and presents a consideration of (i) the environment, location and recovery of items in water. This is achieved through a summary of what techniques and strategies are available, with relevant examples in each. Following this, more complete case studies are presented where either dual methods or a more multi-proxy search approach was used, as a means of establishing a 'fit for purpose' best practice approach.

The forensic search for objects submerged in water has not followed the well-developed methodology established for terrestrial searches (Killam, 2004; Pringle et al., 2012; Donnelly and Harrison, 2013), with specific methods (for example, searching using divers) or specific devices (e.g. side-scan sonar, as presented in Dirkmaat et al., 2008; Dupras et al., 2011; Schultz et al., 2013; Healy et al., 2015) being described. Our objective in this work is to develop an overall strategy, based on geoscientific methods, for the search of water for items of forensic interest. The general search sequence currently adopted is summarized below. It is acknowledged that this is not a definitive process but is provided here as an example to facilitate the following descriptions.

1. A search is initiated with intelligence (a reason to go and search is identified, such as a report of a missing person, a sighting of an object or witness/suspect confession).
2. For aqueous environments, a conceptual model of the water body is built up from pre-existing records and site visits, including water depth, currents and the nature of the basal sediment. Liaison with local users and owners of the water and its margins (fishing clubs, sailing, environment/rivers agencies) is essential at this time. This is commonly followed by deployment of a search team, divers, trained rescue dogs, and/or sonar (and not always in this order). This compares to a typical terrestrial-based search, that would also begin with intelligence, followed by a desktop study (obtaining the underlying geology, land-use and, various historical maps) and development of a conceptual model of the target and the burial environment, plus some form of feasibility study, such as a RAG (red, amber, green) map that prioritises search locations, based on their accessibility, viewability and on land, diggability (Donnelly and Harrison, 2013; Pringle et al., 2012). Such desktop studies and vulnerability maps are not currently produced prior to aqueous searches.

In this review, we advocate the use of a desktop study in the pre-search phase of a water-based search. Whilst this may seem counterintuitive, with water being a seemingly homogenous mass without the characteristics of land, however, intelligence will provide information on the target; scientific surveys of the water will tell us something about the submergence medium, and historical maps and imagery may indicate what the history of the water body has been (for example, belowwater construction, subsequent erosion/deposition, dredging, exploration/fishing, etc.).

This work makes the case inclusion of three parts in the forensic search of aqueous environments.

1. A desktop study of the environment which will include hydrological/navigation and survey maps of the area (especially models of water flow, which may transport missing objects), any past search reports or surveys for sand/aggregate extraction; mining/hydrocarbon exploration; dredging of sediment; engineering works; and naval operations (historical and recent). The chemistry of the water involved and makeup of the basal sediment are both key in selecting possible methods to be

deployed in the search. 2. Intelligence informs the search personnel of what the nature of the target is. An important objective in searching water is finding human remains (due to accident, suicide, homicide or genocide) and thus our consideration of targets is expanded in this area. 3. Consideration and selection of aqueous search assets, (remote sensing, geophysics, search dogs deployed on boats), with possible field testing, based on both desktop study and use of intelligence, specifically the nature of the target (e.g. size, makeup, state of preservation) and the type of enclosing medium (e.g. residing in the water column; sedimentwater interface; or sunken into sediment), again based on the above.

2. Overview of current police and environmental search methods

2.1. Importance of water-based search

Geoscience methods for forensic-based searches currently focus (primarily) on the terrestrial analysis of surface and subsurface landscapes (mainly macro-scale: see Pringle et al., 2012) and soils and sediments (micro-scale, or trace evidence: see Bergslien, 2012 and Pirrie et al., 2013). However, the Earth is approximately two thirds covered by water, yet the forensic search of aquatic environments is less well developed compared to the terrestrial realm. This apparent contradiction may be explained by the behaviour of a perpetrator, as it can be difficult to transport objects like a dead body to a boat, and then dispose of such entities from a boat, it can also be difficult to find a covert

location next to or on water. Water is an unpredictable medium, where the movement and behaviour of a submerged object may be less easy to predict than that buried in a terrestrial location. Terrestrial and aqueous search methods merge when considering the burial of objects in snow and ice, these being essentially solid water (Annan and Davis, 1977; Arcone, 1996). Whilst there are famous archaeological examples (e.g. 'Otsi' the Ice Man), forensic examples are less common, with the freezing over of water bodies where bodies were sunk being more likely (Thomsen et al., 1989) than the effort of digging into ice, and the likely melting of snow/ice around a hidden object.

2.2. Review of terrestrial forensic geoscience search techniques

The requirement for a terrestrial search to take place is often the same as that for an aquatic location: something or someone is missing and may be buried/sunken, and needs to be found. A consideration of the location comes first, with a desktop study of the environment, including local bedrock geology, soils, past and present and historical land-use. This background information may be combined with human intelligence on the possible scenarios in the incident. This desktop study, combined with a reconnaissance field visit, indicates what search assets may be deployed, from different types of remote sensing, geophysics, topographic surveys, line searches, diggability surveys and use of search dogs, to water/soil sampling and test augering/trenching (see Killam, 2004; Pringle et al., 2012 for details). Whilst this process applies equally to terrestrial as to aquatic locations (for instance, we show below how past use of an area can be informative even in water bodies, such as re-routing of channels, dredging, where boats have been moored, amongst others), the search of water relies more on certain methods and technologies best suited for this type of search. Following consideration of the location (above), some information on what is being looked for is highly desirable, because, for example, the methods of searching a body of water for a victim of homicide differ from those needed in the location of a metallic weapon or a plastic barrel of explosives. In short, to begin a search, the nature of the environment (desktop and reconnaissance visit) and the nature of the target are required in order to deploy appropriate geoforensic search assets.

3. Nature of the environment (desktop and reconnaissance field/ survey visits)

3.1. Spatial location – mapping

A search is usually initiated for a reason (missing person, accident), which defines the possible nature of the target and usually in a spatial location, be it large (tens of km), small (tens of metres) or multiple locations (different rivers, sections of coastline) areas. The target location(s) may have previous spatial maps of local solid and drift geology, soils and landuse types available, and perhaps previous hydrographic surveys and historical maps associated. Combining in a Geographic Information System software such as ArcGISRC or QGIS (see Fig. 1 for example), these data may prove invaluable in terms of assessing any geological constraints on water flow, how watercourses may have changed and what human influences in the area there were in the past (Fig. 2). In our example of a combined sonar and water penetrating radar search (below), we show how the historical presence of a sunken boat explained numerous geophysical targets not associated with the investigation, showing how making a desktop study and examining pre-existing information may not provide the target but may explain false-positive anomalies.

3.2. Provenance

There are two aspects to provenance that concern the search of water: the origin and movement of the water itself and that of the target itself. The rate and turbulence of water is critical in understanding the hydrology and hydrogeophysics of the search medium. It is likewise important for understanding where a contained object may be (Bassett and Manhein, 2002) and whether it may be degraded (Haglund and Sorg, 2002). A cadaver deposited in a location with flowing water has the potential to be transported a considerable distance from the original deposition site. An example of this can be seen off the coast of Portugal and Spain, where currents have been reported to transport bodies up to 380 km in as little as 60 h (Pampin and Rodriguez, 2001). Ocean current and water circulation maps have been replicated for many lakes (e.g. the Great Lakes system of N. America being the prime example). These have been used to predict fish migrations, oil spill movements, and where objects may travel through the oceans. The most recent example is the computer simulations of where crashed aircraft may come ashore, most especially the missing Malaysia Airlines Flight MH370, which crashed somewhere west of Western Australia (Colgan, 2015): the same sort of models are applied to missing persons, whether they are homicides, suicides or accidents (Ebbesmeyer and Haglund, 1994; Hardisty, 2003; Mateus et al., 2013). Ebbesmeyer and Haglund (1994) constructed a hydraulic model of the Puget Sound, Washington, US, which aided them in locating and recovering the beached remains of a young man 32 km from where he originally entered the water. In his work, Hardisty (2003), discusses the provenance of human remains following large spatial movements such as marine drift trajectories that may allow prediction of where a floating or submerged object may be or have come ashore. This is critical as it provides a search area, or areas, for which a further desktop study (see above) may be made. Similar predictive work has been conducted for rivers: Dilen (1984) considers the movement of both floating and submerged objects in the Chattahoochee River (Atlanta) in the US, describing how a body moves vertically through the water column as well as drifting patterns observed at the surface.

3.3. Aqueous landscape geomorphology

This subject is too vast for a thorough review, with entire textbooks devoted to the subject that include biogeography, oceanography, hydrology, ecology, geography, and limnology: these show the importance of involving a multidisciplinary team of researchers in both the desktop study and the survey itself, of which this review (hydrogeophysics: Vereecken et al., 2004) is but one element. The nature of both the water body (e.g. the water depth, body size, chemistry, currents, temperature) and it's surrounding geomorphology (e.g. river catchments, length of flow paths, uplands/lowlands: see Beres and Haeni, 1991) is important as part of the desktop and reconnaissance

survey prior to an aqueous search. Water flow is obviously critical (see above) for the movement of objects. The size and depth of the water body to be searched will determine what geophysical assets (see below) are appropriate or even possible: water chemistry may be critical, for instance water penetrating radar (WPR) will not work in marine locations and seismic methods are hampered where methane gas bubbles are present (Parker et al., 2010). Conversely, water temperature can change and also provide optimal survey conditions, with cooler environments favouring GPR (see below, with the early work on lacustrine surveys being made on frozen lakes). A study of the landscape geomorphology of and around the water body may allow determination of any disturbances in the natural environment or pre-existing features that may have been caused by a 'forensic event' such as the movement of sediment if an object is slipped into water (see Ruffell and McKinley, 2008), the scour from currents that may develop around an object may be more easily detected (for example from Sonar) than the object itself. Included in landscape geomorphology are changes humans have made to the water. Even in the deep oceans, the results of dredging for minerals and seafood, drilling and cable-laying can be seen and must be included in an aqueous search desktop study to avoid surprises, such as cutting through deep telecommunications cables whilst surveying (e.g. see Coffin-Snout and Herbert, 2000). Closer to land, and with water enclosed by land, human activity becomes more and more evident with engineering works (that may have exposed or buried a target), alteration of water courses (that may have done likewise, flooded a search area or exposed it) and the movement of boats and ships that inevitably drop debris into the water that may be mistaken for a forensic target (see the search of a canal basin case study provided below).

4. The nature of the target

The 'target' part of this review focuses on two broad areas of the aqueous world. First; water in the terrestrial realm, mainly ditches, streams, rivers, ponds, lakes, water-filled caves and mines and humanbuilt water-filled structures (e.g. slurry pits, sewers, water channels/ culverts, storage tanks). Second; are estuaries, lagoons, marine harbours/docks, and the seas and the oceans. According to the World Health Organization, drowning is the third leading cause of unintentional mortality worldwide, accounting for more than 370,000 deaths annually. Submerged human bodies, especially those associated with homicide, have generated the most publications on detection methods (see, for example, Dix, 1987; Haglund, 1993; Haglund and Sorg, 2002; Schultz and Dupras, 2008; Dupras et al., 2011; Schultz et al., 2013), which we also concentrate on for review purposes. Animals may also be placed in water (see, for example, Ruffell and McKinley (2008) who report on the dumping of a diseased sheep in a ditch). However, in the authors experience, weapons connected (or not) with such homicides are also commonly submerged and thus searched for, ranging from rocks, bricks, hammers/mallets/spades, to knives, cleavers, machetes

and guns/firearms. Wire, string, belts and rope ligatures, containers of poison, vehicles and other items involved in criminal activity may also be thrown or placed in water. All of the above examples have different chemical compositions, decay rates, likelihood of sinking or floating and overall size: these dictate the means of exploration as well as the likelihood of detection. In our 'methods' section (below, Section 5), we provide example objects that may not be detectable by a certain method (s).

The submerged human body is by far the target of most interest in the published forensic literature (see, for example, Haglund, 1993; Megyesi et al., 2005; Armstrong and Erskine, 2010), and whilst the types of locations are of interest (below), we first concentrate here on methods of disposal in water, as this will initially dictate some features of the target. Simply pushing or sliding a body into water is the simplest form of water-assisted homicide. If the victim is not dead, this risks the possibility of survival, so some form of injury or restraint causing incapacitation or weighing the victim down is often observed. Research has shown that up to 95% of deceased individuals will sink immediately upon entering the water (Heaton et al., 2010). However, since the specific gravity of the human body (0.97–0.98 g c) trapped in the lungs or clothing, will have an effect on buoyancy. Weighing down of bodies (alive or dead) requires heavy objects such as rocks or metal, and some form of attachment (clothing, ropes, bags, packs). For concealment during transport, to assist weighing down, and to hide a submerged object, wrappings are often used. These are frequently permeable, to assist water-logging, so cloth, hessian, netting are used in preference to plastic, which traps air and may allow the object to float. Wrappings can also restrict abdominal bloating, reducing the probability of a body resurfacing. Taphonomy plays a crucial role in how the nature of the target evolves in water, with currents being critical in transport and breakup of the remains. Oxygen and light availability are sometimes connected (not always) and play an equally important role in rates and products of decomposition/preservation, biologically-associated decay activity. Research on the bog bodies (Iron Age – Bronze Age) of NW Europe (Browthwell, 1996; Brothwell and Gill-Robinson, 2002) are useful in this regard, peat being frequently composed of 70% or more water, and the bases of some stagnant ponds and ditches being likewise composed of 70–80% organic matter, making the difference between a pond and a bog negligible from a search strategy viewpoint.

A critical factor in assessing the search potential for a submerged cadaver is the extent of decomposition, as this will influence the size and content of the target and the potential for post-mortem movement or drifting. Bodies decomposing in water display similar soft tissue modifications to their terrestrial counterparts, progressing through what was originally believed to be six observable stages; submerged fresh, early floating, floating decay, bloated deterioration, floating remains and sunken remains (Payne and King, 1972). However, variation between water environments in regards to their biological, chemical and physical properties, as well as factors related to the body (e.g. age, weight, level of clothing, etc.) and the circumstances surrounding death, all affect decomposition and can cause these stages to overlap considerably. As a result of this, water decomposition is often divided into four broader stages; fresh, bloated, decay and skeletonized (Heaton et al., 2010). Whilst bodies decomposing in water follow the same deterioration pattern as those on land, the process is significantly slower in aqueous environments (Hobischak and Anderson, 2002). This is primarily due to the cooler water temperatures and lack of insect activity, both of which are major factors in influencing decomposition (Simmons et al., 2010). Other factors influencing how a body decomposes include oxygen availability, salinity, water depth, wrapping/ clothing, scavengers, trauma to the body, water currents, season and substrate type (Heaton et al., 2010; Notter and Stuart, 2011; Haglund, 1993; Armstrong and Erskine, 2010).

Once a cadaver descends below the water surface, hydrostatic pressure begins to increase with depth, compressing any gases that might remain in the lungs and body tissues and promoting further sinking of the remains (Haglund and Sorg, 2002). Bodies will eventually settle on the waterbed, often in a facedown position, and begin the process of putrefaction, which results from the uncontrollable growth of

bacteria in the gastrointestinal tract. Putrefaction causes the soft tissues of the body to liquefy and decompositional gases to be released. These gases accumulate in the abdomen causing the body to bloat. As the cadaver becomes more buoyant its specific gravity decreases and it eventually ascends to the surface. Research has shown that in UK rivers, cadavers not snagged on debris or weighed down are able to resurface after approximately 10–14 days (Heaton et al., 2010), although this time frame varies depending on the season (warmer summer temperatures cause bodies to bloat sooner than winter, for the obvious reasons of temperature). The timing of resurfacing is also dependent on the depth of the water, with bodies deposited in deep waters (i.e. sea, ocean, large lakes) experiencing cooler temperatures and an increase in hydrostatic pressure, which will retard the rate of decomposition and reduce bloating (Heaton et al., 2010). In the correct conditions, the authors have observed the bloated cadaver to rise to the thermocline (in lakes and seas), where it may remain for sometime. When the body does resurface it will either float until recovered or continue to deteriorate until it eventually becomes skeletonized and disarticulates. Constant agitation whilst suspended in water, amplified by any currents or turbulent flow, will not only increase the rate at which the body becomes skeletonized, but also accelerate disarticulation of the remains. As currents weaken the soft tissue connections between joints, the body begins to separate, often starting with the skull and mandible, and then shortly followed by the limbs (Haglund, 1993). Disarticulated limbs sink to the waterbed whilst the torso continues to be transported by currents, resulting in elements being separated by considerable distances and complicating the recovery process. Eventually the remaining trunk of the body loses its buoyancy and also sinks to the waterbed (Haglund, 1993).

There is no set time period for the evolution of these stages (fresh, bloat, putrefaction, disarticulation [Haglund, 1993]), being dependent on temperature, oxygen availability, wrapping/clothing and presence of scavenging animals. Experimental work (Haglund, 1993; Armstrong and Erskine, 2010) has shown bodies to decay differently in apparently identical environmental conditions. Little experimental work has been done on the geophysical detection of fresh human remains, as there is usually a time period between the report of a missing person or a homicide and a search. Human scent dogs have traditionally been the preferred method of searching for decaying remains in order to expedite recovery following drowning (Judah, 2011; Rebmann and Sorg, 2000), or burial in an avalanche/landslide. The bloat phase of decomposition is the most advantageous for a water-based search, this being when a submerged body may rise to the surface (if not well weighed-down) and, if still submerged, provides an excellent geophysical target (giving off a gas [carbon monoxide, hydrogen sulphide, ammonia and methane] pocket in water/sediment), whether on the sediment surface, or buried. The putrefaction stage (the deterioration of the corpse and loss of soft tissues) is something of an unknown in terms of the geophysical response in water, there being few casework or experimental examples from human cadavers. Parker et al. (2010) show the successful GPR imaging of a decomposed (but not skeletonized) badger, recovered in a hessian bag with rocks, submerged and within 30 cm of sediment in a ditch in Ireland, suggesting that location of decayed animal remains is possible. The composition of the surrounding sediment becomes critical at this stage, because the variable geophysical response of a decaying body, compared to that of the enclosing sediment, may at times be similar. The skeletonized remains of a cadaver present the greatest challenge in search, when scent for recovery dogs is limited and dissipated and the geophysical target becomes minimal, especially if the host sediment contains calcium carbonate, so the chemical and density difference between skeleton calcite and aragonite will be negligible.

Taphonomy plays a critical part in the search for human remains: as the body decomposes and eventually disarticulates, becoming scattered over a large area, it provides a secondary geophysical target, but diminishes the overall size of the object (Haglund, 1993). Not only will currents accelerate this process, but the presence of aqueous scavengers will also have an influence, likewise reducing the size of the geophysical target. The type of scavenger is highly dependent on the environment (freshwater, saline and brackish species) and it's geographical location; small scavengers (fish, crustaceans) will consume the soft tissues on the hands and face and cause minimal damage to the remains, whilst larger scavengers (sharks, alligators) can consume huge quantities of soft tissue and bone. Carrion birds have also been observed feeding on cadavers as they float at the surface (Haglund, 1993). Currents are, of course, dependent on both the location (rivers, seaways) and changing water flows (precipitation, tides, storms) (Mateus et al., 2013). It is also feasible that cadavers deposited in a tidal system could be transported upstream from their initial point of entry or travel repeatedly along the same section of river as the tides turn.

Human remains form the most important submerged target, yet numerous others exist that require a forensic-based search. Closest in terms of target type are animals that may have been intentionally drowned or hidden in water due to age or disease, to avoid veterinary or abattoir costs and/or negative publicity for farmers. Common in this scenario are domestic sheep, goats, cows and horses, but two more unusual examples are presented here. In this unpublished case by one of the authors (AR), a drug-dealer in the north of Ireland liked to display his status by keeping dangerous animals, including an illegally-held tiger. This was known to local people, who kept quiet for fear of reprisal, until the suspect moved away and animal welfare investigators were asked to locate the tiger. The animal had died, and the protagonist dragged the animal behind a tractor to a ditch (just outside his land), where he rolled the animal in and then used a mini-digger to cover the submerged animal with sediment. Over time, the sediment settled and the ditch appeared as it was before, except that at some place along its length was a submerged mound with the corpse of a tiger below. Sonar was used to map this mound for the authorities to investigate and the animal carcass was recovered. In a second case, during World War 2, animals were moved from Belfast Zoo (N. Ireland) in order to minimise chances of their deaths during Luftwaffe air-raids, given that there was a searchlight position nearby. An elephant was moved to a park close to Belfast Lough, where it died of other causes other than from the air raids. During war time, there were limited resources for animal disposal, so the carcass was dragged by mechanical means to a creek running across the mudflats of the sea lough, deposited and covered up. This was well-known in the local community, and fears of the remains being uncovered by marine erosion (sea level rise and increased fastferry traffic generating large bow waves and wakes) led to a search. In 1947, the RAF aerial photography branch flew over all of the UK. The images were examined, and even 4 years after the event, the effect of the burial was visible in the tidal creek and the elephant remains located. Other submerged items associated with criminal or humanitarian/accidental events that have been successfully searched for include explosives (hidden or for detonation), drugs, contraband (especially alcohol), weapons, stolen goods such as jewellery, illegal fishing and hunting gear (especially if poachers or illegal hunters are disturbed). All have specific properties that will determine the most appropriate sequence of search methods, with the nature of disposal/ weighing down, weight, metallic vs. non-metallic composition and durability being critical factors.

5. Geoforensic search assets (geophysics, remote sensing)

Various papers discuss both general and specific geophysical methods for aqueous searches (Armstrong and Erskine, 2010; Becker, 2006; Bowens, 2009). Parker et al. (2010) carried out a comprehensive review of the geophysical methods and devices that may be used in this part of the search in water and since their review, there have been advances in the technology, reviewed here. The authors of this paper have carried out both experimental research and casework and these can now be brought together with the above considerations of the environment and the target (above) to generate an overall approach to the geoforensic search of water, to compliment the focus of the Parker et al. (2010) review on geophysical water search methods.

5.1. Magnetometers and underwater metal detectors

These devices operate in a similar manner, with the magnetometer being specifically designed to detect local variations in magnetic fields caused by ferrous objects, whilst metal detectors use an alternating electro-magnetic field to measure all metal based conductivity (see Reynolds, 2011). Both are used routinely in the searches for weapons, mines and other ordnance, in water and on the land (Ginzburg et al., 2008), as well as in archaeology (the proton magnetometer described by Hall

(1966)). A magnetometer has the advantage of detecting ferrous objects to greater depths than most commercial or military grade metal detectors. Both are used routinely in water and land-based searches (examples include the SeaQuest Gradiometer and the SeaSpy Magnetometer), yet like GPR (below) very little has been published in the scientific literature on their use in water-based forensic searches, with the exception of unexploded Ordnance (UXO) detection: see Nelson and McDonald (2001); Pope et al. (1996); Lenham et al. (2006). Zafrir et al. (2001) describe the use of mapping magnetic anomalies from a vessel in UXO detection, whilst Aponick and Bernstein (2003) show how terrestrial line searches may be made in a 'crawler' style ('fingertip search' is the term more commonly used in police operations) in the intertidal zone for searches of weapons. Environmental forensic studies (not strictly considered here) have been published to a greater extent than other serious crime, and have deployed magnetometers for the location of barrels, pipes and other containers (see, for example, Missiaen et al., 2010; Missiaen and Feller, 2008; Reynolds, 2011).

5.2. Sonar and sidescan sonar

Sonar is one of the traditional machine-based assets commonly deployed in search, due to the speed of survey and the clarity of images. Early uses included single-path sonar deployed from a boat in multiple tracks over a search area. The development of side-scan sonar, which allows a broad swath of the sediment base to be imaged, was quickly deployed by search teams working in water (see Schultz et al., 2013), usually in advance of a dive team (in order to locate targets and assist in low water visibility, such as described in McGrane et al., 2013). Combining side-scan sonar with differential global positioning systems (or more strictly, Global Navigation Satellite System or GNSS) allows both clear pictures of the target, it's shadow (and thus height above the sediment surface) and very accurate location for dive teams. Side-scan sonar deployed from boats has been incorporated into a hand-held device, operated by a diver in the water to image horizontally, at an angle or directly onto the water bottom (see Healy et al., 2015). This is commonly carried out in low-visibility locations in a two-person team, with one sonar operator and one diver in communication. A further advance in this system avoids the use of a diver, with an automated system (e.g. CodaoctopusTM or KonsbergTM) that sits on the sea or lake/ river bed and images 360°, like a terrestrial laser scanner, only using sound not light. This underwater drone type machine is advantageous in areas that could be hazardous to a diver, but does require constant retrieval and re-deployment and does not allow real-time search by a second diver. Side-scan sonar waves detect acoustic shadows in the water and allow wide area searches, depending on the reflected wave strength: generally if the target is larger than the background (e.g. a body lying on sand), so the results will be better. If a body is lying amongst rocks and boulders that are over approximately 1–2 m in size, then the body will not be imaged. Controlled research has also shown flat sandy floors are optimal for target detection as irregular terrain/ vegetation can obscure target(s), see Healy et al. (2015). An example can be seen in Ruffell (2014), where the body of a suicide victim (by drowning) was lying in around 2 m water depth, parallel to the strike of the rocks the person was wedged in against: considerable processing of the data was required to resolve even a poor image of the target.

5.3. Water penetrating radar

The first experiments on using GPR in fresh water are a little difficult to disentangle, there being three distinct applications. First is using conventional radar by walking or driving on solid ice above frozen lakes (Annan and Davis, 1977). Second is the suspension of regular radar antennas* or specialised air horns over river bodies for flow measurements, often in conjunction with Sonar and Lidar (for the latter, see Pe'eri and Philpot, 2007 and Wang and Philpot, 2002) and the placing of GPR (termed water penetrating radar or WPR) in a boat on water (Sellmann et al., 1992). It is the latter application we are concerned with here as this method has direct relevance to the search of freshwater: Haeni et al. (1987) and Sellmann et al. (1992) appear to have been the first workers to publish the results of using WPR in direct contact with freshwater, with excellent results. Given this, it is remarkable that so few published works followed, with the exception of studies into sediment scour around bridge supports, which have been produced in abundance (see Sambuelli et al., 2009 for a comprehensive overview). Even more surprising is that there has only been one geoforensic research publication on using WPR on water (Ruffell, 2006) and one review that includes the method (Parker et al., 2010).

Freshwater WPR is generally successful (Sambuelli et al., 2009) although like all geophysical surveys there is the choice of improved resolution at shallow depths (in WPR with higher frequency antennas) vs. poorer resolution but with greater depth range (lower frequency antennas). Most surveys of sediment thickness/type deploy lower frequency antennae, attempting to image subsurface sediment geometry and thickness (Haeni et al., 1987; Haeni, 1996; Sellmann et al., 1992). Variations in water conductivity (e.g. salt content) and suspended matter affect radar wave propagation and reflection (Parker et al., 2009) such that in some brackish lakes and lagoons, WPR will not work well. This is because freshand saltwater have similar dielectric properties (about 80 SI each) and radar velocities (fresh is 0.033 m/ns, saltwater is 0.01 m/ns) but very different conductivities (freshwater is 0.5 mS/m, saltwater 30,000 mS/m). This results in radar wave attenuation in freshwater of 0.1 (very low) and 1000 (high) in saltwater, radar signals are simply 'soaked up' by the conductivity. Parker et al. (2010) give a summary of WPR, suggesting that because water is relatively homogeneous, radar waves penetrate easily but slowly. Radar wave transmission is facilitated along the water – air interface, causing out-of-plane anomalies when floating objects are present. Conversely, excellent cross-sections of water depth, with suspended objects, as well as sediment subsurface are obtained using WPR. Two data outputs are possible: 2D radargrams (vertical soundings of water and sediment) and plan (mapped) views of amalgamated radargrams at various depths, together forming 3D datasets. Although WPR has been used (for instance) to successfully image scour around bridge supports (Gorin and Haeni, 1989) and sediment thicknesses (Haeni, 1996; Haeni, et al., 1991; Sellmann et al., 1992) the current work shows there is significant further potential for forensic applications, as well as potential pitfalls unless we understand the action of radar waves in non-saline water. In summary, the use of radar on freshwater has been published for purely experimental (Sellmann et al., 1992), forensic search (Parker et al., 2010) and engineering (Gorin and Haeni, 1989) purposes, the studies of which were very much applied to a specific issue or application. WPR fills a niche in the application of aqueous geophysics for sub bottom profiling in that it allows exploration of the size of freshwater bodies where deployment of seismic or CHIRPS is problematic (for example, due to the size of boat and towfish required), if previously impossible. The speed with which WPR data can be gathered in such locations makes this method a potentially very useful tool for the search of small water bodies. Challenges also exist in terms of what technical (e.g. antenna type, design, floatation method, survey method) and environmental (e.g. water chemistry, temperature, gas content) constraints exist. There remains potential for the use of geophysics in search and rescue however: one example is the efficiency of ground penetrating radar in snow and ice from the air (Reynolds, 2011) which makes deployment by aerial platform and thus wide coverage for target identification and focussed use of the rescue dogs (Judah, 2011; Rebmann and Sorg, 2000; Snovak, 2004) a possibility (Table 1).

5.4. Seismic methods

Seismic reflection and refraction have found limited use in terrestrial searches of the subsurface, with experiments using seismic tomography to image buried oil drums and in one case a dinosaur skeleton (Witten et al., 1992). Other 'forensic' applications of seismic methods occur, including assessing illegal waste dumps (Reynolds, 2002), the investigations of the Kursk submarine disaster (Koper et al., 2001), and in the wide-scale monitoring of explosions, especially nuclear weapons monitoring (see Douglas et al., 1999). The limited use of seismic methods on land is likely due to the time taken to gather data along a single profile, let alone a search grid. What is surprising is that conventional reflection seismic profiling is a standard tool in the marine exploration for oil and gas, and is quick to collect (if expensive), compared to terrestrial seismic profiling. The reason for this is already described, there are quicker and more cost-effective ways of searching water bodies than acquiring seismic data. Most applicable to the marine environment is CHIRP: although Compressed High Intensity Radar Pulse sounds like something to do with true radar, the electro-magnetic energy used in CHIRPS is not the same as ground penetrating radar, being in the range of KHz rather than MHz to GHz. Three-dimensional, high resolution imaging by acoustic methods for sub-seabed imaging is now being trialed and developed (Gutowski et al., 2008), including for bottom and sub-bottom profiling for ecology, and thus potentially pollution studies. Again, the limited use of CHIRPS in assisting the search of water is surprising, as unpublished experiments and casework (J. Dix, pers. comm., 2004; R. Quinn, pers. comm., 2004) showed that high frequency (240 KHz) CHIRPS imaged barrels, a sunken boat and a mannequin sunk in a marine location. From the above we can see that

where WPR may not work (e.g. in marine locations, or in polluted waters) then CHIRP, or conventional reflection seismic methods may. The issue with the latter approach is the need for a streamer array, making this only applicable in large (more than 1 km) water bodies. CHIRP also suffers this limitation, although not as crucial as a typical CHIRP towfish is 2 m in length: further issues are (1) the snagging of the streamer or towfish (loss of equipment and in severe cases), the possible safety compromise of the survey boat/personnel and (2) interference from gas (e.g. methane) bubbles in the data. As with all the methods described, one technique alone rarely solves a problem: Lafferty et al. (2005) use both Sidescan Sonar and CHIRPS in their environmental study of a lake in Northern Ireland, to monitor the colonization of an invasion species, the Zebra Mussel.

5.5. Geochemical methods

Whilst terrestrial search commonly uses geochemical markers to potentially pinpoint grave sites (see Dent et al., 2004; Vass, 2012; Pringle et al., 2015), these have been less researched in aqueous environments. Such markers will be present as water search dogs detect decomposition products in water (see Osterkamp, 2011). Water flow and stratification, and potentially other decomposition products (e.g. organic material, peatland, etc.) can make target detection difficult. Recent advances in the analysis of biogenic amines associated with decomposition (e.g. putrescene and cadaverine) have been shown to show promise to be detectable down to 30 ppb. Fig. 3 shows an example from a potential body deposition pond site, with potential elevated values of certain anionic compounds detected.

6. Case studies

6.1. Rifle parts used in a homicide discarded in a lake, NE Canada

Two persons were involved in a homicide using a rifle in the NE of North America (actual location not available for security reasons). One was convicted of another offence and gave testimony against the second as part of a plea bargain. In this, the convicted person claimed that following the shooting, they dismantled the weapon that comprised of plastic and metal parts (a Weatherby Vanguard with 0.257 ammunition (possibly still with bullets associated). They then drove alongside a pond, throwing the parts at various locations from the pond side road, into the water. This evidence was determined only to be credible in a court of law should the weapon parts (or a substantial number thereof) be retrieved. The pond was measured as ~400 m long and 20 m–200 m wide, with a likely depth of 16 m in the centre, with flat to shallow platforms on each side (Fig. 4). This caused the search authorities some considerable concern and experts in the search of water were consulted for a strategy. Examination of the geological maps and aerial photographs of the area during the desktop study of the environment, revealed the elongate nature of the pond lay in the same orientation as the regional fault and fracture tectonic fabric of the underlying metamorphic basement (namely NNW-SSE). This suggested that the deep centre may be narrow, that was aligned on a fault trend. Aerial photographs confirmed the presence of the road along the eastern edge of the pond (Fig. 4). To limit the search area, the same type of weapon (the target) as claimed by the witness was located and dismantled, and each part attached to a spool of 20 lb. strength fishing line. A police officer of similar, if slightly greater build to the accused, was selected to throw each part as far as they could at selected points along the road, from access locations by foot, and by standing on a vehicle. This 'throwability' exercise effectively limited the search area to a narrow strip, with target locations (access points) along the route (Fig. 4). A boatborne magnetometer was not available amongst the available geoscientific methods, and the rocky substrate precluded use of a Sonar, so a GPR system (Pulse-Ekko 100 with 225 MHz shielded antenna) was deployed from a boat, which was propelled by a small electric engine. At the southernmost access point (a small rock promontory), a clear anomaly was observed on the radargram (Fig. 5), which was retrieved by police wading into the water and identified as the stock of the weapon. Further searches were made to find other gun parts or materials associated with the homicide, with 4 live 0.30 80 rounds found in shallow water. The recovery of the main part of the weapon vindicated the witness evidence. Interestingly, the point of disposal of the main part of the weapon was also the closest to where the suspects had come from, and the most accessible, but hidden from view, showing that the 'law of minimum effort expended' is often observable in criminals acting from some compulsion.

6.2. Search for sunken criminal items, undisclosed location and training exercise NW England, UK

This case study has two parts, the first the scenario, the second the research generated. The scenario is that during a police service raid of a house, an adjacent canal and its adjacent lock, some gang member suspects escaped and placed plastic-wrapped 5 kg bags of non-metallic contraband (the targets) into the nearby canal, weighing them down with rope tied around concrete blocks. They presumed they could return later, open the downstream canal lock gates or use a gaff or billhook and retrieve their materials, thought to be drugs and/or explosives. In fact, the gates had not been opened in 12 years, so this was mistaken. Regardless of the recovery of the items by the gang, the police service wished to know how they could detect a non-metallic target, possibly in sediment, in 3 m of freshwater. Drug detection dogs, deployed onshore and on a boat were considered, should the item wrappings have been compromised. However, if they were not, the police would need a more novel way of identifying possible dive targets. Thus a replica location was found in the northwest of England (Fig. 6a) in order to test a new strategy. As a preliminary search, the historical development, repairs, and use of the dock were considered, along with the water source, as part of a desktop study. This was critical, as they showed the water was entirely fresh, the lock probably had some build-up of silt (it being in use since 1858, and only once dredged in 1963), that the area upstream of the lock had been repaired with concrete, also in 1963, and that the last use was when an old barge was moored on the southwestern side of the lock in the late 1990s. A Mala GPR system using 200 MHz unshielded (Fig. 6b) and 250 MHz shielded (Fig. 6c) antennas was deployed on a small rubber 'rib' type boat (Fig. 6b), and sailed up and down using a Trimble GPS and side markers for geolocation. An EchoLocator side-scan sonar was also deployed on the same lock area. The WPR results showed what appear to be both submerged and 'floating' hyperbolic targets: however, the benefit of multiple scans shows that some of these appear to be in the water, when in fact they were out of plane targets in the sediment, and vice versa (Fig. 7a). An area of scour (Fig. 7b) was noted by the upstream lock gates (seen at the far end of the photograph in Fig. 6a), with the concrete platform that was predicted by the desktop study, was imaged (Fig. 7c). All floating, surface and buried targets were marked and identified (Fig. 8), with predictions made concerning what would and would not be seen on the side-scan sonar. The side-scan sonar data confirmed all of the predictions made by the WPR, but identified targets not seen at surface on the WPR (Fig. 8). Targets identified on both data types tended to the clustered close to where houses were, suggestive of objects being thrown in, either as discards (commonly supermarket shopping trolleys, old household items that sink, discarded children's bicycles, etc.), or the suspect target(s) itself. An exception to this appears to be the targets in the southwest of the lock, which are around where a barge was previously located: these are likely objects dropped off or that fell off the barge (Fig. 9). Without this aerial imagery as part of the desktop study, these contacts would have been recommended as dive locations, likely wasting police underwater unit time, showing the value of gathering as much background information in the desktop study as is possible.

6.3. Environmental forensics: badger in a ditch

This incident and resultant search was reported (text only) in Parker et al. (2010), wherein an investigation into possible animal cruelty (badger baiting, or the forced fighting of badgers with dogs) needed to determine the veracity of witness testimony that a badger had been thrown into a ditch, in a hessian bag weighed down with rocks (the target). What this article did not publish was the method of searching or the data that resulted. Not much could be ascertained about the history of the ditch during a desktop study, except it has been there since 1858, fed a local freshwater river, and had not been dredged. Fig. 10a shows how a small inflatable boat was towed along the ditch in question, with various unshielded WPR antennas deployed. In order to assure data quality, negate out of plane reflections and to assess optimal data quality, two antenna frequencies (100 MHz and 200 MHz) were deployed, the latter in a range of modes (see figure caption for details). The rocks (left hand side of images) and badger (right hand side, as in Fig. 10f) were both clearly imaged, although only the badger was imaged on the 100 MHz data. Normally this frequency would not image such a small target, but the dielectric contrast between the badger and the sediment in this case must have been great enough for such a low frequency antenna to show limited success: the rocks comprised greywacke (metamorphosed sandstone) and the ditch sediment comprised quartz silt, probably eroded and derived from the same greywacke, and thus showed limited difference in dielectric contrast for the radar to detect.

6.4. Living human in aqueous environment WPR experiment

The above review and case studies all demonstrate the usefulness of WPR when used in conjunction with other methods, as described the desktop study, intelligence, common-sense [‘throwability’ exercise], Sonar, dogs, other geophysical techniques, etc. However, at the outset of this review, we stressed how the main focus of using such methods, is for the imaging and thence recovery of human remains. WPR has been successful in such (Ruffell, 2014), but this article only showed Sonar images of the submerged body. So, we decided to see what a human body actually looked like on WPR, after obtaining permission from a University swimming pool (our ‘environment’) to disinfect all our equipment and run a trial. We asked a professional diver from the University diving club to swim to the base of the pool and be our target, lay down and expel his lungs as fully as possible, we then (as quickly as possible) ran the Mala Geoscience 200 MHz unshielded radar over him (Fig. 11). Initially, results were poor, as the chlorine in the water increased the conductivity, causing excessive ringing in the data (caused by a mismatch between the antennas). Once processed, the image of the body is clearly seen: however, we suspect that not all the air from his lungs was expelled. This partly only partly invalidates the experiment, although many dead bodies contain remnant air and although methane (depending on time since death, see the section on the Nature of the Target, above). More experimental work, over time, in controlled facilities using live humans and cadavers in freshwater locations is required.

7. Conclusions

This review paper has demonstrated that an integrated approach to the search of water is recommended. This is based on the best practice developed for terrestrial searches (Dupras et al., 2011; Pringle et al., 2012; Schultz et al., 2013; Donnelly and Harrison, 2013), wherein the geoscientist who is asked to assist in a search (be it for legal, humanitarian or environmental reasons) does not go headlong to a location 'blunderbuss' approach (Reynolds, 2011). Instead a desktop study is carried out of the local geology, water and sediment types and depths and the history and present use of the site, in order to inform both the best means and tools of searching, but also to negate the number of (sometimes dangerous) surprises the surveyor may get. This is borne out by the 'canal lock' case study, where the previous existence of the sunken barge could have led investigators to an incorrect location. The need to know as much as possible before the search begins, becomes even more acute when personnel are in the survey boat, or where very expensive equipment may get snagged by hidden obstacles, with possible loss of kit and trained personnel. The desktop study mainly concerns the environment to be searched, but may also consider the nature of the target, as in the 'throwability' exercise developed prior to the search for the dismantled weapon. Like the use of police intelligence, the behaviour of the offender and the likelihood of burial in the terrestrial realm, so similar case background can assist in an aqueous search. The desktop study of the location/environment and the target inform what search assets could be used to optimise the search of a water body: sometimes not all such people, equipment or dogs are available, so the limitations and potential false positives must be

explained to those requesting geoscientific assistance. In the experience of the authors, search personnel can sometimes place too much faith in one or more methods or devices, when these must be used appropriately, conjunctively, and with caution that accommodates the known limitations of a method or a devices, when these must be used appropriately, conjunctively, and with caution that accommodates the known limitations of a method or a piece of equipment. The authors have as many non-successful aqueous searches as the successes provided here. This type of search approach is new (although see Dupras et al., 2011) in the search of water bodies and many more cases and experiments involving different environments and targets need to be completed. Thereafter we can identify the best means to progress a water-borne search that is sensitive to the specific environment, yet sufficiently generalizable in approach to demonstrate good practice. This review highlights the areas of most promise and presents a foundation for the development of the scientific side of this work. Recommendations for searches must include the nature of the environment (Table 1), the nature of the target (Table 1) as well as the available search assets that are applicable to both. Equally, using every device or technique available, whilst comprehensive, may be expensive and time-consuming where fewer assets may achieve as much.

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