Feature

Forensic geoscience on, and in, water

Geoscientists are being increasingly asked by law enforcement, environmental agencies and even wildlife trusts to investigate suspected illegal activities in and around water bodies for criminal or civil investigations. Searches and surveys in aquatic environments can be challenging, depending on the item(s) of interest that is being looked for, the available search teams and equipment and the search area. This article will briefly detail the current work of geoscientists in assisting these aquatic investigations, provide some relevant case studies and discuss future developments.

Alastair Ruffell[1], Jamie K. Pringle[2,3], Neil Powell[1], Amy O'Keefe[1], Kristopher D. Wisniewski[2], Luke Hobson[3]

[1]School of the Natural Built Environment, Queen's University, Belfast, UK
[2]School of Chemical and Physical Sciences, Keele University, Keele, UK
[3]School of Geography, Geology & Environment, Keele University, Keele, UK
a.ruffell@qub.ac.uk

The involvement of geoscientists in the forensic search of water to assist law enforcement, environment agencies, humanitarian organizations and others and to provide scientific support to detect and characterize items of forensic interest, may seem counter-intuitive: surely this is the domain of hydrologists and oceanographers? This is a good question to ask, the answer to which is that it is important to have a variety of disciplines and complementary skill sets working collaboratively for a quality-assured outcome. Aquatic forensic targets can be high-profile active and cold case missing persons; dumped illegal items such as weapons, contraband, solid or liquid waste contaminants or other items of interest.

Geoscientists play a role in this area for a number of reasons: (1) the well-established approach used in terrestrial searches is broadly similar (as described by Jamie Pringle and colleagues in this issue); (2) many of the methods used are the same in hydrology as geology; (3) forensic geology/geoscience (or geoforensics) may be known to investigators, when forensic hydrology may not; and (4) Some search locations are a challenging mixture of firm ground and mobile water with areas in between (e.g. peat bogs, mires and slurry pits), where geology and hydrology overlap with ecology, history and land use.

In addition, forensic searches can occur anywhere in terms of the spheres of the Earth, with the biosphere and atmosphere as unlikely, compared to the geosphere and hydrosphere, making use of appropriate Earth science techniques in these two spheres is sensible.

Why water? What water?

Searching water bodies may be required to assess pollution, investigate accidents, locate missing items or find missing persons, amongst other reasons. Media exposure is greatest when possible victims of homicide are thought to be in water, or with aircraft crashes and sunken ships/boats. For this article, we will focus on serious crime.

Given that ~60 per cent of planet Earth is covered by water, it may appear strange that the seas and oceans are quite rare environments for the illicit disposal of items. This is until a range of limiting factors are considered which include: (a) the logistics of getting an item such as a living or deceased human body into water bodies; (b) ensuring such remains stay sunken or undiscovered; and (c) the psychological effect of being out of control, compared to a terrestrial burial. The casual viewer of Hollywood movies, with no forethought, might see 'throwing the murder victim off a boat' as obvious and easy. That is until one considers the next set of controlling factors: (1) does the perpetrator have access to a large enough vessel; (2) departing from a shoreline—will the perpetrators be seen?; (3) moving a body onto or off the boat (it is not easy!); and (4) weighing the body down and ensuring it stays there.

Once the above factors are considered, inland waterways initially appear as better options than the open sea for body disposal. However, many of the problems faced with such an act at sea, also relate to coastal estuaries, rivers and lakes: access to a vessel, physically moving a body (to shoreline or boat); and being seen all come to play and the chances of the object (such as a human body or parts) reappearing has a strong psychological deterrent. This exclusion of so many types of water bodies often leaves some really difficult places to work, such as swamps, mires, flooded quarries: perhaps this is why so few specialists work in such environments.

Geoforensic aquatic forensic targets

Regardless of the limiting factors discussed, items of forensic interest do end up in water by accident or design. Like buried bodies in the ground, a mistake is to assume that finding the body is so important, that there is a tried and tested method to do it: wrong! All such scenarios of missing people and the related search of the aquatic environment are unique, requiring the planned use of appropriate search resources and a staged investigative approach (Fig. 1). Why? Table 1 shows *some* of the variables at play when an object such as a human body is suspected to be in water: each will complicate the issue—meaning that although time is critical, without a considered strategy (Fig. 1), resources (finance, personnel and equipment) will be wasted.

The aquatic search techniques/methods

For nearly all aquatic searches, there are different approaches used depending on the nature of the target(s) and depositional environment(s), whether they are offensive-type searches (after a crime has occurred) or protective searches to confirm the absence of forensic object(s). Other searches of water can be intelligence-informed, scenario-based, feature-focused on areas/items of interest, open survey searches or even search and rescue if looking for active recovery of individual(s).

Table 1. Examples of two major sets of variables that need consideration to plan a water search for a human body. Further types of variables to the body and the aquatic environment may be information on the perpetrator; a different target (for instance a weapon, contraband or a vehicle) and the search assets needed (below)

The Body (or 'target')	The Aqueous Environment
Age (bone density)	Water flow (rivers vs. lakes vs. seas)
Body mass (size)	Temperature (affecting decomposition)
Seasonality (winter clothes generally keep body more intact)	Salinity (if coastal)
Clothing (buoyancy/ flotation limit)	Other debris (trees and discards)
Footwear (buoyancy or not)	Weed, methane bubbles (limits sonar)
Additional weights (suicide/ homicide)	Nature of substrate type(s)
Time in water (decomposition)	Point of entry
Point of entry	Safety hazards
Wrapped/in container	Changes (storms, floods and vessel movement)

An aquatic search strategy is then generated, based on sound geoscientific principles, search method(s) and technique(s) but also combined with law enforcement or environment agency or other client information, tactical and operational support capabilities. Once the search knowledge is combined, a written search strategy should provide a high degree of assur-

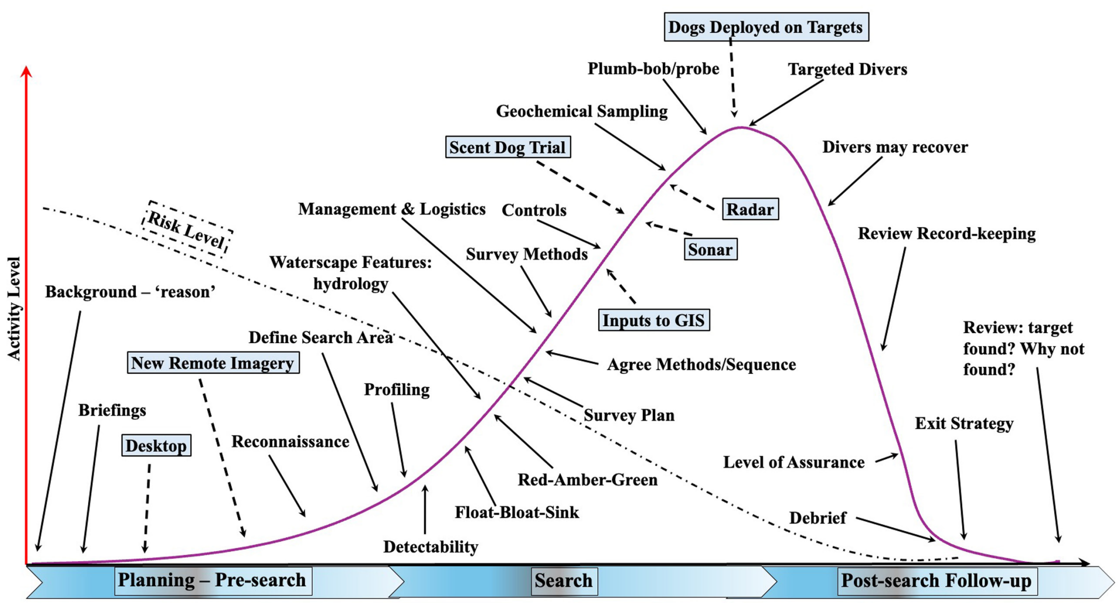

Fig. 1. An aquatic search strategy, showing the complexity, range of resources to be considered and staged approach. Modified, after Donnelly & Harrison (2021). Stages discussed in this work have a blue highlight.

ance when conducting forensic searches of the presence or absence of a specific target being searched for, and importantly an exit strategy if the item of interest is not found to prevent never-ending searches.

Media images of dinghies, search dogs, divers and sonar are appropriate, if selective—because their use must be part of a conjunctive and staged approach using considered assets. Here, we illustrate a search of a freshwater lake or pond as a common example using some of the geological and generally interesting search techniques/methods as examples.

The desktop study

Collating published and online data at the planning/pre-search stage (Fig. 1) is the best practice for all survey work, be it a terrestrial or water forensic search. Sources of data comprise geology (bedrock, superficial and soils); topography; historical and contemporary mapping and imagery (Ordnance Survey or other national mapping agencies, aerial flights, Landsat and Google Earth); and available reports from water management bodies (environment/rivers agency, fisheries and construction). These data should be digital, or digitized for retrieval in a Geographical Information System, such that information from the search stage (Fig. 2) may be added as accurately-positioned layers.

Remote imagery

Historical and even recent satellite and aircraft overflights (e.g. Google Earth) are great resources, but have two problems: first, they may not be suitable for input to GIS; second, even a few months of shoreline vegetation growth or sedimentation renders them out of date. A common approach is to use a GPS-referenced UAV drone flight. An aerial image of water may sound pointless. However, they are routinely used in many forensic searches. UAVs can be quickly deployed, cover significant search areas, are able to carry a variety of detection instrument payloads as well as digital video cameras giving 'live streams' to the operator. Deployed instruments include thermal imaging to locate missing floating individuals, instrumentation to detect specific gases emanating from the suggested target and pinpointing anomalous areas for subsequent water search teams to investigate. Reference to shoreline markers; processing for Normalized Water Variance Index (NDWI—showing spatial changes in the water) and in shallow, clear waters—bathymetry or semi-submerged objects may be visible (Fig. 3).

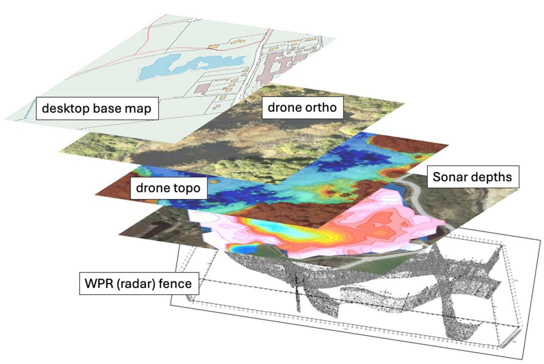

Fig. 2. GIS cartoon of selected geospatial data, illustrating relationships but also the need for teamwork in generating each layer.

Scent dogs and odour release

Human remains detection dogs (HRDD) are widely used by police and voluntary teams to search for persons deceased on land or in water, as their highly developed olfactory system, speed, robustness and trainability make them an effective search asset when used in combination with the other methods described here. The dog and handler may be used from the shoreline, or (when correctly trained) from a boat (Fig. 4).

That said, HRDDs are not without their limitations. For example, there are currently no universally accepted training and assessment standards for HRDDs. There is also disagreement on cadaver odour signatures, uncertainty over detection thresholds for dogs as well as a plethora of training methods some of which mistakenly still use pig carcasses as human analogues. It remains a matter of considerable speculation as to what part of the chemical signature of a target substance is being focussed upon by trained search dogs, impacting the effectiveness of an HRD dog operationally given that *false alerts* may occur where a dog cues on something other than the missing person.

Take our hypothetical situation of a river search for a drowned victim. During the operation, the dog gives an indication which is subsequently searched by sonar and divers, but fails to locate the person. On further investigation, a sewage outlet from a nearby settlement is found. This poses the possibility that the dog may have been responding to certain chemical components contained in the effluent material that are also found in the cadaver odour spectrum. Chemical analysis of accurately positioned organic carbon, volatile organic compounds and isotopes would then be needed to possibly elucidate what the HRDD is reacting to—a future research need.

Therefore, while HRD dogs provide a valuable resource for those searching for drowned victims, their deployment must always be part of a suite of assets to include sonar, radar, aerial surveys and dive teams working in cooperation to support and verify areas of interest.

Sonar

Active Sound Navigation and Ranging and forensic divers are likely to be the two methods of searching water that readers will know. Sonar is an acoustic method (hence the synonym, echo sounding), so requires an upstanding object on the water bottom to work: buried objects, or objects amongst rocks of similar

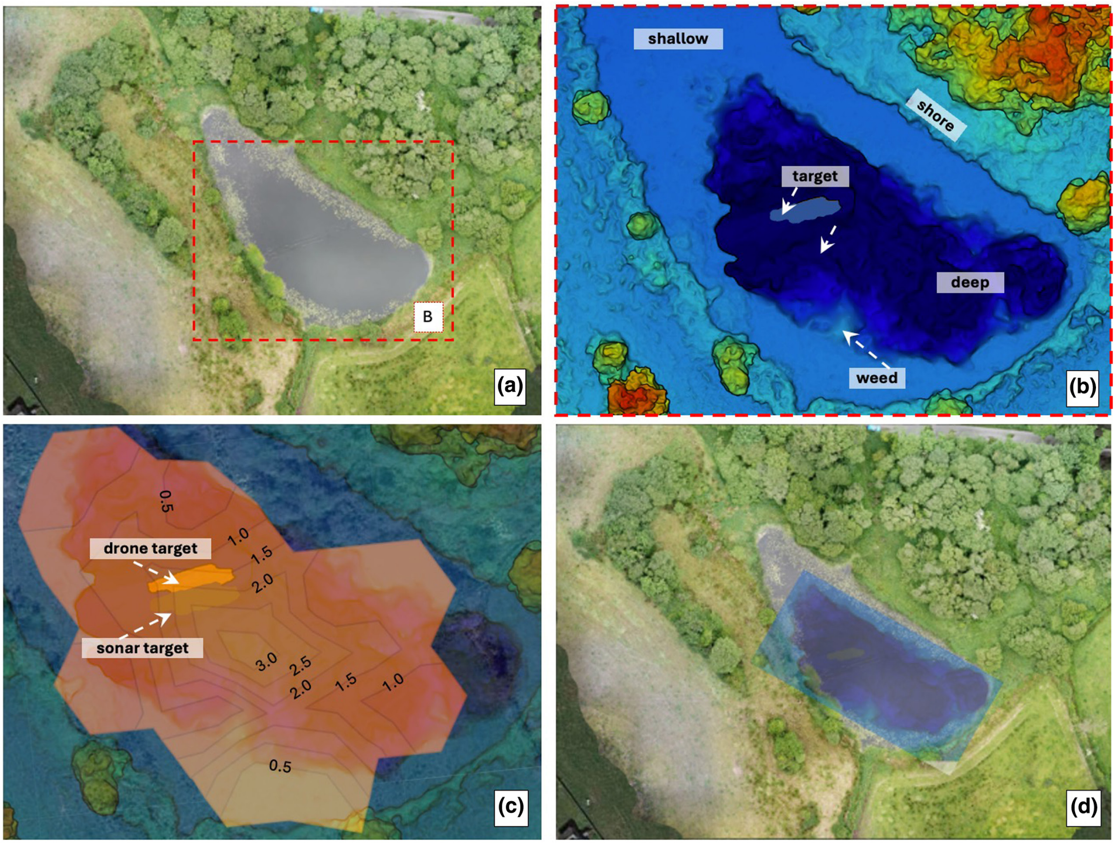

Fig. 3. Drone-derived data in water geoforensic search. (a) Orthoimage montage of site suspected to have a roll of carpet, weighted down and sunk from a boat. (b) Processed montage for topography, where overhead sunlight has reflected from the shallow pond base and aquatic vegetation and target object. (c) Crude bathymetric map, obtained by suspending a fishing sonar from the base of an inexpensive drone ('Dronar': see Bandini *et al.*, 2018). Note how, without Differential GPS in either drone or fishing sonar, slight inaccuracy occurs in the target location. (d) Topographic/bathymetric-proxy data (blue inset) overlain back onto Orthoimage (a) for search team location.

or larger size can severely hinder the technique. Like all geophysical methods, low frequency (~1 kHz) systems can be used in deeper waters and penetrate the sediment as a sub-bottom profiler, but with the decreased resolution of targets that medium (~1–10 kHz) to higher (e.g. 20 kHz) frequency sonar systems achieve: these have minimal imaging into the sediment. The usefulness of sonar is the photograph-like image it generates from widely available devices. The limits include the problem of search items being covered by sediment or amongst rocks (Fig. 5) along with the scattering effect of gas bubbles, suspended sediment/weed and fish.

Water-penetrating radar

Using similar but modified principles to ground penetrating radar, water penetrating radar (WPR) is very effective in freshwater search environments. Advantages over sonar include being unaffected by weed, gas bubbles or rock substrates, with the ability to image

Fig. 4. Human remains detection dogs in operation from a police search dinghy. Each dog has been deployed separately, without the other animal present. Any indications are marked by dead-reckoning and GPS, without a buoy, to provide independent verification of reaction(s).

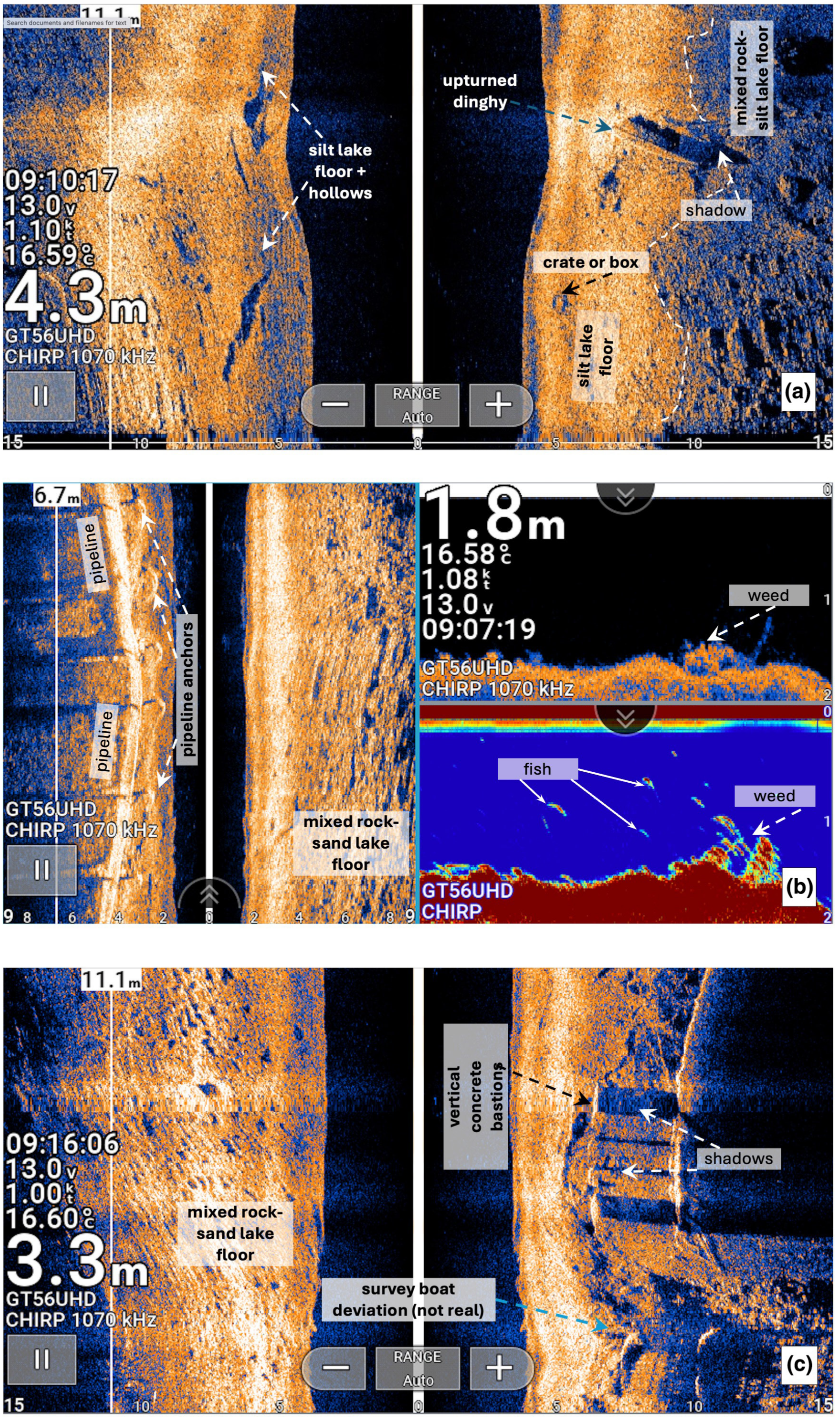

Fig. 5. Examples of sonar data (Garmin UHD 95) from the search for a sunken sailing dinghy in a reservoir. Screenshots of data are intentional illustrating the real-time results and issues in interpretation. (a) The keel of the inverted dinghy, with its sonar shadow. Note what appear to be linear rocks and hollows are falsely stretched by the passage of the survey dinghy and sonar sonde. (b) Illustrates the flexibility of such devices, with the classic top view of lake-floor objects (again, note they are stretched) as well as 2D depth-slice sonar and CHIRP (compressed high-intensity radar pulse) imagery. (c) Illustrates why both maintaining a straight line of survey and caution in interpretation is needed—the bay-like feature is caused by deviation in the survey line, caused by a wind gusting the dinghy.

into sediment (Fig. 6); the disadvantages are the inability to work in conductive (e.g. salty) water and difficulties in generating 3D images. As a consequence, both sonar and WPR are best used together if appropriate.

Magnetics

This is a geophysical technique that is routinely used by civil engineers for both inland and marine environments to detect and characterize potential hazardous magnetic material. In cases of serious crime such as homicide, should a metallic object like a weapon be discarded into water, boat-deployed magnetometry may be a suitable asset in the search process.

Inputs to geographic information systems

The example methods summarized above are all spatial data. Even scent dog indications are GPS-recorded and can be given a subjective grading (e.g. 1–5 or 1–10) by the handler. There are two main reasons why data may be required to be input to a Geographic Information System. First, searches on water are difficult to locate with a physical marker (e.g. a buoy) as once observed, the survey vessel has likely moved on; in addition, buoys or floats may unduly influence search dogs. Placing image locations, anomalies and dog indications in a GIS framework allows impartial assessment of where they coincide: a layered and conjunctive approach (Fig. 2). Second, repeat surveys or dive team deployment may occur at a later date, due to changes in weather conditions, water visibility, additional witness information etc. Therefore, returning to a water body with no landscape markers requires archived geospatial information.

Health and safety, logistics and specialized knowledge require a range of specialists communicating and working together in the forensic search of water. The common language to all is geospatial: unless all agree on where their search asset is indicating a place of interest, then confusion and lack of clarity will affect the ability of divers to investigate and potentially recover target objects. The ultimate aim in the search and location of a human body is the return of the remains to friends and family: however well-intentioned a hasty search is, without a conjunctive approach and information from each asset spatially recorded then relatives, the authorities and the public are let down.

Complex cases

Our everyday interaction with water, such as ponds, lakes, reservoirs, rivers and the sea reflects common search environments. However, the authors have assisted searches of sub-water bases of swimming pools; farm slurry-pits; rooftop water storage cisterns; canal locks and forestry fire

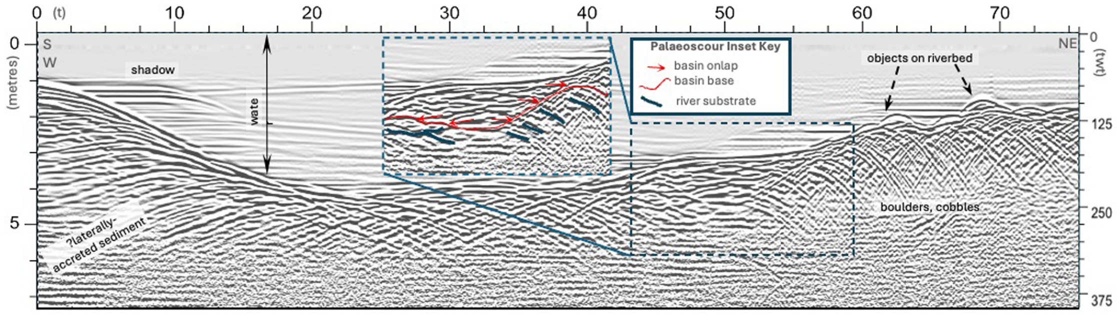

Fig. 6. 2D WPR (water penetrating radar) profile over a weed-filled river search location, where both areas of sediment infill (palaeoscour) as well as water-bottom objects required location. Sonar in this environment was ineffective.

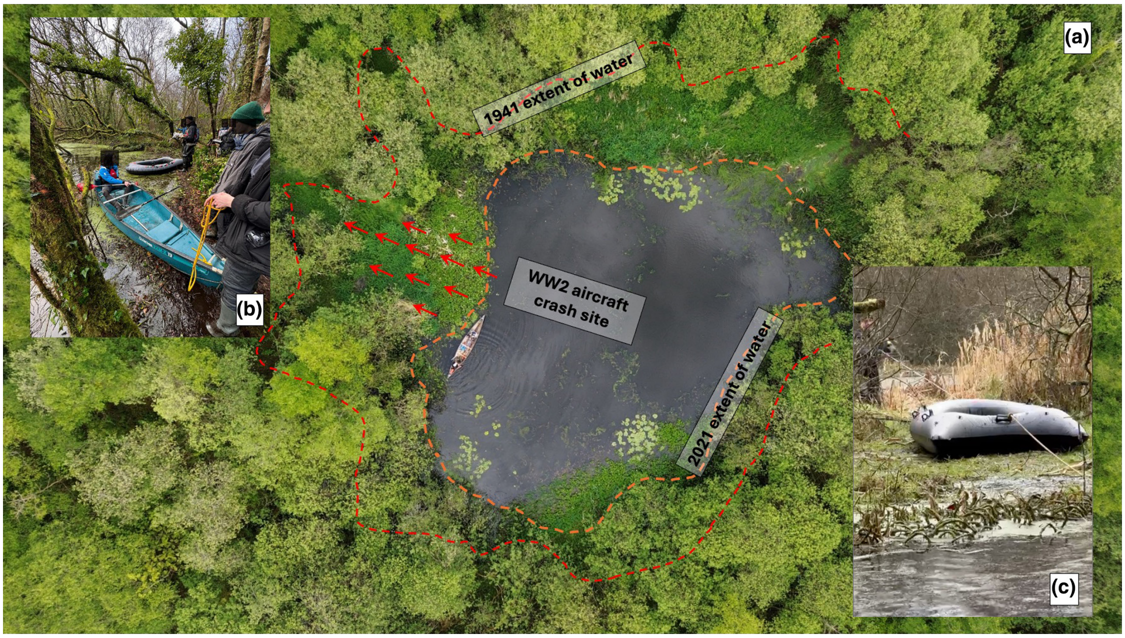

Fig. 7. Example of a complex 'water' search. (a) Drone orthoimage of a woodland-mire-pond location of a World War 2 (1941) aircraft crash site, showing the extent of water then and recently, demonstrating the expansion of weed, rushes and willow/alder across the suspected location. Canoe is 5 metres in length (scale). (b) Volunteer search team. (c) Water penetrating radar (inside dinghy) being manually towed on a Wi-Fi-link over thick weed. The crash location was identified.

dams. In short, water storage containers large enough to contain human remains, contraband, weapons, drugs and stolen goods will be used, on account of physical ease and psychological thoughts of 'out of sight, out of mind'. Frequently encountered are mires: water-filled peat deposits in lowland or groundwater-fed depressions: these are neither land nor water, cannot be walked or floated on and are very tough to traverse by police line-searches. As such, they are often neglected places, where the specialized geological knowledge-based search methods outlined here, using historical data, drones and boats dragged over the bog may be the last resort (Fig. 7). The effect of vegetation overgrowth around mires in historical missing person cases is regularly encountered: be it climate change, lake eutrophication or intentional filling, what was formerly a shoreline 20 or 30 years ago can now appear to be tens of metres 'inland'.

Suggestions for further reading

Bandini, F., Olesen, D., Jakobsen, J., Kittel, C.M.M., Wang, S., Garcia, M. & Bauer-Gottwein, P. 2018. Bathymetry observations of inland water bodies using a tethered sing-beam sonar controlled by an Unmanned Aerial Vehicle. *Hydrology & Earth System Science*, v.22, pp.4549–4565. https://doi.org/10.5194/hess-22-4165-2018.

Donnelly, L.J. & Harrison, M. 2021. Geoforensic search strategy (GSS): ground searches related to homicide graves, counter-terrorism and serious and organised crime. In: Donnelly, L.J., Pirrie, D., Harrison, M., Ruffell, A. & Dawson, L. (eds). *A Guide to Forensic Geology*. Geological Society, London, pp. 21–85. https://doi.org/10.1144/GFG.3.

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