Institution:	Queen's University Belfast	
Unit of Assessment:	14 - Geography and Environmental Studies	
Title of case study:	Innovative Aquatic Geoforensics in the Search for Sunken Objects	
Period when the underpinning research was undertaken: 2004 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Alastair Ruffell	Reader	1990 – present;
Jennifer McKinley	Professor	2004 – present;
Conor Graham	Research Technician	1995 – present;
Brian Johnston	Research Technician	2019 – 2021
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Law enforcement, search and rescue often require forensic search in challenging aquatic environments such as ponds, rivers, ditches and flooded quarries for recovery of human remains, drugs, weapons, explosives and toxic materials. Research at QUB (lead: Ruffell) has developed new methodologies using integrated GI Science and Geoscience tools for assisting the search for buried and water-sunken objects, especially human remains. The impact of this work has included:

- **12** searches for homicide/suicide and drug-related incidents throughout the UK;
- **6** training events in UK, Italy, Australia, Argentina, Brazil and Colombia, which have upskilled law enforcement agencies on aquatic search approaches;
- Significant engagement with community, police and other groups, and articles (e.g. *Police Professional, The Conversation*) promoting geoforensics to wider audiences.

2. Underpinning research

Developing strategies for Geoforensic search methods in freshwater environments

The forensic search for objects submerged in water is under-developed compared to terrestrial searches, providing the impetus for this research. The objective in water-based search research has been to develop a sequential multi-proxy strategy. This includes: GIS-based desktop study; Sonar; geophysics **[R1]** (especially WPR - **water-penetrating radar**) and survey endoscope methods that provide targets for scent dogs and divers **[R2]** in the search of water for items of forensic interest. Working with our professional search partners, we have developed a **three-step methodology** for forensic search in freshwater environments, detailed below:

- **First**, a **GIS-based desktop study** of the environment is undertaken, which includes hydrological navigation/investigation and survey of the area (e.g., models of water flow, which may transport missing objects **[R3]**); analysis of any past search reports or surveys for sand/aggregate extraction; mining/hydrocarbon exploration; dredging of sediment; engineering works; and navigation, both historical and recent). The chemistry of the water and composition of the basal sediment are both key in selecting possible methods to be deployed in the search, because some search tools work optimally in specific environments. This work focusses on the commonly-encountered, yet unsolved issue of where items of forensic interest are sunken (the concept of '***sinkability***' **[R4]** into subaqueous sediment). As the casework and letters of support here demonstrate, this is of major concern in serious crime investigations, as well as searches for missing persons and environmental crime (e.g. illegal waste dumps in water such as abandoned flooded quarries **[R1]**).
- **Second**, intelligence informs the search personnel of **the nature of the target**. A key objective in searching water is finding **human remains** (due to accident, suicide, homicide or genocide) and our work has developed and refined approaches in this area **[R2, R3]**.
- **Third**, evaluation and **selection of aqueous search assets** is undertaken (e.g., remote sensing data, geophysics, search dogs deployed on boats), all field tested and georeferenced

by GPS **[R5, R6]**. Critical here are the nature of the target (e.g. size, makeup, state of preservation), the type of the enclosing medium (e.g. residing in the water column; sediment-water interface; or sunken into sediment), and finally the target(s) location - the GIS-based pre-search strategy allows the most appropriate search assets to be deployed.

Development of WPR in freshwater environments

Through terrestrial-based casework for humanitarian search/rescue and law enforcement, agencies often ask for assistance in freshwater searches: **Ruffell (2006)** applied GPR on water ("WPR") to resolve a dispute following a collision between a jet-ski and speedboat in a recreational lake in Ireland [**R5**]. This was the first geoforensic research publication pioneering WPR use. WPR fills a niche in the application of aqueous geophysics for sub-bottom profiling, in that it allows exploration of small (from ca. 0.1 ha) freshwater bodies where deployment of other techniques such as seismic surveying are problematic due to boat size and tow fish required. The speed with which WPR data can be gathered in such locations makes this method useful for the search of such water bodies. Challenges also exist in terms of what technical (e.g. antenna type, design, flotation method, survey method) and environmental (e.g. water chemistry, temperature, gas content) constraints exist – the research led by Ruffell has refined this technique, testing it for a range of conditions and targets **[R6]**, making it an **attractive and highly applicable tool** in the wider suite of search assets.

Fig. 1. Aquatic Geoforensics in action. A: Operation Amos (weapon search, Leicester); B: Operation Abermule (double homicide search, Inverness); C: Operation Igneous (homicide search, Falkirk); D: Operation Bennet (missing persons search, Fraserburgh). Faces are obscured for security reasons.

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 each technique. The spatial approach outlined above and detailed in the underpinning research section, is new in the forensic search of freshwater water bodies.

In recognition of the pioneering research detailed above and for his outreach contributions to forensic science, Ruffell was awarded the William Smith Medal by the *Geological Society of London* in 2020. McKinley, who has led the application of GIS-based methodologies to forensic problems, was nominated to the *International Union of Geological Sciences* (IUGS) Executive Council by the *Initiative on Forensic Geology* (IFG) (and successfully elected in 2020).

3. References to the research

R1: Ruffell, A. & Kulessa, B. (2009). Applications of geophysical techniques in identifying illegally buried toxic waste. *Environmental Forensics*, 10, 196-207. doi.org/10.1080/15275920903130230

R2: Ruffell, A., Pringle, J.K., Cassella, J.P., Morgan, R.M., Ferguson, M. Heaton, V.G., Hope, C. McKinley, J.M. (2017). The use of geoscience methods for aquatic forensic searches. *Earth-Science Reviews*, 117, 323-327. doi.org/10.1016/j.earscirev.2017.04.012

R3: Ruffell, A. (2014). Lacustrine flow (divers, side-scan Sonar, hydrogeology, water penetrating radar) used to understand the location of a submerged human body. *Journal of Hydrology*, 513, 164-168. doi.org/10.1016/j.jhydrol.2014.03.041

R4: Ruffell, A. & Donnelly, L.J. (2018). Forensic geophysics and the search of building interiors, peat bogs and water. In: Barone, P-M. & Groen, M. (Eds.) *Multidisciplinary Approaches to Forensic Archaeology. Soil Forensics.* Springer-Cham. doi.org/10.1007/978-3-319-94397-8_4

R5: Ruffell, A. (2006). Under-water Scene Investigation using Ground Penetrating Radar (GPR) in the Search for a Sunken Jet ski, Northern Ireland. *Science & Justice*, 46, 150-159. doi:10.1016/S1355-0306(06)71602-1

R6: Parker, R., Ruffell, A., Hughes, D. & Pringle, J. (2010). Geophysics and the search of freshwater bodies: a review. *Science & Justice*, 50, 141-149. doi:10.1016/j.scijus.2009.09.001

4. Details of the impact

Highlights:

- Following our pioneering work [e.g. **R5,R6**], search specialists in the *National Crime Agency* [**E1**] and *Home Office* [**E2**] became aware of the QUB research and criminal **casework** when searching on water. These two agencies have consistently asked for **our support in applying our search methodology in problematic locations for serious crime investigations**. Nine other organisations have requested similar assistance (*Section a*).
- Through the *IUGS Initiative on Forensic Geology* (IFG) and *European Network of Forensic Sciences,* we have provided **training internationally to over 200 police officers/forensic investigators** throughout Europe, Brazil, Colombia, Argentina and Australia *(Section b).*
- Outreach and public engagement have helped to raise the profile of our multi-proxy water-based search methodologies and geoforensic science more broadly *(Section c).*

a. Casework

As a result of our research expertise described above, we received multiple requests from law enforcement bodies (police, environment agency, humanitarian, military ([**E1, E2, E3**]) and search and rescue personnel, to assist in searches of water that ***applied our three-step methodology***. Freshwater locations may possess submerged hazards, limited access, vegetation infestation, and often have few landmarks, making them difficult search environments. This has resulted in innovation-driven aquatic geoforensic research developed ***in conjunction*** with ***law enforcement*** and ***search professionals***, each of whom observed the work and/or report here on the impact. In sequence, the following have asked for assistance described in this Impact Case Study:

1. *Fire & Rescue Service, N. Ireland* - search for sunken jet-ski (Co. Down), 2004 (**R5**)
2. *Northern Ireland Environment Agency* - illegal waste in a flooded quarry, 2006 (**R1**)
3. *An Garda Síochána* search - drowned suicide victim, Fermanagh/Cavan, 2010 (**R3**)
4. Joint *NW England Police Dive Unit / Home Office* - canal survey, Liverpool, 2015 **[E2]**
5. *W. Midlands Police/Home Office* homicide search (flooded quarry), Dudley, 2015 **[E1,E2]**
6. *Police Scotland* search for missing person (flooded bog; Fig.1D), Fraserburgh, 2015
7. *Police Scotland* search for missing child, Coatbridge, Lanarkshire (Fig.1C), 2016 **[E2]**
8. *Leicestershire Police* search for a weapon (attempted homicide; Fig.1A), 2017 **[E2]**
9. *Police Scotland* flooded quarry search (2 x homicide) Inverness, 2018/19 **[E3]**
10. *National Crime Agency*, Cyprus - survey advice, two flooded quarries, 2019 **[E1]**
11. *Netherlands Forensic Institute* - advice to search for sunken vehicle, 2019 **[E4]**
12. Training for the *International Commission on Missing Persons* (ICMP) and EQUITAS (humanitarian organisation), Bogota, Colombia, 2020 **[E5]**

The Major Crime Investigation Support Inspector of the ***National Crime Agency*** (responsible for advising on strategic, tactical and operational matters relating to major crime, complex and high-profile Police search operations throughout the UK) said of our work in 2019:

"*Dr Alastair Ruffell, who assists myself, other Police colleagues and staff from the Defence Science & Technology Laboratory (Home Office) during such operations where* ***his advanced knowledge and technical abilities are essential****… he has developed (and continues to research) a standard operating procedure for forensic searches that deploys a GIS-based desktop study, modified boats/equipment and a geospatial multiproxy approach using the GPR together with Sonar and lightweight probes.* ***I am unaware of anyone else in the UK or Europe and indeed much of the world doing this kind of work****: some United States forces have used the method (e.g. the search and recovery of Gregory Reedy, Oregon). Some operations I have worked with Alastair on include:*

- *Search for a missing person, likely a homicide victim in a flooded quarry near Dudley, West Midlands*
- *Canal search for the body of Moira Anderson, believed killed in 1957 (Lanarkshire)*
- *Search for a weapon used in an attempted homicide, Derby (Trent & Mersey Canal)*
- *Search for two victims of suspected homicide near Inverness."* **[E1]**

Writing about Ruffell's work with the *Home Office Defence, Science & Technology Laboratory,* a member of the Frontline Support Search Team said in 2019:

"*His survey allowed divers to recover two items below silt level…* ***which allowed the investigation to move forward****. I have spent many hours with Alastair and have found his help and insight invaluable as we have been able to exchange ideas to aid police investigations... Our combined expertise* ***allows police forces to make informed decisions with the surveys using these unique capabilities****".* **[E2]**

A *Police Scotland* Detective in the Specialist Crime Division stated,

"Without your involvement and expertise I doubt whether we could have come up with the successful search strategy we did." **[E3]**

b. Professional Training and CPD Significance

- ***Law Enforcement Agency Training*****:** The cases above resulted in invited training events in water-borne GPR deployment run by McKinley and Ruffell under the framework of IUGS-IFG, including: (i) Messina, Sicily, 2014 (for Italian Police and university students); (ii) Canberra, Australia, 2014 (for Federal Police); (iii) Brasilia, Brazil, 2013 (for *Brazilian Federal Police*); (iv) Buenos Aires, Argentina, 2015 (for Colombian and Argentine law enforcement); (v) a training session in the *European Meeting of Forensic Archaeologists* (EMFA) 2016, Dublin (with *Garda Síochána* and >5 other agencies); (vi) an EMFA training weekend in Preston, *University of Central Lancashire* (UCLAN) (attended by 45 participants, including the *Netherlands Forensic Institute*, Swedish and UK police) (2019). **These events all included demonstration geophysical tests (for forensic search) and forensic GIS workshops, with discussions around specific applications and needs.** For example, in the EMFA event (vi above) the focus was on canal search techniques. In the Australian and Brazilian events, McKinley organised more advanced training in the use of spatial data in criminalistics for search, sampling and scene management for crime scene management.

The ICMP Scientific Advisor in Colombia stated in 2020:

"Search and recovery in aquatic contexts is a topic of great importance in Colombia, and is considered a very complex topic. We were honoured to have Dr. Ruffell share his knowledge with us and discuss the process of search and recovery with us…we all learned a great deal about novel and advanced techniques and approaches, some of which the participants will surely put into practice…" **[E5]**

➢ *In summary, training has been provided for law enforcement, search and rescue, fraud investigations, humanitarian agencies, government forensic scientists, and NGOs who use and develop the methods shown here.*

- ***Other events:*** In addition to the above, we promoted our aquatic geoforensics work through the following **conferences:** (i) ***European Meeting of Forensic Archaeologists*** annual conference which we hosted in **Belfast, 2018** (with 59 participants, including major crime forensic advisors (e.g. Head of ICLVR; Head of PSNI *Body Recovery Unit*) and a crime scene fieldtrip; (ii) *Japanese Geological Society Annual Conference, 2015, Nagano* (at the invitation of Detective Sugita, Japanese Police); and (iii) *Institute of Forensic Archaeologists* conference (Bradford, 2016), amongst other events.

c. Public engagement and outreach

- ***Media articles:*** Our aquatic search casework has stimulated and enhanced public understanding of forensic science, as indicated by our non-specialist outputs and media publications (see **E6**). These include articles in *The Conversation* and *Police Professional*. In some instances where aquatic search was undertaken (e.g. the Coatbridge Canal case for *Police Scotland 2016*), significant profiling in the media led directly to outreach publications and newspaper articles [**E6**A, **E6**B]. Wider high profile crime-related news (e.g. the death of Ian Brady) provided further opportunities to promote our work through outreach [e.g., **E6**D**, E6**E]. *Collectively, these outreach activities widened public knowledge and understanding of the role our work plays in criminal search.* Because much of our casework is sensitive in nature, it is not always appropriate to publicise details of our activities, and we often request to remain anonymous due to the security situation in Northern Ireland.
- ***Community and School Events*****:** To further extend the reach of our work, we delivered >20 invited talks to community groups and school/university students in NI and GB including: (i) annual talks to the *Blind and Partly Sighted Group, N. Ireland*; (ii) *University of the Third Age* (Taunton, 2018); (iii) *SW England Geological Society Regional Group* (2017); (iv) Leicester University Geological Society (2016); and (v) *Donegal County Council* (2019). The latter event was attended by Garda officers, widening our network in RoI. We also ran popular sessions at two large *Science Festivals* (*Belfast 2016; Monaghan 2017*), both including interactive 'problem-based' learning where participants were tasked with solving a crime.
- ***Education*****:** Geoforensic water-search approaches are integrated within a QUB UG module (GGY3049 *Geoforensics*; ~70 students) and UG dissertations (2-5 per year). Former student *McCutcheon* used this training to secure employment as a Detective Inspector in PSNI. Ruffell delivers an annual class on forensic science to Ulster University Law students, increasing forensic knowledge in the next generation of lawyers. Ruffell and McKinley delivered an invited forensic geoscience workshop for Hong Kong University in 2015, raising awareness of the impacts arising from the research amongst students and staff.

5. Sources to corroborate the impact

[E1] Letter from the Major Crime Investigation Support Inspector, *National Crime Agency.*
[E2] Email from a member of the Frontline Support Search Team, DSTL (*Department of Science & Technology*, UK *Home Office*/MI5)
[E3] Email from a *Police Scotland* Detective in the Specialist Crime Division.
[E4] Email from a Forensic Archaeologist, the *Netherlands Forensic Institute.*
[E5] Letter from a Forensic Coordinator for the *International Commission for Missing Persons* (ICMP) in Colombia
[E6] Geoforensics in popular media. Multiple sources in one pdf comprising:

A. Ruffell, A. & Pringle, J. 2019. Buried Evidence. *Police Professional**, 24th January, 2019, p. 22-23. **a UK-based magazine on new advances, distributed to all police forces.*
B. Ruffell, A., Pringle, J. & Morgan, R. The long arm of the (geoforensics) law. *Geoscientist,* 29, 26-27, 2019; https://www.geolsoc.org.uk/Geoscientist/Archive/
C. Ruffell, A. 2017. How science is helping the police search for bodies in water. *The Conversation.* 23rd March, 2017. http://theconversation.com/how-science-is-helping-the-police-search-for-bodies-in-water-73931
D. Pringle, J. & Ruffell, A. 2017. The science of finding buried bodies. *The Conversation*, 17th May, 2017. https://theconversation.com/the-science-of-finding-buried-bodies-77803
E. Ruffell, A., 2017. How science is helping the police search for bodies in water. *The Independent*, 29th March, 2017. https://www.independent.co.uk/news/science/how-science-helping-police-search-bodies-water-a7647421.html