Institution: University of Manchester

Unit of Assessment: 7 (Earth Systems and Environmental Sciences)

Title of case study: Making drinking water safe by enabling 'smart' water distribution networks

Period when the underpinning research was undertaken: 2005 - 2018

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:
Stephen Boult	Senior Lecturer (2017 – present) Lecturer (2004 – 2017)	1993 – present
John Gaffney	PDRA	2007 – 2011

Period when the claimed impact occurred: 1 August 2013 – 30 November 2020

Is this case study continued from a case study submitted in 2014? N

1.Summary of the impact

Population and economic growth are placing increased demands on water distribution networks (WDN) in developed and developing countries. To maintain performance, more proactive – "smart" data-driven – management of this critical infrastructure is required. The University of Manchester research has played a critical role in moving the industry toward this goal. This research enabled hardware specifically designed for extensive monitoring of water quality (e.g. turbidity, disinfection) to be developed and, subsequently, new methods to turn the produced data into knowledge. This resulted in

- commercialisation and licensing of the unique hardware - HydraClam®; ChloroClam® - bringing direct revenue of more than GBP3,650,000;
- additional sales of at least GBP9,200,000 through establishing a new global market for the network wide instrumentation;
- providing a means for water distribution companies to transition to smart-water management; and
- enabling reliable water monitoring in 'fragile' WDNs, such as refugee camps.

2. Underpinning research

Research from The University of Manchester (UoM) into water quality monitoring in the environment has been co-produced with Salamander Ltd, a spinout company formed, and owned by Boult (since 1996). This relationship resulted in a progressive sequence of research, moving from the natural environment to the engineered environment of water distribution networks driven by the commercial imperatives of Salamander Ltd. These include:

i. Research on instrumentation for high resolution monitoring in WDN:
Underpinning research at UoM included hydrogeochemical investigations, which were distinguished by the efforts to be relevant to real (field) systems and, therefore, required field monitoring to set samples and processes into context [1]. This demonstrated that; (i) water quality was highly variable in the field and so management required measurement at higher spatio-temporal resolution, and (ii) existing monitoring equipment was inadequate for extensive use in the field. UoM developed custom hardware to address this need, which was commercialised through Salamander Ltd. In 2003 the research instrumentation evolved into HydraClam® (measuring turbidity – Figure 1) and ChloroClam® (measuring chlorine concentration). These patented products for monitoring water quality in water distribution networks (WDN), were licensed to Siemens. Research activity tested instruments in difficult environments to make iterative developments of the

hardware [1, 2]. This demonstrated that the data was more important than the hardware, consequently research was necessary to develop an appropriate telemetry system.

Figure 1. The HydraClam instrumentation, as an example of the Clam hardware

ii. Research on wireless sensor networks that function in challenging environments:

In order to develop an appropriate telemetry system, research projects were undertaken between UoM, Salamander, and BT plc through several Technology Strategy Board, NERC Small Business Research Initiative (SBRI), and EPSRC/BBSRC projects, including a CASE PhD studentship. The research included testing wireless sensor network telemetry in an offshore environment, in order to optimise use of hardware resources such as battery and bandwidth [2]. This research facilitated commercial development of a machine-to-machine (M2M) telemetry system that enabled the high-resolution monitoring of HydraClam® available in real-time; a critical requirement for proactive (smart) WDN management. Large volumes of data were collected once this was made possible, and it became apparent that further research was required to turn data into knowledge (see below).

iii. Research to demonstrate the utility of high-resolution real-time data in managing a Water Distribution Network (WDN):

From 2009, the research focus shifted from hardware development towards turning WDN quality data into knowledge for operational management decisions. Specifically, this included the use of a mass-balance approach to predict (and thus manage) potable WDNs in relation to discolouration caused by metal oxides. This research demonstrated that high temporal resolution measurements were necessary to fully resolve the relationship between water turbidity (and hence discolourations) in a distribution network, hydraulic flow disturbance, and sediment availability [3]. UoM research also showed that water quality variation can be used as an ad-hoc tracer to measure discharge and manage chlorine decay [4]. Eight UK Water Services Providers (WSP) collaborated in these projects, comprising more than 50% of UK WSPs.

Since 2018, further ChloroClam® research projects funded by an EPSRC Impact Acceleration Account (IAA) in partnership with Save the Children and Evoqua WT Plc in refugee camps in Iraq and Bangladesh, have also reported that the proportionate benefit of smart monitoring is practicable, and preferable, in “ad-hoc or fragile” WDNs than in developed countries [5].

3. References to the research

These outputs are all peer reviewed and [1], [3] and [4] are all published in international journals. The research has been funded through EPSRC and BBSRC funding programmes (total approximately GBP660,000). Citation counts are from Web of Science (November 2020).

[1] **Gaffney, J.W**., K.N. White, and **S. Boult**, (2008) Oxidation state and size of Fe controlled by organic matter in natural waters. *Environmental Science & Technology*, **42**(10), p3575-3581. DOI: 10.1021/es702880a (34 citations).
[2] Price, M.C., H. Li, N. Boyd, **S. Boult** and I. W. Marshall (2008) *Development & Demonstration of the Utility of Wireless Environmental Sensors Incorporating a Multi-hop Protocol*, Second International Conference on Sensor Technologies and Applications (sensorcomm 2008), Cap Esterel, 2008, p288-293, DOI: 10.1109/SENSORCOMM.2008.141
[3] **Gaffney, J. W**. and **S. Boult** (2012) Need for and use of high-resolution turbidity monitoring in managing discoloration in distribution, *Journal of Environmental Engineering,* **138**(6): 637-644. DOI:10.1061/(ASCE)EE.1943-7870.0000521 (3 citations).
[4] Mounce, S. R., **J.W. Gaffney, S.Boult**, J.B. Boxall (2015) Automated Data-Driven Approaches to Evaluating and Interpreting Water Quality Time Series Data from Water Distribution Systems. *Journal of Water Resources Planning and Management* **141** (11), DOI:10.1061/(ASCE)WR.1943-5452.0000533 (7 citations).
[5] King, K., D. Starczewska, O. Enwiya and **S Boult,** *(2018)* Continuous Safe Water Monitoring Using 3G telemetry in Internally Displaced Camps in Iraq. 41st WEDC International Conference 2018 https://repository.lboro.ac.uk/articles/conference_contribution/9592886

4. Details of the impact

Society depends on WDNs to provide the fundamental need of clean drinking water. Globally, the WDN infrastructure is ageing, deteriorating, and increasingly under pressure from climate change, urbanisation and population growth in developed and developing countries. To address these challenges, and to support the United Nations Millennium Development Goal of increasing access to safe drinking water, WDN infrastructure must become adaptable and resilient whilst avoiding substantial investment costs. To maintain the performance of critical WDN infrastructure, more proactive – "smart" data-driven – management has become a necessity. Ideally, extensive monitoring and rapid decision-making can be used to prevent failures rather than retroactively responding to them.

The UoM research has been critical in moving the industry toward this goal. Initially the research showed the spatio-temporal resolution of existing data was insufficient as a reliable representation of the network. This confirmed existing monitoring equipment was neither designed for the specific environmental settings it was used in, nor to function as part of an extensive network. The UoM research initially developed extensive, cost-effective monitoring instrumentation. Subsequent research addressed the ongoing knowledge constraints, turning the collected data into the required understanding to proactively manage WDNs.

Pathway to impact
Salamander and UoM provided research which brought HydraClam® and ChloroClam® to market in 2003 [1]. This research demonstrated the utility of products and embedded technology into industry/regulators through collaborative trials with industry, and workshops [3,4]. In parallel with this, the HydraClam® and ChloroClam® instruments evolved into separate sensor packages around a central Clam control telemetry unit. Iterative interaction between Salamander and UoM research has maximised the potential benefit arising from this research by enabling the product to be continually refined, both creating and developing a new market.

Reach and significance of the impact

i) **Revenue generation from sales and licensing of Clam technology**
The HydraClam® and ChloroClam® products allow continual monitoring and management of water quality [A], and have been sold by Salamander since 2003. Within this current REF period, HydraClam® and ChloroClam® have been licensed

(globally) to Evoqua plc (divested from Siemens Water Technologies), generating royalties of GBP2,000,000 for Salamander [B]. HydraClam® and ChloroClam® have become well-established in the Australia-Pacific (APAC) market: since 2015, sales of 300 units to over 50 water companies has generated approximately AUD3,000,000 revenue (GBP1,650,000, November 2020) for Evoqua [C].

ii) **Establishment and development of a new market for network instrumentation**
Through the creation of HydraClam® and ChloroClam®, the underpinning research [1-5] has directly stimulated demand and shaped a new market for network-wide instrumentation, which "*only came into existence with the advent of the Clam products and continues to be dominated by their Chloroclam in APAC*" [C]. Having established a market for water quality monitoring instrumentation, the ongoing research collaboration between UoM and Salamander highlighted Clam technology could be used to proactively manage the network [B]. Salamander confirm that this "*potentially lucrative market [by Salamander] attracted competition, particularly from [Analytical Technologies Inc] ATi*" [B].

ATi are a globally leading manufacturer and supplier of electrochemical analytical monitoring instrumentation, focused on water quality. In 2020, ATi had a global annual turnover of USD30,000,000, and attributed 37% of their business to the UK market [D]. ATi have confirmed that they became aware of the HydraClam® and ChloroClam® products in 2007; and in 2008, invested in developing their own products (NephNet® and MetriNet®) [D], that follow the unprotected parts of the UoM-informed Salamander design. Since 2013, ATi have sold 700 Nephnet, 600 Metrinet and 300 Chlornet units in the UK and Australia [D], (at GBP5000, 8000, 3000 respectively) totalling GBP9,200,000 in sales. This reinforces the increased demand for extensive monitoring in WDN.

Since 2019, Salamander and ATi have collaborated on products to jointly benefit from the Clams and ATi sensor solutions [D]. ATi's Executive Director has confirmed that "*Boult's research and the Clam products his team have developed, continues to help and without a doubt contributes to [ATi's] ability to produce appropriate water quality instrumentation for [their] strategic goal to expand [their] market share and increase revenue."* [D].

As of June 2020, ATi have confirmed 50 orders of the new NephNet/Salamander configurations by UK water companies, and that upon annual servicing, the 800 units already in use by UK WSPs will be retrofitted with Salamander Clams [D]. ATi have confirmed that "*the quality and the perception of water quality to the paying customers is now a top priority to most UK water companies"* [D]. Further, ATi estimate that UK water companies will invest around GBP7,000,000 in Smart water quality sensors across the seventh Asset Management Period (AMP7, 2020-2025) [D].

iii) **Changing working practises of water supply companies – enabling the transition to 'Smart Water Management' through data integration and machine learning**
Clam telemetry has enabled the level of data integration necessary to transition to 'Smart Water Management'. As confirmed by SafeGroup Automation (SGA) – a leading Australian provider of control systems engineering - "*the availability of this effective hardware and the high-resolution data it produces is a critical part of opening up the possibility of more proactive "smart" management"* [C]. Specifically, as SGA note, in combination with "*the design of the Clam telemetry [which] will allow it to be easily integrated into the large SCADA systems that SGA manage for large water companies – and potentially other businesses – across APAC*" [C].

In early 2018, Siemens UK secured funding to create a new Centre of Competence for accelerating and embedding digitalisation in the water and wastewater sector [E]. Through a secure cloud based Internet of Things application, water companies would be able to better meet stringent regulatory targets and manage their network

infrastructure more efficiently. In 2018, based on his role in the Clam research [1,3,4], Gaffney was appointed onto the Siemens UK team [E].

Siemens UK developed MindSphere – an industrial cloud-based platform for collection, storage and use of data. MindSphere resulted from significant strategic investment by Siemens UK, who have targeted the water industry to be early adopters of this technology MindSphere enables automated data analytics to turn the data (produced from Clam style telemetry) into knowledge, operational control and management decisions [E]. Siemens UK have confirmed "*fundamental aspects of the applications targeted at water quality management are based on the underpinning research done at University of Manchester into the use of extensive monitoring*" [E].

From inception, Clams and Clamnet® were designed to meet the need for increased spatial and temporal resolution – large numbers of units and large amounts of data – a large number of units cannot physically be readily visited. Also the amount of data and datasets can grow quickly, so uploading and accessing data must be scalable. Siemens UK have selected Clams and Clamnet® to be their favoured remote telemetry unit (RTU) to connect sensors to – Clams are currently the only MindSphere-enabled devices that can be used in low-cost extensive water quality monitoring and are therefore a fundamental element of these developing solutions [E]. In relation to MindSphere, Salamander state that "*the quality of the input data and the machine learning outputs are direct results of the University [of Manchester] research*" [B]. Siemens have confirmed that as of July 2020 the first 7 MindSphere enabled Clams were installed with a UK water company as a pilot for a larger programme monitoring clean water service reservoirs [E]. Further evidence that Clams are enabling "smart" water management, globally, is the contracted provision for 60 of the latest version of Clams, at an Australian water company serving 1,750,000 customers [C].

iv) Improving service provision in refugee camps

In 2016, Boult worked with Save the Children – a major international aid and development agency operating in over 100 countries, to demonstrate the utility of extensive monitoring in WDNs in fragile contexts (refugee camps) [5] [F]. Ill-health consequences of failures in chlorination in these contexts are very high compared to well-founded WDNs. ChloroClams were deployed in several refugee camps in Iraq, housing 20,000 people [F]. The trials demonstrated that monitoring devices that require no infrastructure – such as power and telephone lines – and minimal user input, are capable of operating successfully in these environments, and that these devices provide measurements at a temporal resolution that enables any inadequacies in chlorine dosing regimes to be exposed [F].

As a result of these trials, Save the Children have identified further opportunities to use ChloroClam®: ChloroClams® on site at a Bangladeshi camp (housing approximately 850,000 people) [F]. Further, "*the potential of this type of monitoring is now being factored in as a tool in future [Water, Sanitation and Hygiene] activities at Save the Children*" [F].

5. Sources to corroborate the impact

[A] HydraClam® and ChloroClam® product brochures
[B] Letter of support from Managing Director, Salamander Ltd (November 2020)
[C] Letter of support from Smart Utilities Product Manager, SGA (November 2020)
[D] Letter of support from Co-founder, ATi (November 2020)
[E] Letter of support from Product Owner, Water Quality Analytics, Siemens Digital Industries UK (November 2020)
[F] Letter from Head of Humanitarian WASH (Water, Sanitation and Health), Save the Children (November 2020)