Institution: 10007822

Unit of Assessment: 12

Title of case study: From source to tap: management of natural organic matter during drinking water production

1. Summary of the impact (indicative maximum 100 words)

New characterisation tools for natural organic matter (NOM) in drinking water are now used as standard practice within water companies such as Severn Trent Water, United Utilities and Yorkshire Water. The tools inform decisions, and help develop strategic plans on catchment management, source selection, treatment optimisation, and disinfection practice. Water companies experienced difficulties in treating high levels of NOM. Cranfield created a novel characterisation toolkit to measure NOM for its electrical charge and hydrophobicity. Also, new techniques for measuring aggregate properties and emerging disinfection by-products have provided a comprehensive analysis. Two novel treatment technologies are currently marketed. These technologies have raised international interest, resulting in industrial development in Australia.

2. Underpinning research (indicative maximum 500 words)

UK Water companies have experienced difficulties in treating source waters from peat moorland catchments since the 1990s. These sources account for 30-40% of all the water used to produce drinking water in the UK. The focus of the research has been on translating established theoretical understanding to generate practical benefit that can be applied in treatment works.

The initial work was the first to identify and publish seasonal changes in the flux and character of NOM leaching into source waters [G1, P1]. Critically, the work identified that existing indicators, such as water colour, were inadequate in defining NOM load for treatment purposes. Further industrially funded projects led to Cranfield becoming the first university outside North America to be funded by the American Water Works Association Research Foundation (now called the Water Research Foundation) [G2]. The project produce a novel diagnostic toolkit – still used by both researchers and water company practitioners – to fully characterise both NOM in the source water and the resultant coagulated NOM aggregates (flocs) formed during treatment [P2]. This, for the first time, enabled the link between source water changes and treatability to be understood and managed.

Application of the toolkit led to discoveries which changed the understanding of NOM removal in relation to treatability and optimisation of coagulation. Traditional approaches involved empirical batch testing to (re)establish the optimum dosing conditions. As a result of the work, it is now possible for operators to monitor and change the effect of surface charge on the coagulation process. Direct measurement of the particle charge is used to optimise coagulation irrespective of the source water, coagulant used, or pH level, without the need for empirical testing, through a universal range of zeta potential values [P3].

In relation to treatability, we demonstrated that characterisation of the organic matter within untreated raw water, by non-specific ion exchange resins, can be used to identify both the likely coagulant demand and the achievable residual dissolved organic matter concentration for optimised dose conditions.

These key findings have been used for assessment and deployment of new technologies and in adapting existing systems to cope with changing environmental conditions. Work examined the

potential of a novel ion exchange process for NOM removal. We established the beneficial impacts provided by ion exchange processes, such as reducing disinfection by-product formation (DBP) and increasing floc strength, and thereby reducing downstream processing costs [G3, P4]. This underpinned a decision by Yorkshire Water to invest in the technology for full-scale application at three treatment sites.

This was applied to other systems including algal laden reservoirs and lowland water sources [G4]. Critically, and in conflict with conventional thinking, the findings pertaining to peat based catchments were shown to apply for all source waters. The work led to the discovery that sufficient charge can be coated onto a bubble through surfactant and polymer adsorption to obviate pre-coagulation of algae, a major limitation on many operational sites, generating significant savings in energy and operating costs (P5).

At the disinfection stage of water treatment, pioneering work in DBP formation at Cranfield led to the first published work identifying the risk associated with emerging DBPs such as haloacetic acids (HAA) and nitrogen based DBPs in the UK [G5]. A critical discovery was the absence of a link between treatability and DBP formation, meaning that targeted removal of high DBP forming compounds in not possible [P6]. Recent work funded by the Scottish Government identified that switching to chloramination is insufficient to minimise the risk of non compliance and highlighted the need for integrated solutions.

Key Researchers	Post details and dates involved	Research
Prof B Jefferson	Professor (2011-present) Reader (2009-2011) Senior Lecturer (2006-2009)	Coagulation and flocculation, advanced oxidation processes, floatation processes, algae, zeta potential
Dr P Jarvis	Senior Lecturer (2012- Present) Lecturer (2009-2012) Academic Fellow (2007-2009)	Coagulation and flocculation, ion exchange processes, floc characterisation
Dr E Goslan	Senior Research Fellow (2013-present) Research Fellow (2008-2013) Research Officer (2003-2008)	Disinfection by products, Characterisation

3. References to the research (indicative maximum of six references)

Evidence of quality – peer-reviewed journal papers

P1. Goslan, E.H., Fearing, D.A., Banks, J., Wilson, D., Hills, P., Campbell, A.T. and Parsons, S.A., Seasonal variations in the disinfection by-product precursor profile of a reservoir water. *Journal of Water Supply: Research and Technology – AQUA*, **51**(8), pp. 475-482, 2002.

P2. * Jarvis, P.R., Jefferson, B. and Parsons, S.A., Breakage, Regrowth, and Fractal Nature of Natural Organic Matter Flocs. *Environmental Science Technology*, **39**, pp. 2307-2314, 2005. doi: 10.1021/es048854x

P3. Sharp, E.L., Parsons, S.A. and Jefferson, B., The impact of seasonal variations in DOC arising from a moorland peat catchment on coagulation with iron and aluminium salts. *Environmental Pollution*, **140**, pp. 436-443, 2006. doi: 10.1016/j.envpol.2005.08.001

P4. Jarvis, P., Mergens, M., McIntosh, B., Nguyen, H., Parsons, S.A. and Jefferson, B., Pilot scale comparison of enhanced coagulation with magnetic resin plus coagulation systems. *Environmental Science Technology*, **42**, pp. 1276-1282, 2008. doi: 10.1021/es071566r

P5. * Henderson, R. K., Parsons, S. A. and Jefferson, B. (2008) Surfactants as bubble surface modifiers in the flotation of algae: Dissolved air flotation that utilizes a chemically modified

bubble surface. *Environmental Science Technology,* **42**, 4883-4888. doi: 10.1021/es702649h

P6. * Bond, T., Henriet, O., Goslan, E., Parsons, S. A. and Jefferson, B. (2009) Disinfection By-Product Formation and Fractionation Behaviour of Natural Organic Matter Surrogates. *Environ. Sci. Technol.*, **43**, 5982-5989. doi: 10.1021/es900686p

* 3 identified references that best indicate the quality of the research

Further evidence of quality – underpinning research grants

G1. Yorkshire Water, United Utilities, Natural Organic Matter Character and Reactivity: Assessing Seasonal Variation in a Moorland Water, £60,000, 10/1999-10/2003, PI: Parsons.

G2. WRF project number 2874, Treatment of elevated organics waters, £284,000, 10/2002-10/2005, PI: Parsons, CI: Jefferson.

G3. Orica Watercare, Impact of MIEX® on downstream processes, 10/2004-10/2007, £70,000, PI: Parsons, CI: Jefferson.

G4. Anglian Water Northumbrian Water, Thames Water, Yorkshire Water, PosiDAF, 10/2004-10/2007, £42,000, PI: Jefferson, CI: Parsons.

G5. Anglian Water, Northumbrian Water Limited, Severn Trent Water, United Utilities, Yorkshire Water, HAA precursors and treatment, 10/2005-10/2008, £180,000, PI: Parsons, CI: Jefferson.

4. Details of the impact (indicative maximum 750 words)

Our toolkit developed through this work, for characterising organic matter and flocs, is now routinely used by a number of UK water companies, as evidenced from testimonials from Severn Trent Water [C1], United Utilities [C2] and Yorkshire Water [C3]. The fundamental process understanding underpins significant operational activity related to NOM removal.

Our work helped shape the operational policy relating to the scheduling of the blending of water of different sources based on their characterisation [C3]. The use of fractionation has been central to a recent study looking at water intake contributions from different input sources into two drinking water treatment works in the Yorkshire Water region. The work on the role of zeta potential as a universal guide to optimisation of coagulation now forms the basis of routine monitoring in operating the largest drinking water works within the Severn Trent region [C1]. The research findings have been embedded into operational practice and have resulted in significant savings in chemicals and energy consumption. Scottish Water recently adopted the combination of both sets of techniques as standard tests as part of a detailed investigation programme of its existing coagulation sites for process optimisation, works audits and to guide investment decisions [C4]. Additionally, United Utilities now routinely uses the tools as part of their coagulation diagnostics in relation to problematic operational sites [C2]

The diagnostic tools have also been central to the assessment of new technologies, such as novel magnetic ion exchange processes. This work informed Yorkshire Water's decision in 2009 to invest £50M in the technology at three drinking water treatment sites, including the first example of the technology to be implemented in Europe. More recent work has been utilised by the water companies to assess a number of other technologies such as nanofiltration, electro coagulation and novel adsorbents where the tools and approaches developed by Cranfield are used to understand the potential of the technology and shape future investment plans [C1, C3].

The application of the tools is being developed through industrially funded projects related to catchment management [C5] so that the impact of the research in terms of the drinking water treatment works can be properly understood [C1, C3]. These projects represent some of the first examples of such an approach: the findings of these studies are changing the water companies' understanding of catchment management and shaping future policy [C1].

The team's research has resulted in two novel technologies, marketed by Water Innovate limited, part of the Bluewater Bio group [C6].

- The first is PosiDAF®, a novel adaption of the dissolved air flotation process that utilises positively charged bubbles by coating them with either surfactants or polymers. In Australia, there is a demonstration of the potential for Cranfield's invention for algae removal from both drinking water sources and final effluent lagoons for wastewater treatment. The work has industrial support from five water companies and the Australian Research council [C7]. Cranfield continues to collaborate through a transfer of staff to the University of New South Wales.
- The second technology is the membrane chemical reactor (MC-R^{TM}). This is a photocatalytic reactor linked to a membrane to ensure the containment and reuse of nano particulate titanium dioxide catalyst particles. The technology, patented in 2005 [C8], is under further development as part of a programme of work funded by Severn Trent Water for the removal of a recalcitrant pesticide (metaldehyde) from river waters. Funding has now been secured for a demonstration of a photocatalytic pilot plant to refine the business case a full-scale version of the technology in the next asset investment plan [C9].

Our work has helped to shape investment programmes, and assist utilities in meeting future risks from new legislation related DBPs that are currently unregulated such as haloacetic acids. Work for the Scottish Government on use of alternative disinfectants led to a report published by the water quality regulator for Scotland that has influenced policy on water compliance for Scotland [C10]. The work on emerging DBPs was funded by a consortium of UK water companies to understand the risks.

5. Sources to corroborate the impact (indicative maximum of 10 references)

C1. Contact: Senior Process Scientist, Severn Trent Water, Coventry, UK
C2. Contact: Senior Process Scientist, United Utilities, Warrington, UK
C3. Contact: Research Development and Implementation Project Manager, Yorkshire Water, UK
C4. Contact: Process Optimisation Team Manager, Scottish Water, Edinburgh, UK.
C5. Goslan, E., Jarvis, P and Jefferson, B. (2011). NOM Fractionation and DOC: the True Link. Yorkshire Water Framework Project.
C6. http://www.waterinnovate.co.uk/product-datacentre/posidaf. [last accessed 12 March 2013]
C7. ARC Linkage LP0990189, South Australia Water and Australian Water Quality Centre, United Water, Seqwater and Melbourne Water. Optimising dissolved air flotation for algae removal by bubble modification in drinking water and advanced wastewater systems. AUD$621,000.
C8. Parsons, S. A. and Jefferson, B. (2005) Membrane chemical reactor. British Patent No.0501688.6
C9. Contact: Research and Development Manager, Severn Trent Water, Coventry, UK
C10. Study into the formation of disinfection by-products of chloramination, potential health implications and techniques for minimization. Drinking Water Quality Regulator for Scotland (dwqr) website www.dwqr.org.uk. [last accessed 12 March 2013]