

<b>Institution:</b> Cardiff University		
<b>Unit of Assessment:</b> Earth Systems and Environmental Sciences (7)		
<b>Title of case study:</b> Evidence based reservoir management strategies solve taste and odour problems of drinking water supply in the UK, US and Brazil		
<b>Period when the underpinning research was undertaken:</b> 2000 – 2018		
<b>Details of staff conducting the underpinning research from the submitting unit:</b>		
<b>Name(s):</b> R. Perkins	<b>Role(s) (e.g. job title):</b> Senior Lecturer	<b>Period(s) employed by submitting HEI:</b> 20/09/2004 – present
<b>Period when the claimed impact occurred:</b> 01/11/2017 – 31/12/2020		
<b>Is this case study continued from a case study submitted in 2014?</b> No		
<b>1. Summary of the impact</b> (indicative maximum 100 words)		
<p>The United Nations recognises acceptable taste and odour (T&amp;O) in drinking water as a human right, and UK legislation dictates that all water companies ensure acceptable T&amp;O standards. Cardiff's research discovered how varying nutrient levels from water catchment areas trigger the production of metabolites by the cyanobacteria that cause T&amp;O problems. This discovery enabled more proactive and less invasive reservoir management strategies, leading to the following impacts:</p> <ul style="list-style-type: none"> <li>• saving over £5M through redefining Welsh Water's reservoir water treatment strategy and avoiding use of ineffective technologies;</li> <li>• defining industry best practice and policy through the formation of the UK's first T&amp;O Working Group, including representatives from the Drinking Water Inspectorate and UK water companies supplying over 14M customers;</li> <li>• international influence through improvement of reservoir management techniques for US and Brazilian water companies.</li> </ul>		
<b>2. Underpinning research</b> (indicative maximum 500 words)		
<p>Perkins joined Dŵr Cymru Welsh Water on a NERC Innovation secondment <b>[G3.1]</b> in 2017 to determine the triggers for cyanobacteria that result in taste and odour (T&amp;O) problems. Perkins was selected based on his understanding of the importance of nutrients in driving harmful algal blooms <b>[3.1]</b> as well as knowledge of applied reservoir and lake management across Europe and Australia <b>[3.2, 3.3]</b>. The aim of the secondment was to improve reservoir and catchment management and water treatment efficiency within Welsh Water, with these advances subsequently applied across the wider UK water industry.</p>		
<b>2.1 Identifying the causes of T&amp;O problems</b>		
<p>Certain species of filamentous cyanobacteria (blue-green algae found in almost every aquatic environment) are known to produce the compound metabolites 2-Methyl-Isoborneol (2-MIB) and trans-1,10-dimethyl-trans-9-decalol (geosmin). Even in miniscule quantities (as little as 5 ng per litre), these compounds produce T&amp;O issues in potable water, the most common customer complaint to the UK water industry. To address this issue, these metabolites need to be removed through costly water treatment processes.</p>		
<p>Although cyanobacteria are known to produce 2-MIB and geosmin, the triggers for their production went unrecognised for decades. Analysing the Plas Uchaf and Dolwen reservoir system in North Wales, Perkins determined that the critical trigger was fine scale changes in nutrient ratios; specifically, the amount of ammonium relative to nitrate and phosphate resulting from catchment processes, such as farming, that cause significant pulses of ammonium <b>[3.4]</b>. Changes in farming activities with ammonium-rich slurries, specifically at times when nitrate availability was low, but phosphate supply was high, stimulated cyanobacteria to produce 2-MIB and geosmin <b>[3.4]</b>. Cardiff research was the first to reveal</p>		

the mechanistic pathway that resulted in T&O problems affecting Welsh Water since 2010 [3.4].

## 2.2 Wider application of the research

Through several Welsh Water-funded projects [G3.2, G3.3], Perkins designed a new water sampling strategy for Welsh Water and improved laboratory analysis methods to detect changes in nutrient levels. This yielded further data from additional reservoir systems (e.g. Pontsticill, Pentwyn, Llwyn-Onn, Rosebush and Talybont reservoirs), allowing Perkins to test the prevalence of the nutrient ratio trigger. The research suggested that there was a widespread problem with control of T&O, emphasising the importance of catchment area management and the development of new strategies for water companies to optimise treatment and intervention [3.5].

The identification of causal links to T&O causing cyanobacteria were then confirmed through additional testing sites across the UK. Perkins collaborated with Wessex Water and Bristol Water to test the research findings in the Durleigh, Chew Valley, and Blagdon lowland reservoirs. These studies fully corroborated the initial findings demonstrating that nutrient ratio triggers of ammonium, nitrate and phosphate produce 2-MIB and geosmin, which results in T&O problems [3.5]. These research outcomes enabled Welsh Water, and other UK-wide water companies, to begin evidence based countermeasures to address T&O issues linked to cyanobacteria.

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

[3.1] Spears, B.M., Carvalho, L., Perkins, R.G., Paterson, D.M. (2008) Effects of light on sediment nutrient flux and water column nutrient stoichiometry in a shallow lake. *Water Research* 42(4-5), 977-986. doi.org/10.1016/j.watres.2007.09.012

[3.2] Meis, S., Spears, B.M., Maberly, S.C., O'Malley, M.B., Perkins, R.G. (2012) Sediment amendment with Phoslock® in Clatto Reservoir (Dundee, UK): investigating changes in sediment elemental composition and phosphorus fractionation. *Journal of Environmental Management* 93(1), 185-193. doi.org/10.1016/j.jenvman.2011.09.015

[3.3] Meis, S., Spears, B.M., Maberly, S.C., Perkins, R.G. (2013) Assessing the mode of action of Phoslock® in the control of phosphorus release from the bed sediments in a shallow lake (Loch Flemington, UK). *Water Research* 47, 4460-4473. doi.org/10.1016/j.watres.2013.05.017

[3.4] Perkins, R.G., Andrade, T.M.C., Pearson, P., Froggatt, T. (2018) Obtaining the evidence for "Evidence based management": The taste and odour problem. *Institute of Water Journal* 2, 41-44. [https://issuu.com/instituteofwater/docs/0118\\_iow\\_journal\\_issue\\_interactive](https://issuu.com/instituteofwater/docs/0118_iow_journal_issue_interactive)

[3.5] Perkins, R.G., Slavin, E.I., Andrade, T.M.C., Blenkinsop, C., Pearson, P., Froggatt, T., Godwin, G., Parslow, J., Hurley, S., Luckwell, R., Wain, D.J. (2019) Managing taste and odour metabolite production in drinking water reservoirs: The importance of ammonium as a key nutrient trigger. *Journal of Environmental Management* 244, 276-284. doi.org/10.1016/j.jenvman.2019.04.123

### Selected grants:

[G3.1] PI: Perkins, R.G. NERC Directed Internship NE/PO1111X/1 NERC. Extended by Welsh Water, including reservoir management secondment during the Covid-19 pandemic (30/3/2020). Total award £71,188.

[G3.2] PI: Perkins, R.G.. Welsh Water "Multiple site taste and odour investigation", June 2019 - September 2020. Total award £134,398.

[G3.3] PI: Weightman, A., CI: Perkins, R.G., and Kille, P.. Welsh Water "Understanding the role of water treatment works microbiome for removal of taste and odour (T&O) compounds", June 2019 - September 2020. Total award £115,000.

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

The United Nations recognised the importance of acceptable T&O in their 2010 definition of water as a human right, and UK legislation since 1991 mandates that water companies ensure acceptable T&O standards. Cardiff research identified a causal pathway to T&O problems which facilitated Perkins' work with water companies delivering the following impact:

1. redefined Welsh Water's strategy for reservoir water treatment;
2. improved industry best practice and policy, honing strategies and economic savings for UK water companies;
3. redeveloped reservoir management techniques for water companies in the US and Brazil.

##### 4.1 Redefining Welsh Water's strategy for reservoir water treatment

Through collaboration with Welsh Water, Cardiff's research identified the relationship between nutrient ratios and cyanobacteria-producing T&O metabolites in drinking water reservoirs. Joanne Burford, Catchment Manager at Welsh Water, said: "*Perkins has brought new knowledge and skills that have led to the successful identification of a key driver for the production of these compounds... the first time Welsh Water or any water company in the UK was aware of this trigger for T&O compound production*" [5.1].

Welsh Water stated: "*The critical research provided by Perkins have been applied to improve Welsh Water's water quality monitoring programmes*" [5.1]. These programmes measure ammonium and phosphate to manage the risk of cyanobacteria T&O metabolite production across all 66 reservoirs, servicing the Welsh Nation of three million people with daily drinking water. Perkins' central mechanisms of nutrient control of T&O risk is now the basis for Welsh Water's projects to investigate site-specific dynamics and identify management measures to address T&O, and has "*driven changes to Welsh Water's policies to now treat reservoirs holistically*" [5.1].

Cardiff's research also "*greatly influenced the future strategy of Welsh Water*" [5.1] by moving beyond reactive and expensive water treatment policies, such as activated granular or powdered carbon filtration. Welsh Water are now actively working towards catchment area monitoring solutions to improve water quality [5.1]. As a result, both Welsh Water's five-year plan, Asset Management Programme (AMP7), for submission to the Water Services Regulation Authority (OfWat), and the company's 30-year strategic plan, 'Journey to 2050', implemented changes informed by Cardiff research. These include a move towards Smart Catchment Management and improved evidence based management that are "*more cost-effective and environmentally friendly solution[s]*" [5.1].

The Cardiff research also enabled immediate financial savings by avoiding expensive and inappropriate infrastructure projects. Welsh Water previously planned installing ResMix turbines: devices that continuously mix reservoir water to maintain oxygenation. Following Perkins' research, it became apparent the turbines would not provide a comprehensive solution, and the company halted the purchase of five ResMix units. Welsh Water estimate that Perkins' work saved "*at least £5M in investment costs and considerable resources over time*" [5.1].

Following UK Government guidance on COVID-19, Welsh Water's monitoring of reservoir sites was significantly reduced throughout 2020. During this period, Cardiff devised and instigated a new predictive model that provided site-by-site risk assessments of T&O metabolite production for Welsh Water reservoirs: "*This new approach to predictive risk monitoring set up by Perkins has worked extremely well and is to be continued post lockdown*" [5.2].

##### 4.2 Strategic changes and economic savings for UK Water Companies

In 2018 Perkins and Welsh Water jointly led creation of the first UK-wide working group (UK Water Industry Taste and Odour Working Group) to share T&O best practice with other water companies [5.1]. After demonstrating the findings from Plas Uchaf and Dolwen Reservoirs, the group instigated a new policy of information sharing between the water companies [5.1].

This was led by Perkins and involved collecting and analysing data from numerous water companies. From the datasets provided, 11 were suitable for analysis, including those of United Utilities, Severn Trent, and Northern Ireland Water. The analysis revealed the same T&O risks as seen in Welsh Water affected reservoirs across the UK [5.1]; Perkins used this information to provide the companies with individual water management plans [5.1]. Since the group's formation, the research led to benefits for water companies across the UK, including:

**a) Jersey Water** (serving 170,000 daily customers, 350,000 during summer tourism influx)

Perkins advised on intervention management, specifically against ultrasound as a preventative T&O mechanism. Jersey Water stated: *“Based on this information and the findings of Perkins’ research, we did not pursue this option and hence have made savings of approximately £150K per site”* [5.3]. Jersey Water is now working towards catchment area monitoring solutions for its six reservoirs, saving the company £900,000.

**b) Bristol Water** (serving 1.2M daily customers).

Bristol Water received guidance on T&O risk through analysis of Cheddar, Chew Valley and Blagdon reservoirs, where Perkins identified T&O risk management measures and advised against the use of ResMix turbines [5.4]. Bristol Water stated: *“Perkins’ work has been instrumental in developing new strategies to detect T&O risk”,* which *“improved the quality of drinking water for people across Bristol and the South West of England”* [5.4].

**c) Yorkshire Water** (serving 5M daily customers).

Yorkshire Water Service stated that partnering with Cardiff University *“identified the opportunity to use molecular analytical techniques at one of our high-risk reservoirs”* [5.5]. This enabled new opportunities for *“carefully designed management intervention and ideally preventative strategies”* [5.5].

**d) Scottish Water** (serving 5.4M daily customers).

Perkins’ *“critical research”* was shared with Scottish Water through the UK Water Industry T&O Working Group in 2019 [5.6]. Scottish Water detailed how this was *“extremely helpful in providing knowledge that has aided our investment programme to improve reservoir monitoring and understanding T&O events”*; it was essential to Scottish Water’s key transition to catchment area monitoring, rather than costly water treatments [5.6].

An additional member of the UK Water Industry T&O Working Group was the Drinking Water Inspectorate (DWI), the England and Wales water regulator that investigates T&O issues and prosecutes water companies, with fines as high as £500,000 in 2019 [5.7]. The Inspector at the DWI, praised the identification of nutrient ratio triggers as *“a significant new development”* for the water industry, with DWI incorporating the results of Perkins’ analysis of data into its water companies’ assessment procedures [5.7].

Further building on UK Water Industry T&O Working Group, in 2019 Perkins and the GW4 Water Security Alliance (a research partnership between Bath, Bristol, Cardiff, and Exeter Universities) established the new Reservoirs Management Special Interest Water Research Group. The group includes 29 partner organisations, including 19 water companies, such as Thames Water, United Utilities, Wessex Water and Severn Trent; this provides a unique partnership model to further explore and address issues related to T&O in reservoirs.

#### **4.3 Improving reservoir management techniques for water companies in the US and Brazil.**

In collaboration with Welsh Water, Cardiff also engaged in knowledge-exchange programmes with The Bureau of Water Supply at New York City Department of Environmental Protection (NYC DEP), in response to an emerging T&O risk detected in their catchments [5.8]. Specifically, since 2019, Perkins supported the NYC DEP to demonstrate preventative management for T&O risks in the Catskills catchment area. Lori Emery, Director of Water Innovation and Research at the NYC DEP, stated that Perkins’ work on T&O triggers is *“assisting us in identifying improvements to our water quality monitoring programs and to determine the causes of T&O events”* [5.9]. As a result, Emery highlighted *“increased*

*organizational efficiencies and improved resource allocations*” which ultimately “*benefit the quality of drinking water for millions of people across New York*” [5.9].

Similarly, Perkins was invited to present his research to the Brazilian Water Research Centre (BWRC - University of Campinas) and the Sanasa Water Company. Professor Cassiana Montagner, Research Coordinator of the BWRC, stated that Perkins advised on T&O aspects of the water safety plan for the Capivari river, serving 1.1M people [5.10]. By highlighting the link between metabolites and T&O, Montagner stated that “*we have now begun to incorporate Perkins’ research into our Water Safety Plan to mitigate the risk of T&O issues*” [5.10].

#### 4.4 Summary

Cardiff’s research was instrumental in identifying core causes of T&O problems in drinking water, which enabled regional and UK-wide institutional changes and widespread financial savings including:

- defining the future T&O strategy of Welsh Water, resulting in both immediate financial savings of £5M and enabling a proactive risk management strategy;
- changes across the UK water sector instigated by the creation of the first UK-wide T&O Working Group for the water industry, and implementation of Perkin’s approaches UK-wide;
- benefiting water companies in the US and Brazil, further evidencing Cardiff’s international influence and reputation.

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

[5.1] Testimonial: Joanne Burford, Catchment Manager, Welsh Water.

[5.2] Testimonial: Dr Phillippa Pearson, Head of Water Services Science, Welsh Water.

[5.3] Testimonial: Natalie Passmore, Finance Director, Jersey Water.

[5.4] Testimonial: Robert Luckwell, Water Quality Scientist and Sampling Technician Manager, Bristol Water.

[5.5] Testimonial: Dr Jenny Banks, Technical Specialist, Yorkshire Water Service Ltd.

[5.6] Testimonial: Graeme Moore, Senior Programme Manager for Water Research, Scottish Water.

[5.7] Testimonial: Frank White, Drinking Water Inspectorate (DWI).

[5.8] Presentation by Adam Bosch, Director of Public Affairs, The Bureau of Water Supply. New York City Department of Environmental Protection.

[5.9] Testimonial: Lori Emery, Director of Water Innovation and Research, The Bureau of Water Supply. New York City Department of Environmental Protection.

[5.10] Testimonial: Brazilian Water Research Centre in conjunction with Sanasa Water Company, Brazil.