Institution: University of Sheffield

Unit of Assessment: 14 - Civil and Construction Engineering

Title of case study: Management of discolouration in drinking water distribution systems.

1. Summary of the impact

Research, undertaken at the University of Sheffield since 2001, into the discolouration of drinking water occurring within distribution systems has had economic, policy and professional practice impacts on the water supply sector since 2008. This has resulted in improved levels of service, has safeguarded water quality delivered to the public and has delivered substantial economic savings. For example, in one of the few cases where monetary value is available, Wessex Water made 63% savings on two trunk main schemes with an initial estimated cost in excess of £1M. The 4 and 7 km lengths of these trunk mains represent less than 1% of the trunk mains being impacted by our research. Our research has resulted in a step change in the concept and approach to the management of discolouration in water distribution systems.

2. Underpinning research

Discolouration is the single biggest cause of customer contacts related to drinking water quality. Research undertaken exclusively at the University of Sheffield since 2001 has proposed, developed, validated and applied a novel approach to the conceptual and practical understanding of discolouration in drinking water distribution networks. This has led to new operational and management strategies and has seen the development of the PODDS model for the Prediction and management Of Discolouration in Distribution Systems. The research initially proposed a unique concept for understanding discolouration in potable water distribution networks. Rather than considering gravity driven sediment transport processes, as in river environments, PODDS considers the build-up of discolouration material on pipe walls as cohesive layers and describes how these layers interact with hydraulic conditions to dictate material behaviour. This step change has its basis in the analysis and characterisation of material responsible for discolouration undertaken by Saul, Skipworth and Boxall. This initial analysis was fundamental to the 3-year PODDS 1 project funded by the EPSRC in 2001 (GR/R14101/01). Subsequently, a consortium of water companies has funded, in the form of 'club contracts', a further 3 rounds of completed research PODDS II – IV, thereby illustrating the importance, timing and impact of the research to industry.

PODDS 1, 2001-2003, included detailed research into material characterisation, model formulation and initial validation through fieldwork, as presented in [R1]. From 2002 onwards Boxall led the research supported by Husband. Following the completion of PODDS 1, the benefit and practical potential of the new approach and modelling tools were recognised by industry and this led to PODDS II, 'Realising the potential of the PODDS model for the UK water industry', 2004-2006. This research resulted in a national validation of the conceptual approach through extensive field studies and the initiation of supporting controlled laboratory based experiments to fully verify the approach [R2]. Subsequently, PODDS III, 'Managing Discolouration: Research informing practice', 2007-2009, enabled the development of risk based computational tools, repeat testing of field sites to explore the impact of asset deterioration, the development of an internationally leading full scale temperature controlled laboratory facility and initial exploration of discolouration issues associated with trunk mains. Key practical results were published in [R3] and later these and further deterioration studies were reported in [R4].The role and importance of discolouration in trunk mains was recognised and led to PODDS IV, 'Discolouration in trunk mains'. 2010-2013. Here attention was firmly focused on trunk main applications with further fieldwork to understand and predict long term performance and to inform management decisions, as reported in [R5].

When the original PODDS EPSRC funding proposal was written, the decision was made that any software developed with public funding should be open source. Hence there is no revenue stream associated with the software. The PODDS modelling tool was developed and incorporated into the United States Environmental Protection Agency freeware software, EPANET. The calculation engine and functionality of EPANET are recognised as internationally leading, globally applied in research and practice and provided the ideal opportunity to ensure that the discolouration research was recognised as world leading and internationally relevant. For example, [R6] provides evidence of application to Australian networks.

Person	Affiliation / position and relevant dates
Boxall, J B	UoS - PDRA 2001-02; L 2002-07; SL 2007-09; Prof. 2009-current
Husband, P S	UoS - RA 2002-10; PDRA 2010-current
Saul, AJ	UoS - Prof. 2001-current
Skipworth, P J	UoS - PDRA 2001-02
Whitehead, J	United Utilities – co-author, acknowledging industrial input and support
Prince, R A	Swinburne Uni. Australia - co-author, acknowledging international dataset

3. References to the research

In total 10 leading peer reviewed journal publications and over 20 presentations at international conferences have been made. * denotes best indicator of quality of research.

R1. * Boxall, J.B., and Saul, A.J. (2005) 'Modelling discolouration in potable water distribution systems'. Journal Environmental Engineering ASCE. Vol 131, No. 5. pp 716-725. doi: 10.1061/(ASCE)0733-9372(2005)131:5(716)

R2. Husband P.S., Boxall J.B. and Saul A.J. (2008) 'Laboratory studies investigating the processes leading to discolouration in water distribution networks' Water Research Vol. 42, No. 16, pp 4309-4318. doi: 10.1016/j.watres.2008.07.026

R3. * Husband, P.S. and Boxall J.B. (2010) 'Field Studies of Discolouration in Water Distribution Systems: Model Verification and Practical Implications' J. Environmental Engineering, ASCE, Vol. 136. Vol. 136, No.1, pp 86-94. doi: 10.1061/(ASCE)EE.1943-7870.0000115

R4. Husband, P.S. and Boxall J.B. (2011) 'Asset deterioration and discolouration in water distribution systems' Water Research, Vol. 45, No. 1, pp 113-124 doi: 10.1016/j.watres.2010.08.021

R5. * Husband, P.S., Whitehead, J. and Boxall, J.B. (2010) 'The Role of Trunk Mains in Discolouration' Proc. of the Institution of Civil Engineers, Water Management, Vol. 163 Issue WM8 pp 397-406. doi: 10.1680/wama.900063

R6. Boxall, J.B. and Prince, R.A. (2006) 'Modelling discolouration in a Melbourne (Australia) potable water distribution System' Journal of Water Supply: Research and Technology - AQUA. Vol. 55, No. 3, pp. 207-219. doi: 10.2166/aqua.2006.029

4. Details of the impact

The application of PODDS research has had economic impact and has promoted efficient and effective asset management. It has also had an impact on policy and practice within the water sector. The impact is based on a fundamentally new concept to describe the processes of discolouration in drinking water distribution systems, together with the delivery of operational management tools. The impact of the research has been well appreciated by [text removed for publication], as evidenced by the following quotes:

"…the conceptual approach and resulting tools and techniques from the discolouration research from the University of Sheffield have contributed to a step change in culture and practice in the [text removed for publication]" [S1, [text removed for publication]].

"…provide testimonial to the impact of the University of Sheffield discolouration research… ranging from a shift in general perception of the processes and mechanisms involved to full scale adoption of the PODDS modelling approaches and tools. Impacts from day to day operational practice and the on-ground to long term strategic. Improvements to overall levels of customer service and serviceability levels, leading to reduced levels of discolouration contacts. Improvements to operational efficiencies. Particularly evident through application of PODDS for trunk main applications." [S1, [text removed for publication]].

Process:

Delivering impact from PODDS has been a long process, but has been a key ambition from the outset. Organisations in the water sector have been actively engaged with a view to influencing both policy and practice, including running bespoke dissemination and training events. Notably in 2004 and 2007 invited presentations were made at UK Water Industry Research (UKWIR)

technology transfer workshops. The former was instrumental in gaining UK water supply sector support, the latter to set best practice standards for inclusion in Distribution Operation and Maintenance Strategies submissions in water company Asset Management Plans 2009. Perhaps the single most influential factor in ensuring impact has been the strategy for, and success of, industry consortium funding. This has ensured the generation of knowledge, tools and techniques that are practicably applicable and include wide spread programmes of fieldwork for validation.

Impact on practice and policy:

The PODDS concept, tools and techniques feature in the majority of water companies 'Distribution Operation and Maintenance Strategies', submitted as part of their 5 year Asset Management Plans to OFWAT. These sensitive strategy documents are highly confidential and hence cannot be directly referred to here [S1], however:

> *"PODDS research has had an impact on all Distribution and Operation Maintenance Strategies (DOMS) and Asset Management Plan (AMP) documents"* [S1, [text removed for publication]].

This indicates that there has been a consequential change in culture, planning and practice.

Engineering consultancy companies use PODDS to facilitate the design and planning of operational and maintenance activities and for strategic asset management planning. For example [S2] provides exemplar evidence of the use of PODDS modelling by [text removed for publication] to help [text removed for publication] provide resilient supply options following the flood risk to [text removed for publication] when 350,000 customers were without mains water supplies for up to ten days.

> *"Application of PODDS-style strategies, typically by controlled flow increases, enables networks to remain operational thereby minimising both operational costs and discolouration risk"* [S2]

[S3] provides evidence of the development and review of a strategic discolouration investment model by [text removed for publication] also for [text removed for publication]. [S3] is based on the PODDS concepts, with Boxall acting as a consultant.

Commercial software used to model distribution networks has also been impacted. For example Infoworks®, one of the most used commercial packages in the international water industry, now calculates and provides shear stress as per the PODDS model [S4].

When substantial undertakings with potential water quality implications are necessary, or when 'major' events occur, water companies are required to report to the Drinking Water Inspectorate (DWI),demonstrating planning and due diligence. PODDS has been a feature in such reports since 2005. [S5] provides an example of the use of PODDS modelling to defend and explain a recent major discolouration incident occurring in [text removed for publication] to the DWI; 760 discolouration contacts were received over three days, covering an area of approximately 60 square kilometres. Initially such application of PODDS research was directly facilitated by the researcher team. However, the knowledge and tools, with support from bespoke training given by the PODDS research group, are now embedded within water companies. PODDS has become part of the usual business process within many water companies [S1, 5, 6, 7, 8, 9]. [S6] provides an example of the use of PODDS modelling and fieldwork (using PODDS based equipment) by [text removed for publication] modelling team to plan major trunk main operational activities. This work forms the basis of reports to the DWI for undertakings relating to 20 particularly strategically important and high risk trunk mains.

> *"PODDS model was initially run so that the operational conditioned state of the system could be determined.... Modelled discolouration responses were then produced"* [S6].

Economic impact:

One of the few examples where a water company, Wessex Water, has been able to make monetary saving figures available shows immediate one-off saving of £0.6M on two schemes; one with an initial estimated cost of over £1M, a 63% saving, and one where an estimated spend of £2M was deferred indefinitely by operations costing only £0.04M [S7]. The 4, 7 and 6 km lengths of the trunk mains in these examples represent a tiny percentage of the trunk main in Wessex Water. Extrapolation of the values suggests multi million pound savings as well as service improvements and risk reduction [S7]. These figures relate solely to large trunk mains; economic impacts associated with local distribution infrastructure are un-quantified. Equivalent savings and benefits

are being made by other PODDS consortium member companies and beyond [S1, 7, 8, 9].

"*PODDS has changed the way Wessex Water thinks about managing the risk of discoloured water… providing alternative cost effective options*…" [S7]

"…*led to a fundamental change in the way [text removed for publication] understands and now operates our strategic and distribution networks in relation to the identification of risk and, therefore, prevention of discoloured water… a key business and regulatory driver… a key measure of the quality of service we deliver to our customers*" [S8]

"*PODDS theory has also created a change in mind-set in our asset strategy…directly supports the delivery of OFWATS serviceability targets*…" [S9]

The UK water sector is widely regarded as internationally leading and customer focused due to its privatised nature, as recognised by [text removed for publication].

"*[text removed for publication] are internationally leading and I am aware of international interest in and impact from the research from countries as diverse as the Netherlands to China"* [S1, [text removed for publication]].

The adoption of PODDS concepts can be viewed as a critical factor in helping water companies improve the service they provide to customers, by ensuring water is clean and safe to drink. The extent and scope of adoption of the PODDS concepts, and the implementation of tools and management approaches that use the approach, has been a key factor in ensuring that the quality of this essential service is delivered at least cost. Over the five year water industry review period since 2006 the number of consumers contacting their water supplier to report a problem with the quality of drinking water, comprising 80% discolouration issues, in their home or workplace has fallen by one- third [S10]. While many factors contribute to this reduction, PODDS is recognised as one of the most influential factors, through its widespread application and inclusion in water company Distribution Operation and Maintenance Strategies.

5. Sources to corroborate the impact

S1. [text removed for publication] testimonial to impact of PODDS.

S2. "[text removed for publication] Resilience; Conditioning Plan – Phase 1. [text removed for publication]" (2013) Consultancy report from [text removed for publication] for [text removed for publication].

S3. "Model Review and Enhancements Specification, [text removed for publication] - Phase 1 – Discolouration" (2011) Consultancy report from [text removed for publication] For [text removed for publication].

S4. http://www.innovyze.com/news/fullarticle.aspx?id=1068 [accessed 14/6/13]. Web site listing shear stress functionality [text removed for publication] as an integral part of the international industry leading hydraulic network modelling software.

S5. [text removed for publication] Document prepared by [text removed for publication] explaining and defending a major recent discolouration incident by making extensive use of PODDS.

S6. [text removed for publication] Detailed report evidencing internal water company use of PODDS modelling tools in planning major operational activities. One in a series of 20 such undertakings by [text removed for publication].

S7. Distribution Risk Manager at Wessex Water testimonial to impact on trunk main activities including numerical data for 3 trunk mains and key details for a further 8.

S8. Research and Development Manager at [text removed for publication] testimonial to impact on business process, practice and overall performance.

S9. Research and Development Manager at [text removed for publication] testimonial to impact on business process, practice and overall performance.

S10. http://dwi.defra.gov.uk/about/annual-report/index.htm [accessed 14/6/13]. DWI chief inspectors report providing data on overall discolouration performance.