Institution: University of Exeter

Unit of Assessment: 15 General Engineering

Title of case study: Informing best practice and enhancing business performance in the water sector

1. Summary of the impact

Exeter Engineering's Centre for Water Systems (CWS) undertakes internationally leading fundamental and applied research in the $500bn global water sector. EPSRC-funded research has underpinned impacts with both reach and significance in the areas of **practitioner and professional services** and **economic impact**. CWS staff have co-authored authoritative best practice guides with highly respected practitioner publishers: the Construction Industry Research and Information Association (CIRIA), the Building Research Establishment (BRE) and Spon Press. These have been widely used in the water sector, and construction and built environment sector. CWS software and knowhow have been used extensively by water service providers (such as Scottish Water) and their consultants (including SEAMS, originally an Exeter spinout) to enhance business performance by identifying efficiencies, saving costs and improving operation. Optimisation software has been made freely available and has hundreds of users worldwide including consultants and financial organisations.

2. Underpinning research

Founded in 1998, the Centre for Water Systems (http://tinyurl.com/nvgs5uv) is an internationally leading research centre within Exeter Engineering's Water & Environment Group. It is co-directed by Professor Dragan Savić FREng (Joined Exeter 1994) and EPSRC Established Career Fellow Professor David Butler (Joined Exeter 2006) and addresses current and future challenges in the sustainable management of water in cities, with particular emphasis on the development and application of artificial intelligence techniques.

Butler's research has focused on the challenges associated with how more integrated and sustainable water management can be delivered in urban developments. As part of the EPSRC-funded WaND *Water Cycle Management for New Developments consortium* (2003 – 2008), which he led and managed, Butler developed the Urban Water Optioneering Tool (UWOT), with particular application in new developments. This unique software uses multi-objective optimisation to identify promising alternative and/or composite water management strategies based on trading-off the objectives of water use, energy consumption and cost [1]. Systematic analysis allowed the benefits and drawbacks to be captured and included in best practice guidance (detailed further in section 4).

From **2008-2012**, attention turned to the challenges of retrofitting existing cities. Building on expertise developed in WaND, Butler joined the EPSRC *Sustainable Regeneration: From Evidence-based Urban Futures to Implementation* consortium as co-investigator [ii]. Plausible socio-economic 'futures' were developed together with a new assessment framework. This was used to evaluate and plan the long-term performance of a set of water management schemes for an uncertain future [2]. Insights, advice and recommendations were incorporated into published good practice guidance. In parallel research (**2009-2011**) applicable to new and existing urban areas, Butler led EPSRC's *Ashford's Integrated Alternatives consortium* [iii] in close partnership with the local delivery vehicle Ashford's Future. This work found that more integrated urban utility service provision (e.g. multi-utility service companies) could significantly enhance urban sustainability in Ashford itself and as demonstrated in a series of other cases such as London's innovative BedZed development [3]. Much of this work has fed into a key practitioner book (see section 4).

Centre researchers have a strong track record in the development and application of novel optimisation and decision support (DSS) tools applied within the water industry [4]. For example,

Savić was the principal investigator of an EPSRC-funded project *A Whole-Life Costing Approach to Distribution Network Management* (1999-2001) [iv] which produced a decision-support methodology that links underground asset costs to performance. The main CWS contribution was to develop a number of key performance indicators and deterioration models which were integrated into the decision support tool *WiLCO*, to guide water utilities in developing pipe rehabilitation priorities [5]. This was followed by a companion EPSRC-funded project, also led by Savić, to extend and further develop the methodology for sewer systems (2003-2005) [v]. An asset deterioration modelling tool based on a novel data-mining approach (Evolutionary Polynomial Regression, EPR) was also developed and shown to outperform other approaches for developing relationships between underground asset attributes and probability of failure [6]. The resulting impact has been considerable as explained in section 4.

CWS researchers were also co-investigators of the multidisciplinary EPSRC-funded consortium Neptune (**2007-2010**) [vi]. The project, co-funded by industrial partners Yorkshire Water, United Utilities and ABB Ltd, developed and tested new methodologies to support real-time decision-making for operators of water distribution systems dealing with a variety of anomalies (pressure and flow) with a primary focus on pipe bursts. A new prototype DSS was developed by CWS to analyse, process and present data efficiently, enabling the operator to reach timely and informed decisions (see Section 4).

3. References to the research

1. Makropoulos, C.K., Natsis, K., Liu, S., Mittas, K.& Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management, *Environmental Modelling and Software*, **23**, 12, 1448-1460 **
2. Farmani, R., Butler, D., Hunt, D., Memon, F., Abdelmeguid, H., Ward, S. & Rogers, C. (2012). Scenario based sustainable water management and urban regeneration. *ICE Engineering Sustainability*, **165**, ES1, 289–98.
3. Shirley-Smith, C. & Butler, D. (2008). Water management at Bedzed – Some lessons, *ICE Engineering Sustainability*, **161**, ES2, 113-122. **Trevithick Fund award for the best paper on sustainability.**
4. Savić, D.A., Bicik, J., Morley, M.S. (2011). A DSS generator for multiobjective optimisation of spreadsheet-based models, *Environmental Modelling & Software*, **26**, 5, 551-561. **
5. Engelhardt, M., Savić, D.A., Skipworth, P., Cashman, A., Saul, A.J. & Walters, G.A. (2003). Whole life costing: application to water distribution networks, *Water Science and Technology: Water Supply*, **3** 1–2, 87–93
6. Savić, D.A., Giustolisi, O., Berardi, L., Shepherd, W., Djordjevic, S. and Saul, A. (2006). Sewers Failure Analysis Using Evolutionary Computing, *ICE Water Management,* **159** 2, 111-118. **

** Papers that best indicate quality of underpinning research.

Grant support related to this research

i. Butler, D. (PI), *Water cycle management for new developments: WaND*, EPSRC GR/S18373/01-02, £2,471,328; Industry, £76,000, April 2003 - March 2008.
ii. Butler, D. (CoI) *Sustainable regeneration: From evidence-based urban futures to implementation*, EPSRC EP/F007426/01, £3,148,359, May 2008 – April 2012.
iii. Butler, D. (PI), Ashford's integrated alternatives, EPSRC EP/F04819X/01, £502,743, April 2009 – March 2011.
iv. Savic, D (PI) *A whole-life costing approach to distribution network management*, EPSRC GR/M16115/01, £131,906, January 1999 - December 2001.
v. Savic, D (PI) *A whole-life costing approach to sewerage*, EPSRC GR/R98617/01, £144,581, February 2003 – October 2005.
vi. Savic, D., Butler, D. (CoI) *Delivering sustainable water systems by optimising existing infrastructure via improved knowledge*, understanding and technology - project NEPTUNE, EP/E003192/1, £2,326,981, March 2007 – Sept 2010.

4. Details of the impact

Impact on practitioners and professional services

CIRIA's Guidance on Water Cycle Management for New Developments: The **2010** guide [a] was produced as an outcome of the WaND project [i]. It summarises and distils extensive research from CWS [1], to meet the urgent challenge of how to provide water services for new housing developments in water-stressed areas. The report was guided by a steering group with representatives from government bodies (e.g. Environment Agency), consultants (e.g. Arup) and water companies (e.g. Thames Water). It is widely used by practitioners in construction and the built environment, a sector with a gross value added of £89.5bn amounting to 6.7% of the British economy in 2011.

BRE's Designing Resilient Cities. A Guide to Good Practice: The **2012** Guide [b] sets out a framework for implementing robust, future-proofed solutions for urban regeneration. It was the key outcome of the industry-guided Urban Futures project [ii] and four of the case studies included are specifically derived from CWS research [2]. The guide is unique in supporting city planners, councillors, architects and their consultants to redesign cities to be sustainable whatever the future holds. For example, multinational construction and engineering firm CH2M HILL is using the future scenario framework for "key future projects", and is influencing the sustainability planning of cities across the world [c].

Spon's Urban Drainage: This book [d] was originally conceived as a text for students which may also be of use to practitioners. However, it has also been widely taken up and used by professionals. For example, unsolicited Amazon customer comments include: "Essential reading for any drainage *engineer* (or those aspiring to become one). The best text for UK drainage design and *practice"*; "A good value for money book that should be on the shelf in every consultant's *office*"; "I have just bought the book as the *office* copy is frequently borrowed" [e]. In the third edition (**2011**) the chapter, 'Towards sustainable water management' draws on research from completed projects [i], best practice [a] and CWS's published research findings [1, 3]. The book has sold 5000+ copies worldwide, considered to be 'very good' for a specialist text [f].

Economic impact: enhancing business performance by uptake and adoption of CWS hydroinformatic software

Asset management: The Centre's EPR sewer deterioration model [6] has been data validated by an industry funded research project [g] and subsequently widely used to model water asset deterioration and to develop infrastructure risk models for the water industry price review process PR09 (**2009 - 2014**). Users include Anglian Water, South West Water (in collaboration with Mouchel), Severn Trent Water (in collaboration with RPS Water) and Wessex Water. In 2002, the Universities of Exeter and Sheffield span out the company SEAMS. Today (**2013**) the company has an annual turnover of £3.4m and is the industry leader in software and analytic services for asset investment planning decisions [h], still using the WiLCO software [5] developed by the Centre. For example, SEAMS used WiLCO extensively to support Scottish Water's £1.1bn strategic infrastructure investment decisions for their PR09 business plan [i]. Benefits were not only the transparency of the decisions made under strict audit conditions but also that the approach identified significant efficiencies of up to 15% over the utility's own investment plans.

Infrastructure operation: The Neptune project [vi] decision-support system developed by CWS improves real-time fault management of water distribution networks. The system takes advantage of intelligent computational methods and tools applied to real-time logger data providing pressures, flows and tank levels at key locations to allow managers to assess and respond to service provision risk. The prototype was tested on networks in Yorkshire Water (**2009-2010**) and was so successful, it is now (**2013**) being customised for United Utilities via a TSB Knowledge Transfer Partnership. This methodology has been granted a **2009** patent [j] and this was subsequently sold to project partner ABB Technology.

Optimisation software & studies: The optimisation software GANetXL [4] has been developed and

perfected by the Centre since **2008** and has over 400 users worldwide including consultants (e.g. Mouchel), financial institutions (e.g. JP Morgan) and industrial research organisations (e.g. SCION Research). The software provides easy access to evolutionary, multi-objective optimisation algorithms for non-specialists. It has recently (**2012**) been used by consultants AECOM for South West Water to optimize successfully sewer rehabilitation planning considering costs, structural improvements and critical risk of failure. Cost reductions of almost 50% have been demonstrated compared with original estimates of £4-5m per annum spend [k].

5. Sources to corroborate the impact

a. CIRIA best practice guidance document: Butler, D., Memon, F.A, Makropoulos, C., Southall, A., Clarke, L (2010). *WaND. Guidance on Water Cycle Management for New Developments*, Construction Industry Research & Information Association Rep 610. ISBN 978-086017-690-9.

b. BRE good practice guidance document: Lombardi, D.R., Leach, J.M., Rogers, C.D.F. eds. (2012). *Designing Resilient Cities: A Guide to Good Practice*, IHS Building Research Establishment Press. ISBN-10: 1848062532 | ISBN-13: 978-1848062535.

c. How Urban Futures Influenced the Design Decisions of Cities around the World. Quote from CH2M Hill European Head of Sustainability (2012): http://www.urbansustainabilityexchange.org.uk/media/ISSUES%20Outputs/BS%20Success%201/urban%20futures.pdf.

d. Spon practitioner guide and reference: Butler, D. & Davies, J.W. (2011). *Urban Drainage*, 3rd Edition, Spon Press, London. ISBN 0-203-84905-1.

e. Amazon reviewer quotes (2013) indicating professional uptake: http://www.amazon.co.uk/Urban-Drainage-Third-Edition-Spon/dp/041545526X.

f. Corroboration of 2013 sales figures for Urban Drainage by Spon Press Senior Editor.

g. UK Water Industry Research Report *Deterioration Rates of Sewers* (2006) UKWIR Report Ref No. 06/RG/05/15, www.ukwir.org/web/ukwirlibrary/91085 ISBN:1 84057 411 9.

h. Letter (2013) from the Science Director of SEAMS indicating research impact (PDF).

i. News item reporting long term use of WiLCO software by SEAMS. A Regulatory Framework Case Study; Scottish Water – water and wastewater investment programme http://www.seamsltd.com/index.php/a-new-regulatory-framework.html.

j. Patent. Savic, D., Kapelan, Z., Morley, M., Vamvakeridou-Lyroudia, L., Bicik, J. & Awad, H. (2009). *Water Distribution Systems* (WO2010061157, Filing date: 19 May). https://www.google.co.uk/patents/WO2010061157A1

k. Letter (2013) from AECOM Director indicating impact of research (PDF).