Institution: University of Portsmouth		
Unit of Assessment: UoA 12: Engineering		
Title of case study: Providing environmental and commercial benefits through the implementation of novel wastewater treatment technology		
Period when the underpinning research was undertaken: 2001-2020		
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:**
John Williams	Professor	12/09/1988 - date
Mark Gaterell	Professor	15/09/2014 - date
David Hutchinson	Innovation/Impact Manager	01/01/2010 - date
Fay Couceiro	Senior Research Fellow	01/04/2008 - date
Muhammad Ali	Senior Lecturer	16/08/2010 - date
Period when the claimed impact occurred: 2013-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

UoP research has led to the development and implementation of water management technologies. New treatment technologies and site modelling implemented by a major UK water company improved wastewater treatment performance giving enhanced environmental protection and substantial cost savings. Increased performance of novel and enhanced package sewage treatment plants has reduced cost and stimulated commercial growth of SMEs. Research on blue-green water management systems has informed policy, improved environmental protection and provided commercial benefits to industrial collaborators. Lastly, novel soil washing technology has been developed and applied to achieve large scale hydrocarbon remediation at industrial sites.

2. Underpinning research

UoP research has led to the development and implementation of novel wastewater technologies. Research is undertaken at our unique Environmental Technology Field Station (ETFS) or at real-world sites to understand wastewater treatment processes through a combination of fundamental science and engineering approaches. The body of research underpinning the impact is across four technologies in particular:

- Conventional Small waste-water treatment works (WwTW)
- Package treatment plants
- Sustainable Drainage Systems (SuDS)
- Novel materials in combination with natural systems for wastewater treatment

The team apply a range of approaches, for example: focusing on specific pollutants (e.g. phosphorous, hydrocarbons), optimising design and operation, and/or demonstrating the efficacy of technologies in real-world settings.

The UoP ETFS is a unique facility located at a waste-water treatment works which was extensively upgraded in 2015 with a UoP investment of over GBP150,000. Pumped sewage supplies from various WwTW stages allow research at operationally relevant pilot-plant scales. Test bed facilities, including a 20m greenhouse and dedicated laboratories, also allow environmental technologies and monitoring to be assessed at scales and intensities relevant to real world applications. The overarching objective of the multidisciplinary research is to characterise high variable environmental technologies and systems with extensive multivariate monitoring. This alongside detailed mechanistic studies contribute to the design and operation codes for improving the performance of environmental technologies.

Research using large-scale pilot plants at the ETFS currently involves industrial collaborations with the regional water utility Southern Water (SW) (G1) and WPL Ltd (G3, G4). Research with SW encompasses several technologies that address their current Research & Development (R&D) concerns such as increasing the technological options for phosphorus (P) removal from effluents, especially at their hundreds of small waste water treatment plants. Discharge consents are becoming more strict and commonly used options to mitigate negative environmental impacts

at large sites, such as chemical (ferric) dosing, pose significant operational challenges at smaller sites, making the same interventions economically unsustainable. A potential alternative is to use granular materials that can remove P from wastewater, utilising mechanisms such as precipitation and adsorption, through passive filters. A key piece of research with SW has therefore been improving the understanding of the kinetics of phosphorous attachment to these "reactive media" through large-scale long-term comparative studies of different media, using real sewage, rather than laboratory simulations (G2). This has highlighted the interaction of uptake rates and ultimate uptake capacity over various flow regimes and hydraulic residence times. This has been augmented by characterisation of deposits using advanced imaging and analysis techniques at the UoP (XRD, XRF, SEM-EDAX) to inform understanding of the mechanisms and potential for nutrient recovery (R1). Some of these materials increase effluent pH, so passive pH correction experiments have also been undertaken to allow these effluents to be released. Other studies with SW have examined immobilised bacteria for P removal and novel methods for optimising and diagnosing WwTW operations, based on modelling and analysis of historic data to improve treatment performance and inform future treatment requirements (R2).

Collaborative R&D with WPL has been in operation throughout this REF period (G3, G4). WPL Ltd provide a range of products and services to the water sector including "package" wastewater treatment plants, where a series of processes in one container provide treatment solutions typically used at small WwTP or where mains sewerage is not available. The application of these technologies are deployed around the world in low, middle and high income countries. Their long established submerged aerated filter range has been refined through a series of monitoring full-scale units installed at the ETFS and operated under modified aeration patterns and various internal configurations. This has informed the development of numerical models to develop optimised aeration and design strategies to reduce energy use.

The group has a >40 year track record of research into blue-green water technologies in the UK and overseas, particularly focussed on using wetland plants to promote treatment (R3, R4, R5, R6). In addition, our focus on wetlands has extended to Sustainable Drainage Systems (SuDS) and the research at the ETFS has focussed on characterising pollutant removal in vegetated systems. The international consultancy Mott MacDonald and the Highways Agency funded a study of detention ponds to manage flows and treat runoff from trunk roads. This assessed treatment performance and the fate of metals and hydrocarbons, through intensive multivariate monitoring of field systems. This characterised accumulation rates and speciation of metals that were uncertain at the time and key to long term management and performance (R4). Research into the treatment performance of SuDS in housing developments (with infrastructure consultancy Mayer Brown Ltd and the Environment Agency) demonstrated the pollutant removal capacity of swales and vegetated ponds, particularly for metals and hydrocarbons (G5, G6). Following these field studies, modelling studies used computational fluid dynamics to examine how pond geometry can enhance sedimentation, and the understanding of Poly-cyclic Aromatic Hydrocarbon removal rates in swales was enhanced through monitoring a 10m greenhouse model fed with simulated storms mimicking polluted road runoff. The various economic, policy and social barriers to SuDS uptake in England were investigated in a NERC Green Infrastructure Innovation project, ProSuDS (R5, G7), which included evaluation of residents' perceptions (R5). Studies of hydrocarbon treatment in SuDS have also been extended to phytoremediation studies of contaminated land (R6, G8).

3. References to the research

(R1) Benzing. S, F. **Couceiro, F**., Barnett, S., **Williams, J.B**., Pearce, P. & Stanford, C. (2020). Impact of hydraulic retention time on phosphorus removal from wastewater using reactive media. *Water Science and Technology, 82*(12), 2920-2928. https://doi.org/10.2166/wst.2020.526

(R2) Holloway, T.G. **Williams, J.B**., Ouelhadj, D., & Cleasby, B. (2021). Process stress, stability and resilience in wastewater treatment processes: A novel conceptual methodology, *Journal of Cleaner Production, 282*, 124434. https://doi.org/10.1016/j.jclepro.2020.124434

(R3) Stefanakis, A.I., Bardiau, M., Trajano,D., **Couceiro, F., Williams, J.B. &** Taylor, H. (2019). Presence of bacteria and bacteriophages in full-scale trickling filters and an aerated constructed

wetland. *Science of The Total Environment, 659*, 1135-1145. https://doi.org/10.1016/j.scitotenv.2018.12.415

(R4) Pontier, H., **Williams**, J.B., & May, E. (2004). Progressive changes in water and sediment quality in a wetland system for control of highway runoff. *Science of the Total Environment, 319*(1-3), 215-224. https://doi.org/10.1016/S0048-9697(03)00410-8

(R5) **Williams**, J.B., Jose, R., Moobela, C., **Hutchinson**, **D.J**., Wise, R. & **Gaterell, M.** (2019). Residents' perceptions of sustainable drainage systems as highly functional blue green infrastructure. *Landscape and Urban Planning, 190*, 103610. https://doi.org/10.1016/j.landurbplan.2019.103610

(R6) Pinchin, H., **Williams, J.B**., May, E, Mant, C., & Hodkinson, B. (2012). *In situ* and microcosm investigations into the phytoremediation of hydrocarbon contaminated lagoon sediments using *P. australis*. *Journal of Environmental Engineering, 139*(4), 488-495. http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000591

Statement in support of underpinning research quality

Underpinning research programmes are either original research or research-led innovation studies employing robust design and appropriate techniques, data analysis, and interpretation. These are supported by external funding, either directly from industry or competitively awarded, peer-reviewed funding. All references (R1-R6) are published in relevant peer-reviewed academic journals: R2, 3 and 5 are returned to REF 2021.

Research grant funding

(G1) **Williams, J**. & Couceiro, F. *Innovation Hub for Evaluation of Technologies & Associated Mechanisms for Compliance and Optimal processes in Water and Wastewater*. Funded by Southern Water Services Limited, May 2017-April 2020, (GBP1,302,000).

(G2) **Williams, J.** *Assessment of Phosphorus Removal Technologies*. Funded by Southern Water Services Limited, October 2016-March 2020, (GBP63,998).

(G3) **Williams, J**., & **Couceiro, F.** *Improved Energy Performance for HiPAF Sewage Treatment*. Funded by WPL Ltd, February 2018-January 2021, (GBP103,000).

(G4) **Williams, J**. *KTP - WPL Ltd*. Funded by Department of Trade and Industry and WPL Ltd, June 2004-June 2008, (GBP209,832).

(G5) **Williams, J** & Mant, C. *KTP Mayer Brown Ltd*. Funded by the Technology Strategy Board and Mayer Brown Ltd, May 2008 -May 2010, (GBP89,100).

(G6) **Williams, J**. *Sustainable urban drainage systems for pollution control*. Funded by the South East England Development Agency, January 2008-September 2008, (GBP17,088).

(G7) **Williams, J.**, Moobela, C., **Gaterell, M**. & **Hutchinson, D.** *PROSuDs: Providing Real-world Opportunities for Sustainable Drainage Systems*. Funded by the Natural Environment Research Council, January 2016-September 2018, (GBP100,453).

(G8) **Williams, J**. *Phytoremediation of Horsea Lagoon*. Funded by the Ministry of Defence, February 2007-February 2013, (GBP42,000).

4. Details of the impact

Introduction

Research undertaken at the ETFS has underpinned the development and application of novel wastewater technologies leading to significant commercial and environmental benefits within the REF period. This impact is demonstrated through five key strands:

1. Improved performance and cost savings for a major UK water company;
2. Influencing national policy for the implementation of SuDS;
3. Economic growth and job creation for UK SMEs;
4. Innovation and new product/service for Kuwaiti energy technology company;
5. Environmental and amenity benefits through strands 2-4.

Background: Impact through industrial collaboration

A major component of our impact has occurred through collaborative, industrially funded research investigating wastewater treatment mechanisms and performance. Our research has provided an evidence base for improvements to the performance or efficiency of the technology, essentially underpinned by our research contributions that have led to a more complete understanding of the underlying treatment processes, and also the development of independently assessed evidence that can further support the adoption and commercialisation of the technology. This is valuable for SME innovators, as the UK wastewater industry is traditionally risk adverse and requires robust evidence before adopting new technologies.

Impact strand 1: Improved performance and cost savings for a major UK company

The University's long term strategic partnership with Southern Water (SW) led to "The Hub" being established at the ETFS in 2017. The University employs 2 dedicated full-time scientific officers at The Hub to carry out research onsite and act as a bridge to the research expertise and facilities at the University of Portsmouth thus expanding the R&D capacity of SW. This research has focussed on assessing phosphorus (P) removal from effluents, particularly for small WwTP where increasingly tight discharge consents challenge the efficacy and economic viability of conventional technologies. Southern Water operates 367 WwTW, of which 224 serve ≤2,000 people and 136 ≤500. Installing the most common P solution, chemical dosing, could cost over GBP100,000 for each site requiring significant investment and increased costs for customers. A number of technologies have been evaluated to increase SW's approved list of options, to date this has involved practical research studies into treatment options for P removal such as enhanced dosing/coagulation, electrocoagulation and immobilised bacteria at both the laboratory and pilot plant scales. These studies have resulted in systematic technical reports used by SW in investment decisions and provided design guidance to SW's Engineering and Technical Services informing in-house design of WwTP. SW stated: **"Research outcomes and other support provided by The Hub have increased our options to meet future regulations and reduced our reliance on existing, highly expensive, solutions"** (S1). Furthermore, data from these and other studies conducted by the team underpinned new models that enabled simple visualisation of stress to wastewater treatment plan informing operation and capacity at WwTW. This work led SW to a saving of GBP8,500,000 on plans for future investment. SW stated: **"The Hub provided an intensive monitoring campaign, analysis and calibration of modelling to assess process resilience in real time, which provided realised capital benefits of GBP8.5million**" (S2). SW has also benefited from the contributions that the publicity, conference presentations and academic papers resulting from the collaboration make to its Public Relations strategy, by demonstrating its commitment and investment in improving environmental performance and process efficiency to customers and regulators (S2).

Impact Strand 2: Influencing national policy for the implementation of SuDS

Our research in the use of wetlands and sustainable drainage systems (SuDS) has promoted the national use of nature-based solutions for improving water management; adding to the stock of validated case studies that demonstrate the value of SuDS to policy makers and informing design guidance for pollutant removal. This influenced the 2006 policy of the Highways Agency (Design Manual for Roads and Bridges: Vegetated Drainage Systems for Highway Runoff (DMRB HA 103/06 (S3)), that has seen wider uptake of vegetated SuDS on the road network in the period 2013-2020 (S4). Highways England stated: **"This work influenced our policy and informed past and current practice in relation to road runoff control in vegetated systems. Vegetated detention pond systems are now an integral part of highway design and the runoff management treatment providing enhanced environmental protection for many watercourses."** Major infrastructure projects in this period (e.g. A1, A14 improvements) have included vegetated drainage systems designed in accordance with DMRB HA 103/06.

Impact Strand 3: Economic growth and job creation for SMEs

A number of SMEs have also exploited the research expertise and ETFS test facilities to develop novel package sewage treatment plants and improved performance, and therefore competitiveness of existing products. The strongest example of this is the long term collaboration with WPL who, in addition to large scale installations for water utilities, provide package sewage

treatment plants to homes and communities not connected to the main sewerage network. The company has used the outcomes of research collaboration to develop a novel package technology for sludge management and made several refinements to the design of the aeration systems of the HiPAF Submerged Aerated Filters that have maintained the competitiveness of this well established technology; WPL sell >50 plants a year ranging in scale from 150 to 1,000 population. WPL stated: ***"The research has supported the growth and economic prosperity of a local SME contributing to over GBP3million of sales and an estimated 20 jobs in the supply chain."*** (S3). Another SME, Mayer Brown Ltd, exploited the outcomes of our SuDS research to secure new clients. Our research validated the performance of their vegetated SuDS designs in housing developments. This led to commercial benefits in the form of increased sales in the REF period (estimated GBP300,000) (S5).

Impact strand 4: Innovative new product/service for Kuwaiti energy technology company

The team developed expertise in green-blue water technologies for the removal of hydrocarbons (R6). This expertise was developed further through a Kuwaiti government funded PhD that developed a novel soil washing technology using bio-surfactants from natural products and ultrasound. This ex-student has since patented the process in the US and Gulf States (US10072469B2 (S6) and GC0006708 (S7)). The technology has been through several stages of scale-up trials in collaboration with the Kuwait Institute for Scientific Research. The technology has been certified for full-scale use by the Kuwait Oil Company and has so far remediated a decommissioned oil production facility and a refinery. The technology is now being applied to other contaminated sites significantly contributing to environmental protection (S8).

Impact strand 5: Environmental and amenity benefits

In addition to the commercial and policy benefits there is a significant environmental benefit arising from the implementation of the technologies described in impact strands (IS) 2 to 4: SuDS built to design standard DMRB HA 103/06 in the period (IS2), small-scale WwTP installed by WPL Ltd (IS3), and the two field sites for the novel hydrocarbon remediation (IS4). Benefits are reduced pollution, and enhanced ecological and amenity quality in natural water bodies.

5. Sources to corroborate the impact

(S1) Letter of support Southern Water

(S2) Letter of support from WPL Ltd

(S3) Design Manual for Roads and Bridges

(S4) Letter of support Highways England 30/11/2020

(S5) Letter of support Buckland Developments

(S6) US patent US 2017/0136504 A1: Meshari AlMutari

(S7) Gulf States Patent GC0006708: Meshari AlMutari

(S8) Letter of support Enertech Holding Company Kuwait 13/12/2020