Institution: University of Salford

Unit of Assessment: 12

Title of case study: Providing sustainable solutions to create global wetland systems

Period when the underpinning research was undertaken: January 2011 – December 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:
DProf. DProf. Prof. Prof. Dr Dr Miklas Scholz	Professor and Chair in Civil Engineering	October 2010 – Present
Dr Yu (Wayne) Wang	Lecturer in Civil Engineering	August 2007 – Present

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Water pollution, flooding, droughts and poor agricultural practices are damaging ecosystems and presenting challenges related to food security and human wellbeing. University of Salford research has demonstrated that a nature-based solution of planted wet aggregate is a means to address these issues. This novel integrated constructed wetland system approach also helps transform vulnerable landscapes into sustainable and resilient environments. Professor Scholz's research findings have been widely recognised, internationally funded and utilised worldwide. This is mirrored in (i) the incorporation of wetland research findings into (inter-)national guidelines, policy and legislation by organisations such as DEFRA and the Environment Agency; (ii) industry exploitation of findings leading to newly implemented systems that have improved the natural environment in the UK, Europe and Asia; and (iii) the shaping of knowledge and public attitudes towards the role of wetlands.

2. Underpinning research

2.1. Engineering science context

Natural wetlands are essential features in the landscape because they provide beneficial services for humans, fisheries and wildlife. These functions include improving water quality, mitigating climate change, delivering fish and wildlife habitats, storing storm water and maintaining sufficient surface water flow during dry periods.
Constructed wetlands mimic natural ones and are cost-effective natural treatment technologies for purifying wastewater streams (e.g. domestic, industrial and storm water) with low operational, maintenance and management costs. They can store large volumes of water, are aesthetically pleasing and attract wildlife. Some sustainable drainage and retention basin systems have been formed through constructed wetlands and they can also support opportunities for recreation, education and research.

2.2. Research focus and themes

Salford's research focuses on wetland systems in close collaboration with both national and international partners to provide case studies and scientific support in diverse areas such as ecology, microbiology, computer science and sociology. The body of research has been summarised in textbooks and peer-reviewed journal paper publications including **3.1 – 3.8**. The output indicates the transformation of traditional landscapes into *sustainable and resilient environments* supported by wetland system engineering. Our research on urban water management challenges has received major international funding such as a Water JPI 2018

grant entitled RainSolutions (led by Scholz and hosted by Lund University, with University of Salford as a collaborating institution) of over GBP1,300,000 and an ongoing H2020 WATERAGRI project worth GBP6,300,000. The following research themes **[2.3 – 2.5]** reflect the areas in which Salford has contributed to the development of pioneering engineering solutions:

2.3. Sustainable drainage innovations
We developed with Heidelberg, Hanson and Marshalls a *combined ground source heat pump and permeable pavement system* representing the next generation of drainage systems to support the *water-energy nexus*. The systems treat storm water, which is either recycled or used to recharge groundwater. Nearby buildings are heated in winter and cooled in summer **[3.1]**.

2.4. Wetland design and management
Water pollution, flooding and drought challenges have been addressed with our internationally leading research on wetland systems. Due to the wide reach and depth of the research, a step change in water resources practices has occurred. With the Irish Department of Environment, we developed the *integrated constructed wetland* (ICW) concept of man-made wetlands that blend into the landscape **[3.2, 3.3]**. This comprises guidance on addressing water quality and quantity problems **[3.4]** and provides ecosystem services. Our research on *planning, design* (e.g. hydraulic loading rate **[3.2]**, modelling **[3.5]**, planting **[3.6]** and clogging **[3.7]**), *implementation, management and monitoring* of wetland systems has led to the incorporation of corresponding findings into international guidelines on wetland systems.

2.5. Retention basin management
We developed the concept of the *sustainable flood retention basin* (SFRB), which has at its heart a waterbody that has both flood and diffuse pollution control functions **[3.2, 3.7, 3.8]**. Our concept has dual advantages. Firstly, it includes guidance material addressing water quality and quantity challenges. Secondly, it integrates systems into the landscape, providing ecosystem services and economic and social benefits as a result. Key contributions of partner institutions relate to access to funding (European Union and Swedish Government Agency (VINNOVA)), experimental sites and manpower in terms of analytical services and sampling efforts in Scotland, England, Germany (University of Freiburg) and Sweden (Lund University).

3. References to the research

3.1. Tota-Maharaj K. and **Scholz M.** (2012), Artificial neural network simulation of combined permeable pavement and earth energy systems treating storm water, *Journal of Environmental Engineering,* 138(4), pp. 499-509. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000497
3.2. Dong Y., Wiliński P., Dzakpasu M. and **Scholz M.** (2011), Impact of hydraulic loading rate and season on water contaminant reductions within integrated constructed wetlands, *Wetlands*, 31(3), pp. 499-509. https://doi.org/10.1007/s13157-011-0176-5
3.3. Dzakpasu M., Hofmann O., **Scholz M.**, Harrington R., Jordan S. N., and McCarthy V. (2011), Nitrogen removal in an integrated constructed wetland treating domestic wastewater, *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering*, 46(7), pp. 742-750. https://doi.org/10.1080/10934529.2011.571592
3.4. Sani A., **Scholz M.** and Bouillon L. (2013), Seasonal assessment of experimental vertical-flow constructed wetlands treating domestic wastewater, *Bioresource Technology,* 147, pp. 585-596. https://doi.org/10.1016/j.biortech.2013.08.076
3.5. Meyer D., Chazarenc F., Claveau-Mallet D., Dittmer U., Forquet N., Molle P., Morvannou A., Pálfy T., Petitjean A., Rizzo A., Samsó Campà R., **Scholz M.**, Soric A. and Langergraber G. (2015), Modelling constructed wetlands: scopes and aims – a comparative review, *Ecological Engineering*, 80, pp. 205-213. https://doi.org/10.1016/j.ecoleng.2014.10.031
3.6. Liu X., Huang S., Tang T., Liu X., **Scholz M.** (2012), Growth characteristics and nutrient removal capability of plants in subsurface vertical flow constructed wetlands, *Ecological Engineering,* 44, pp. 189-198. https://doi.org/10.1016/j.ecoleng.2012.03.011
3.7. Sani A., **Scholz M.**, Babatunde A. and **Wang Y.** (2013), Impact of water quality parameters on the clogging of vertical-flow constructed wetlands treating urban wastewater, *Water, Air and Soil Pollution*, 224(3), pp. 1488-1506. https://doi.org/10.1007/s11270-013-1488-2

3.8. Yang Q., Boehm C., **Scholz M.**, Plant C. and Shao J. (2015), Predicting multiple functions of sustainable flood retention basins under uncertainty via multi-instance multi-label learning, *Water*, 7(4), pp. 1359-1377. https://doi.org/10.3390/w7041359

Key associated grants:
Scholz M. (2019 **–** 2024) Water Retention and Nutrient Recycling in Soils and Streams for Improved Agricultural Production (WATERAGRI). European Union, Horizon 2020. EUR7,000,000 (ca. GBP6,300,000) (of which EUR225,000 to the University of Salford).
Scholz M. (2008 **–** 2012) Strategic Alliance for Integrated Water Management Actions (SAWA). European Union INTERREG grant - 22 partners from five countries. Overall budget GBP6,450,500 (50% EU funds), of which GBP387,100 (50% EU funds) to the University of Edinburgh and to the University of Salford (from 2010 onwards).

4. Details of the impact

By working in collaboration with partners around the world, Salford's research has led to multi-faceted impacts on wetland-related systems in the period up to December 2020 **[5.1 – 5.10]**. This is measurable in terms of incorporation of wetland research findings into both national and international guidelines, policy and legislation; industry exploitation leading to newly implemented systems; and shaping of knowledge and public attitudes towards wetlands.

4.1. Informing national and international guidelines, policy and legislation

At national level, research on permeable pavements, below-ground storage tanks, detention ponds and wetland design and management **[2.3, 2.4]** has been influential in the following ways: Scholz was part of an expert panel that conducted a systematic review on behalf of the Department for Environment, Food and Rural Affairs (DEFRA), published in 2015 **[5.1]**, which has **informed its formulation of policies regarding the benefits of wetland systems to mitigate pollution from agriculture**. Salford's findings have subsequently **been incorporated into national and international guidelines on wetland system management [see 5.2 – 5.5]**; Scholz was also a scientific advisor on an Environment Agency report in 2016 relating to *Design, Operation and Adaptation of Reservoirs for Flood Storage* **[5.2]**, which **incorporated Salford's guidelines on SFRB operation and management [2.5]** and which is designed for a range of stakeholders, including planners, developers, reservoir owners, contractors, environmentalists, educational institutions and the public to **inform good practice in the design, operation and maintenance of flood storage reservoirs [5.2]**.

At international level, with regard to **adopting sustainable drainage system findings in the construction industry**, Salford's research **[2.4]** is cited in the Global Water Partnership Central and Eastern Europe Natural Technologies of Wastewater Treatment 2014 report **[5.3]**, which specified natural ways in which water engineers could solve sanitation problems in small, neglected communities of Central and Eastern Europe; Scholz's findings are also cited in wetlands management resources published on the public information website of the Department of Environment and Science, Queensland Government, Australia in 2018 **[5.4]**. A report by the Minnesota Department of Transportation, USA, into Permeable Pavements in Cold Climates in 2015 **[5.5]** uses Salford's research **[2.3]** as part of an extensive review into permeable pavement systems in order to better understand processes and performance around this technology. This work has subsequently led to the **implementation of hundreds of novel sustainable drainage systems, including wetlands [5.6]**.

Research into wetland design and management **[2.4]** has additionally **contributed to ICW design, construction and management**, which is used by farmers to treat farmyard runoff. VESI Environmental Ltd., a company specialising in water and land services and a key contributor to the initial ICW concept, has used Salford's ongoing research to **further develop this concept in the management of a wide range of water-associated challenges** (rural, urban, industrial and mining) in the Republic of Ireland and Northern Ireland post-2013. As VESI's Senior Scientist acknowledges: '*The ICW concept is being continually developed as part*

of the on-going (since 2018) European RainSolutions grant (led by Scholz) […] This research is instrumental for the further development of the ICW concept and its practical use within Europe and elsewhere' **[5.6]**.

4.2. Improving the natural environment through newly implemented systems

Wetland treatment systems have improved as a result of the uptake of research-informed knowledge on wetland systems based on Salford's research. These findings **[see 2.2]** have contributed to the **successful sustainable management of urban and rural landscapes using wetland systems** during the impact period at locations around the world, including the UK, Europe, Australia and China **[5.4, 5.6, 5.7, 5.8]**.

As a consequence of Salford's sustainable drainage research findings **[2.3]** and design recommendations, **quantifiable impact indicators have been improved**. These encompass: (a) water quality parameters, suspended solids, nitrogen and phosphorus; (b) reduced flooding events; (c) increased house prices near the sustainable drainage systems; and (d) higher (local) visitor numbers to the nature-based solutions **[e.g. 5.5]**.

Salford's research is **standard reference material for the design and operation of wetland, pond and runoff retention systems** for engineers and scientists working for the water industry, non-governmental organisations, local authorities and governmental bodies **[5.1 – 5.4]**. New water and environmental engineering science insights in the underlying wetland processes within ICW, along with vertical-flow systems, have resulted in **authorities implementing wetland systems both for wastewater and storm water treatment**. Salford's research **[2.4]** has led to the **international implementation of novel wetland system concepts** including thousands of ICW systems. For example, more than 80 wetlands have been designed and constructed by the consultant company VESI Environmental Ltd across Ireland since 2014 alone **[5.6]**. This has made a **significant contribution to ecosystem services**, such as pollution control, biodiversity enhancements and climate change adaptation and mitigation **[5.1 – 5.4]**.

Impact indicators and **corresponding improvements** (percentages in brackets) **due to the application of the ICW concept [see 2.2]** and concerning the monitoring of thousands of new wetland systems located in the British Isles include: (a) improved water quality parameters (up to 70%) such as suspended solids (up to 50%), nitrogen (up to 70%) and phosphorus (up to 90%); (b) reduction in flooding events (up to 50%); (c) increase in house prices (up to 20%); (d) higher (local) visitor numbers (up to 100%); and (e) higher numbers (up to 200%) of birds, amphibians and insect species and total species numbers **[e.g. 3.2, 3.5, 5.1 – 5.4, 5.6]**.

Among the key beneficiaries of Salford's SFRB research are farmers: an example of this is the farmer and landowner of AB Gårdstånga Nygård in Sweden, who, based on Salford's research into wetlands and retention basins **[2.5]**, has built an SFRB for water purification and irrigation purposes and has made an **investment of EUR980,000** in the EU H2020 WATERAGRI research consortium **[5.7]**. Many SFRBs are linked to water treatment plants in which sludge is being produced. Water companies such as Evides in Belgium have benefitted from the research on sludge dewaterability technology development, confirming in 2018 that Salford's *'DET (Dewaterability Estimation Test) turned out to be the **most effective sludge dewaterability testing method** because it is very user-friendly, simple to operate, provides high reliability results and need very little operational time for determination of sludge dewaterability'* **[5.9]**.

Research undertaken at Salford and collaborating institutions (Lund University, The University of Edinburgh and University of Electronic Science and Technology of China) **[2.5]** has led to the **international implementation of SFRB [5.2, 5.8]**, with the corresponding SFRB concept being presented to the Chinese Hydraulic Engineering Society in 2015, which provided water resources managers in China with valuable guidance on flood control structures **[5.8]**.

4.3. Shaping of knowledge and public attitudes towards wetlands

Salford's research **[2.3]** has also been used creatively to bring science and engineering to the wider community. For example, a collaborative Arts Council England-funded theatre project through Shared Productions entitled *"Water is Attracted to Water"* and featuring research by Scholz, was first performed in the UK in 2019 to 64 people (audience members aged between 11 and 62), as a means of **educating the public about sustainable water management and wetland systems through an accessible medium [5.10]**. Shared Productions Company Director confirmed: '*Integrating this into a performance increases the reach of the research, but also it generates impacts in terms of public engagement, changing perceptions and building understanding and enthusiasm around science and engineering'* **[5.10]**. Participants commented that they '*[…] really enjoyed the clarity of Miklas' descriptions and insights'* and that *'the research was very interesting and eye opening and refreshing.'* One participant also confirmed that after the performance *'I have started to think about the climate crisis […] and think about what I can do practically'* **[5.10]**.

This has been followed up by a short film (funded by the H2020 WATERAGRI grant), which has attracted media interest in Sweden, Romania and Poland. There are plans to tour with the show in the future to build on this interest (currently on hold due to COVID-19).

The **wider educational benefits** of Salford's research **[2.4, 2.5]** can be felt around the world, with wetland systems workshops being held regularly in countries including the UK, China and South Africa. Audiences range from undergraduate university students to industry professionals, such as the Chinese Hydraulic Engineering Society **[e.g. 5.8]**. The farming community similarly now benefits from wetland guidelines to **educate and inform their practice both in the UK and overseas**, with one Swedish farmer stating in 2020: '*Inspired by Prof. Scholz's work […] I believe that using wetlands and ponds for irrigation is directly beneficial to all parties involved including farmers, nature and the built environment'* **[5.7]**.

5. Sources to corroborate the impact

5.1. Report: Constructed Wetlands Systematic Review - WT0989, Department for Environment, Food and Rural Affairs (January 2015), citing Scholz's input as scientific advisor throughout and in the references section (pp. 2, 15, 16, 21, 36, 40, 51, 56-60, 78) (4.1, 4.2)
5.2. Report: Design, Operation and Adaptation of Reservoirs for Flood Storage SC120001/R, Environment Agency (November 2016), citing Scholz's input as a scientific advisor in the acknowledgements and on p. 144 (4.1, 4.2)
5.3. Publication: Natural Technologies of Wastewater Treatment, Global Water Partnership Central & Eastern Europe (February 2014), referencing Scholz on p. 120 (4.1, 4.2)
5.4. Screenshot: Department of Environment and Science, Queensland Government: Wetland info web pages. Available at: https://wetlandinfo.des.qld.gov.au/wetlands/management/treatment-systems/for-agriculture/treatment-sys-nav-page/constructed-wetlands/links-and-references.html (September 2018), referencing Scholz in the references section (4.1, 4.2)
5.5. Report: Permeable Pavements in Cold Climates: State of the Art and Cold Climate Case Studies 2015-30, Minnesota Department of Transportation (June 2015), citing Scholz throughout and in the references section (pp. 41, 63, 68, 146) and the appendices (4.1, 4.2)
5.6. Testimonial: VESI Environmental Ltd., Ireland (January 2021), on the ongoing development of and investment in the ICW concept (4.1), sustainable management of urban and rural landscapes in Ireland (4.2)
5.7. Testimonial: Landowner and Farmer, AB Gårdstånga Nygård, Sweden (February 2020), as a beneficiary of SFRB and investment made in the project (4.2) and benefits to farmers (4.3)
5.8. Testimonial: Associate Professor, on behalf of the University of Electronic Science and Technology of China, China (February 2020), confirming guidance provided on flood control structures (4.2) and wider educational benefits (4.3)
5.9. Independent Report: Sludge Dewaterability Estimation, Evides Industriewater, Belgium (October 2018), referencing Salford's DET innovation in the Preface and on p. 4 (4.2)
5.10. Testimonial: Shared Productions, Greece (January 2020), on shaping public attitudes (4.3)