Institution: University of Southampton		
Unit of Assessment: 12 Engineering		
Title of case study: 12-19 Advancing Sustainable River Engineering – Mitigating Environmental Impacts on the International Stage		
Period when the underpinning research was undertaken: February 2005 – July 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:**
Paul Kemp	Professor in Ecological Engineering	February 2005 – present
Timothy Leighton	Professor in Underwater Acoustics	January 1991 – present
Paul White	Professor in Signal Processing	September 1988 – present
Suleiman Sharkh	Professor in Engineering Science	October 1990 – present
Andrew Vowles	PDRA Ecohydraulics	September 2011 – present
James Kerr	PDRA Ecohydraulics	May 2016 – present
Jasper De Bie	PDRA Ecohydraulics	June 2017 – March 2019
Frances Davis	New Frontiers Fellow in Bioengineering	February 2015 – October 2019
Tooru Tsuzaki	Experimental Officer Hydraulics	April 2014 – December 2018
Period when the claimed impact occurred: January 2014 – July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Ecological Engineering at the University of Southampton (UoS) has improved the sustainability of river infrastructure throughout the world and has achieved savings conservatively estimated to exceed GBP20 million since 2014. This has been possible through novel approaches to:

1.1 Innovative fish passage and screening to improve ecology around industrial development in Europe (UK and Netherlands), South America (Chile and Brazil) and Asia (China and Laos);

1.2 Preventing spread of invasive fish to preserve fisheries and livelihoods of thousands in the North American Great Lakes and to conserve unique species endemic to Lake Malawi;

1.3 Dam decommissioning in Europe, and North and South America to the benefit of the water supply and electricity generating industry, low income fisheries stakeholders in developing nations, regulatory agencies, and the general public.

2. Underpinning research

Globally we face unprecedented challenges in managing our freshwater resources to achieve sustainability, security and equity of supply. Assuming "business-as-usual", in 2050 the global demand for water will have increased by 55% from a 2000 baseline (OECD). Water is an essential component of our energy systems, with the generation of electricity being dependent on large quantities taken from rivers, e.g. at hydroelectric dams and power stations. This exploitation can have considerable negative consequences for other ecosystem services, such as fisheries (annually 11.9 million tonnes of fish are captured in inland waters, FAO 2014) that provide a self-sustaining source of protein for millions of people. Inland fresh waters are the most threatened of all ecosystems, being much more extensively degraded by humans than any other (Convention on Biological Diversity 2016). In light of the need to mitigate the negative impacts of freshwater exploitation, this case study focuses on the protection of water resources, particularly fisheries, in-line with the UN Sustainable Development Goals. Since 2005, researchers at UoS have achieved this by developing new approaches to enhance the sustainability of water and energy infrastructure.

2.1 Innovative fish passage and screening:

2.1.1 UoS developed a new Cylindrical Bristle Cluster (CBC) fish pass that is installed on gauging weirs to enhance passability for fish by reducing drag without impacting weir function [**3.1**]. Funded by the UK Environment Agency (EA).

2.1.2 UoS developed a behavioural rule-base of multi-species fish response to hydrodynamics associated with fishways that has proven critical to the design of the world's most innovative fish pass, the fish migration river, in the Netherlands.

2.1.3 Led by UoS in collaboration with HR Wallingford and the University of Nottingham, an integrated hydrodynamic and Agent Based Model (ABM) to predict the movement patterns of endangered European eel has been adopted by the UK and Swedish power industry. Funded by the EPSRC "Vaccinating the Nexus" programme (EP/N005961/1).

2.1.4 A novel electric deterrent has been developed at UoS to deflect European eel from power stations on the St Lawrence River, Canada and US. Funded by the US Electric Power Research Institute (EPRI 17982/01).

2.1.5 In collaboration with several South American partners the impact of rapid decompression during turbine passage has been quantified to help improve hydropower operation procedures. Funded by British Council [20181003], FAPEMIG, EU Keepfish [690857], and CONICYT, and by industry (e.g. Cemig).

2.1.6 In collaboration with the Institute of Hydroecology and the Three Gorges University (China) and the University of Concepcion (Chile) a database on the swimming performance (e.g. [**3.2**]) of a range of fish species has been created and used in the innovative design of multi-species fish passage facilities on large-scale dams on the Mekong River in Lao People's Democratic Republic.

2.2 Preventing spread of invasive fish:

Understanding of fish response to environmental stimuli and their locomotory performance, particularly of rarely studied species such as those belonging to the anguilliform group (i.e. long bodied fish such as eel and lamprey) [**3.3**], has proven essential to the development of strategies to prevent the geographic spread of invasive species. UoS has played a pivotal role in developing guidance to limit the impacts of invasive fish, including (1) the sea lamprey in the Great Lakes of the US and Canada, and (2) Tigerfish in Malawi.

2.3 Dam decommissioning:

UoS provided expertise to quantify impacts, and plan decommissioning of, redundant infrastructure that acts as barriers to fish migration. Impact has been attained in (1) the UK and Europe, (2) South America and (3) Canada. The development of a rapid barrier assessment tool enabled the creation of the first European Atlas of River Barriers as part of the AMBER project (**3.4**), which fed directly into European Policy related to the "Green Deal". The development of models to predict sediment release under varying dam removal scenarios, impact of turbines on fish passage, and hydropower planning decision support tools [**3.5**], including those based on catchment-scale optimisation approaches [**3.6**], in collaboration with the University of Kent, have informed international power companies and influenced their business development. Funded by the EU H2020 AMBER (Adaptive Management of Barriers in European Rivers – EU 689682) programme, FAPEMIG (Brazilian research council of Minas Gerais state), Cemig (Brazilian power industry), and the Canadian River Institute.

3. References to the research

3.1 Montali-Ashworth, D., Vowles, A., De Almeida, G., and Kemp, P. (2020). Use of cylindrical bristle clusters as a novel multispecies fish pass to facilitate upstream movement at gauging weirs. *Ecological Engineering* **143**, https://doi.org/10.1016/j.ecoleng.2019.105634

3.2 Newbold, L. R., Shi, X., Hou, Y., Han, D. and Kemp, P.S. (2016). Swimming performance and behaviour of bighead carp (*Hypophthalmichthys nobilis*): application to fish passage and exclusion criteria. *Ecological Engineering* **95**, 690-698. https://doi.org/10.1016/j.ecoleng.2016.06.119

3.3 Kerr, J., Karageorgopoulos, P. and Kemp, P. S. (2015). Efficacy of a side-mounted vertically oriented bristle pass for improving upstream passage of European eel (*Anguilla anguilla*) and river lamprey (*Lampetra fluviatilis*) at an experimental Crump weir. *Ecological Engineering* **85**, 121-131. https://doi.org/10.1016/j.ecoleng.2015.09.013

3.4 Belletti, B. et al. (2020). More than one million barriers fragment Europe's rivers. *Nature* **588**, 436-441. https://doi.org/10.1038/s41586-020-3005-2

3.5 Laborde , A. A., Habit, E., Link, O., & Kemp, P. (2020). Strategic methodology to set priorities for sustainable hydropower development in a biodiversity hotspot. *Science of the Total Environment* **714**. https://doi.org/10.1016/j.scitotenv.2020.136735

3.6 O'Hanley, J., Pompeu, P. S., Louzada, M., Zambaldi, L. P., and Kemp, P.S. (2020). Optimizing hydropower dam location and removal in the São Francisco River basin, Brazil, to balance hydropower and river biodiversity tradeoffs. *Landscape and Urban Planning* **195**. https://doi.org/10.1016/j.landurbplan.2019.103725

4. Details of the impact

4.1 Innovative fish passage and screening in Europe, South America and Asia

4.1.1 The UK national hydrometry network comprises over 1500 gauging weirs. The EA faces the conflicting challenge of maintaining flow monitoring capability while improving ecological status of rivers degraded by this infrastructure which disrupts fluvial connectivity. In 2018, the EA adopted the Cylindrical Bristle Cluster fish pass developed by UoS as best practice for a low-cost mitigation option for gauging weirs and their preferred "technology of choice" when ameliorating the impact of gauging weirs on fish movement. Since 2018, the low-cost design has been installed by several conservation groups, including the Ouse and Adur Rivers Trust [**5.1**], who have fitted the fish pass on multiple weirs to open up several kilometres of previously inaccessible river. Dr Peri Karageorgopoulos from the EA states that, "*It is simple to design and quick to fit. As a result the cost per site can be as little as [GBP5,000]. The alternative solution which requires a bypass of the structure can easily cost [GBP200,000-GBP500,000]. As a result we are not only making tremendous savings but we are also planning to install many more bristle passes than we could ever deliver as bypasses…… the University of Southampton have created a novel, cost effective and efficient fish pass which will help improve fish populations worldwide*" [**5.2**].

4.1.2 The Fish Migration River is the first large-scale innovative fish pass of its type under construction in the Netherlands. Funded by Nieuwe Afsluitdijk, a consortium of five regional authorities, this is the largest hydraulic engineering project undertaken in the Netherlands in the 20th Century and will set a global precedent by reconnecting the Ijsselmeer and Wadden Sea, cut-off by the 32.5 km long Afsluitdijk dam as part of the Zuiderzee Works since 1927. Since 2014, UoS has been a key participant, providing expert advice based on research experience since the early phases of the design, and ensuring that several modifications have been made to accommodate fish behaviour during the design phase. Erik Bruins Slot, the hydraulic engineering lead for the Province of Fryslân, estimates that the advice provided by UoS has saved the project between EUR5,000,000 and EUR10,000,000 and enabled planning consent to be achieved. He states "*The advice provided by the University of Southampton allowed the designs to be modified and optimised based on expert knowledge of fish behaviour. This input was essential in enabling the project to go-ahead and for appropriate funding to be secured because we could show that the design was state-of-the-art and based on sound scientific understanding*" [**5.3**].

4.1.3 In May 2017, the integrated hydrodynamic ABM to predict eel movements at power stations was validated at a hydropower site on the Motala ström, Norrköping in Sweden, enabling energy company RWE to meet regulatory requirements and continue their operations. Since then it has been used to inform planning and operation of RWE Generation plants at Tilbury and Pembroke, respectively. Dr Waygood from RWE said, "*Based on the potential shown* [in relation to the Swedish project]*, RWE Generation UK engaged with the Southampton team to further develop the ABM to predict the potential for fish to encounter intake screens on the tidal Thames*" [**5.4**].

4.1.4 Based on experiments conducted at UoS, fundamental information on threshold and behavioural response of eel to electric fields has been used by the Electric Power Research Institute (EPRI) to develop behavioural deterrents to facilitate safe downstream passage at hydropower dams for American eel on the St Lawrence River since 2017. This has enabled the industry to demonstrate compliance with regulatory requirements. Results of experiments conducted at UoS were published in an EPRI Technical Report in 2018 [**5.5**]. Paul Jacobson (EPRI) states that, "*The results are also applicable on other rivers throughout the geographic range of the American eel and the European eel, potentially saving facility owners substantial sums of money where electrical deterrence is not appropriate (more than $1.5M for field scale experimentation in the case of the St. Lawrence River) and identifying environmental settings for which further investigation is warranted*" [**5.6**].

4.1.5 As part of Cemig's (responsible for 12% of Brazil's generation and distribution of electricity) *Peixe Vivo* (Fish for Life) programme, measures to protect fish at South American hydropower plants have been advanced, and engagement with regulators and the public achieved. UoS was responsible for the transfer of knowledge related to the effects of turbine passage on fish and the mitigation of these since 2007, which has continued until today. Funded by the British Council, researchers and students from the EPSRC Centre for Doctoral Training in Sustainable Infrastructure Systems (CDT-SIS) collaborated with Brazilian partners to investigate the impacts of barotrauma on commercially important fisheries. The results helped Cemig plan the operation regimes of its plants to minimise negative environmental impacts (individual fish mortality events can be measured in

several thousand tons and result in fines of up to 50 million Brazilian Real [GBP9,750,000]). This project won the 2017 Brazilian National Odebrecht Award for Sustainable Development and Kemp gave the keynote address at a special session on dam decommissioning at the 10th Anniversary conference to celebrate the achievements of Peixe Vivo in 2018.

4.1.6 Building on the EU *Keepfish* project, UoS has developed strong links with the Chilean hydropower industry, e.g. Colbun. Student exchange, including group projects conducted by those on the EPSRC funded CDT-SIS programme in 2017, enabled the development of novel fish passage technology to protect threatened native fish species seldom previously studied. As a result, new fish passage technology has been implemented in Chile. In collaboration with Fishtek Consulting Ltd., in 2015 UoS helped design a unique fish pass installed at the Xayaburi Dam (Mekong River in Laos) that enables a high degree of flexibility to provide alternative routes for the widest variety of species. The development of a methodology for assessing fish swimming capability represented an important transfer of knowledge to initiate an ongoing programme of research that would enable the dam owners to alter the operation of the fish pass to enhance efficiency. Dr Toby Coe (Fishtek), stated that, "*The fish pass design was updated dramatically following your input into the project. It has gone from a relatively small vertical slot pass up to a very large vertical slot pass that takes fish up to a huge double fish lock/lift. …. The information gleaned for the fish swimming trials developed was used to inform the fish pass design"* [**5.7**].

4.2 Preventing spread of invasive fish

4.2.1 Sea lamprey, a parasitic fish native to the Atlantic Ocean, was introduced to the Laurentian Great Lakes system in the 1830s as a result of the construction on locks and shipping canals. The impact of this parasite on Great Lake fisheries, currently worth more than $7 billion annually and supporting around 75,000 jobs, as a result of damage and mortality was immense, resulting in significant declines in several stocks. As part of the lamprey control programme, UoS has worked closely with the Great Lake Fisheries Commission (GLFC) since 2016 to design a new "selective bi-directional" fish pass and research facility that will allow the movement of desirable fish species from the lakes into the tributary streams where they spawn, while at the same time blocking and potentially trapping the unwanted lamprey. In conjunction with this, and based on experience of running a world-class ecohydraulics laboratory, UoS has worked with the GLFC to develop a multipurpose laboratory and visitor centre (total project cost approx. $20 million) on the Boardman River in Traverse City, Michigan, with the capability to develop and test prototype fish passes and educate the public. Kemp is a member of the expert panel tasked with advising on the co-ordination of these initiatives. Andrew Muir, the Science Director of the Great Lakes Fisheries Commission states that, "*The advice provided by the University of Southampton helped inform the design criteria of FishPass based on expert knowledge of fish behavior. This input, founded on sound scientific understanding, was essential to receiving appropriate funding to complete the engineering design in 2019 and start construction in 2020*" [**5.8**].

4.2.2 In Malawi, the planned Shire Valley Irrigation Project (SVIP) is designed to provide irrigation services to 42,000ha. As part of this scheme, the main feeder canal is designed to abstract up to $50m^3s^{-1}$ of water from the Shire River and convey it via gravity to agricultural fields. SVIP will be implemented by the Government of Malawi, with external funding from the World Bank, African Development Bank, and other sources. UoS provided expert advice on methods to prevent the movement of fish from two distinct assemblages naturally separated by the 75m high Kapichira Falls. Of particular concern is the spread of Tigerfish from the Lower Shire-Zambezi ecoregion (below the falls) to globally significant and unique Lake Malawi ecosystem, with many hundreds of fish species found nowhere else. As a voracious predator, introduction of the Tigerfish could have very severe ecological consequences, including potentially the global extinction of numerous fish species endemic to Lake Malawi. Since 2017, Kemp was recruited as a member of the expert panel convened by the World Bank based on his experience with fish passage engineering. He was tasked with advising on potential options to prevent introduction of invasive species, such as the Tigerfish. Pieter Wallewijn from the World Bank stated that, "*Professor Kemp reviewed the design and made recommendations for improvements based on expertise on how different fish species are capable of movement within irrigation canal systems and crossing various types of physical barriers. While the design process is still ongoing, these insights have contributed greatly to improving the efficacy of the design for this critical issue. His advice was of high quality, very timely and provided constructive practical guidance to the designers"* [**5.9**].

4.3 Dam decommissioning

4.3.1 Working through the EU H2020 AMBER and the Brazilian FAPEMIG programmes, UoS has been a key participant in quantifying the abundance of river barriers in Europe, and weir and dam removal feasibility projects in the UK and Europe (e.g. Bossington weir), Brazil (e.g. Pandeiros Dam) and Canada (e.g. Mactaquac Dam). In AMBER, the UoS developed and applied a rapid barrier assessment tool that provided and validated data on which the European Atlas of River Barriers was based, and helped prioritise restoration actions, including dam decommissioning, by the most cost-effective means while providing the greatest gains for biodiversity. The project identified more than one million barriers in Europe's rivers, a result that fed directly into the EU 2030 Biodiversity Strategy setting a target of reconnecting at least 25,000 km of Europe's rivers by 2030. In the UK, expert advice has been provided to the EA since 2014 in relation to weir removals on the River Test in Southern England. In addition, the UoS provided one of the few long-term assessments of physical, chemical and ecological response to weir removal in the UK.

4.3.2 In association with the Peixe Vivo programme and the University of Kent, the UoS developed an optimisation-based decision support planning tool that was shared with the Cemig in 2018. The outputs of the model were used to evaluate plans for developing the São Francisco River through simultaneously combining the information on proposed new build sites and potential for decommissioning existing infrastructure. As a result, a decision was made to remove the Pandeiros Dam, which if sanctioned will be the first dam removal in South America. A cohort of students enrolled on the CDT-SIS programme investigated the potential impact of removal and associated sediment release on the downstream geomorphology of the river, including on a wetland of high conservation significance. The results were fed back to the project managers who incorporated the findings of the studies into their overall hydropower planning strategy. Rafael Fiorine from Cemig states that, "*The contributions from the University of Southampton professionals were crucial for the advance of the Pandeiros' Dam Decommissioning Project… Additionally, the sediment dynamic model built was a major support for requesting a legal authorization for the second stage of the decommissioning viability study. We estimate that Cemig would save a minimum of GBP17,453,334 in the period of ten years following dam removal as a result of the reduced maintenance costs related to the safety of the dam structure*" [**5.10**].

4.3.3 Since 2014, a similar feasibility assessment of dam removal was conducted for the Mactaquac dam, Canada, in collaboration with Canadian Rivers and New Brunswick Power. UoS researchers joined international collaborators at the University of New Brunswick to use innovative modelling techniques to predict the effect of dam removal on stored reservoir sediments and identify potential environmental and economic impacts. New Brunswick Power used the information to identify that dam removal was not the most sustainable option, opting instead for more environmentally friendly turbine units. Prof. Katy Haralampides, the Mactaquac Project leader representing Canadian Rivers at the University of New Brunswick, said, "*… the impact that you and your research have had on our project has been substantial. It is difficult to quantify, but convincing NB Power to consider an Alden turbine will have lasting positive environmental effects for generations. Our research focus has changed as a result of your input, and we have successfully received additional funding from the industry partner to continue the projects. We are awaiting word from the Natural Sciences and Engineering Research Council about our ~[USD2,000,000] proposal for matching funding*" [**5.11**].

5. Sources to corroborate the impact

5.1 Ouse and Adur River Trust Newsletter. Summer 2018. https://oart.org.uk/wp-content/uploads/2018/10/OART-11-Summer-2018-E-Newsletter-1.pdf
5.2 Testimonial from EA in relation to adoption of the CBC fish pass for gauging weirs.
5.3 Testimonial from Hydraulic engineering lead for the Province of Fryslân.
5.4 Testimonial from Steve Waygood, RWE Generation UK.
5.5 EPRI Eel Passage Research Centre: 2013 – 2018 Synthesis Report. EPRI, Palo Alto, CA.
5.6 Testimonial from Paul Jacobson, EPRI.
5.7 Testimonial from Toby Coe, Fishtek.
5.8 Testimonial for Andrew Muir, Great Lakes Fisheries Commission.
5.9 Testimonial from Pieter Wallewijn, World Bank.
5.10 Testimonial from Rafael Fiorino, CEMIG.
5.11 Testimonial from Katy Haralampides, University of New Brunswick.