Institution: Staffordshire University

Unit of Assessment: Computer Science and Informatics (B11)

Title of case study: Computer-Based Methods for Diagnosing and Predicting River Health

1. Summary of the impact

Good quality water is essential for life on earth. The 'Centre for Intelligent Environmental Systems' (CIES) has developed computer-based solutions for the assessment of river water quality by environmental agencies, working to improve the quality. CIES research has informed discussions and decisions of the UK Technical Advisory Group for the Water Framework Directive (UKTAG WFD). UKTAG WFD have selected the WHPT (Walley, Hawkes, Paisley & Trigg) method, for assessing river water quality throughout the UK, in the context of river management to meet the targets set in the Water Framework Directive (Directive 2000/60/EC from the European Union), which the UK government signed up to in 2000 (Beneficiaries: UKTAG WFD; Environment agencies; The public). Indirect impacts can also be attributed to CIES research, as it enables improvements of river quality, which triggers positive impacts on the natural environment, public health and quality of life (Beneficiaries: The public). CIES software has also been released to environment agency biologists as second opinion tools, thereby resulting in improved delivery of the public service provided by these biologists, when they use the software (Beneficiaries: Environment agencies; Environment agency biologists; The public).

2. Underpinning research

2.1 Research challenge

Research conducted by CIES aims at devising artificial intelligence techniques for use in diagnostic tools which can assess river water quality in the UK and identify the causes of poor quality (focussing on causes which are linked to pollution).

Biological methods, for assessing the quality of river water, relate pollution to its effect on the ecological community of river creatures; this effect often provides evidence of the type of pollution. Existing water quality assessment solutions fall somewhat short of achieving the required precision and accuracy. Research to produce new scientific knowledge and new assessment methods is a key enabler for compliance with the WFD legislation. Hence, CIES engages in research to develop new techniques for intelligent systems to be used for assessing water quality, based on biological methods.

2.2 Intelligent environmental systems for assessing river water quality

Walley and Hawkes (Walley and Hawkes, 1997) carried out a computer-based revision of the BMWP (Biological Monitoring Working Party) system for scoring river water quality. This work produced a method for deriving BMWP scores, together with indicator values incorporating the effects of *abundance* rating for invertebrates and type of river site. These derived scores give a more realistic representation of the sensitivities of river invertebrate families to pollution, than do the original BMWP scores. These derived scores have been widely accepted as reflecting better the differential sensitivities to the combined effects of organic and other major forms of pollution. The revised scoring method was improved further by Walley and co-workers, yielding a novel method named 'WHPT' after its contributors: Walley, Hawkes, Paisley, and Trigg (Paisley et al. 2007; 2013). The WHPT method is designed to be integrated into biological assessment tools for river water.

CIES research has also contributed AI systems for the biological monitoring and diagnosis of river health. A key insight of the research from CIES is that computer systems can be made capable of modelling relationships between biological, chemical and environmental components of river ecosystems by using a synergy of pattern recognition and plausible reasoning, as human experts do. CIES produced a novel generic pattern recognition algorithm (named 'MIR-Max') which is based upon information theory [Walley RAE 2008 (1, 4)], together with the River Pressure

Diagnostic System (RPDS) which includes the MIR-Max algorithm, and the River Pressure Bayesian Belief Network (RPBBN) (O'Connor and Walley, 2002; Walley, 2005).

2.3 Key researchers and dates

CIES research by Walley (Emeritus Professor) and his co-workers [Walley RAE 2008 (1, 2, 3, 4)] began around 1992 and it has spanned over 20 years; it is currently conducted by Trigg and Paisley. Walley led the CIES research team which included Trigg (initially a PhD student, subsequently a post-doctoral research assistant), Paisley (senior lecturer), Martin (Research Fellow), Fontama (post-doctoral research assistant), O'Connor (initially a PhD student, subsequently a post-doctoral research assistant), and Buxton (PhD student). Walley collaborated with Hawkes of Aston University. Walley has since retired from employment; Trigg is now the principal researcher, while Paisley manages CIES.

3. References to the research

3.1 References to research outputs

Some key outputs, from the research which underpins the impact, are listed below. The WHPT work strand is reported in (Walley and Hawkes, 1997; Paisley et al, 2007; 2013). An overview of the work of CIES up to 2005 is given in (Walley 2005), which is an invited book chapter that summarises the findings of early CIES work on their novel AI-based approach to modelling river ecology.

- Walley W.J. and Hawkes H.A. (1997). A Computer-based Development of the Biological Monitoring Working Party Score System Incorporating Abundance Rating, Biotope Type and Indicator Value. Water Research, 31 (2), 201-210.
  Output type: Journal article
- Paisley M.F., Trigg D.J., Walley W.J. (2007). Revision and Testing of BMWP scores. Final report SNIFFER Project WFD72a. Edinburgh, SNIFFER. Available at: http://www.sniffer.org.uk/files/1513/4183/8007/WFD72a.pdf [Accessed on 10 November 2013]
  Output type: Research report for external body
- Paisley M.F., Trigg D.J., Walley W.J. (2013). Revision of the Biological Monitoring Working Party (BMWP) Score System: Derivation of Present-Only and Abundance-Related Scores from Field Data, River Research and Applications, Article first published online: 30 July 2013. DOI: 10.1002/rra.2686
  Output type: Journal article
- Walley W.J. and Fontama V.N. (2000). New Approaches to River Quality Classification Based upon Artificial Intelligence. In “Assessing the Biological Quality of Fresh Waters. RIVPACS and other Techniques” (eds. Wright J.F., Sutcliffe D.W. and Furse M.T.), 263-280. Freshwater Biological Association, Ambleside.
  Output type: Edited book chapter
- O'Connor M.A. and Walley W.J. (2002). River Pollution Diagnosis System (RPDS) - Computer-based analysis and visualisation for bio-monitoring data, Water Science and Technology, Vol. 46, No. 3, pp. 17-23. ISSN: 02731223
  Output type: Journal article
- Walley W.J. (2005). AI-Based Models of Ecological Health, Environmental Protection Agency (EPA) - Republic of Ireland, Series No. 29, pp. 168-197
  Output type: Research report for external body. Publisher / Commissioning body: Environmental Protection Agency (EPA) - Republic of Ireland

3.2 Evidence of the quality of the research

CIES ground-breaking computer-based techniques for assessing river quality were among the first in the UK. In a field where manual scoring and indexing methods are still predominant, the systems developed by CIES are still ahead of their time. The high quality of CIES research was recognised by the ‘million+’ university think-tank (further details are given in Section a.2 in REF 3a).

CIES research has been published as peer-reviewed papers in reputed international journals and conference proceedings, reports to environmental agencies, and PhD theses. Some of the

publications were included in the Faculty's UoA 21 submission for the RAE 2008 [Walley RAE 2008 (1, 2, 3, 4)].

The British Computer Society (BCS) acknowledged the quality and significance of CIES research; the RPDS software came second in the finals of the BCS Technology Awards (24 September 2003), in the 'Social Contribution' category; the software was runner-up to London's Congestion Charging Scheme, developed by Capita Group plc
(see http://www.bcs.org/content/conWebDoc/1946 [Accessed on 16 November 2013]).

Sustained external research funding for over more than 20 years, by environmental agencies (UK and Northern Ireland Environment Agencies, Scottish Environmental Protection Agency (SEPA), and Scottish and Northern Ireland Forum For Environmental Research (SNIFFER)), is further acknowledgement of the quality and practical relevance of the research. Examples of grants secured over the assessment period are listed below:

- Martin Paisley (Principal Investigator), David Trigg (Co-Investigator), Revision of BMWP Scores, Funder: Scottish and Northern Ireland Forum for Environmental Research (SNIFFER), R&D Project, 2008 (1 year project) (£39,285).
- Martin Paisley (Principal Investigator), David Trigg (Co-Investigator), Water Framework Directive River Basin Planning Project, Funder: EA, Jan – Mar 2008 (£15,000).
- Martin Paisley (Principal Investigator), David Trigg (Co-Investigator), Extension to Development of an Integrated Classification, Diagnosis and Prediction System Relating Pressures and Ecological Monitoring Elements Based on Pattern Recognition and Plausible Reasoning, Funder: EA, Jan – Mar 2008 (£30,000).
- Martin Paisley (Principal Investigator), David Trigg (Co-Investigator), Further Development of an Integrated Classification, Diagnostic and Prediction System, Funder: EA, Nov 2008 – Mar 2009 (£45,000).
- David Trigg (Principal Investigator), Martin Paisley (Co-Investigator), Identifying Risks to Good Ecological Status, Funder: EA, December 2009 - March 2010 (£38,000).
- David Trigg (Principal Investigator), Expansion of Existing River Quality Management Support Tools to Include River Morphology Parameters, Funder: EA, January - August 2012 (£32,000).
- David Trigg (Principal Investigator), Development of an Automated Marine Biotope Classification System, Funder: Joint Nature Conservation Committee (JNCC), January - June 2012 (£30,000).

4. Details of the impact

4.1 Impacts on public policy

Research has informed discussions of a public body about standards: CIES research challenged the established perspective of the EA on the measurement and management of river quality in the UK, which have traditionally used the BMWP scoring system. The WHPT method demonstrated the weaknesses of existing river quality measurement and management systems, and challenged preconceived ideas about the relationships between river ecology and water quality. The river water quality indexes produced using the WHPT method were submitted to the EA and DEFRA (Department for Environment, Food and Rural Affairs), who sent them to the UK Technical Advisory Group for the Water Framework Directive (UKTAG WFD), for adoption into UK river water assessment standards to be used for implementing the Water Framework Directive.

UKTAG WFD then proposed the WHPT method, for inclusion into measurement protocols for river water quality standards. This proposal went through a stakeholder review which opened to the public on the 10th of December 2012 and closed on the 28th of February 2013 (the URL for the stakeholder review is given in [3]; see Section 5).

Research has informed changes to standards: Following the stakeholder review, the WFD UK TAG selected the WHPT method for inclusion in its revised standards for river quality assessment. The final recommendations of the UKTAG WFD about the new and updated biological standards can be downloaded from the UKTAG WFD website (the URL is given in [4]; see Section 5).

4.2 Impacts on public services and practitioners

Improvement of the delivery of a public service (increased confidence in assessments by environmental biologists): The EA is using (from 2013) the WHPT method to classify rivers according to quality. The results based on WHPT will go to EA planners, so that they set objectives for the second 6-year River Basin Management Plans (2015-2021). The Water Framework Directive uses a series of 6-year cycles; the first 6-year cycle will end in 2015. The draft plans for the second cycle will be published in the summer of 2014.

In addition, technology (namely, RPDS and RPBBN) developed from CIES research was released to the EA and SEPA, for use by environmental biologists as a secondary tool to validate, where needed, water quality assessments made using other primary tools adopted by the agencies. In particular, RPBBN provides the capability of modelling the impacts of changes in river chemistry on river ecology. This capability allows users to perform scenario testing and assess the cost-effectiveness of various remediation options.

4.3 Impacts on the natural environment, health and society

Public benefits arising from the improvement of a key factor associated with the natural environment, public health and quality of life: CIES research has important indirect impacts on the world and its people. CIES techniques for river water quality monitoring enable better diagnosis of river pollution and better assessment of potential restorative measures. The resulting improvement of the management of river water, which is an important natural resource, has a positive impact on the natural environment, public health and quality of life. Indeed, cleaner rivers impact on tourism and its associated economies, agriculture and higher standards of farming, and tighter controls on industrial waste management.

5. Sources to corroborate the impact

- Environment Agency:
  - [1] National Ecology Advisor, Environment Agency
    (Can corroborate the impacts detailed in Section 4)
  - [2] Senior Environmental Monitoring Officer, Analysis & Reporting Team, Kent & South London Area, Environment Agency
    (Can corroborate the impacts detailed in Section 4)
- The United Kingdom Technical Advisory Group for the Water Framework Directive:
  - [3] Information about the stakeholder review of biological standards, conducted by the UK Technical Advisory Group for the Water Framework Directive. Available at: http://www.wfduk.org/stakeholders/final-recommendations-new-and-updated-biological-standards-0 [Accessed on 10 November 2013]
  - [4] Final recommendations on new and updated biological standards. Available at: http://www.wfduk.org/sites/default/files/Media/UKTAG%20Final%20recommendations%20on%20biological%20stds_20131030.PDF [Accessed on 10 November 2013]