Institution: Imperial College London

Unit of Assessment: 14-Civil and Construction Engineering

Title of case study: 5: Improved flood risk management through advances in rainfall modelling, experimental evidence, and catchment and urban modelling

1. Summary of the impact

Our research and resulting impacts extend across a wide range of flooding problems, from localised urban floods to river basin flooding. The underpinning research ranges from extending the evidence base, to improved rainfall estimates, and to advances in hydrological and hydraulic models. The impact of our research has been through the creation and application of new methodologies (e.g. AOFD) and software tools (e.g., TSRSim) for the design and analysis of flood management systems in the UK and internationally, via joint projects with consulting engineering companies, and through the influence of our research on national and regional policies towards improved land use management practices (e.g., Glastir, Wales).

2. Underpinning research

Our research in flood risk management has addressed two major gaps in floods science: the lack of evidence and understanding about factors affecting flood flows; and the lack of numerical models to help convert understanding into decisions. Since its inception in 1993, this programme of research has involved a number of academics including H. Wheater (1993-2010), N. McIntyre (1999-2013), C. Maksimović (1997-2013); C. Onof (1995-2013), N. Bulygina (2007-13) and D. Butler (1993-2005).

Three aspects of this research have led to major impact and are summarized here: (a) rainfall modelling; (b) land use management and (c) urban pluvial flood modelling.

2.1 Rainfall modelling

Traditional flood design using design events relies upon unrealistic assumptions about rainfall. Our programme of rainfall research has provided the basis for improvements using continuous simulation of rainfall. Building on fundamental research into stochastic rainfall modelling from 1993-2002, Onof and Wheater subsequently (2002-05) developed new methods for generating daily rainfall simultaneously at a number of sites while maintaining its complex space-time properties, including the ability to synthesise extreme rainfall [1]. This was achieved by developing techniques based on point process and generalised linear models. This Defra funded research was extended (2005-2006) to adapt the method so that it can estimate space-time rainfall under climate change. In a third aspect of the work, based on continuous studies since 1993, Onof has developed methods for the downscaling of daily rainfall to high-resolution (e.g., hourly or 5-minute) rainfall, to provide a unique ability to simulate bursts of rainfall, including under climate change, thus, in particular, meeting the needs of urban drainage design [2]. Together, these elements of underpinning research led to the software packages, HYETOS, GLIMCLIM, and TSRSsim, which have been widely used by consultants and government agencies during 2008-2013 (see section 4).

2.2 Land use management

There is widespread speculation that reverting towards a more natural rural landscape will reduce downstream flood risk, and there is major interest and activity in UK government in implementing “natural flood management”. However, prior to our series of RCUK funded research projects in the period 2004-2012, there was insufficient evidence and methods to evaluate the efficacy of such “natural” approaches. From our sets of experimental sites at Pontbren, Wales (2004-2012), Wheater, McIntyre and Bulygina produced evidence of the links between soil type, land management and flood flows; and how upland land management can (and cannot) be used to control floods; and how it can also provide other environmental benefits as part of agri-environment schemes [3,4]. Furthermore, so that scenarios of change can be assessed in terms of flood risk and associated costs and benefits for a range of catchments, we developed new generalisation

and upscaling techniques [4]. This modelling research programme is providing an evolving national capability for continuous-time simulation of floods, leading in 2004-2012 to the focus on solving the "natural flood management" question.

2.3 Urban pluvial flood modelling

For the urban environment, Maksimović and Butler have conducted research that has promoted the use of physically based approaches to improve models of urban pluvial flooding, and to reduce the uncertainty in the spatial and temporal modelling. From 1999-2009, our research into processing of digital terrain data led to improved automatic delineation of flood-prone areas in urban catchments and the development of our Automatic Overland Flood Delineation (AOFD) method [5]. Research from 2004-2012 produced new methods for 1D/1D urban flood modelling suitable for real time applications, incorporating the AOFD method [6]. These latter two items of underpinning research produced the predecessors to the modern commercial models for urban pluvial flood modelling (see section 4).

3. References to the research (*References that best indicate quality of underpinning research)

*[1] Wheater H.S., Chandler R.E., Onof C., Isham V.S., Bellone E., Yang C., Lekkas D., Lourmas G. and Segond M-L. (2005) 'Spatial-temporal rainfall modelling for flood risk estimation', *Stochastic Environmental Research and Risk Assessment* **19**(6) pp 403-416, doi:10.1007/s00477-005-0011-8.

[2] Onof C. and Arnbjerg-Nielsen, K. (2009) 'Quantification of anticipated future changes in high resolution design rainfall for urban areas', *Atmospheric Research* **92** pp 350-363, http://dx.doi.org/10.1016/j.atmosres.2009.01.014

[3] Marshall M.R., Francis O.J., Frogbrook Z.L., Jackson B.M., McIntyre N., Reynolds B., Solloway I, Wheater H.S., and Chell J. (2009) 'The impact of upland land management on flooding: Results from an improved pasture hillslope *Hydrological Processes'* (2009) **23**(3) pp 464-475, doi:10.1002/hyp.7157.

*[4] Bulygina N., McIntyre N., Wheater H. (2009) 'Conditioning rainfall-runoff model parameters for ungauged catchments and land management impacts analysis' *Hydrology and Earth System Sciences* **13**(6) pp 893-904, doi:10.5194/hess-13-893-2009.

*[5] Maksimović Č., Prodanović D., Boonya-aroonnet S., Leitão J.P., Djordjević S. and Allitt R. (2009) 'Overland flow and pathway analysis for modelling of urban pluvial flooding'. *Journal of Hydraulic Research* **47**(4) pp 512-523, doi:10.1080/00221686.2009.9522027.

[6] Leitão J.P., Simões N.E., Maksimović Č., Ferreira F., Prodanović D., Matos J.S. and Sá Marques A. (2010) 'Real-time forecasting urban drainage models: full or simplified networks?' *Water Science and Technology* **62**(9) pp 2106-2114, doi:10.2166/wst.2010.382.

Research Grants and Funding

A significant part of the underpinning research was carried out through our membership of the National Flood Risk Management Research Consortium (FRMRC 1&2) funded by EPSRC, NERC, EA, Defra, and others, during 2004-2012. EP/F020511/1. FRMRC 1&2 has been the largest UK research programme on flood risk science in recent years and within both phases we led the land use management part of the programme.

4. Details of the impact

Our floods research has had substantial impacts on floods policy and design practice, and on attitudes and understanding of flood risk solutions by audiences ranging from land owners to national governments. These impacts extend across all components – rainfall modelling, experimental evidence, and catchment and urban modelling.

4.1 Rainfall modelling

Research into rainfall modelling has led to the development of tools for hydrological and drainage system design using continuous simulation rather than single design events, a development

encouraged by the Environment Agency. The software tool HYETOS for hourly rainfall generation, originally developed as part of a 30%/70% ICL/NTUA Athens collaboration, is downloaded on average 140 times per year in particular by consultants in the water industry. GLIMCLIM is a spatial daily rainfall generator originally developed as part of a 50%/50% Imperial/UCL collaboration, which Halcrow has used in projects with total benefit of about £15K, and are investing £5K in developing a user interface for.

For urban drainage applications, the software tool TSRSim, based entirely upon work by Onof, has been developed at a cost of over £20,000 by HR Wallingford Software in 2005 in collaboration with Onof [A]. It has been purchased by a number of consultancies and water companies (e.g. MWH, B&V, Yorkshire Water, United Utilities and Southern Water) at a unit cost of £900 [A]. TSRSim was used as an alternative to traditional design storms across the Southern Water area to estimate floods with a return period of 1 in 30 years. The flexibility of this tool is estimated by MWH to have enabled savings of the order of £2 Million on a programme valued at £80 Million [B].

4.2 Land use management

Our experimental evidence on the physical links between rural land use and floods (Wheater et al.) has fundamentally changed national attitudes and policy. For example, we refer to the Pontbren hydrology work, described in Section 2 (underpinning research) which was jointly run by Imperial College and CEH Bangor (50%/50%). From the Woodland Trust Wales report, the “Pontbren work has fundamentally changed our understanding of the role of broadleaved trees in the farmed landscape and is now changing policy and practice” [C]. Hence the research on trees and flooding has had a direct influence on the Welsh Government’s new land management scheme for Wales [D] (‘Glastir’) and local implementations The Coed Cadw will confirm that the next Rural Development Plan for Wales (2013-2020) is drawing heavily on the experience and the evidence derived from Pontbren and that it will influence the shape and focus of future agri-environment payments to farmers [E].

The underpinning research on soil hydrology and land use has been used directly by the Environment Agency Wales to map priority areas for improved land management. One of the GIS water quantity layers was based around the evidence from Pontbren and key areas in Wales have been identified where similar activities to those within Pontbren could lead to a reduction in flood risk in the upper Severn [D], with consequent benefits for western England. Another example of the impact of the new evidence and numerical model results was their use in the Foresight Future Flooding update, which contributed to the Cabinet Office’s 2008 policy report (the “Pitt Review”) recommendation that “rural land management approaches should be considered as part of the portfolio of measures to deal with flood risk and, where appropriate, as part of the programme to deliver more working with natural processes” [F]. They have also been used to guide the Office of Public Works (Ireland) in informing the Directorate General’s review of climate proofing. Our research into flood flow modelling approaches has also had a major impact on training and education of students and practitioners, demonstrated by sales of our books [G] and downloads of our teaching software.

4.3 Urban pluvial flood modelling

The urban floods research has delivered models that have impacted practice in flood studies in the UK and internationally. In 1998 we took part in the CIRIA (Construction Industry Research and Information Association) Committee for development of CIRIA555 Sustainable Urban Drainage Design and Best Practice Manual, in which the term “SUDS” was coined, resulting in the industry training module which has been used ever since. Our AOFD method and software tool (see underpinning research section) has been independently evaluated and recommended for practical use by the UK Water Industry Research organisation (UKWIR). Before this model there was no appropriate software product on the market that would enable automatic processing of urban drainage features needed for reliable modelling of urban runoff, and it now forms the basis of commercial software (e.g. Infoworks and TuFlow) which are dominating UK and many international markets [H].

This tool has been used extensively by consultants for mapping surface water flood risk in the UK (Colindale, Borough of Barnet [H]) and in several cities in Serbia (e.g. Novi Beograd, Novi Sad, Sabac). Its inclusion into an integrated modelling system, 3DNet-SewNet, has led to the software being used by a significant percentage (cc 50%) of younger and mid-career professionals in Serbia and neighbouring countries. Similarly, the AOFD method and its principles have been incorporated into the latest version of the main commercial software package in Germany (Graphical Interactive Planning system - GIPS) by ITWH (Hannover) [I]. The GIPS "has over 500 users predominantly in German speaking countries. This is now a customer system with about €2.5M market value"[I]. Our methodology for storm drainage master planning has had clear societal and economic impacts: it has been adopted by the Brazilian consortium (Enger, Promon, CKC) and used by the chief consultant company Hidrostudio in development of the Master Drainage Plan for the River Tiete in Sao Paulo, Brazil, which was then used over the last 12 years for detailed planning of improvements to Sao Paulo's drainage. Additionally, in the most recent project for urban flood mitigation project of the Sao Paulo's central commercial area (Anhangabau), the AOFD model has been used for assessment of flood risk.

5. Sources to corroborate the impact

[A] Technical Director, HR Wallingford to corroborate the investment of £200,00 into the development of TSRSim by HR Wallingford Software in 2005

[B] Principal Engineer, MWH UK Ltd. To corroborate the enabled savings of the order of £2 Million on a programme valued at £80 Million by MWH.

[C] Coed Cadw (Woodland Trust) Wales Needs More Native Trees!: An information briefing for the Petitions Committee of the National Assembly for Wales and associated press release. http://www.woodlandtrust.presscentre.com/ImageLibrary/detail.aspx?MediaDetailsID=565 Also available here

[D] "Glastir Targeted Element: An Explanation of the Selection Process", p4, Welsh Assembly Government and accompanying explanatory email from EA Wales). http://wales.gov.uk/topics/environmentcountryside/farmingandcountryside/farming/schemes/glastir/advanced/document/glastirteexpanselectionprocessmaps/?lang=en. Also available here

[E] Director , Coed Cadw to confirm that the next Rural Development Plan for Wales (2013-2020) is drawing heavily on the experience and the evidence derived from Pontbren hydrology work.

[F] The Pitt Review - Learning Lessons from the 2007 floods - p 132 , Cabinet Office. Available at http://webarchive.nationalarchives.gov.uk/20080906001345/http://cabinetoffice.gov.uk/thepittreview/final_report.aspx. Also available here

[G] For example: Wagener, T., Wheater, H. and Gupta, H.V. (2004) *Rainfall Runoff Modelling in Gauged and Ungauged Catchments*. Imperial College Press, 306 pp. Sales to date >500. ISBN: 978-1-86094-466-6 (hardcover). ISBN: 978-1-78326-066-9 (ebook)

[H] Program Delivery Manager, Golder Associates Ltd to confirm that the model developed forms the basis of commercial software (e.g. Infoworks and TuFlow) which are dominating UK and many international markets extensively being used by consultants for mapping surface water flood risk in the UK

[I] CEO of the Institut für Technisch-Wissenschaftliche Hydrologie GmbH (ITWH) confirm that the method and its principles have been incorporated into the latest version of the main commercial software package in Germany (Graphical Interactive Planning system - GIPS) by ITWH (Hannover)