Institution: Newcastle University

Unit of Assessment: 14 Civil and Construction Engineering

Title of case study: Robust risk assessments of climate change, flood and drought

1. Summary of the impact

Research at Newcastle University into stochastic rainfall models and their application has transformed the practice of impact assessment of climate change and risk assessment of environmental hazards across multiple sectors. The Newcastle methods underpin the "*Weather Generator"*, a web-based tool which has been made available since 2009 by DEFRA as part of their official UK Climate Projections (UKCP09). The tool's incorporation into this official data source means that the models generated underpin multi-sectoral risk assessment throughout the UK and subsequently have led to the adoption of stochastic methods in general, particularly in the water and insurance industries to produce more robust risk assessments.

2. Underpinning research

Computer modelling of rainfall has been a principal research area at Newcastle University's Water Resource Systems Research Laboratory for over 20 years with continual research funding received from the EU [G1], UK government [G2] and RCUK [G3] totalling over £2.5M. The laboratory has become known in the research community as the prime exponent of developing and using stochastic methods in performance assessment of hydrosystems (*e.g.* water resources, urban drainage). Stochastic (including "Monte Carlo") approaches to modelling infrastructure and natural systems allow performance to be assessed and optimised for conditions outside of those observed, including future climates. The research utilised new mathematical formulations of models to provide wider functionality and demonstrates their utility in real-world application. The research advances may be characterised in the following three areas:

Stochastic modelling of rainfall: developments from 1993 started with an existing basic method, the Neyman-Scott Rectangular Pulses (NSRP) model. O'Connell initiated a research programme, with PhD student Cowpertwait, producing key developments over the following decade including: improving the ability to reproduce extremes [P1], extending from single-site to space-time [P4], providing national [P2] and European [P1] coverage. The nature of the developments was mathematical (new analytical derivations of parameter estimates) and statistical (*e.g.* robust model optimisation, and choice of intensity distribution for reproduction of extremes).

Rainfall information for future climates: methods for downscaling climate model outputs were developed from 1998 onwards by Kilsby [P2] and Fowler for her PhD thesis. Climate models operate on large grid squares so the generation of fine-scale rainfall information and properties of extremes for future climates has been an enduring problem. This was addressed for the first time in the UK by the Newcastle team using atmospheric circulation patterns as predictors of rainfall in a statistical framework [P2]. The NSRP model was further developed and applied in this context in a series of EU projects [G1] for climate impact assessments on water resources and flooding.

Probabilistic frameworks for climate change impact and risk assessments: extension of the rainfall model to other variables (*e.g.* temperature) was led by Kilsby in collaboration with UEA from 2006 [P5, G5] leading to the "*Weather Generator*" (WG) used by the Environment Agency (EA). A new era of "*probabilistic*" climate change projections was entered in 2009 when the Met Office Hadley Centre developed an ensemble approach to address uncertainty in the DEFRA-funded UKCP09 programme, the first example worldwide of such projections being available to the public. However, these are limited in that only *distributions* of change are provided, so *actual time series* are not available, an essential requirement for impacts modelling. DEFRA therefore commissioned Newcastle to develop a tool to provide these essential missing series [G2]. Newcastle was responsible for the rainfall component and overall implementation, whilst UEA addressed the other weather variables. The generation of large ensembles of data for use in Monte Carlo assessments has continued with further developments of models for droughts by Kilsby and Serinaldi [P6].

Key staff:

O'Connell, P. E.	Professor, 1985-present
Kilsby, C. G.	SRA/Lecturer/Senior Lecturer/Reader/Professor 1991-present

Cowpertwait, P.S.P.	PhD 1992; Part-time Lecturer, 1993-1996
Burton, A.	SRA 1993-present
Fowler, H.J.	PhD 2000, RA 2001, NERC Fellow 2006, Professor 2012 – present
Serinaldi, F.	SRA Willis Research Fellow 2011- present

3. References to the research

[P1] * Cowpertwait, P. S. P., Kilsby, C. G., O'Connell, P. E. (2002), A space-time Neyman-Scott model of rainfall: Empirical analysis of extremes. Water Resour. Res., 38(8): 61-614. (*Development of NSRP model including extremes: output of WRINCLE project)*

[P2] Kilsby, C. G., Cowpertwait, P. S. P., O'Connell, P. E., Jones, P. D. (1998), Predicting rainfall statistics in England and Wales using atmospheric circulation variables. Int. J. Climatol., 18(5): 523-539. (*Links climate variables to stochastic model: output of POPSICLE project)*

[P3] Fowler, H. J., Kilsby, C. G., O'Connell, P. E. (2000), A stochastic rainfall model for the assessment of regional water resource systems under changed climatic conditions. Hydrol. Earth Syst. Sci., 4(2): 263-282. (*Application to Yorkshire Water resource system: from Fowler's PhD supervised by Kilsby and O'Connell)*

[P4] Burton, A., Kilsby, C. G., Fowler, H. J., Cowpertwait, P. S. P., O'Connell, P. E. (2008), RainSim: A spatial-temporal stochastic rainfall modelling system, Environ. Modell. Softw., 23(12): 1356-1369. (*Definitive description of software package– 11th most cited paper in journal in REF period)*

[P5] * Kilsby, C. G., Jones, P. D., Burton, A., Ford, A. C., Fowler, H. J., Harpham, C., James, P., C.G. Smith, A., Wilby, R. L. (2007), A daily weather generator for use in climate change studies. Environ. Modell. Softw., 22(12): 1705-1719. (*Primary description of WG arising from EARWIG project. Cited 129 times as of October 2013 – source Scopus)*

[P6] * Serinaldi, F. and Kilsby C. G., (2012), A modular class of multisite monthly rainfall generators for water resource management and impact studies. J. Hydrol., 464: 528-540. (*Description of stochastic model developed and used for water resource planning studies)*

[***** indicates references that best indicate the quality of the underpinning research]

Key Grants

[G1] EU and other projects developing downscaling tools and stochastic models for climate scenarios and applying in risk assessments:

- *POPSICLE 1994 - 1996*: EU FP3 EV5V-CT94-0510, *development of downscaling methods using NSRP with climate variables,* PI overall: O'Connell, Newcastle. Total value €0.45M;
- *WRINCLE 1998 - 2000*: EU FP4 ENV4-97-0452, *application of NSRP for Europe for future climates and water resources*, PI overall: O'Connell, Newcastle. Total value €0.54M;
- *SWURVE 2000 - 2004*: EU FP5 EVK1-2000-00075, *further developments of NSRP in water case studies across Europe,* PI overall: Kilsby, Newcastle. Total value €1.5M;
- *AQUATERRA 2004 - 2009*: EU FP6-SUSTDEV 505428, *further developments and application of NSRP in groundwater protection, water resources and flooding studies*, PI: Fowler, Newcastle. Total value €20.2M;
- *ECLISE 2011 - 2014*: EU FP7 265240, *provision of climate services – development of NSRP for better representation extreme rainfall*: PI: Fowler, Newcastle. Total value €4.5M;
- *CARIWIG 2012 - 2014*: CDKN RSGL0024h, *provision of climate services to Caribbean region*, PI overall: Burton, Newcastle. Total value £640k.

[G2] DEFRA and EA programmes – developing Weather Generator technology:

- *EARWIG* 2005 - 2006: *Environmental Effects of Agriculture and Land Use: Weather Generator Tool - development of freely available national WG with graphical interface*; PI: Kilsby, total value £28K;
- *UKCP09* 2007 - 2010: DEFRA, *commissioned web service and overall web portal design for WG as part of UKCP09 national programme*; PI: Kilsby, total value £155K.

[G3] RCUK programmes – focussed on development and applications of stochastic methods in infrastructure robustness studies under climate change:

- *NERC* 2007 - 2010: NE/E002501/1, *FRACAS: next generation national Flood Risk Assessment under climate Change Scenarios*; PI: Kilsby, value to Newcastle £204K;
- *EPSRC* 2009 - 2011: EP/G061254, *ARCADIA: Adaptation and Resilience in Cities: Analysis and Decision making using Integrated Assessment: developed spatial Weather Generator*, Co-I: Kilsby, value to Newcastle £651k;

Further EPSRC projects using UKCP09 WG include: RESNET EP/I035781 (2011-15), Co-I Kilsby; FloodMEMORY EP/K013513 (2013-16) PI: Kilsby.

4. Details of the impact

Newcastle research into stochastic models for environmental hazards has revolutionised capabilities and practice in the design and planning of resilient infrastructure systems. The use of stochastic methods allows much larger and more detailed data sets of hazards (*e.g.* extreme rainfall, droughts, and wind storms) to be generated for present and future climates providing a more robust basis for risk and reliability assessments. These assessments include expected damages from flood, failure of water supply and damage to infrastructure networks from multiple environmental hazards, which inform plans and designs for resilient infrastructure systems adapted to future climates.

The impact of the research has been achieved through two main impact routes a) the provision of the "*Weather Generator*" (WG) software encompassing new methods as part of the UKCP09 used for climatic risk assessments, and b) the provision of a tailored model for water resource planning.

a) Impact through the Weather Generator: Research at Newcastle into stochastic rainfall models underpins the web-based WG software [E5] technical details of which are published in the DEFRA report [E8]. This work uses both the NSRP rainfall model [P1, P4] and methods for downscaling future climate [P2, P3]. The WG was initially developed for the Environment Agency (EA) funded EARWIG project and further developed for DEFRA's official UK Climate Projections (UKCP09). The free and online provision of WG has made new, more robust methods for risk assessment of climate change, floods and droughts available to a wide user-base where previously it was restricted to academic research or highly specialised consultancy. This accessibility has resulted further in the transformation of industry and academic best practice in design and planning of resilient infrastructure systems across multiple sectors *e.g.* energy utilities & transport operators. Specific beneficiaries include:

- National government (DEFRA & EA) were responsible for the UKCP09 programme. The first national Climate Change Risk Assessment (CCRA) in 2012 used WG [E5] as detailed in the water sector report [E1, pp 12, 14, 39, 59, 88]. The CCRA informs national policy through the *National Adaptation Plan* which sets out the main priorities for adaptation for the UK;
- Government Office North East commissioned Royal Haskoning to carry out its Climate Change Adaptation study (2008) which used the WG and won the Institution of Civil Engineers *Stephenson Award for Sustainability* (2009) [E4];
- Atkins, one of the world's leading design, engineering and project management consultancies, uses the WG extensively (since 2009) to analyse data for their clients, predominantly in the water sector. Most notable is the UKWIR (UK Water Industry Research Ltd.) project "*Climate Change Modelling for Sewerage Networks"* which resulted in the provision of guidance on incorporating climate change impacts into the modelling of sewerage networks [E2, E3]; The software tool "WRAPT" (which uses WG outputs) commissioned by UKWIR is the new national water industry standard recommendation. The principal consultant at Atkins indicates in [E3] that the UK water industry spent over £1 billion on reducing the risk of sewer flooding between 2005 and 2010 and that this will become more significant in the future:

  "Understanding the risk – in the current climate and under climate change projections – is vital to ensure appropriate and timely investment. Analysis using WG is integral to this" [E3];

Overall uptake of the WG can be gauged by usage statistics which show it was run 16,132 times by 1338 unique users from 2009 to May 2013 [E5, E6]; a national portfolio of RCUK funded programmes with industrial partners [E7] who rely on the UKCP09 *e.g.* the EPSRC Adaptation and Resilience in a Changing Climate Coordination Network [E3].

b) Impacts through models for water resource planning: Stochastic methods have been accepted as a new practice by water industry companies and used for future investment and asset management planning of *e.g.* reservoirs and water transfers. One direct beneficiary is Southern Water (SW) whose consultants, Atkins, have specified and used stochastic rainfall models and their outputs in driving water resource models, subsequently used for assessing future requirements and planning capacity and investment. The Newcastle research contribution here was in provision of stochastic rainfall models which were refined and applied with knowledge from climate downscaling projects [G1,G2] dealing with droughts to develop computer models for monthly multi-site rainfall [P6] with realistic extremes and spatial correlation needed for application across large water resource zones under climate change conditions. SW's management plan [E9, pg.6] describes this "*innovative approach*" based on pioneering work with Newcastle University using *"mathematical modelling techniques to look at alternative weather patterns and droughts*". This much more robust approach, "*an industry first*" [E10], to possible future drought was used to formulate SW's water resources management plan submitted to industry regulators, Ofwat. This planning case is valued at £283.4 million as SW serves around 4 million customers and was published in draft for consultation in May 2013 [E9, E10].

Further developing and international impacts: simulation methods using stochastic inputs are now becoming standard in international insurance and re-insurance. Newcastle enjoys membership of the Willis Research Network which provides a close relationship with Willis and their insurance and re-insurance clients. Newcastle has developed rainfall models to generate large-scale extreme daily rainfall fields for Willis, who are developing a large basin flood model to be driven with ensembles of synthetic rainfall data. Insured losses of around €400 million were estimated from flooding in Austria due to the Danube in the last major flood event and improved models and flood risk estimates at greater resolution and with higher accuracy will allow significant improvement in premium setting and avoidance of costly over-exposure. Collaborations with partners for international WG applications are underway with Deutsche Wetter Dienst (Germany), Global Change Impact Studies Centre (Pakistan) and Caribbean meteorological agencies (*via* a Climate and Development Knowledge Network project funded by DFID8882083).

5. Sources to corroborate the impact

[E1] Climate Change Risk Assessment 2012: Water Sector report. http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=water&link=LinkTarget_1 [accessed 21/10/2013] (*WG software used as detailed on pp 12, 14, 39, 59, 88*)

[E2] UKWIR Report: "Climate Change Modelling for Sewerage Networks (10/CL/10/15)" UKWIR (2010) ISBN: 1 84057 573 5; at http://www.ukwir.org/web/ukwirlibrary/93903. *(design guidelines on incorporating climate change impacts into the modelling of sewerage networks*)

[E3] Testimonial: Principal Consultant, Climate Change & Environmental Futures, *Atkins* & Manager of UKWIR project "Climate Change Modelling for Sewerage Networks".

[E4] North East Climate Change Adaptation Study. http://www.royalhaskoning.co.uk/en-gb/Publication/Documents/projects/North-East-Climate-Change-Adaptation-Study.pdf and http://www.climatenortheast.com/contentControl/documentControl/Climate%20Change%20Adaptation%20Study.pdf

[E5] Testimonial: Research Expert - Climate Change, *Environment Agency (EA)* & Manager of national government "Climate Ready" programme.

[E6] Statistics of downloads and usage of UKCP09 WG: source Ag Stephens, CEDA Head of Partnerships, Met Office, Exeter, EX1 3PB, ag.stephens@stfc.ac.uk, +44 01392 884263

[E7] Industry affiliated RCUK projects listed at http://ukclimateprojections.defra.gov.uk/23081

[E8] UKCP09 Weather Generator report: http://ukclimateprojections.defra.gov.uk/22586. ISBN 978-1-906360-06-1

[E9] Southern Water- Water Resource Management Plan Draft Strategy: consultation document at http://swhaveyoursay.co.uk/wrmp/our-plans/#consultation-document.

[E10] Testimonial: Principal Consultant, *Atkins.*