Institution: Durham University

Unit of Assessment: 17B

Title of case study: River flooding and diffuse pollution

1. Summary of the impact

Rapid runoff from rural parts of river catchments can pollute downstream water bodies by transmitting sediment, agricultural fertiliser, or other pollutants from extensive diffuse sources, and can also lead to downstream flooding. Environmental managers often try to mitigate these problems by encouraging interventions, such as changes in farming practice or the construction of physical obstacles, which delay runoff from rural catchments. DU geographers have worked with stakeholders to develop a family of flexible user-friendly computer modelling tools which predict and map the likely critical sources of pollution or flooding and the downstream locations that are most at risk. This helps environmental managers target the best locations for intervention and compare the effects of alternative interventions. The software tools have been used by regulatory bodies (e.g. the Environment Agency) and NGOs (e.g. Rivers Trusts) to plan mitigation works and benefit local communities and the environment in many parts of England.

2. Underpinning research

A new approach to modelling catchment processes based on the analysis of water flow pathways was developed at Durham by Lane (DU Staff, 2004-11), Reaney (PDRA 2005-7, RCUK Fellow 2007-2012, Lecturer 2012-), and Milledge (PDRA 2008-9, NERC PDRF 2010-13) in a 2005-9 NERC knowledge exchange grant to Durham and Lancaster Universities(PI Lane) with co-funding from Defra, the Environment Agency, and the Eden Rivers Trust. Subsequent development and application has involved the active participation of regulatory agencies and other stakeholders in the customisation and application of models, partly within a collaborative Oxford-Durham-Newcastle-UEA ESRC/NERC Rural Economy and Land Use (RELU) project on flooding (Lane co-I, Odoni PDRA 2007-11 at DU) and also in several Durham-only projects in 2008-11 which were funded by the Environment Agency, Forest Research, the EU and other sources; some of these supported PhD students who contributed to the research and its impact.

The NERC grant developed a software package called SCIMAP, which is short for Sensitive Catchment Integrated Modelling And Prediction. The approach utilises digital elevation models, land cover maps, hydrological theory, and GIS analysis to map the relative risk of generating a 'problem' (e.g. rapid runoff, fine sediment, nutrients, or coarse sediment) at each pixel of the digital map of a rural area, and the likelihood of the 'problem' connecting to a particular river or lake. These 'problems' are then routed along their individual flow paths into and along the stream network, taking into account disconnections and dilution effects, to predict which parts of the network are most at risk from the problem. This is scientifically novel in three ways:

- it treats both source risk levels and rapid-flow connectivity as spatially variable over short distances (down to as little as 1 m), whereas most previous work operated at resolutions of order 1 km and either ignored connectivity or treated it in a very simplified way;
- it aims to identify critical source locations of pollution, rather than precisely predicting a particular water quality parameter at a vulnerable downstream location;
- it can predict the effects of interventions at key source areas or transmission points.

This re-conceptualisation of the problem (Reference 1) draws strongly on a sophisticated minimum-information requirement framework for describing hydrological connectivity (Reference 2). It allows identification of key transmission routes or pollutant source areas, and enables limited funds for mitigation to be targeted for maximum benefit. Specific modelling tools have been developed for coarse sediment (Reference 3), fine sediment, nutrients, and elements of in-stream ecology (References 2 & 4).

A second major innovation is the close involvement of stakeholders during all stages of the model development and application process. Stakeholders were initially involved in determining questions

and specifying outputs (e.g. in SCIMAP), but subsequently also suggested and evaluated alternative action plans. In the EU-funded Adaptive Land Use for Flood Alleviation project (PI Lane, then Reaney), we worked closely with the Eden Rivers Trust to devise ways to reduce flood risk with minimal impact on agricultural productivity, thus obtaining acceptance by farmers. In the RELU project on flooding in Pickering (North Yorkshire), local stakeholders worked with academics in 'environmental competency groups' to share local knowledge and co-develop modelling approaches that reflected both scientific and local understanding (Reference 5). The modelling part of the RELU project was done entirely by DU researchers, who used a minimum-information requirement approach based on the analysis of flow pathways to respond to the competency groups by devising model variants to evaluate novel upstream flood mitigation measures, leading for example to the development of 'Bund' and 'Overflow' models (References 5 & 6). The flexibility of the model framework and map-like visualisation of the catchment meant that stakeholders could participate directly in the modelling and evaluation process.

3. References to the research

(**Bold** denotes Durham University staff at time of research, underline denotes DU research student. Journal impact factors and citations are from Web of Science as of 31/7/2013. All six papers acknowledge funding from RELU and/or NERC.)

1. **Lane** SN, **Brookes** CJ, Heathwaite AL, **Reaney** SM (2006). Surveillant science: challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57: 239-257(JIF 1.50; 29 citations)
2. **Lane** SN, **Reaney** SM, Heathwaite AL (2009). Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45, W08423. (JIF 3.15; 25 citations)
3. **Lane** SN, Reid SC, Tayefi V, **Yu** D, **Hardy** RJ (2008). Reconceptualising coarse sediment delivery problems in rivers as catchment-scale and diffuse. *Geomorphology* 98: 227-249. (JIF 2.55; 18 citations)
4. **Reaney** SM, **Lane** SN, Dugdale LJ, Heathwaite AL (2011). Risk-based modelling of diffuse land use impacts upon instream ecology. *Ecological Modelling* 222: 1016-1029 (JIF 2.07; 6 citations)
5. **Lane** SN, **Odoni** N, Landström C, Whatmore SJ, Ward N, Bradley S (2011). Doing flood risk science differently: an experiment in radical scientific method. *Trans. Inst. British Geographers* 36: 15-36. (JIF 4.12; 22 citations)
6. **Odoni** N, **Lane** SN (2010) Knowledge-theoretic models in hydrology. *Progress in Physical Geography* 34: 151-171 (JIF 3.42; 9 citations)

4. Details of the impact

SCIMAP and the related research described above has delivered a family of modelling tools for public agencies and other UK users concerned with river catchment management. The research has had impact partly because stakeholders were involved from the outset but also because its emphasis on runoff and pollutant sources, connectivity, and risk was in tune with three policy drivers which we mention here because they are important context for the impact.

(1) The UK government's 2004 Foresight Report on flooding, its update in the 2007 Pitt Review following widespread flooding that year, and Defra's 2005 policy document *Making space for water* all recognised that upstream interventions in rural catchments might alleviate flood generation and transmission and thus reduce the risk at vulnerable downstream towns. The Defra document flagged this as a knowledge gap and research priority, and Defra, the Environment Agency (EA below), and Natural England subsequently funded three 'Slowing the Flow' pilot projects in 2009-2011. Pickering was chosen as one of the sites, partly because of the work already done by DU (Source 1, p.10).

(2) The European Union's Water Framework Directive, adopted in 2000, requires member states to assess the environmental quality of all rivers and other water bodies by December 2013 and have improvement plans in place by 2015. In England and Wales the status assessment is being done by the EA, which is consequently having to devote considerable effort to mapping diffuse pollution (mostly farming-related) in rural catchments in addition to its longstanding responsibility for licensing or penalising pollution from major point sources such as industry and

sewage works.

(3) Reducing diffuse pollution from agricultural fertilisers is also the driver for the ongoing Defra-funded EA/Natural England Catchment Sensitive Farming initiative, which started in 2006 and offers grants and advice to farmers in almost half of England.

Flooding: the RELU project led to new ideas on how to alleviate flood risk at Pickering (References 5, 6) by small-scale interventions at key locations within the catchment. Following endorsement of these ideas by the local councils, we helped plan their implementation in collaboration with Forest Research and a local community group (the Ryedale Flood Research Group, established during the RELU project). Our 'Bund' and 'Overflow' models were used in 2009-2011 for detailed planning of a package of interventions. These include tree planting, blocking moorland drains, building artificial logjams in small forested tributary streams to add to those formed naturally by tree fall, and constructing low earth dams (bunds) across stream floodplains near Pickering. The final Forest Research/Defra report on the project highlights the value of the modelling in identifying the most effective locations for intervention (Source 1, p.13).

Most of the measures have now been implemented, but additional modelling led to a preference for fewer but larger bunds. The North York Moors Park Authority approved the bund plans in May 2013. Source 1 states (p.7) that "Slowing the Flow at Pickering has gained a national profile [and has helped] guide and integrate the implementation of government policy on flood risk and land use management". Source 1 (p.7) also notes that the project "succeeded in fully engaging the local community, who have largely embraced the concept of a whole-catchment approach to flood risk management", and this assessment is endorsed by community groups (Source 2). A spokesperson for the Ryedale Flood Research Group testifies that "the RFRG project was critical in listening to local opinion and expertise, effectively developing it into a 'feasibility study', then providing the credibility for ideas to be taken further. The role of flood scientists from Durham played a key part in this … both [through] flood modelling and by providing a sound learning experience" (Source 2).

Diffuse pollution: from 2005 onwards successive versions of the SCIMAP model have been embedded in an open-source GIS, freely downloadable under a Creative Commons licence, with user-friendly visual interface. The software and training resources are freely available at www.scimap.org.uk. In the year to mid-April 2013 the website had over 1500 visitors (33% of them from outside the UK) and there were over 200 downloads of the software. Within the REF period we have organised and run training events for over 70 managers and practitioners from rivers trusts, national and regional EA offices, Defra, and the Scottish Environmental Protection Agency (SEPA). We also organised, with EA support, an inaugural user group meeting for 30 participants in October 2012 and have prepared downloadable videos and training documents for those unable to attend training in person.

SCIMAP is relevant to the EA's work on the Water Framework Directive and Catchment-Sensitive Farming initiative because the model can predict not only which stretches of stream or river are at greatest risk from diffuse pollution, but also where the likely critical source areas are. By late 2012 EA officers trained by DU had used the model to produce risk maps for phosphorus and fine sediment (two of the main causes of failure to reach WFD 'good' status) in 11 top-priority Catchment-Sensitive Farming catchments distributed throughout England, Wales and the Scottish Borders. SCIMAP is now mounted on the EA's central modelling platform so that it is available to all EA staff. The EA keynote speaker at the October 2012 user group meeting stated that the EA found SCIMAP useful because it could interface with existing national-scale datasets, is computationally efficient, has easily-understood output, and helps target source areas for detailed inspection on the ground (Source 3). The Irish agricultural authority (Teagasc) has used elements of SCIMAP in six catchments, and SCIMAP is being used for characterisation of fine sediment and phosphorus pollution and assessment of test mitigation measures in Defra's £2m 2009-2014 Eden Demonstration Test Catchment project.

The other main users of SCIMAP are Rivers Trusts: charitable organisations which make practical catchment and river improvements in the interests of anglers, riparian landowners and other river users in all parts of the UK (www.theriverstrust.org/riverstrusts/trust_movement.html). SCIMAP has been attractive to Rivers Trusts because, as Source 4 puts it, "[unlike some models] it supports knowledge collection and delivery on the ground rather than trying to circumvent it".

The first collaboration, during the original SCIMAP grant which spanned the start of the REF

period, was with the Eden Rivers Trust. It changed the Trust's approach to land management within 2300 km^2 of NW England: the Trust had previously focused on the main river and river-bank areas, but now considers the pressures on river ecology and fisheries as diffuse-source problems (Source 4). Since 2008 the Trust has liaised with farmers to reduce soil compaction at critical sources of flood runoff and to plant trees at key transmission points.

This collaboration with Eden Rivers Trust provided a pathway to broader impact, with nine other Rivers Trusts subsequently using SCIMAP to understand the hydrology of individual catchments and to plan effective interventions to reduce flooding and/or pollution. For example, the Yorkshire Dales Rivers Trust funded a DU PhD project which used SCIMAP to produce source connectivity and erosion risk maps in the Ripon multi-objective project, where interventions such as hedge planting to trap floodwaters and allow sediment to drop out have led to "massive improvements" in managing diffuse pollution across an area of 140km^2 to the west of Ripon (Source 5).

As a final example, the Westcountry Rivers Trust has used SCIMAP in its contribution to South West Water's 5 year £3m 'Upstream thinking' initiative, which will save the water company money by reducing treatment costs when it draws sediment-laden water directly from rivers. As one of the Trust's officers puts it (Source 6): "The model helps us to quantify the scale of the problem and target high-risk areas …. Putting our farm advisors and our capital investment into the right bits of the catchment to achieve the most possible benefit". As well as this application specifically to fine sediment, the Westcountry Rivers Trust has used the hydrological core of the model in ecosystem services work with farmers who are considering planting trees on low-grade wet land in order to receive carbon sequestration payments. Source 6 reports a farmer being shown SCIMAP maps as part of a multi-agency farm visit and saying "how did you possibly know where those wet bits were? Because by looking at them in dry weather you'd never know that when it rains they become really boggy". In this and other ways SCIMAP was regarded by this user as "a powerful tool for engaging and communicating these issues to stakeholders" (Source 6).

5. Sources to corroborate the impact (indicative maximum of 10 references)

Source 1: Nisbet T *et al* (2011) *Slowing the flow at Pickering – final report*. Defra, London, FCERM Project RMP5455, 29 pp. Available at www.forestry.gov.uk/pdf/stfap_final_report_Apr2011.pdf/$file/stfap_final_report_Apr2011.pdf

Source 2: Testimony letter from Ryedale Flood Research Group, 27 May 2013. [Participant and Reporter in impact delivery]

Source 3: Environment Agency: 'Diffuse Pollution, the Water Framework Directive and SCIMAP – an Environment Agency View'. Keynote at DU/EA SCIMAP User Group Meeting, 26 October 2012. Mary Summer House, Westminster, London. Video of presentation is available at https://vimeo.com/62781907 [Participant and Reporter in impact delivery]

Source 4: Rivers Trust Director North 'SCIMAP: a history of the rivers trust movement and hydrological connectivity' from SCIMAP User Group Meeting, 26 October 2012. Mary Summer House, Westminster, London. Video available at www.scimap.org.uk/2013/03/scimap-a-history-of-the-rivers-trust-movement-and-hydrological-connectivity/ ; see 07'17"-08'20" for key quote. [Participant and Reporter in impact delivery]

Source 5: Yorkshire Dales Rivers Trust, "SCIMAP and the Yorkshire Dales Rivers Trust" from SCIMAP User Group Meeting, 26 October 2012. Mary Summer House, Westminster, London.Video available at www.scimap.org.uk/2013/03/scimap-the-experience-of-the-yorkshire-dales-rivers-trust/ ; see 06'07" to 07'07" for key quote. [Participant in impact delivery]

Source 6: Westcountry Rivers Trust, "SCIMAP for upstream thinking" from SCIMAP User Group Meeting, 26 October 2012. Mary Summer House, Westminster, London. Video available at www.scimap.org.uk/2013/03/the-scimap-modelling-framework-a-powerful-tool-for-targeting-the-planning-and-delivery-of-integrated-catchment-management-interventions/ ; see in particular 11'13" – 11'53" and 19'17"- 20'14". [Participant and Reporter in impact delivery]