Institution: University College London

Unit of Assessment: 17B – Geography, Environmental Studies & Archaeology: Geography

Title of case study: Provision of data on freshwater acidification and recovery for monitoring and policymaking

1. Summary of the impact (indicative maximum 100 words)

UCL research underpins Government requirements to monitor the effectiveness of its policies with respect to international legislation to combat the impact of acid deposition on surface waters. UCL led two programmes: the Acid Waters Monitoring Network and the Freshwater Umbrella programme. Since 2008 these programmes have been used to: (i) set national thresholds to identify the extent of acidification of surface waters; (ii) model and measure recovery of freshwaters from reductions in acid deposition; (iii) set new acidification standards for pollution of UK rivers; (iv) determine ecological status of key UK protected habitats; and (v) guide upland forestry planting.

2. Underpinning research (indicative maximum 500 words)

Acid Waters Monitoring Network: Acid rain has been a global concern since the 1970s. Freshwaters were increasingly polluted by the products of fossil fuel combustion, especially sulphur (S) and nitrogen (N) gases, leading to acidification of surface freshwaters and a decline in biodiversity. Acid rain, however, is a trans-boundary problem, which required international agreements to be set up through the United Nations Economic Commission for Europe (UNECE) to curb and ultimately reverse the damage caused by emissions of acid-forming compounds. Because of their world-leading research into the causes of surface water acidification, the Environmental Change Research Centre (ECRC; led by Battarbee) was selected by the UK Government to design and lead a programme to monitor freshwater ecosystem responses to policy-led reductions in sulphur and nitrogen emissions. The Acid Waters Monitoring Network (AWMN) was thus established in 1988, and since its inception, researchers at UCL Geography have managed the Network as well as utilising the long-term datasets for original research. Since 1988, stream water chemistry has been measured monthly and lake water chemistry quarterly by UCL. UCL also contributes the majority of the data gathered through annual programme surveys of fish (UCL and Marine Scotland), diatoms (Flower, UCL), plants (Shilland, UCL), and metals and spheroidal carbonaceous particles (Rose, UCL).

UCL led the work on long-term hydrochemical trends in acid-sensitive waters to show that policy reductions in sulphur deposition have resulted in significant reductions in sulphur concentrations in surface waters, with concomitant increases in pH [a]. However, the research also revealed distinct spatial differences in the extent of recovery, caused by confounding factors such as organic acids and catchment afforestation [a]. Unfortunately, the effects of reductions in nitrogen deposition were mixed, with nitrate concentrations still elevated in some Scottish sites [a]. UCL-led research into recovery from acidification has also thrown up surprises. In a landmark study, analyses of AWMN data showed that reductions in sulphur deposition were also responsible for rising trends in dissolved organic carbon in remote European freshwaters, further offsetting declines in surface water acidity [b].

UCL have also played a key role in demonstrating that biological recovery has, at best, been only very modest, despite significant increases in pH. For example, diatoms show limited responses, but the recovered biodiversity is often different from pre-acidification states [c]. Moreover, significant recovery in fish stocks was observed at only two of the most acidified sites, although new standards were developed to monitor the best indicators of acid impact in relation to freshwater fisheries [d].

Development and improvement of critical load models: UCL Geography also led the Freshwater Umbrella programme, commissioned between 1990 and 2011 by the Department for Environment, Food and Rural Affairs (DEFRA) to complement the AWMN. In particular, the programme provides the expert input and method development for freshwater critical load modelling using the First-order Acidity Balance [FAB] model, a model specifically modified for use in the UK by UCL (Curtis) [e]. The model is used to identify the extent of damage to surface waters caused by acid deposition, taking into account the separate and combined effect of sulphur and nitrogen. UCL-led research identified the threat of nitrogen deposition, by showing that almost all upland lakes in the UK exceed their UNECE-established critical loads for nitrogen [f], necessitating further reductions in nitrogen emissions [f].

3. References to the research (indicative maximum of six references)
(UCL authors [at time of research] in **bold**)

[a] **Monteith, D. T.**, Evans, C. D., Henrys, P. A., **Simpson, G. L.** & Malcolm, I. A. (2013) Trends in the hydrochemistry of acid-sensitive surface waters in the UK 1988–2008. *Ecological Indicators* (In press). doi: 10.1016/j.ecolind.2012.08.013. (ISI Journal Impact Factor [JIF]: 2.890).

- Policy-initiated reductions in sulphur deposition have resulted in very clear signs of chemical recovery in acid waters monitored by the AWMN.

[b] **Monteith, D. T.**, Stoddard, J. L., Evans, C. D., de Wit, H. A., Forsius, M., Hogasen, T., Wilander, A., Skjelkvale, B. L., Jeffries, D. S., Vuorenmaa, J., Keller, B., Kopacek, J. & Vesely, J. (2007) Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature* 450, 537-540. doi: 10.1038/nature06316. (JIF: 38.597; SCOPUS Citations 347).

- AWMN data used in a meta-analysis to show that reductions in sulphur deposition have resulted in increased concentrations of dissolved organic carbon in Northern Europe and North America, which is off-setting declines in surface water acidity.

[c] **Battarbee, R. W., Simpson, G. L., Shilland, E. M., Flower, R. J., Kreiser, A., Yang, H.** & **Clarke, G.** (2013). Recovery of UK lakes from acidification: An assessment using combined palaeoecological and contemporary diatom assemblage data. Ecological Indicators (In press). doi: 10.1016/j.ecolind.2012.10.024 (JIF: 2.890).

- Despite legislation resulting in major declines in atmospheric pollutants, biological recovery of diatoms from freshwater acidification is still minor in comparison to pre-acidification targets.

[d] Malcolm, I. A., Bacon, P. J., Middlemas, S. J., Fryer, R. J., **Shilland, E. M.** & Collen, P. (2013) Relationships between hydrochemistry and the presence of juvenile brown trout (*Salmo trutta*) in headwater streams recovering from acidification. Ecological Indicators (In press). doi: 10.1016/j.ecolind.2012.02.029. (JIF: 2.890).

- There is evidence of limited recovery in fish presence at some of the most acidified sites, and that the best indictor of fish fry presence was labile aluminium, which should be adopted as an indicator of acid impacts.

[e] **Curtis, C. J.**, Allott, T. E. H., Hall, J., Harriman, R., **Kernan, M.**, Reynolds, B. & Ullyet, J. M. (2000) Critical loads of sulphur and nitrogen for freshwaters in Great Britain and assessment of deposition reduction requirements with the First-Order Acidity Balance (FAB) Model. *Hydrology and Earth Systems Sciences* 4(1): 125–140. http://www.hydrol-earth-syst-sci.net/4/125/2000/hess-4-125-2000.pdf. (JIF 3.587).

- Critical load modelling showed that international commitments to reduce sulphur deposition were insufficient to protect the most sensitive ecosystems, and that action needed to be taken to reduce nitrogen emissions as well.

[f] **Curtis, C. J.**, Evans, C. D., Helliwell, R. C. & **Monteith, D. T.** (2005) Nitrate leaching as a confounding factor in chemical recovery from acidification in UK upland waters. *Environmental Pollution* 137, 73–82. http://www.sciencedirect.com/science/article/pii/S0269749105000552. (JIF: 3.730).

- This study showed that with declining excess sulphur, nitrate would become the dominant agent of continued anthropogenic acidification in many UK upland waters.

Evidence of Quality: The two programmes have received successive funding commitments from DEFRA (contract renewals every ~3 years for 24 years):

- 2002–2014 approximately £3.4 million awarded to the UK AWMN: (2000–04 EPG1/3/160; 2004–07 RMP2036; 2007–10 AQ0804; 2010–14 AQ0820)
- The Freshwater Umbrella programme has secured funding from DEFRA 2002–2011 of just over £1.3 million (2002–07 EPG1/3/183; 2007–11 AQ0803)
- Between 1993–2013, 130+ reports and over 110 peer-reviewed papers referencing AWMN and Freshwater Umbrella programme data were published, the majority in leading disciplinary journals.

4. Details of the impact (indicative maximum 750 words)

UCL research into the effects of, and potential for, recovery from acid rain damage has influenced national pollution policy and habitat management, with a reach spanning local, national and international agencies. The AWMN is the key provider of information on surface water acidification to UK Government and Devolved Administrations. It is also the sole UK provider of data and expertise to the UNECE International Cooperative Programme on the Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes (ICP Waters), set up under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) [1]. Through the Freshwater Umbrella Programme, AWMN data are further used to develop and apply critical load models used on a national basis for the provision of data for freshwater ecosystems under the 1999 UNECE Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. As well as providing original, high-quality data to guide decision-making by DEFRA, the data are a major resource for organisations responsible for the management of UK upland water catchments.

Set national thresholds to identify the extent of acidification of surface waters: The UK National Focal Centre (NFC), based at the Centre for Ecology and Hydrology (CEH) (Bangor), has used UCL research for freshwater critical loads mapping and modelling since 1991. The NFC submit national critical loads data to the Coordination Centre for Effects (CCE) in response to their calls, usually every year [2]. These data are used in the integrated assessment of European air pollution agreements. In 2005, the freshwater critical loads dataset developed at UCL was expanded to include 38 new exceeded sites from the North Yorkshire Moors. In 2008, application of the FAB model to the expanded dataset was undertaken. This showed that 37% of freshwater sites were still exceeded with 2004–06 deposition data, and that 25% of all sites will continue to exceed critical loads beyond 2020. These 2008 revised data for freshwaters contributed to the national critical loads dataset submitted to the NFC and were subsequently used to revise the Gothenburg Protocol, which was adopted by CLRTAP signatories 2012. Nitrogen deposition was shown by the UCL research to be responsible for a major part of continued exceedances.

Model and measure recovery of freshwaters: Using data provided by UCL, the NFC also generates annual summary statistics of (i) catchment area and (ii) the percentage of 1,700 freshwater sites with critical load exceedances for England, Wales, Scotland and Northern Ireland and for the UK as a whole [2]. These data formed the basis of the critical load maps presented in the DEFRA 2012 Review of Transboundary Air Pollution report to evaluate the current state of rural air pollution issues in the UK (RoTAP 2012; pp. 132–135) [3]. The same data were used by DEFRA's Joint Nature Conservancy Council towards UK indicators with respect to international biodiversity targets [4].

Set new acidification standards for pollution of UK rivers: Historically, pH standards for rivers were set using values that protect against extreme events. The full time-series of AWMN data produced at UCL highlighted a stronger relationship between mean pH and acid neutralising capacity and biological communities than there was for extreme-event minimum values [5]. In 2012, the UK Technical Advisory Group accepted these new acidity standards. This is beneficial because extreme events are rare and difficult to capture. Using the mean allows more robust relationships to be modelled between chemistry and biology. These new standards are now used to help classify the ecological status (e.g. High, Good, Moderate, Poor, Bad) of water bodies for WFD statutory reporting, and because the standards come from an improved science base, they reduce the discrepancies with observed biological status.

Determination of ecological status of key UK protected habitats: The Habitats Directive is the cornerstone of Europe's nature conservation policy; the AWMN provides advice and data to Natural England, Scottish Natural Heritage (SNH) and Countryside Commission for Wales (CCW) to support their obligations under Article 17. UK conservation agencies use AWMN outputs in their on-going reporting on the condition of the EC Habitats Directive Annex 1 habitat type oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea* (Habitat code H3130). For example, SNH established the 'favourable conservation status' of the Merrick Kells, a Special Area of Conservation, using AWMN data from the Round Loch of Glenhead. In 2011 UCL was contracted by SNH to update the organisation on the recent acidification status of the Merrick Kells. The resulting report [6] showed that acidity had decreased over the past 20 years because of UK pollution reduction strategies, but that post-2008 the area's critical load still failed to meet UNECE targets. SNH have since used these findings to report on the condition of the Merrick Kells and the wider habitat type for Europe to the Scottish Government.

Guide upland forestry planting: The Forestry Commission relies heavily on the AWMN data to inform policy on managing forestry within acid-sensitive areas. For example, forest managers are required to undertake a catchment-based critical load assessment when new forests are planted, especially if the planted area exceeds 30% of the catchment [7, p. 4] [8, p. 30]. These assessments are compared to the acid deposition load received by the catchment (determined from UCL data provided to the NFC). Where a catchment-based assessment shows acid deposition exceeding the freshwater critical load, approval is unlikely to be granted for new planting or restocking above certain thresholds of forest cover until there are further reductions in pollutant emissions [7]. In 2011–2012, 24,500 ha of new planting and restocking took place; where this exceeded 30% of the catchment they were required to undergo the assessment [9]. AWMN datasets underpin the critical load assessment mandated in the 2011 guidelines, and are a key component of the draft guidelines under consultation in 2013.

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

[1] In 2010 the publication of the 20-year AWMN report was publicised by a DEFRA press release accompanied by a statement on the contents from the Environment Minister Lord Henley (https://www.gov.uk/government/news/acid-rain-20-years-on). The article also featured on the front page of DEFRA's website. The AWMN report itself (http://awmn.defra.gov.uk/resources/interpreports/20yearInterpRpt.pdf) corroborates that contributors are all UCL staff (p. i), and AWMN provides data for ICP Water (p. 1).

[2] UK National Focal Centre (UK NFC) for critical loads mapping and modelling is based at CEH Bangor (http://cldm.defra.gov.uk/UK_NFC.htm). The CEH contact corroborates submission of data and generation of summary statistics of freshwater critical load exceedance by country (England, Wales, Scotland and Northern Ireland) and for the UK.

[3] For use of the UCL research in the RoTAP (2012) Review of Transboundary Air Pollution, see pages 114–135 (incl. Figs 5.22 and 5.33), 168, and 198–199: http://www.rotap.ceh.ac.uk/sites/rotap.ceh.ac.uk/files/CEH%20RoTAP.pdf.

[4] For use of the data by DEFRA's Joint Nature Conservancy Council towards identification of indicators with respect to international biodiversity targets see p. 17 of the 2012 report "B5 Pressure from pollution": http://jncc.defra.gov.uk/page-4229.

[5] Acidification Environmental Standards. Paper Number FTT017, which details the quantitative rationale for altering acidification environmental standards for rivers, see p. 5, Fig 3 & Table 7 http://bit.ly/189qYsn. Reference to UCL research contribution: see Fig 3, and reference [c] in Section 3 above.

[6] For the report commissioned by SNH see http://www.snh.org.uk/pdfs/publications/commissioned_reports/469.pdf; The SNH's response to the findings of that report are covered in the following BBC News article (2012). http://www.bbc.co.uk/news/uk-scotland-south-scotland-16579154.

[7] Practice guide: managing forests in acid sensitive water catchments: http://bit.ly/1hZnICy. This guide details the process of comparing catchment-based critical loads with critical load maps produced by the NFC, based on UCL research (e.g. see p. 4).

[8] Forestry Commission (2011) Forests & Water. UK Forestry Standard Guidelines. Forest Commission, Edinb. 80pp. http://www.forestry.gov.uk/pdf/FCGL007.pdf/$FILE/FCGL007.pdf.

[9] For the 2012 forestry statistics cited above see p. 26 of: http://www.forestry.gov.uk/pdf/ForestryStatistics2012.pdf/$FILE/ForestryStatistics2012.pdf.