

Institution: University of Glasgow	
Unit of Assessment: 10 – Mathematical Sciences	
a. Context	
<p>The School (submitted FTE 43) undertakes internationally leading research which (a) addresses fundamental issues in the mathematical sciences and/or (b) is motivated by important scientific, industrial or societal questions. The impact of the former can be profound, but often long-term and unpredictable. The impact of the latter can be immediate, and in many application areas.</p>	
Primary beneficiaries	Significant examples
Environmental agencies and government	Environment Agency (EA), the Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH), the Centre for Ecology and Hydrology (CEH)
Medicine and health	Medical guideline authorities, pharmaceutical companies
Industry	Shell Global Solutions, Scottish Water, Abaqus, Devro
Principal types of impact	Contributing research groups
Policy advice	Environmental Statistics, Biostatistics & Genetics
Models for real-world phenomena and management	Continuum Mechanics, Biostatistics & Genetics, Environmental Statistics, Mathematical Biology
Software tools for practitioners	Biostatistics & Genetics, Environ. Stat., Cont. Mech.
b. Approach to impact	
<p>The high value which the University of Glasgow and the School place on impact is indicated by its significance in staff review and in professorial zoning, where impact is placed on an equal standing with publications and grants. The College of Science and Engineering employs 3 Business Managers to support initiatives and projects and organise a biennial Industry Day where professionals from industry view current research, interact with staff and make presentations of problem areas. The School makes major contributions to these events, principally through its environmental research. The University of Glasgow's <i>Research Strategy and Innovation</i> office supports all these activities at strategic and operational levels. The School publicises opportunities, assists with engagement and provides funding and logistical support.</p>	
Initiating contact and developing relationships with non-academic partners	
<ul style="list-style-type: none"> • <i>Statistical training.</i> Courses in modern statistical methods are regularly offered to environmental scientists. This activity demonstrates the value of statistical modelling, strengthens links with organisations and generates ideas for project-based research. NERC has funded us since 2003 (£273k, c.350 students) to train its own PhD students and institute staff, with a new award (£73k) for enhanced training in 2013-14. Courses are also given to SEPA, CEH, the National Oceanography Centre, and internationally (Sicily, 2009; India, 2012). • <i>Workshops and Study Groups.</i> Relevant organisations regularly attend themed workshops, to take advantage of the School's expertise. Our growing links with Scottish Water were initiated in this way and a recent <i>Water Day</i> extended participation to SEPA and SNH. A forthcoming <i>Sensors Day</i> will bring together scientists whose work on modelling, inference and visualisation is key to the national sensors initiatives. The School is principal organiser of both these events. Bourne has addressed issues of ship manoeuvrability with the Maritime Research Institute Netherlands, through Maths with Industry Study Groups, using dynamical systems theory, with the results published and developed by the company. • <i>Participation in major cross-disciplinary initiatives.</i> This creates significant opportunities for 	

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collaboration with industrial partners. For example, the School leads the University of Glasgow's *Sustainability Network* and Scott co-ordinates the University's involvement in the TSB *Future Cities Demonstrator* project (£24m) awarded to the City of Glasgow.

- *Membership of advisory bodies.* Through membership of national policy, advisory and liaison committees, where strategic issues relevant to impact are debated and advice prepared, the School makes important contributions from the mathematical sciences. Examples include the Scottish Science Advisory Council, Scottish Government Natural Environment Statistics Advisory Committee, Scottish Census Advisory Group.
- *Jointly funded studentships.* We view this as an excellent way to deliver specific impact and to develop and cement our relationships with partners; the table below gives examples. The value placed on this by industry is also indicated by numerous MSc studentships awarded to the School by ISD (Information and Services Division of the NHS Scotland, £200k), the Scottish Qualifications Authority (£18k), Novartis (£60k), GSK (£36k), Boehringer Ingelheim (£18k), and ICON (£18k). The School is also a leading partner in four PhD studentships awarded by the University of Glasgow to grow research capacity in the strategic area of sensors. Shorter term industrial secondments of research students can also produce significant impact; one example is with SEPA in producing visualisation tools for pollution over river networks.

Partner for studentship	Topic
Biomathematics & Statistics Scotland (EPSRC)	Spread of pollution over a river network
CEH (NERC)	Spread of mosquitos due to climate change
Shell Global Solutions	Spatiotemporal groundwater monitoring
Skills Development Scotland	Transition from education to employment

Knowledge exchange

The success of our approach is indicated by the repeated requests for provision of training and consultancy and, notably, through several subsequent knowledge exchange awards.

- NERC *Knowledge Exchange* funding (Scott, Bowman, Miller, Lee; £248k) enabled co-ordinated impact across all the main environmental agencies in Scotland (SEPA, CEH, SNH, Scottish Government), delivering improved evidence for the support of their environmental policies. This was achieved through training workshops, specific research projects on bathing water quality and health (with Health Protection Scotland), and the evaluation of ecosystem services. This led to membership of *INQUEST*, a NERC-funded *Valuing Nature Network*, within which we will deliver statistical tools to support the quantification of uncertainty.
- University EPSRC KTA funding (Luo; £32k) was awarded for work with the international company DEVRO on the design and improved performance of sausage casings. This was followed by grants of £21k and £50k for further developments, with funding split between the company and EPSRC Impact Acceleration Account/Scottish Funding Council respectively. The success of the project was reported in the *Scotsman* newspaper.
- University EPSRC KTA funding (Scott, £30k) for analysis of data held by Scottish Water, who provided further financial support, delivered a web tool which allows the company to visualise and interpret complex data collected across their network and to identify patterns.

In each case, success is indicated by the delivery of specific impact, the commitment of further funding by partners, and forthcoming bids to larger funding schemes to increase the scope of the impact we have already generated.

Examples of strong and sustained relationships with key partners

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1. **Environmental agencies and government.** Over the last twenty years, our relationships with environmental bodies have strengthened considerably. Numerous research projects have been conducted in conjunction with, and often sponsored by, SEPA, EA, CEH, SNH, delivering impact through evidence to support policy and regulation. Scott's outstanding contributions to this area were recognised by the award of an OBE in 2009. She also served on the *Royal Commission on Environmental Pollution* (2010-11) and has been a regular adviser to site operators at Sellafield and Dounreay on radioactive particles in the environment. The closeness of our relationship with SEPA was expressed in the appointment of the CEO as an Honorary Professor in the University. Lee has new links with the Met Office through an EPSRC funded project on improved air quality predictions, while Miller's work with the EA on the modelling of nitrate and phosphorus in river catchments, initiated by the agency in response to a published paper, formed part of a derogation report to the EU.
2. **Medicine and health.** Biostatistics has been a key part of the School's profile for over thirty years. The Robertson Centre for Biostatistics was created in 1993; led by Ford since 1996, the Centre has played a leading role in the design, conduct and analysis of major clinical trials, including ground-breaking research on the use of statins, with direct influence on subsequent health guidelines worldwide [case study]. Senn's expertise in medical statistics has also been widely sought by the pharmaceutical industry, and as a result of his high profile, he has now been appointed to lead biostatistics research in Luxembourg. Our strong connection with this industry is reflected in the appointment of Anisimov from Quintiles as an Honorary Professor. In genetics, the high profile work of Macaulay has led to major impact in the public understanding of historical population movement, widely publicised in print and broadcast media [case study].
3. **Industry.** The relevance and impact of the School's research is indicated by the uptake of methods and results by a wide range of industrial and other organisations. The spatiotemporal and statistical computing work of Bowman and Evers has been adopted by Shell Global Solutions with the consequent development of a widely used groundwater monitoring tool [case study]. The fundamental advances developed by Ogden for the behaviour of rubber-like solids have been adopted and implemented by all the major developers of 'finite element' packages (Abaqus, ADINA, ANSYS and others), with these models central to engineering design and analysis in the automotive and aeronautical industries [case study]. Scott's interdisciplinary research with the University of Glasgow Vet School on the measurement of animal pain produced the Glasgow acute pain scale [case study] which is now used around the world (>3,000 downloads). This work attracted significant investment from Pfizer and was awarded the inaugural Universities Federation for Animal Welfare prize. It has also led to the creation of a start-up company NewMetrika under the University of Glasgow's innovative Easy Access IP system. Miller and Scott are developing methodology and computing tools to be embedded within the operational arm of Scottish Water for the analysis of water quality data and its drivers, with impact on subsequent operational planning. Scardia's work with the international company Tata Steel produced significant mathematical advance [Scardia output 1] as well as industrial insight.

The School seeks to be agile in its approach to opportunities for impact by reacting positively and constructively to requests and by seeking opportunities proactively. Two examples follow.

- Toshiba Medical Visualisation Systems and the SAS software company recently expanded their operations in Scotland and approaches from the School about possible areas of common research interest led to the provision of an MSc research project, sponsorship of a student prize and participation in student induction events.
- A response to a Scottish Government policy consultation on data linkage led to the

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commissioning of a report from Scott and Miller in the environmental arena. This led to the creation of a consortium including Scottish Water, SEPA, the Scottish Government and the James Hutton Institute to focus on issues connected with the Scottish Government *Hydro Nation* agenda.

Outreach and public engagement

We place high value on outreach and public understanding. For more than 15 years, we have run Mathematics Masterclasses for pupils from the Strathclyde region, as part of the UK-wide programme organised under the auspices of the Royal Institution of Great Britain. We also operate broader Taster Weeks and encourage our students to participate in the Ambassador Programme which places them in schools (10-12 per year). We aim to inspire pupils, broaden their appreciation of mathematical topics and encourage them into further study in the subject. We have also played a leading role in the Scotland-wide Mathematical Challenge scheme for schools, over many years. For a more general audience, the Glasgow Science Festival is one of the largest events of its kind in the UK, attracting around 40,000 visitors each year. The School has organised mathematical science events as part of the Festival since its launch in 2007.

c. Strategy and plans

The School has strong upward momentum in its impact-related activities and this will be maintained as an important part of our strategic aims.

- We will grow our relationships with existing industrial partners (Shell, Scottish Water, Pfizer) through workshops, studentships, grants and direct industrial funding.
- We have significant involvement in University of Glasgow-supported initiatives, in particular *CENSIS*, the new *Innovation Centre for Sensors and Imaging Systems*, led by the University, funded by the Scottish Funding Council and with participating industrial institutions across Scotland. Under *Big Data*, we are in discussion with the *Scottish Data Linkage Service* to enhance the linkage of environmental, business and administrative data sets. Under *Future Cities* and the link to sensors, we are developing visualisation tools to aid interpretation of high volume data. Under *Sustainable Glasgow*, we have been working on the creation of meaningful environmental indicators. With the *West of Scotland Space cluster*, we are investigating the statistical design of a network of space weather sensors.
- We will extend our involvement with medical and health partners, through the soft tissue heart modelling work of Luo and Ogden, and the analysis of three-dimensional images by Bowman. All these areas have substantial potential for major impact.

d. Relationship to case studies

All our case studies developed over significant time periods, allowing trust to be built through increasing activity and perceived value to the partners. The *Shell Global Solutions* case study illustrates the value of studentships, through employment of one of our PhD students and subsequent sponsorship of another. The *WOSCOPS* and *Animal Pain* case studies arose from significant medical and veterinary issues and these indicate the success of our strategy of motivating methodological research from challenging real world problems. The *Rubber modelling* and *Genetics ('Out of Africa')* case studies illustrate the success of outstanding research, the value of which was recognised by industrial partners and the impact subsequently pursued.