Institution: University of Reading

Unit of Assessment: 10 Mathematical Sciences

a. Context

Within the Department of Mathematics and Statistics at the University of Reading, research is organised into groups with significant overlap and interaction:

- **Pure, Applicable and Numerical Analysis** (including Data Assimilation and Inverse Problems);
- **Statistics and Applied Statistics**;
- **Complex Fluids and Theoretical Polymer Physics**;
- **Centre for the Mathematics Of Human Behaviour** (CMOHB); and
- **Mathematical Biology.**

All research groups have the propensity for their research to lead to impact, but it is more obvious for some than others. Economic benefit is the most common and established form of impact for research undertaken within the department. Our research most naturally translates into new and innovative ways for businesses and organisations to improve their existing processes, whilst also aiding in the development of new procedures. Furthermore, our work with partners relating to activity in the developing world has impacted upon policies and, indirectly, on society and the environment in the countries involved. To date research having key economic impact has mainly come from the CMOHB, the Data Assimilation and Inverse Problems areas and Applied Statistics. Policy impacts affecting the developing world have come from Applied Statistics.

Historically, impact from research undertaken within the Department of Mathematics at the University of Reading has been nurtured by contact with a range of industrial and government organisations (e.g. the Atomic Weapons Establishment (AWE), the Royal Aircraft Establishment (now QinetiQ & the Defence Science and Technology Laboratory), Hydraulics Research Wallingford, British Petroleum, British Gas, and the Met Office). Links have been predominantly formed through personal contacts, or by reputation and referral. Over time, collaborations with some of these historical partners, in particular AWE and the Met Office, has grown. More recently, with new appointments and the subsequent evolution of current research groups within the department, additional partnerships have been formed. These include collaborations with Syngenta, Unilever, Pfizer, Scottish & Southern Electricity, Vodafone, the Ministry of Defence and Bloom Media. In addition, a merger with the Applied Statistics group in 2010 to form the Department of Mathematics and Statistics facilitated links with medical research institutes and the pharmaceutical industry - including Novartis, GlaxoSmithKline and AstraZeneca, together with partners working in developing countries such as TRAFFIC International (the wildlife trade monitoring network) and the Wildlife Conservation Society.

b. Approach to impact

Research in Mathematical Sciences typically derives impact via two main routes, either through take-up of methods directly by industry or implementation by researchers in neighbouring disciplines. The department has always encouraged **contact and collaboration** with both other academic and non-academic groups. Support has ranged from facilitation of interactions through workload arrangements and travel expenses, to strategic appointments. The nature of the contact/collaboration varies from CASE studentships, to strategic partnerships, to industrial involvement in research council grants, to direct research contracts and consultancy agreements with companies and organisations.

In the assessment period a large strategic emphasis has been placed on building inter-disciplinary links both externally and within the University and the wider academic network, to maximise routes to impact. Strategic decisions have included the following:

We have recruited several new academic staff with industry track records. Professor Peter Grindrod was appointed in 2007 and established the CMOHB. During his time at Reading a lecturing position within CMOHB was created and filled by a candidate who had previously worked for Unilever. In making other recent appointments to lectureships we have valued industrial track records; for example, a lecturer in Statistics who previously worked for QinetiQ started in

September 2012. These people come with the both the skills and contacts needed to bridge the gap from academic research to application and impact.

The strategic investment in interdisciplinary centres at Reading since 2006 has played an important part in fostering impact, bringing new potential external partners, including industry and government partners. This investment has allowed us to recruit new staff with strong interdisciplinary track records, specifically four joint appointments with other departments at Reading – a joint Mathematics/Biology appointment, two joint Mathematics/Meteorology appointments and a Statistics/Meteorology appointment. In the last year, through University investment in interdisciplinary themes, four new appointments linking Mathematics further with Meteorology and with the University's Centre for Integrative Neuroscience and Neurodynamics (CINN) have been created. The creation of the latter Centre, with Mathematics as a key partner, built on an EPSRC 'bridging the gap' award and the Centre's original Deputy Director was a Mathematician. Mathematics staff were integral to the successful bid to establish the NERC National Centre for Earth Observation led from Reading. The Centre was launched in 2008 and subsequent appointments have been made to strengthen the large role we play in it, in particular through the Data Assimilation research group.

We have hosted an impressive number of CASE studentships (15 students were supported by CASE awards between 2008 and 2013, predominantly EPSRC, but also NERC and BBSRC). In addition the department has actively encouraged further links with external colleagues. Currently we host two Visiting Professors (Cullen and Grindrod) and a Royal Society Industry Fellow.

Our strategic decisions and successful interactions over the period have resulted in three main approaches to the way in which the department establishes impact for its work:

(1) Bespoke Research is where research is effectively commissioned either by direct contracts or industrial involvement via grant awards or PhD CASE studentships. Examples of impact in this area range from adopting new mathematical methodologies for use in in-house software, to substantial improvement in social network data analysis systems and incorporating mathematical techniques into production codes (e.g. operational weather forecasting models). The CMOHB employs a number of research fellows funded either directly by external partners who approached the Centre to work on specific projects or through successful joint bids for interdisciplinary funding opportunities. Much of its research is targeted towards concepts, methods and real-world applications that are required now and deliver high impact and value (see case study). Data Assimilation is another highly successful group, which, through a series of CASE studentships with the Met Office, has developed techniques now implemented in operational forecast models (see case study). The work in wildlife conservation (a third case study) also comes under this category.

(2) Targeted Research is undertaken in areas of potential impact, but is not initially driven by a specific company or another academic discipline's involvement. In Applied Statistics there has been a long tradition of medical statistics research, with connections to medical research institutes and the pharmaceutical industry; our MSc students undertake dissertations on research questions posed by industry collaborators, part-time PhD students (currently three) are employed by the pharmaceutical industry, and there is direct research collaboration with statisticians both in companies and in medical research institutes. Research is motivated by the needs of scientists in the field and work is disseminated back to these end-users through conferences and presentations at companies. Examples of impact in this area are described in another of our case studies.

(3) General Research is initiated by individual academics, but can then be identified as relevant to industry at a later date via the traditional routes of academic dissemination (e.g. journal publication and conferences). A success story here is the uptake of techniques covered by a patent to control instability of magnetohydrodynamic interfacial gravity waves in aluminium reduction cells.

In some cases, initial targeted or general research leads to bespoke work in the form of CASE studentships or grant awards with industrial collaborators; these in turn may become a source of impact. Good examples include work which prompted the multinational company Schlumberger to commission an efficient tool for optimisation relating to oil well location sites, the Applicable Analysis group's high frequency scattering research, and the Data Assimilation examples above.

A number of PhD studentships (both CASE and directly funded) have had impact in their own right

and strengthened collaborations with the non-academic partner: for example, an undergraduate student undertook summer work for AWE, became partly supported by them on her degree, received funding from them for her PhD, is now working for AWE and is the industrial supervisor on a present CASE studentship.

c. Strategy and plans

The Department of Mathematics and Statistics' overall strategy and plans for future impact will build upon current strengths, formalising the avenues of impact described above, whilst exploring new areas for exploitation. We have identified the following four priorities to maximise impact:

(1) To continue expansion of all three modes of operation: Here we will capitalise on our bespoke, targeted, and general research activities, each of which has been successful in ensuring that our mathematical and statistical expertise has impact in industry/external organisations and in other academic fields. We see no reason to depart greatly from these approaches; however, we aim to increase the impact of our work through annual reviews of each staff members' research outputs and work in progress within the department to ascertain which work should be highlighted for impact potential. This will reduce the likelihood of such work "falling between the gaps".

(2) To enhance inter-disciplinary research within and beyond the University: Staff in the Department of Mathematics and Statistics have, to date, played clear roles in inter-disciplinary research both within and outside the University of Reading. This benefits the profile of the department, enhances income streams and brings challenging, interesting and relevant research questions to the attention of researchers. A number of multi-disciplinary interactions (for example with Meteorology, Systems Engineering, Psychology) have already led to impact described by the case studies submitted for this REF and are likely to continue to do so in the future. The likelihood of collaborations (both with industry/organisations and academia) having substantial impact has been greatly increased by recent recruitments, which have been the result of a deliberate policy within the University to foster links between disciplines as part of Reading's Academic Investment Project. These have already led to the establishment of the CMOHB as described earlier, the introduction of a Mathematical Biology group and the growth and strengthening of both our Data Assimilation and our Analysis and Numerical Analysis groups, all of which have strong connections to industry and other departments within and beyond the University. We will utilise our strategy outlined in (1) above to ensure inter-disciplinary connections continue to thrive and further develop.

(3) To create wider awareness of theoretical work: Such awareness has, to date, mostly occurred as a result of industrial or academic collaborations individual members of the department have with industrial partners/organisations and other academic departments. We will seek opportunities to publicise our theoretical work more widely, for example through a greater web presence, giving detailed examples of where impact has resulted from such research as a way of highlighting possible future types of interaction with end users.

(4) To continue with our current appointment strategy: A number of new appointments over the past few years have already delivered impact or have a high likelihood of delivering impact in the future given current research in progress. Through our mentoring system and centrally run formal training programmes, we will ensure that new staff, particularly those recently recruited via strategic interdisciplinary investment posts, are aware of the importance of impact. Our continuing recruitment strategy will be informed by the need to ensure that appointments are made to capitalise on and strengthen impact in each of our research groupings.

d. Relationship to case studies

Three of our case studies (on Data Assimilation, CMOHB and elephant monitoring) are examples of our bespoke research. They illustrate that strong proactive links with external organisations (the Met Office, Bloom and conservation networks respectively) over an extended period of time result in both parties being actively engaged in the research direction and the resultant impact. The success of the impact arising from this research has informed the continued development of our approach to future impact. The case study on clinical trial methodology is an example of targeted research. Development of the initial methodology was motivated (and funded) by a pharmaceutical company, but not with a specific application in mind. The resultant work was presented to end users. The dissemination of information in this way subsequently led to the impact.