Institution: University of Bath

Unit of Assessment: 10: Mathematical Sciences

(a) Overview

In Bath, UoA10 coincides with the Department of Mathematical Sciences. We carry out internationally excellent mathematical research guided by the following strategic aims.

(S1) To advance and disseminate mathematical knowledge.

(S2) To collaborate across mathematical boundaries and to foster inter-disciplinary research.

(S3) To achieve real social, environmental and economic benefit through our research.

(S4) To support and train researchers in mathematics at all career stages.

(S5) To enhance our research activity through excellent appointments.

The research groups of the UoA are: *Algebra & Geometry*, *Analysis & Differential Equations, Continuum Mechanics, Dynamical Systems & Complexity*, *Industrial Applied Mathematics, Mathematical Biology, Mathematical Control Theory, Numerical Analysis, Probability, Statistics*.

The UoA maintains a unified vision of the mathematical sciences, embracing pure and applied mathematics, probability and statistics and their intradisciplinary interactions, a vision shared by the International Review of Mathematical Sciences (IRM) (2010, Sec. 3.1). We have fostered strong intradisciplinary connections, such as (i) the theory of partial differential equations with their applications to continuum mechanics, mathematical biology, mathematical control theory and numerical analysis, (ii) statistical modelling and probability theory with numerical analysis and (iii) analysis with geometry.

In our multidisciplinary and industrially applied research, we foster synergies between research teams, while simultaneously emphasising mathematical rigour underpinning the applications. Many projects have been supported by industry, such as our long-running collaboration with the Met Office, which combines activity in stochastic processes, continuum mechanics, and scientific computing. Our research has environmental and economic impact in areas as diverse as forestry and fisheries, energy distribution and radioactive waste disposal, weather forecasting and climate modelling, surgery for cleft lip, and clinical trial design.

The Department provides a stimulating and supportive research environment. We appoint high-calibre staff whose expertise complements and extends our research profile and we provide mentoring for new appointees appropriate to their career stage.

Since RAE 2008, the University of Bath has implemented several strategic investment initiatives. From these, the Department obtained a Professor in Pure Mathematics, two Readers in Applied Mathematics and Statistics, and three Prize Fellows (permanent academic posts with an initial two-year research period). We have also made strong replacement appointments for all staff that have left. In the REF window, the overall expansion of staff numbers in the UoA was 21%. We expect further expansion as our recruitment of high-quality undergraduates continues to rise.

In 2010, the Department moved into a new five-storey building at the heart of the campus, providing bright new staff offices, space for collaborative discussion, and accommodation for support staff. There is also a custom-built lecture room with adjacent social and exhibition space which is used extensively for seminars, meetings and workshops organised by UoA members.

(b) Research strategy

Here we describe the achievement of strategic aims (S1)–(S3), listed in Section (a), assess our current position and outline future plans.

(S1) Advancement and dissemination of mathematical knowledge. The outputs submitted in REF2 form part of the 483 WoS listed publications produced at Bath in the REF period, which now have more than 1900 citations (WoS, 31 July 2013). We draw attention to the following highlights.

Budd's work (with Huang and Russel) on adaptive moving mesh methods led to an invited 131 page paper in Acta Numerica (2009), which introduced a number of novel moving mesh algorithms and gave a detailed description of the parabolic Monge-Ampere algorithm. The latter has subsequently been used to great effect in Met Office operational codes (see REF3b).

Burstall (with Donaldson, Pedit and Pinkall) extended the classical theory of isothermic surfaces in conformal 3-space to the much more general context of submanifolds of symmetric R-spaces, showing that the crucial integrable structure of the theory is maintained (J. Reine und Angewandte Mathematik, 2011).

Galaktionov has published 35 journal articles in the REF period on numerous aspects of nonlinear PDEs, including, for example, his 47-page article on blow-up in a semilinear fourth-order reaction-diffusion equation (Nonlinearity, 2009).

Graham and E Spence's work on wave scattering (including the 217-page invited article in Acta Numerica 2012 and the article in Comm. Pure Appl. Math. 2011) combined new applications of asymptotic analysis with harmonic analysis of elliptic equations on Lipschitz domains to design and analyse novel numerical methods for high frequency scattering problems.

Jennison (with his student Hampson) developed group sequential designs to solve a longstanding problem in monitoring clinical trials when there is a delay between treatment and response. This work formed a Royal Statistical Society read paper (J Royal Statist Soc, B, 2013).

Kyprianou (Ann Appl Probability, 2011) created a simple simulation technique for Levy process based on the Wiener-Hopf factorisation. With new theoretical Wiener-Hopf decomposition results (Ann Appl Probability, 2012), he has translated this work to applications in financial mathematics.

Mörters co-authored the book "Brownian motion" (CUP, 2010) which synthesises recent work and presents new results on potential theory of Brownian motion, intersection properties of its paths (including a new proof of the existence of points of uncountable multiplicity in the plane), and dimension of exceptional sets.

Nordström's work (with Corti, Haskins and Pacini) provides the first significant new supply of compact manifolds with G_2 holonomy for a decade. The computation of their topological types and the construction of rigid associative submanifolds give new impetus to the programme of enumerative geometry and gauge theory in higher dimensions (Geometry & Topology, 2013).

Sankaran (with Hulek and Gritsenko) initiated the study of moduli of polarised irreducible symplectic manifolds (Compositio Math, 2010) building on their earlier work on K3 surfaces that was presented (by C. Voisin) at the Bourbaki Seminar.

Wood (Nature, 2010) presented simple, generalizable methods of inference for biological dynamic models which exhibit chaotic and near-chaotic behaviour. These methods overcome the sensitivity of such processes to tiny changes in the system parameters which produce highly erratic likelihood functions and thus can make conventional modes of inference impossible.

Zimmer (with his former student Kreiner) provided (in a featured article in Nonlinearity, 2011) the first proof of the existence of heteroclinic waves for the dislocation dynamics model proposed by Frenkel and Kontorova in 1939, in the case of a piecewise quadratic interaction potential.

(S2) Intradisciplinary collaboration and interdisciplinary research. IRM 2010 noted the importance of strengthening 'links within the mathematical sciences and between the mathematical sciences, other disciplines and industry'. The importance we attach to intradisciplinary and interdisciplinary research is evident in the four University Research Centres hosted by the UoA (see Section (d)) and in the 19 appointments made since RAE 2008: Dawes, Majumdar and Milewski have upheld our traditional strengths at the interfaces between continuum mechanics, PDEs and dynamical systems; E Spence spans PDEs and numerical analysis; Dooley and Nordström work at the interface of analysis and geometry, and Craw and Su at the interface of algebra and geometry; Shardlow and Lindgren combine probability and statistics with numerical analysis and scientific computing; Jarai, Roberts, Rogers and Stauffer work on mathematical and probabilistic aspects of complex networks with applications in the biological, physical and social sciences, research which is central to the activities of the new Centre for Networks and Collective Behaviour; Evangelou's work on statistical inference and experimental design has applications in ecology and climate research; the statistical research by Anaya-Izquierdo into shared frailty models and self-controlled case series is motivated by applications in medicine and epidemiology; Adams and Hilker's research is at the interface between mathematics and biology, and Di Francesco works on PDEs and their applications in mathematical biology.

Examples of interdisciplinary research include: Adams's research on pathogen evolution (e.g. Proc Roy Soc B 2011), Dawes's models of dry friction with geophysical applications (e.g. J Mech Phys Solids 2010), Faraway's statistical modelling of cleft lip prior to surgery (e.g. JRSS C 2011),

Hilker's work on the role of infectious diseases in food webs (e.g. Am Nat 2009), applications of Shaddick's research to air pollution modelling (e.g. JASA 2012), and Zimmer's coordinating role on an EPSRC-funded national network in Mathematical Challenges of Molecular Dynamics. Hampson and Jennison's (2013) RSS read paper on clinical trial design exemplifies the distillation of a complex application into a mathematical research problem with an elegant solution that meets practical needs. A substantial amount of our interdisciplinary research has been supported by grants from EPSRC (including CASE), BBSRC, NERC, EU, and industry. We continue to form new interdisciplinary partnerships: Britton is working with a national consortium on disease in honey-bees, funded by the Insect Pollinators Initiative; Lindgren and Shardlow have just begun a project funded by the risk management company DNV (with University Impact Acceleration support) which will exploit our expertise on the boundary of applied mathematics and statistics in order to improve industrial uncertainty quantification algorithms.

A major feature of our intradisciplinary research is the central role which analysis plays across many of our activities. This is an example of our unified vision expressed in part (a) and is in line with the recommendations of the IRM (2010, Sec. 5.2). In pure mathematics, analysis is connected with geometry and PDEs, e.g., Dooley's research on non-commutative harmonic analysis and Lie symmetries (J Diff Eqn, 2010) and Moser's on non-linear geometric PDEs, e.g. biharmonic maps (Comm PDEs, 2008). Analysis is at the core of the research by our probability group on geometric probability, stochastic processes and mathematical finance. Much of our applied mathematics research is underpinned by rigorous analysis. We highlight a few examples: in continuum mechanics, Majumdar's research on liquid crystals (SIAM JMA 2012), Moser's on micromagnetics (J Math Pures Appl 2012), and Sivaloganathan's on energy-minimising deformations in nonlinear elasticity (Arch Rat Mech Anal 2010); in control theory, Logemann and Ryan's research on input-to-state stability of differential inclusions (SIAM JCO 2009) and Opmeer's on coprime factorisation and optimal control (SIAM JCO 2012); in mathematical biology, Di Francesco's research on aggregation in nonlocal interaction equations (Duke Math J 2011); and in numerical analysis, Budd's work on moving mesh generation using the parabolic Monge-Ampere equation (SIAM J Sci Comp 2009) and E Spence's research on a synthesis of variables approach to boundary-value problems (SIAM Review 2012).

Wide-ranging intradisciplinary threads permeate our research. An example is scale-bridging, which DiFrancesco, Matthies, Schwetlick and Zimmer treat theoretically, Budd, Graham and Scheichl in a numerical analysis context, Mörters in a probabilistic way, and Dawes, Rogers and A Spence from a networks perspective.

(S3) Research achieving social, environmental and economic benefit. The Department promotes a culture of engagement with industry, building on the wide ranging industrial links described in REF3a/b and the involvement of staff in visiting undergraduates on industrial placements and supervising MSc and PhD projects with industrial partners. We encourage staff to attend fora such as the European Study Group with Industry and application area conferences in order to identify questions of importance to end-users outside academia. University Research Centres (see Section (d)) provide a focus for much of our interdisciplinary research.

UoA members engage in numerous external collaborations which provide routes to impact for our research, with benefit to industry, medicine and the environment. Augustin's collaboration with the French Institute for Exploration of the Sea has informed decisions on European fisheries quotas; Budd, Freitag and Scheichl collaborate with the Met Office and adaptive methods developed at Bath are now in use in the Met Office's daily operational UK analysis; Jennison's work with the Drug Information Association's Adaptive Program Working Group has produced methods for the over-arching design of sequences of clinical trials; Shaddick's long collaboration with Zidek (UBC) on air pollution modelling has produced methodology adopted by the US Environmental Protection Agency. More examples of research collaborations are described in Section (e).

We disseminate research results to potential users by writing applied papers and presenting at conferences with an applied audience. We also deliver short courses and engage in consultancy. We create publicly available software, such as the personal environmental exposure model software, pCNEM, produced by Shaddick and co-workers. Wood's mgcv software, implementing his work on generalized additive models, has been used in a wide variety of applications.

Future strategic aims and plans and their relationship to the structure described in (a). Driven by strategic aims (S1) – (S5) outlined in (a), we will firstly vigorously pursue our core activity

of advancing knowledge at the highest international level, within a unified vision of mathematics**.** We will make new appointments - through retirements and as a result of strategic bids within the University - which will both strengthen existing research areas and establish novel contiguous directions (as we have done recently with network theory). A priority will be to maintain Professorial leadership for each research grouping. Key strategic objectives for appointments in the immediate future are: (1) strengthening the analysis group, building on the appointment of Dooley, and (2) enhancing our activities at the interface of Statistics and Applied Mathematics. Key industrial collaborations such as with the Met Office and with Pharma companies will be continued and strengthened. We will propose and pursue the formation of a University Research Institute centred in Mathematical Sciences, which will promote interdisciplinary collaboration, and enhance our external profile and industrial linkage**.** As a part of this project, we will further develop our industrial internship scheme, providing more industrial training for PhD students.

(c) People

The strategic aims (S4) and (S5) in Section (a) form the basis of our people strategy.

(i) Academic staff

Staffing strategy and staff development. In the REF period, we have appointed 13 academic staff to new posts and 6 to replacement posts, totalling 2 Professors, 4 SL/Readers, 10 Lecturers and 3 Prize Fellows. Our reputation and research environment attract excellent applicants (typically 150 for posts at lecturer level), allowing us to appoint staff of the highest calibre. New and established staff are supported and trained at all career stages.

Relation of staffing strategy to research strategy. Central goals of our staffing strategy are (1) to strengthen and consolidate existing areas, and (2) to create new intra- and interdisciplinary links, and to form new research groups in emerging fields contiguous to existing areas. At interview, candidates are asked to show how they will contribute to these goals. The 19 new appointments described in (S2) of Section (b) demonstrate the results of this strategy. Probability and its applications has seen particularly strong growth, with three new posts in the period. The recent appointments of Roberts, Rogers and Stauffer have substantially strengthened our emerging networks theme initiated by Dawes and A Spence. Moreover, existing capability (Scheichl) in the new multidisciplinary field of uncertainty quantification has been considerably expanded through the appointments of Lindgren and Shardlow.

Within the REF period, a total of 28 post-doctoral research staff have been members of the UoA, including a Royal Society Newton Fellow; first destinations on leaving Bath include Fellowships and Lectureships. For example, Hornung moved to a prestigious DFG Emmy Noether Fellowship in Leipzig, Varvaruca (LMS Whitehead Prize 2012) is now an Associate Professor at Reading and Giansiracusa, an EPSRC CAF, took up a Lectureship in Swansea.

Career Development. The Department provides staff with the unfragmented research time needed for mathematical research. We enable and recognize research activity through our workload model: all members of staff are allocated time for research and grant applications; additional research time is allocated to staff in the first years of their academic career and to staff holding grants and supervising PhD students. Conference attendance is encouraged and financial support is available. Research excellence is rewarded through promotions and accelerated increments. Leadership in gaining research funding is an important criterion for promotion. Within the REF period 5 staff have been promoted to SL, 6 to Reader, and 4 to Personal Chairs**.**

Through the Staff Development Performance Review system, we support staff in the development of personal research plans. We hold annual staff Away Days where research issues are discussed, thereby encouraging all staff to engage with development and implementation of research strategy. Furthermore, we encourage engagement with the staff development opportunities offered by the Researcher Development Unit within the Learning & Teaching Enhancement Office. We support all staff who have opportunities for extended collaborations outside the Department.

The University Sabbatical Scheme allows members of staff to take 6 or 12 months sabbatical leave and provides funds for Teaching Fellow appointments to cover their teaching. Since 2008, 12 members of staff have taken leave under the scheme. In addition, Freitag and Scheichl spent 6 months in 2011 at the Radon Institute and Opmeer spent 6 months in 2012 as a Visiting Professor at U Hamburg (all three funded by their host institutions).

New lecturers, in particular Early Career Researchers, are given minimal administration and

reduced teaching loads (normally one small course in the first year), and receive priority in studentship allocation and travel funding. Each is assigned a mentor to provide support in all aspects of work, including the development and implementation of a personal research strategy. Further support is provided by the Staff Development Performance Review system. Probationary staff take the Bath Course on Enhancing Academic Practice which includes units on research management. The University's Research Development Support Office assists with the preparation of First Grant bids, which all eligible staff are expected to make. The Faculty of Science provides start-up funds for selected projects of recent appointees.

Our 'Prize Fellows' scheme provides a two year individual research fellowship followed by a Lectureship (with three year probation period). It is designed to create a focus on building strong research skills, particularly in publication and research income generation, before teaching duties commence. Our three current Prize Fellows are supported within the Department by a senior colleague acting as a mentor, and each receives start-up funds of £5000 and is allocated a University Research Studentship. The Prize Fellows work with their counterparts across the University as an inter-disciplinary group of young scholars: they participate in a dedicated training programme from the Research Development Unit, organize a Research Symposium, and deliver Skills Training workshops for postgraduate students.

PDRAs are provided with financial support for conferences, take part in seminars, have access to staff development courses and benefit from the standard appraisal procedures. They are further supported by the departmental Research Staff Coordinator, the institutional Code of Practice for the employment of research staff and the institutional Researcher Development Unit. PDRAs are encouraged to engage with all aspects of academic life; in particular, they are offered the opportunity to gain experience of lecturing or MSc supervision. PDRAs are invited to participate in Staff Meetings and departmental Away Days, where they gain insight into the academic life of the UoA. We encourage them to join mentoring circles run by the Faculty of Science, which provide a forum to discuss career plans and share experiences with peers and more senior colleagues.

Implementation of the Concordat to Support the Career Development of Researchers. Bath is fully committed to implementing the Concordat to provide a productive and supportive working environment for researchers. As recognition of this, Bath was awarded the "HR excellence in research" badge by the European Commission. The University code of practice for the employment of research staff provides guidance on implementation of the Concordat. Our departmental Research Staff Coordinator is responsible for compliance with the Concordat and, at University level, Research Staff are represented by the Research Staff Working Group.

Personal Research Fellowships. Since 2008, 10 UoA members have held fellowships won in open competition, (see Section (e) for details) and we have appointed 3 new staff members to Bath-funded Prize Fellowships.

International Staff and visiting scholars. International recruitment has long played a vital role in the UoA and about 40% of academic staff are from outside the UK. Since 2008, new staff have come from Australia, Brazil, China, Cyprus, Germany, Hungary, Italy, Mexico, Sweden and USA, joining staff in post from Austria, Iceland, Ireland, Netherlands, Russia and Switzerland.

Within the REF period, a total of 24 international Post-doctoral Research Staff have been members of the UoA, funded by, for example, EPSRC, Marie Curie Fellowships and CONACyT (Mexico).

The UoA has also accommodated many international visitors, with some 25 staying for a month or more. These include Last (Karlsruhe) for 6 weeks in 2011, Zidek (UBC) for 5 visits (8 months in total) between 2008 and 2013, and Plotnikov (Novosibirsk) who held the first Parkin Visiting Professorship (Nov 2007-June 2008), a Bath scheme supporting visits by outstanding international academics. Short term visitors include Barlow (UBC), Kurtz (Wisconsin), Lewis (Alberta) and Staffans (Abo, Finland).

Equality and diversity. Bath is a member of the Athena Scientific Women's Academic Network, and White is a member of the University's Athena SWAN team. In 2009, the University received the Bronze Athena SWAN award, recognizing its commitment to women's career progression in Science, Engineering and Technology. Our departmental Equalities Coordinator promotes awareness of equality and diversity issues and we have carried out Equality Impact Assessments in the research-related areas of Workload Models and Funding for Conference Travel. Our new building is very accessible to disabled people with special toilets and wheelchair turning areas on

all five levels, and a special shower for disabled staff and students on the ground level.

(ii) Research students

The Institutional Audit (May 2013) reported "The University promotes a vibrant, sustainable and supportive research community. The Researcher Development Unit provides development opportunities, workshops and projects to support research students and encourage collaboration and interaction between staff and students. The University has also provided a Graduate Centre as a dedicated work and study space for research students".

We attract high quality PhD students and aim to develop them as future research leaders. As highlighted in the IRM (2010, Sec.16.2 and 16.3), the quality of research training provided by standard UK PhD programmes is an issue of current concern. As a response, our Doctoral College (initiated in 2004 and further developed in the REF period) offers PhD-level research combined with targeted taught courses. Our graduate students are highly competitive in the employment market in academia and industry. 63 PhD students completed their degrees in the REF period (before 31 July 2013). Their destinations include UK industry (including finance and statistics), and post-doc positions and lectureships at HE institutions. For example: Broomhead, Brown, Guiver, Norton and Teckentrup went on to post-doc positions at Hannover, Michigan, Exeter, Otago and Florida; Chamchod, Giani, Hampson, Ibrahim and Ke went on to lectureships in Bangkok, Durham, Lancaster, Kuala Lumpur and Jinan (China).

PGR recruitment. We maintain a vibrant PGR community across the breadth of our research activities. The formal recruitment procedure is managed through the Faculty of Science Graduate School. Extensive information for applicants is provided and formal applications are managed online. A variety of funding sources are available, including University Research Studentships, Faculty Studentships, and Faculty Fee Waiver awards, as well as EPSRC DTG and CASE awards. Students are selected on their achievements, the strength of their references, their performance at interview and the match of their research interests to those of our staff.

The Department's two PGR admissions tutors match students to supervisors and funding opportunities. We run open days to tell potential candidates about research opportunities in the Department and invite individual candidates to discuss research possibilities. We send staff and current PGR students to describe research at Bath to final year students at events organised by universities with large mathematical cohorts, such as Cambridge and Warwick.

Training and support mechanisms. PGR students have a supervisory team, typically comprising a lead academic supervisor and a second supervisor with a pastoral role. Reviews for MPhil and PhD students are conducted every 6 months. Students are normally considered for confirmation of PhD registration after 12 months, with a second opportunity at 18 months.

The Doctoral College route offers a 3½ year PhD programme in which students must pass six graduate courses taken over the first three semesters of the programme. These courses are also available as electives for PGR students not formally following the Doctoral College route. The Department is a partner with Bristol, Imperial, Oxford and Warwick in the Taught Course Centre (TCC) in Mathematics, in which students benefit from graduate courses offered by all participating institutions. These courses are transmitted using Access Grid software, for which the UoA has a dedicated lecture room. Bath is also part of the EPSRC funded Academy for PhD Training in Statistics (APTS), which provides courses for first-year PhD students in statistics and applied probability. All our statistics PhD students attend the 4-week APTS residential programme, to which we contribute one module. The UoA is active in organising graduate conferences (e.g. Analysis Day, Bath, May 2011, and SW Regional PDE Winter School, Bath, January 2013).

Our integrated PhD is a four-year programme with personalized study routes, the first year of which has a large taught element leading to an MSc as the first step towards the PhD.

We offer all research students a broad spectrum of taught material in research-level mathematics modules, in modules from our MMath and MSc programmes, and through the TCC and APTS. We maximize the take-up and benefit of these taught elements via the Doctoral College and Integrated PhD routes. Generic skills training is provided through the University's PGSkills facility which runs workshops and professional and career development programmes. Skills training provided by the Department includes a course on mathematical typesetting in LaTeX and workshops on writing mathematics.

We encourage student participation in national and international conferences and fund this through

the student support fund and departmental resources. The departmental Mathematical Landscapes colloquium, aimed at both staff and PG students, features distinguished external speakers talking on topics of general mathematical interest. Recent speakers include Allaire (EPF), Ball (Oxford), Bickel (Berkeley), Bobenko (TU Berlin), Bona (Chicago), Friesecke (TU Munich), Kingman (Bristol), Tillmann (Oxford) and Toth (Budapest). More specific seminar series are available to PG students in: Analysis, Geometry, Mathematical Biology, Mathematical Control Theory, Nonlinear Mechanics, Numerical Analysis, Probability and Statistics. We also run many informal seminar series, most recently in Applied Analysis and Networks. The students manage and organize Postgraduate Informal Seminars and organize two Postgraduate Away Days each year, consisting of a morning session with invited speakers on research-related topics, followed by a more informal afternoon session.

Our PG students gain teaching experience through tutoring Year 1 and Year 2 UG units, with the Department providing appropriate training and observation by members of staff. Our contribution to the training of the next generation of researchers also includes supervision and mentoring of visiting PhD students or visiting ECRs. For example, Jennison provided supervision and advice to a visiting PhD student from Göteborg and a visiting ECR from U Malaya**,** as did Scheichl for a visiting PhD student from ENS Cachan (France).

(d) Income, infrastructure and facilities

Infrastructure and facilities. The University recognises Mathematical Sciences as one of its flagship Departments and actively supports our research environment. In 2010 the Department was re-housed in the new building 4 West funded by a £23M University investment. This includes the state of the art Wolfson lecture theatre (of which the departmental has priority use), together with a suite of rooms for postgraduate students, postdocs and visitors.

Our postgraduate students make extensive use of the University Graduate Centre, also located in 4 West. This provides social and informal work areas and a training and seminar room, and accommodates the Researcher Careers Advisor and the Postgraduate Skills Training Team.

The University Library is open 24/7. It provides online subscription to most journals relevant to our research. The Library budget for Mathematics has increased 13% since 2008, with a matching increase in our subject holdings. Since then, an increase in specifically targeted ebook collections has resulted in more than 3000 additional mathematical titles. An efficient inter-library loan service supplies electronic copies of articles published in journals to which the Library does not have access. The Library manages Opus, an outward-facing research repository which aids dissemination by showcasing research publications by University of Bath authors.

It is departmental policy to refresh desktop computers and laptops every three years. The University runs the high performance computing facility, and members of the UoA have attracted grant income to help develop this into a powerful research platform. The University is committed to invest a further £1 million in this HPC facility in the near future. A Scientific Computing course given by the Department provides a service to the whole University HPC community.

The University and Faculty provide administrative support for conference organization, and members of the UoA have taken full advantage of this in the REF window. The University also provides administrative support for international exchanges for PGR students.

Research funding portfolio and strategy. Since 2008, members of the Department have been awarded research grants worth a total of £4.9 million. Our portfolio includes grants from the EPSRC, NERC, BBSRC, the EU, and government.

We encourage and support staff in applying for research funding. Success is rewarded through the University's probation and promotion procedures. Peer review of draft applications is offered in the Department and, for major bids, at University level. Members of the Department have participated in Research Sandpits run by the University to promote interdepartmental and interdisciplinary bids for research grants in areas prioritized by funding bodies. The University provides strong financial support for large collaborative bids from the Department. Applications for EPSRC Fellowships are enhanced with the promise of a PhD studentship if successful.

The departmental Research Committee provides overall research leadership: it discusses strategic directions, provides advice on preparation of research proposals, and monitors activities across the research groups. It liaises with the central administrative and research support services provided by the University, including Bath's Internal Peer Review College, and with the Faculty of Science

Research Committee in order to coordinate activity across Bath's six Science Departments.

Research Centres. Intradisciplinary and interdisciplinary collaboration is strongly supported by the University through University Research Centres hosted by the UoA.

The Bath Institute of Complex Systems (2005-2009), directed by Budd, was a major interdisciplinary programme funded through an EPSRC Critical Mass Grant, with personnel from the UoA and from departments in engineering. Much of its research continues through the Centre for Nonlinear Mechanics, directed by Budd, which has as members over 15 academic staff from the UoA and from engineering.

The Centre for Mathematical Biology (CMB) directed by Britton, has over 25 members from the UoA, Biology and Biochemistry and other University Departments. CMB staff teach on our MSc in Modern Applications of Mathematics, which played a key role in Bath's contribution to the successful bid to BBSRC (with Bristol, Exeter and Rothamsted) for the South-West Doctoral Training Partnership. SWDTP projects are in world-class bioscience and food security, and fund two PGR students in the UoA.

Since January 2013, the Centre for Networks and Collective Behaviour (CNCB), directed by A Spence, together with Dawes and James (Physics) has brought together 35 staff from across the University, including 9 members of the UoA. This timely initiative is firmly in line with the University's inter-disciplinary strategy, with existing UoA research expertise (e.g. Mörters, Jarai), and with the appointments of Dawes, Stauffer and Rogers.

Prob-L@B (Probability Laboratory at Bath) has been an informal grouping since 2007 and has recently become a University Research Centre. This timely development reflects the ever increasing role of probability within mathematics and across many other disciplines. Directed by Kyprianou and Mörters, Prob-L@B has currently 13 members and associated members from across the UoA.

Research impact support. The University provides support to achieve research impact. This includes: the Knowledge Transfer Partnership Office for development, support and monitoring of KTP projects; the Research Development and Collaborations Team for links with external research users and support for pathways to impact; the Researcher Development Unit which provides training in impact for postgraduates and early career researchers; and the Staff Development Office which provides regular impact seminars and workshops.

Consultancies and professional services. The Department encourages members to increase the impact of their work through research and consulting with government and industry. Consultancies undertaken since 2008 include: Augustin (Forest Research Institute Baden-Württemberg, Freiburg, Germany); Budd (Airbus, Met Office), Faraway (BASF); Graham (AMEC, Institute of Cancer Research, Schlumberger); Jennison (EISAI, Merck Serono, Takeda); Kyprianou (Home Office); Mörters (Microsoft Research); Sankaran (Heilbronn Institute); Scheichl (AMEC, Livermore Lab - US Department of Energy, Met Office, UK Nuclear Decommissioning Authority); Shaddick (Wessex Water); Wood (EDF, Finnish Society for Biostatistics, HSE, IPCC).

(e) Collaboration and contribution to the discipline or research base

(i) Research collaboration

National and international collaboration, within the discipline, with other academic disciplines and with industrial partners is key to our research culture. Members of the UoA collaborate extensively with individual researchers in more than 30 countries world-wide.

Collaborations with academic, industry and other bodies. Highlights include:

Augustin's collaboration with the Forestry Research Institute Baden-Wuertemberg, Germany (funded through consultancy contracts and the Royal Society) has influenced future sampling schemes of forest health, with outputs now routinely used for official reporting.

Budd, Graham and Scheichl have had a series of CASE and Great Western Research Awards supporting PhD research collaborations with Schlumberger, AMEC and the Met Office.

Jennison collaborates with AstraZeneca, Pfizer (2 CASE awards), and the DIA (Drug Information Association). He is an investigator in a European consortium for research into diabetes (2012-19; funded by industry and the EU Innovative Medicines Initiative).

Lindgren collaborates with the National Centre for Atmospheric Research in Colorado and Washington, Seattle and Lund (funded by Swedish agency STINT) and with NTNU, Trondheim and St Andrews (funded by Norwegian Research Council), developing methods for weather forecast

verification and for spatial statistics in climate data analysis.

Scheichl collaborates with Nottingham, Oxford, the Nuclear Decommissioning Authority and Serco TAS on Radioactive Waste Disposal (EPSRC Energy Mission Programme Grant) and with Exeter, Leeds, Manchester, Reading, Imperial College, the Met Office and STFC Daresbury on Elliptic Solvers in Weather and Climate Prediction (NERC Programme Grant).

A Spence was a Visiting Professor in the group of Professor Fengshan Bai, Dept of Mathematical Sciences at Tsinghua University (Oct-Dec 2009) to collaborate on problems in numerical linear algebra. There is continuing contact between Bai's group, the Numerical Analysis group at Bath and the new Centre for Networks and Collective Behaviour.

How collaborations with end-users have informed research activity and strategy

Budd, Freitag & Scheichl's collaboration with the Met Office has triggered further research into moving mesh techniques, elliptic solvers and data assimilation strategies in large scale atmospheric flow simulations. Graham's collaboration with Schlumberger has informed the investigation of solvers for the Helmholtz equation in the high frequency case in heterogeneous media. These interactions fed into and were further enhanced by workshops organised by Freitag, Graham & Scheichl during the RICAM special semester in Linz, 2011.

Other examples include: Evans' collaboration with Smith (HBOS) motivated his finance work on American options; Kyprianou's visit to Morgan Stanley, NY led to a Royal Society Isaac Newton Fellowship for a postdoc at Bath on convertible contingencies; Mörters' visits to Microsoft Research have inspired an interest in networks and participation in the CNCB. Wood developed methods for generalized additive modelling of large datasets to meet the needs of an electricity load forecasting collaboration with EDF.

Research collaborations have also grown through contacts forged or enhanced via the Industrial Advisory Board for the MSc with Modern Applications (e.g. Airbus, BT, Unilever).

(ii) Contribution to the discipline

Leadership. Highlights include:

Britton. Elected member of the Board of Directors of Soc. for Math. Biology, 2006-10.

Budd. Scientific advisory board for KT Network in Industrial Maths; LMS Council member; IMA Vice-President; Prof of Mathematics at the Royal Institution.

Burstall. Senior Scientist, Hausdorff Institute Trimester on "Integrability in Geometry and Mathematical Physics", Bonn (2012).

Calderbank, *Jennison* and *Milewski* have served on the EPSRC Strategic Advisory Team.

Dooley. Inaugural Director of Australian Centre for Commercial Mathematics; Member of the Australian Academy of Sciences National Committee on Mathematics.

Freitag. Elected Sec. & Treasurer of SIAM UK & Ireland Section (2012-14).

Milewski. Member of US NSF panels (Fluid Mechanics, Applied Analysis and Career awards).

Mörters. Served on Leverhulme Prize panel in Mathematics and Statistics (Sept 2012).

Smith. Serves on the International Maths Olympiad Advisory Board 2011-14, and was awarded an MBE for Services to Mathematics Education in 2011.

17 members of the UoA are (or have been) in the EPSRC Peer Review College.

Conferences/workshops organised. In the REF period, 15 workshops have been organised at Bath involving a total of about 625 participants, together with 3 large conferences:

1-15 Aug 2009, "Groups St Andrews in Bath" (250 participants, with edited proceedings).

7-11 Sept 2009, British Probability Meeting (100 participants).

12-13 June 2013, "Uncertainty in Interaction Networks" (100 participants).

Two LMS funded networks are coordinated in part from Bath: Patterns, Nonlinear Dynamics and Applications (Dawes); COW Algebraic Geometry Seminar (Sankaran). They have each hosted 3 one day meetings in Bath during the REF period, while the Bath-Exeter-London-Southampton Control Theory seminar has met here twice. Conference organisation outside Bath includes:

Dawes. 11th SIAM Conference "Applications of Dynamical Systems", Snowbird, 2011.

Di Francesco. ESF Research Conference "Applied PDE in Physics, Biology and Social Sciences: Classical and Modern Perspectives", CRM Barcelona, 2012.

Evans. ICMS Workshop "Scale Transitions in Chemistry and Biology", 2012.

Graham (Chair) & *Scheichl*. LMS Durham Symposium "Numerical Analysis of Multiscale Problems", 2010. (with edited proceedings).

Jarai. CRM Conference "New Directions in Random Spatial Processes", Montreal, 2009: part of CRM-PIMS Programme "Challenges and Perspectives in Probability".

Logemann & Ryan. ICMS Workshop "Stabilization of Dynamical Systems and Processes", 2011.

Milewski. BIRS Workshop "Computation of Water Waves", Banff, 2013.

Mörters & Zimmer. Oberwolfach Workshops "Analysis and Probability in Physics", 2008 & 2012.

Scheichl (Chair), *Freitag & Graham*. 6th RICAM Special Semester "Multiscale Simulation and Analysis in Energy and Environment", Radon Inst., Linz, 2011 (3 edited workshop proceedings).

Major conference/workshop talks. Amongst plenary and special invited talks, highlights include:

Britton. Models in Population Dynamics and Ecology, Santa Maria, Brazil, 2012.

Budd. Maths for Planet Earth, Melbourne, 2013.

Burstall. Symposium on Riemann Surfaces, Harmonic Maps and Visualization, Osaka, 2008.

Calderbank. Workshop on Geometry and Representation Theory, ESI Vienna, 2012.

Evans. Inst. of Non-Newtonian Fluid Mechanics Conference, Chicheley Hall, 2013.

Freitag. 18th Householder Symp,Tahoe City, 2011; 17th ILAS Conference, Braunschweig, 2011.

Graham. 9th ENUMath Conference, Leicester, 2011; 11th Waves Conference, Tunisia, 2013.

Jennison. ADAPT Conference, Philadelphia, 2011.

Kyprianou. Stochastic Processes and their Applications, Oaxaca, 2011.

Milewski. South African Symposium on Numerical and Applied Maths, Stellenbosch, 2009.

Mörters. Stochastic Processes and their Applications, Berlin, 2009.

Sankaran. Moduli, Berlin, 2009.

Scheichl. 20th Domain Decomposition Methods Conference, San Diego, 2011.

Shaddick. 1st Conference on Spatial Statistics, Enschede, 2011.

A Spence. 3rd International Conference on Numerical Algebra and Scientific Computing, Beijing.

White. SIAM CSE Annual Meeting, Miami, 2009.

There have been 25 invited talks by UoA members at Oberwolfach workshops and 12 at Banff.

Editorial activity. Members of the UoA have served on editorial boards of 47 journals including Ann. Appl. Probability, Ann. Appl. Statistics, Nonlinear Phenomena, Physica D, Proc/Jour/Bull LMS, Proc. Royal Soc. A, Stud. Appl. Mathematics.

Britton and Faraway serve as joint Series Editors for the Chapman & Hall/CRC Series in Mathematical & Computational Biology and Statistical Science, respectively.

Wood and Jennison have served on the Research Section of the Royal Statistical Society (Editorial Committee for read papers).

Fellowships, awards and prizes

Dawes. Royal Society University Research Fellowship (2007-12, extended to 2015).

Freitag. GWR Fellowship with the Met Office (2007-10).

Giansiracusa. EPSRC Career Acceleration Fellowship (2010-15).

Jeffrey. EPSRC Career Acceleration Fellowship (2011-16).

Majumdar. EPSRC Career Acceleration Fellowship (2011-16), British Liquid Crystal Society Young Scientist Prize (2012).

Milewski. Royal Society Wolfson Award (2011), Special Visiting Researcher IMPA, Brazil (2013-15).

Mörters. EPSRC Advanced Research Fellowship, (2005-10).

Penrose. Humboldt Foundation Bessel Research Award (2008-09).

Roberts. EPSRC Postdoctoral Fellowship (2013-16).

E Spence. EPSRC Postdoctoral Fellowship (2011-14).

Wood. EPSRC Established Career Fellowship (2013-18).

Zimmer. EPSRC Advanced Research Fellowship, (2004-09).