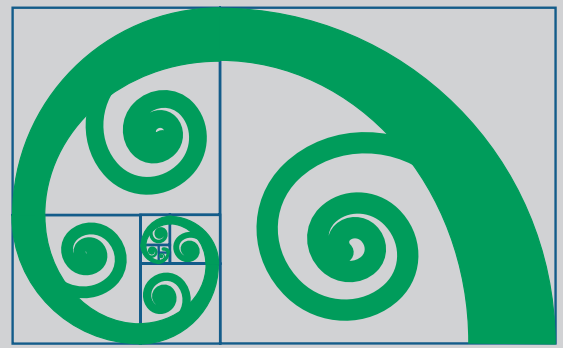


THE NEW ZEALAND INSTITUTE OF MATHEMATICS & ITS APPLICATIONS

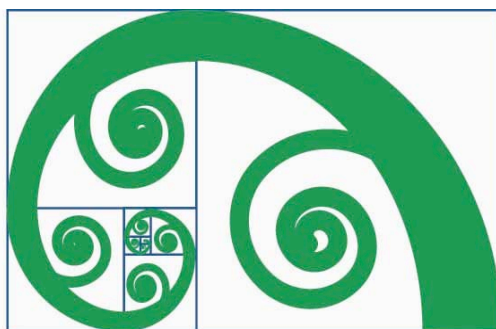


NZIMA



THE UNIVERSITY OF AUCKLAND
NEW ZEALAND





**New Zealand Institute of
Mathematics & its Applications**

ANNUAL REPORT for the year 2006

Approved by the NZIMA Governing Board on 17 May 2007

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OVERVIEW FROM CHAIR OF THE NZIMA BOARD

Sir Ian Axford DSc FRS FRSNZ, Chair of the NZIMA's Governing Board, reports:

Once again I am delighted to present the annual report of the New Zealand Institute of Mathematics and its Applications (the NZIMA), on behalf of its Governing Board.

The year 2006 has been one that has seen the NZIMA mature in many respects, from a fledgling organisation establishing a platform of research programmes under excellent leadership, to an institute that is developing an impressive international reputation, building up substantial communities of researchers, achieving beneficial outcomes for New Zealand, and reaching out to the wider scientific and educational community.

This has coincided with the NZIMA's application to the Tertiary Education Commission for a further six years of Centres of Research Excellence status and funding. The NZIMA has lodged a compelling case, not just for its continuation as a CoRE, but also for a significant increase in its funding that would allow it to exploit the enormous potential it has shown in just over four years of existence.

In 2002 the NZIMA set itself the goals of creating and sustaining a critical mass of researchers in concentrations of excellence in mathematics and statistics and their applications, and "lifting the game" for the mathematical sciences in this country, using as models a number of other renowned mathematical sciences institutes overseas.

Among the many things that have impressed me about the way in which the NZIMA has set about achieving these goals are the following three.

The first is about setting high standards of excellence. The list of honours and awards being won by the NZIMA's researchers and students is a long one and keeps growing year after year. Publications in top international journals, special issues of these devoted to the NZIMA's programmes, and large and increasing citation rates (far in excess of the worldwide average for the mathematical sciences) all attest to world class standing.

The second is the fact that this excellence has not been confined to particular branches of the discipline — we are seeing wonderful outcomes in both fundamental and applied aspects of the mathematical sciences, very positive interactions with a wide range of other disciplines (including not just the traditional ones like engineering and physics but also with biology, computer science, ecology and medicine), and concrete applications to business, industry and society in general.

The third is the way in which the principals of the NZIMA have used their CoRE status and funding to support the development of the mathematical sciences in New Zealand far beyond the confines of their own research groups — witness the nature of the NZIMA's thematic programmes, its support of a wide range of postgraduate student projects, visitors and local conferences, and its new initiatives like the NZ-IMAgEs bulletin and the MathsReach resource for schools. The outstanding letters of support that the NZIMA received from New Zealand university departments and professional societies for its CoRE bid further underline its effectiveness.

These things have come about because of the talents and leadership of the NZIMA's principals, and their desire to achieve good things for science (in the broadest sense) and for New Zealand.

I congratulate the NZIMA and all those involved in it, especially the two Co-Directors, the Research Manager and the Executive Committee for their vision and efforts. There is no doubt in my mind that the NZIMA is pursuing the goals of the Centres of Research Excellence Fund in outstanding fashion.

The Governing Board will play its role in the ongoing development of the NZIMA, and continue to shape its strategy in the years ahead. We look forward to its continued success.

REPORT FROM DIRECTORS AND EXECUTIVE COMMITTEE

We are very pleased to report on another great year for the NZIMA.

The year began in the best possible way in January with an excellent summer meeting at Taipa, as part of our new thematic programme on Geometric Methods in the Topology of 3-Manifolds. This meeting was regarded by those present as *one of the best NZ summer mathematics meetings ever held*. A focus of the meeting was on the recent proof of the Poincaré conjecture, with overseas experts giving clear accounts of the approaches, concepts and methods used by Richard Hamilton and Grigori Perelman in reaching the answer. Aside from the wonderful surroundings of Northland, being able to bring these latest developments to the New Zealand mathematical community was very satisfying, and highlights what the NZIMA is able to achieve.

This meeting was followed soon after by a very well attended and entertaining *public lecture* by our Visiting Maclaurin Fellow John Conway (who is Distinguished von Neumann Professor at Princeton University). Our public lectures are proving to be very popular, and we plan to continue them (with at least three per year) in the future.

We had another good reason to celebrate in March, with the publication by Elsevier of a *special issue* of the prestigious journal *Annals of Pure and Applied Logic*, based on research coming out of one of our very first programmes, on Logic and Computation. This follows a special issue in 2004 of *Progress in Biophysics and Molecular Biology*, which resulted from another of our first programmes, on Modelling Cellular Function.

As we commented in last year's report, however, we recognise that being a Centre of Research Excellence is not just about conducting world class research, international linkages, publication in top journals and participation in major conferences, but also involves high quality training of postgraduate students and postdoctoral researchers, fostering new collaborations, engaging with the end-users of the research, and outreach to relevant communities and the general public.

During 2006 we undertook a fundamental review of *the NZIMA's long-term strategic direction*, the alignment of our goals with the expectations of CoRE funding and the needs of New Zealand, the structure and sponsorship of our programmes, and other means by which we can build the identity and profile of the NZIMA.

One very positive initiative resulting from this has been our *new glossy bulletin NZ-IMAgEs*, which highlights (in words and pictures) many of the NZIMA's activities — with a focus on people and what they are doing. This bulletin is being distributed throughout New Zealand to a wide range of stakeholders (including all intermediate and secondary schools). The first issue appeared in September and a second was ready for production early in the new year. We are already getting a lot of positive feedback about *NZ-IMAgEs*, which is putting much more of a human face on the mathematical sciences in New Zealand, and opening the eyes of many to what is being achieved and what is possible.

Another (in the same vein) is our *new schools outreach initiative*, called “*MathsReach*”. This is a resource we are developing with the aim of showing school students and teachers what lies beyond the school curriculum in mathematics and statistics — in terms of professional careers, research activity, hot topics, and interesting and important applications. We are doing this through a variety of media (including video interviews with active mathematicians and

statisticians, colourful and informative articles, and web links to further resources), again with a focus on people and what they do. The *MathsReach* resource is available on a website (<http://www.mathsreach.org/>) and the initial version is being released on a CD for distribution to schools, following its official launch in February 2007.

Also in 2006 we decided to pursue several new initiatives aimed at **improving inclusion and retention** of people from under-represented groups, in consultation with the Mathematics Education Unit, with Michael Walker (Co-Director of Nga Pae o te Maramatanga), and with Dianne McCarthy (Pro Vice-Chancellor for Equal Opportunity) at the University of Auckland. In particular, we decided to run a 2-day workshop in 2007 for **women in mathematics across New Zealand**, following the example of a similar workshop being run by the Fields Institute in Canada. We are sponsoring the **Pangarau:AIM** project, designed to trace mathematically achieving Maori students in Intermediate schools in Northland through their secondary careers to understand what makes them continue or discontinue in this subject. In addition, in 2007 we will sponsor a pilot study for a project aimed at attracting Samoan students into university education in New Zealand.

During the year we initiated three **new thematic research programmes**:

- *Geometric Methods in the Topology of 3-Dimensional Manifolds*, led by Professor David Gauld (University of Auckland), Dr Roger Fenn (University of Sussex) and Professor Vaughan Jones (University of Auckland and University of California, Berkeley)
- *Modelling Invasive Species and Weed Impact*, led by Dr Jennifer Brown, Dr Alex James and Professor David Wall (University of Canterbury)
- *Partial Differential Equations: Applications, Analysis and Inverse Problems*, led by Dr Colin Fox, Dr Mike Meylan, Professor Boris Pavlov (University of Auckland).

Furthermore, we selected three programmes for 2007 and 2008:

- *Applications of Mathematics in the Nanosciences*, to be led by Dr Shaun Hendy (Industrial Research Ltd and the MacDiarmid Institute)
- *Algorithmics: New Directions and Applications*, to be led by Professor Mike Atkinson (University of Otago) and Dr Charles Semple (University of Canterbury)
- *Conformal Geometry and its Applications*, to be led by Professor Gaven Martin (Massey University) and Associate Professor Rod Gover (University of Auckland).

As always, we have selected these new programmes in a way that achieves an **important balance of excellence between fundamental and applied areas of research**. While those in fundamental areas generally emphasise the creation of new knowledge and the development of concepts and mathematical or statistical methods (with significant potential applications to other branches of the discipline and other disciplines), those in other areas involve a significant component of application and outreach.

Two of the programmes begun in 2006 have already involved researchers from CRIs, local government departments and NZ-based industries, in solving problems in areas such as geothermal modelling, nanotechnology, sea-ice interaction, structural vibration and acoustics, and with interaction with the Department of Conservation (DoC) and the Bio-Protection CoRE to investigate issues of importance to New Zealand's environment. Similarly, two of the most recently selected programmes will involve extensive interactions with the physics and computer science communities.

Also since our last report, we have offered *Maclaurin Fellowships* to:

- Professor Peter Lax (New York University), visitor in 2007
- Professor Marcus du Sautoy (University of Oxford), visitor in 2007
- Professor Graeme Wake (Massey University), from March 2007 to February 2008.

Peter Lax is one of the world's most distinguished mathematicians, and won the Abel Prize when it was awarded for only the third time, in 2005. Marcus du Sautoy is a talented mathematician best known not only for his work in group theory, but also for his ability in communicating and popularising mathematics. A frequent radio and TV commentator on aspects of mathematics and society, he is the author of the best-selling book on the Riemann hypothesis, *The Music of the Primes*, for which he won the Sartorius and Peano Awards. Graeme Wake is an applied mathematician with strong interests in industrial applications, and plans to use his fellowship to spend a year working on functional differential equations, motivated by applications such as models for cell/tumour growth.

In addition, during the year we offered scholarship support to eight new postgraduate research students, based at Auckland, Massey and Victoria Universities, undertaking Masters and PhD projects on a range of topics from pure and applied mathematics and statistics — see the section on Research by Postgraduate Students.

As previously, we sponsored several local conferences and short-term visitors, both through our thematic programmes and otherwise, as we find these bring great benefits. Relatively small amounts of money (spent mainly on travel costs) have led to new interactions and an increased level of excitement, especially among early and mid-career researchers.

We received further excellent news in May when both Peter Hunter (one of our principal investigators) and Jerry Marsden (a member of our International Scientific Advisory Board) were elected as Fellows of the Royal Society of London, joining our Board Chair Sir Ian Axford and Co-Director Vaughan Jones in winning that honour.

In August, Rod Downey became the first New Zealand based mathematician to give an invited lecture at the International Congress of Mathematicians, which was held in Spain. Gaven Martin represented New Zealand at the meeting of the International Mathematical Union (IMU), held just before the ICM (every four years), and Cheryl Praeger (another member of our International Scientific Advisory Board) was elected to the Executive Committee of the International Mathematical Union (IMU), making her the first ever member from this part of the world.

Vaughan Jones represented us at a meeting of IMSI (the International consortium of Mathematical Sciences Institutes that run thematic research programmes and have large visitor programmes), held during the ICM in Madrid. Our membership of IMSI and the newly formed Pacific Rim Mathematical Association (PRIMA) are bringing very positive benefits, for example with all students at New Zealand universities now able to take part (at significantly reduced cost) in summer schools run by institutes affiliated with PRIMA.

In late November we lodged our bid for another six year's of funding from the Centres of Research Excellence (CoRE) Fund. We are very grateful to members of our Governing and Advisory Board and to Margaret Woolgrove and many others, for their helpful contributions to preparing what we believe is a compelling case. Our bid was accompanied by outstanding letters of support from university departments around the country and from the three main professional

associations (the NZ Mathematical Society, the OR Society of NZ and the NZ Statistical Association) affiliated with the NZIMA. We are now waiting in anticipation of a good outcome.

In December we circulated a *questionnaire* to ask directors of all current and former programmes for feedback on the NZIMA's programme framework – including what worked well (or not so well) for them, and other matters. We got good responses, and the feedback was almost entirely positive. One clear thing the feedback shows is the continuing need for us to be as flexible as we can. Another concerns the challenge of expecting one of the programmes to run the customary January summer meeting, and as a result of this, we wish to pursue the possibility of separating the summer meeting from NZIMA programmes, to allow it to run independently (and continue what has become a very valuable and successful tradition since its inception in 1994). A decision on this will be dependent on funding implications of the outcome of the CoRE selection round.

In closing, we would like to thank all those who have been involved positively in NZIMA's fourth year of operation, including (but not limited to) the following:

- Sir Ian Axford and other members of the Governing Board for their guidance and oversight
- Members of the Scientific Advisory Board for their advice and insight
- Members of the Executive Committee and others who have been involved in the selection of programmes, scholars and candidates for Maclaurin Fellowships and other support
- Programme Directors and Maclaurin Fellows for their research and research leadership
- Margaret Woolgrove for her amazing efficiency and initiative
- Professor Tom Barnes (DVC (Research)) and the Science Faculty Office at the University of Auckland for their ongoing support
- Directors and managers of the other CoREs for sharing their experiences
- Heads of departments and leaders of professional societies in the mathematical sciences in NZ for their outstanding letters of support for our CoRE Fund re-bid.

COMMENTS FROM SCIENTIFIC ADVISORY BOARD

The NZIMA's International Scientific Advisory Board is consulted regularly about the selection of its thematic programmes and other matters as appropriate.

No formal review by this advisory board of the NZIMA's programmes and other activities has been invited to date, but last year its members kindly offered comments based on their knowledge and experience of these activities so far, and we repeat a selection of them here:

Sir Michael Berry FRS (University of Bristol and the Isaac Newton Institute, UK)

In the few years since its creation, NZIMA has provided a powerful boost for New Zealand mathematics (interpreted in its widest sense). This was achieved with modest resources coupled with determination and commitment. The result is an abundance of activities — thematic programmes, workshops, support for researchers — all of the highest international quality.

Andreas Dress (CAS-MPG Partner Institute for Computational Biology, Shanghai):

I visited New Zealand quite often in the last years, and it was always a great pleasure to participate at NZIMA events and to be hosted by NZIMA-affiliated colleagues. Looking back, I am particularly impressed by the speed with which New Zealand changed from a country whose best young people went abroad (and were even encouraged, for their own best, by their supervisors) to a country that can not only attract its own scientific "offspring", but can also attract very good young mathematicians (and even older ones) from all over the world. I believe that this is by far the most valuable effect the work of the NZIMA has had so far.

Peter Hall FAA FRS (Mathematical Sciences Institute, Australian National University):

It's a pleasure to write to you to tell you how much I admire the Institute that you have created and brought to such a high level of maturity. New Zealand mathematics has fared so much better than that in Australia over the four years since the inception of the NZIMA, and the Institute has made all the difference.

I don't need to convince you, or indeed any wise person with a good awareness of contemporary science, that this new century is the Century of Mathematics. That is no less true in areas of biology and agriculture than it is in engineering and technology. All these fields are ones in which New Zealand has made its international mark, and where the NZIMA has launched and sustained high-level mathematical work. More basically, the Institute's development of theoretical mathematics is providing nourishment to the discipline across all its component parts.

Through the work of the Institute, New Zealand has been positioned to lever economic growth and advantage off the most influential and most cost-effective of all the sciences — the mathematical sciences. The nation is getting extremely good value for its investment in the NZIMA, and you must be particularly proud of what you have done.

PROGRESS WITH RESPECT TO CoRE FUND OBJECTIVES

The Centres of Research Excellence (CoRE) Fund is intended to support research that:

- is of excellent (world-class) quality,
- leads to knowledge transfer, and
- is focussed upon NZ's future development.

Below are some of the highlights of the NZIMA's activities and achievements in 2006 that show we are meeting these objectives. Further details can be found elsewhere in this report.

Research Excellence

- Researchers involved with the NZIMA won numerous awards and honours in 2006, including
 - election to a Fellowship of the Royal Society of London (Peter Hunter)
 - the Waksberg Award for 2006 from the American Statistical Association and the Statistical Society of Canada (Alastair Scott)
 - a James Cook Fellowship (James Sneyd)
 - election to a Fellowship of the Royal Society of New Zealand (Matt Visser)
 - the RSNZ Hatherton Award for 2006 (Catherine McCartin)
 - the Hans Daellenbach Award from the OR Society of NZ for 2006 (Andy Philpott)
 - the NZ Statistical Association's Campbell Award for 2006 (Jeff Hunter)
 - both winners of the NZ Mathematical Society's annual Research Award for 2006 (Robert Aldred and Mick Roberts)
 - four Top Achiever Doctoral Scholarships (Elan Gin, Erin Higgins, Eyal Loz and Inga Wang).
- The NZIMA has brought to New Zealand some of the world's finest mathematical scientists, such as John Conway (Princeton), Fields medallist Mike Freedman (Microsoft Research) and Boris Altshuler (Columbia, winner of the American Physical Society's 2003 Buckley Prize)
- The NZIMA is a member of the consortium of International Mathematical Science Institutes, and is a founder member of the newly established Pacific Rim Mathematical Association
- Researchers involved with the NZIMA have published a large number of articles in some of the world's top mathematics journals, including *Acta Numerica*, *Annals of Pure and Applied Logic*, *Biometrics*, *Journal of Algebra*, *Journal of the London Mathematical Society*, *Journal of Theoretical Biology*, *Mathematische Annalen*, and *Transactions of the American Mathematical Society*
- A 100-page invited paper by John Butcher on General Linear Methods (for the numerical solution of differential equations) was published in the prestigious journal *Acta Numerica*
- Marston Conder has been appointed President of the Academy of the Royal Society of NZ and as a member of New Zealand's new National Science Panel
- Rod Downey gave an invited lecture (the first invited lecture by a New Zealand based mathematician) at the International Congress of Mathematicians, in Madrid in August
- Several of our programmes have involved interactions with other centres of Research Excellence in NZ (and with other leading mathematical science institutes overseas).

Knowledge Transfer

- All the NZIMA's programmes have encouraged large numbers of students and professional mathematical scientists to take part in their conferences/workshops, and have engaged two or more postgraduate students in specific research projects
- All but one of the NZIMA's programmes have engaged at least one postdoctoral fellow, and some have attracted leverage funding to support one or more additional fellows
- A special issue of the journal *Annals of Pure and Applied Logic* (Elsevier), which resulted from the NZIMA's programme on Logic and Computation, was published in 2006 (vol. 138)
- The NZIMA organised or co-sponsored eight conferences and workshops in 2006
- In addition, many of the NZIMA's programmes have included a series of instructional lectures and/or seminars, for researchers from universities and CRIs, students, and interested parties from related disciplines, business/industry and relevant government departments
- Information sharing meetings have been held on our Hidden Markov Models programme with geophysicists (at GNS and Victoria University of Wellington) on earthquake modelling and prediction programmes, and with meteorologists and statistical climatologists (at NIWA) on rainfall related risk modelling, and with others on financial time series, agricultural monitoring and neurophysiology
- Our new programme on Partial Differential Equations involves the application of mathematics to geothermal modelling, nanotechnology, sea-ice interaction, structural vibration and acoustics
- Our new programme on Modelling Invasive Species is stimulating interactions with the BioProtection CoRE, Landcare Research, AgResearch, and the Canterbury Regional Council
- We have facilitated public lectures and newspaper articles (by/about high profile mathematicians such as John Conway), as well as talks in NZ high schools
- Our new glossy bulletin *NZ-IMAgEs*, which profiles research and other activities, is being distributed throughout New Zealand — including all intermediate and secondary schools
- We have developed a new resource (called *MathsReach*), to show school students and teachers what lies beyond the school curriculum in mathematics and statistics, in terms of professional careers, research activity, hot topics, and interesting and important applications.

Contribution to National Goals

- The NZIMA has “lifted the game” for the mathematical sciences in New Zealand, by focusing resources for greatest effect, helping our researchers work at the leading edge of their disciplines, creating new knowledge and also being able to assimilate new knowledge very rapidly, thus strengthening research-led teaching
- We have developed an outreach programme to lift the profile of the mathematical sciences in the eyes of the public, schools, teachers and students, to increase awareness of possibilities and encourage greater enjoyment and participation in science and other subjects having a quantitative focus — one of our slogans being “Maths behind every door”, which highlights the fact the mathematics underlies so much of recent advances in science and technology and everyday life

- Our membership of the IMSI and PRIMA consortia are providing excellent opportunities for New Zealand students to participate in summer schools and other activities organised by our partner institutes overseas
- We have encouraged the involvement of under-represented groups in research and postgraduate study in the mathematical sciences, and are celebrating their success. For example: NZIMA scholar Garry Nathan is the first Maori student to enrol for a PhD in Mathematics Education; three women (Jennifer Brown, Alex James and Vivien Kirk) have been appointed as NZIMA programme co-directors; and we are organising a 2-day workshop in 2007 for women in the mathematical sciences across New Zealand
- We are undertaking research that has potential and actual benefits for New Zealand's economy, society, and environment, such as the following:
 - Students engaged on the our programme on Mathematical Models for Optimizing Transportation Services have been undertaking projects on yacht match-race simulation (for Emirates Team New Zealand), airline network revenue management (for Air New Zealand), multi-objective transportation and routing problems (for the transport industry)
 - Students on our Hidden Markov Models programme have been working on fitting models to geophysical and deep earthquake data
 - Our new programme on Modelling Invasive Species and Weed Impact is helping investigate the spread and subsequent impact of invading organisms in New Zealand ecosystems, in order to determine the optimal use of resources between the competing demands of controlling existing species and limiting new species, while maintaining biodiversity.
- With regard to national identity, the NZIMA's programmes and international linkages (for example through the IMSI and PRIMA consortia), and the high profile of our principals and their work, have fostered a growing international awareness of the quality and diversity of mathematical sciences research in New Zealand.

THEMATIC PROGRAMMES: SUMMARY

The NZIMA has fifteen principal thematic research programmes at various stages of development. Key details of these programmes are given below. The first four were initiated in 2002/03, the next five in 2004 and 2005, three new ones got underway in 2006, and three more are planned to commence in 2007 and 2008.

Modelling Cellular Function: The aim of this programme is to characterise, simulate and elucidate the mechanisms of cell function through the use of analytic and computational mathematical models. This involves integration of spatial-temporal scales and biological function in the hierarchy of cellular models, which will ultimately be required to link genomics with clinical medicine.

Programme director: Dr Nicolas Smith (Bioengineering, University of Auckland)

Status: This programme's main period of activity was in 2003/04 and has now been completed.

Logic and Computation: The central focus of this programme is research on the theories of computability and complexity, and the algorithmic study of randomness. Other areas are finite and computable model theory and logics of programs, including complexity of decision problems and applications to specification and verification.

Programme director: Professor Rob Goldblatt (Victoria University of Wellington)

Status: This programme's main period of activity was in 2003/04 and has now been completed.

Numerical Methods for Evolutionary Problems: Evolutionary problems include ordinary differential equations, delay differential equations and differential-algebraic equations. Although traditional numerical methods for these problems are well established, more general methods are being developed that are capable of more efficient performance.

Programme director: Professor John Butcher (Mathematics, University of Auckland)

Status: This programme's main period of activity was in 2003/04 and has now been completed.

Phylogenetic Genomics: This programme has brought together leading experts to investigate the following topical problem: how can new types of genomic data best be used to infer evolutionary information? This question involves many challenging combinatorial problems.

Programme director: Professor Mike Steel (University of Canterbury)

Status: This programme's main period of activity was in 2003/04 and has now been completed.

Combinatorics and its Applications: This programme's major focus is on recent advances in combinatorics, with the aim of enhancing and developing linkages with the world's best combinatorial researchers, and applications to computational biology, complexity theory, theoretical computer science and abstract algebra.

Programme directors: Associate Professor Paul Bonnington (Mathematics, University of Auckland) and Professor Geoff Whittle (Victoria University of Wellington)

Status: This programme was initiated in 2004 and is ongoing.

Dynamical Systems and Numerical Analysis: This programme deals with the theory and applications of dynamical systems and the numerical analysis of differential equations, with particular attention paid to interactions between the two areas.

Programme directors: Professor Robert McLachlan (Massey University), Dr Vivien Kirk (Mathematics, University of Auckland), Dr Rua Murray (University of Waikato)

Status: This programme was initiated in 2004 and is approaching completion.

Geometry and its Interactions with Algebra and Analysis: This programme is concentrating on recent developments in geometry and related areas of algebra and analysis, including geometric function theory, structure and classification of 3-manifolds, algorithmic and probabilistic group theory, and the “matrix recognition project”.

Programme directors: Professor Gaven Martin (Massey University) and Professor Eamonn O’Brien (Mathematics, University of Auckland)

Status: This programme was initiated in 2004 and is approaching completion.

Hidden Markov Models and Complex Systems: Hidden Markov models form a remarkably general and elastic mathematical framework for modelling partially observed complex systems (in which observed data do not directly reflect the underlying dynamics). Recent developments allow model testing and parameter estimation to be carried out within certain classes. This programme aims to further extend and exploit these developments through applications to a range of problems of both local and international significance.

Programme director: Emeritus Professor David Vere-Jones (Victoria University of Wellington)

Status: This programme was initiated in 2005 and is well underway.

Mathematical Models for Optimizing Transportation Services: This programme’s main focus is on fleet and crew planning under uncertainty, and revenue management, and the interface between mathematical optimization and its applications in practical situations. This is being enhanced by engaging the support and participation of industrial partners.

Programme directors: Professor Andy Philpott, Associate Professor Matthias Ehrgott and Professor David Ryan (Engineering Science, University of Auckland)

Status: This programme was initiated in 2005 and is well underway.

Geometric Methods in the Topology of 3-Dimensional Manifolds: This programme (begun late 2005) is looking at 3-dimensional manifolds and especially the recent progress resulting from the use of geometry. A particular focus will be on the techniques and consequences of recent work on the geometrisation conjecture.

Programme directors: Professor David Gauld (Mathematics, University of Auckland), Dr Roger Fenn (University of Sussex) and Professor Vaughan Jones (University of Auckland and University of California, Berkeley)

Status: This programme was initiated at the beginning of 2006 and is well underway.

Key event(s): An international meeting took place at Taipa in January 2006, and smaller follow-up workshops were held in February and March 2006.

Partial Differential Equations: Applications, Analysis and Inverse Problems:

This programme is devoted to the development of methods for solving partial differential equations (and related “inverse problems”), and the application of these to geothermal modelling, nanotechnology, sea-ice interaction, structural vibration and acoustics.

Programme directors: Dr Colin Fox, Professor Mike O’Sullivan, Professor Boris Pavlov (University of Auckland)

Status: This programme was initiated in the second half of 2006 and is well underway.

Key event(s): An international meeting at Waitangi in January 2007, and smaller follow-up workshops later in 2007.

Modelling Invasive Species and Weed Impact: The main aim of this programme is the design of a mathematical and statistical framework for exploring the spread and subsequent impact of invading organisms in New Zealand ecosystems, in order to determine the optimal use of resources between the competing demands of controlling existing species and limiting new species, while maintaining biodiversity.

Programme directors: Dr Jennifer Brown, Dr Alex James and Professor David Wall (University of Canterbury)

Status: This programme was initiated in the second half of 2006 and is well underway.

Key event(s): A multidisciplinary workshop at Hanmer Springs in April 2007, and a smaller follow-up meeting at the end of 2007 or early 2008.

Applications of Mathematics in the Nanosciences: This programme will focus on mathematical and computational methods for experimentation with and model-based prediction of nanoscale phenomena, and design and control of nanoscale systems.

Programme director: Dr Shaun Hendy (Industrial Research Ltd and MacDiarmid Institute)

Status: This programme will begin in 2007, with a special session at the Advanced Materials & Nanotechnology conference AMN-3 at Wellington in February.

Algorithmics: New Directions and Applications: This programme will investigate the design and analysis of algorithms, and their applications to contemporary problems in computational biology, social sciences, and communication networks.

Programme directors: Professor Mike Atkinson (University of Otago) and Dr Charles Semple (University of Canterbury)

Status: This programme will begin in 2008.

Conformal Geometry and its Applications: This programme will concentrate on the use of conformal geometry and related techniques to study geometric and topological properties of manifolds and partial differential equations defined on them.

Programme directors: Professor Gaven Martin (Massey University) and Associate Professor Rod Gover (University of Auckland)

Status: This programme will begin in 2008.

THEMATIC PROGRAMMES: RESEARCH PROGRESS

This section outlines in some detail the progress of the NZIMA's thematic research programmes initiated recently (2004 to 2006).

- **Dynamical Systems and Numerical Analysis** – Professor Robert McLachlan (Massey University), Dr Vivien Kirk (University of Auckland) and Dr Rua Murray (University of Waikato) et al

This programme's main focus has been on the theory and applications of dynamical systems and the numerical analysis of differential equations, with particular attention being paid to the interaction between the two areas. The programme was initiated in 2004.

Two highly successful one-day workshops were held in 2006: one at Victoria University of Wellington in June (attended by 26 participants from NZ, Australia and the US), and another at the 2006 NZ Mathematics Colloquium held at the University of Waikato in December (attended by over 50 people).

The workshops and series of one-day meetings have been particular successes of this programme, in boosting the development of a strong research community in the theme areas, and especially beneficial for the many students and new colleagues present). Also by having the one-day meetings in various locations, and at regular intervals, student participation has been high; in fact, over 20 students have participated in one or more of these meetings, and typically more than half the contributed talks have been given by Masters or Doctoral students.

Research links with Australia have been significantly strengthened by the activities of the programme, with a number of new collaborations and many visits by Australians to NZ resulting directly from the programme. For example, As a result of Gary Froyland's visit funded by the programme in 2005, Rua Murray has begun a new collaboration with Gary Froyland and Dalia Terhesiu (UNSW), using numerical methods for transfer operators to detect phase transitions in low dimensional maps.

The programme attracted six further expert visitors in 2006, namely Georg Gottwald (Sydney), Bernd Krauskopf (Bristol), Hinke Osinga (Bristol), Bjorn Sandstede (Surrey), Emily Stone (Montana) and Martin Wechselberger (Sydney). These visitors gave seminars, interacted well with students and other researchers, and some began new collaborations as well as continuing current ones.

Dr Bart Oldeman completed his term as a postdoctoral fellow in July. While engaged on the programme Bart worked on several projects in numerical bifurcation theory, and a number of publications are forthcoming. In addition, Bart played an important service role during his tenure by installing, maintaining, and troubleshooting the AUTO software package for numerous students and other researchers, at three universities in NZ and one in Australia.

Postgraduates engaged in this programme include PhD students Elan Gin (University of Auckland), who is working on mathematical models of calcium dynamics, and Philip Zhang (Massey University), who is working on the dynamics of generalized Euler equations on Virasoro groups.

- **Combinatorics and its Applications** – Associate Professor Paul Bonnington (University of Auckland) and Professor Geoff Whittle (Victoria University Wellington) et al

This new programme began in the second half of 2004, with its major focus on major recent advances in combinatorics, and aiming to enhance and develop linkages with the world's best combinatorial researchers and their institutions. Also it has developed connections between combinatorics and computational biology, complexity theory, theoretical computer science and abstract algebra (areas that are already well developed in New Zealand).

The programme has continued to involve overseas experts, such as Prof. Bruce Richter who visited from the University of Waterloo during the year, and others who attended an international workshop on infinite aspects of topological graph theory, in Auckland in February.

Postgraduate student Robin Christian completed a Masters degree with distinction, with a research project on “Separating cycle families in k -connected graphs”, and has now begun a PhD. Postgraduate student Eyal Loz made spectacular progress in his PhD studies by finding several new best-known examples of graphs for the “degree-diameter problem”, and won a Top Achiever Doctoral Scholarship.

Prof. Bert Gerards (of the CWI, Netherlands) gave an invited address at the 2006 International Congress of Mathematicians, held in Madrid in August, on his joint work with Jim Geelen and Geoff Whittle, including research that was supported by this NZIMA programme.

- **Geometry: Interactions with Algebra and Analysis** – Professor Gaven Martin (Massey University) and Professor Eamonn O'Brien (University of Auckland) et al

This programme began at the end of 2004, with a significant emphasis on the interactions between three key areas of pure mathematics. One focus has been on geometric function theory and questions about the structure and classification of 3-manifolds. Another significant focus is on algorithmic and probabilistic group theory, with research contributing to the “matrix recognition project” — a major international research project that seeks to develop well-understood high-performance practical algorithms for the study of linear groups and their representations.

Richard Evans completed his postdoctoral fellowship in March 2006, and subsequently took up another with the NZIMA's programme on 3-Manifolds (see later).

Postgraduate students Tara Bonda (University of Auckland) completed her Masters degree during the year, with first class honours, and Maarten Jordens (Massey University) completed a Masters degree with distinction at the end of the year, and is beginning a PhD in 2007.

The two programme directors have continued their own research at a high level, involving collaborations with a large number of individuals and groups in NZ and overseas, and together they were invited to give nine addresses at international conferences in 2006.

➤ **Mathematical Models for Optimizing Transportation Services** – Professor Andy Philpott, Associate Professor Matthias Ehrgott and Professor David Ryan (University of Auckland) et al

The main focus of this programme is on transportation planning under uncertainty, optimizing the design of transportation systems, and pricing and revenue management, with additional points of focus on applications in practical situations, and engagement with industrial partners. The programme commenced in 2005, is now over half way through its duration.

Six postgraduate students have been engaged in this programme, all in the Engineering Science Department at the University of Auckland, and information on them follows below. A decision was made early on in the programme to involve additional research students in place of a postdoctoral fellow.

- Hamish Sheild completed a Masters degree with first class honours for his research project on “Yacht match-race simulation under a spatial weather model”, for Emirates Team New Zealand. He is now managing the High-Modulus yacht production business, and working in his spare time for the Emirates Team New Zealand weather team.
- Amir Joshan is undertaking a PhD on “Airline network revenue management”. Working with data supplied by Air New Zealand, he is investigating models for airline revenue management that account for competition between airlines.
- Richard Lusby has completed his Masters degree and is now enrolled for a PhD on “Routing trains through railway stations”, a key challenge for railway operations, on strategic, tactical, and operational levels. Richard has implemented optimisation software for the problem, and is currently working on data from Deutsche Bahn, which has shown interest in the development of software in Richard’s PhD thesis.
- Andrea Raith is undertaking a PhD on “Multi-objective transportation and routing problems”. She has completed a study of the biobjective shortest path problem, and will extend that work to multicommodity flow and route choice models in transportation.
- Bassy Tam is studying for a PhD on “Optimisation and simulation in airline crew scheduling”. She is developing extended models for unit-crewing of airline schedules, including a new branch-and-bound strategy and Dantzig-Wolfe decomposition.
- Oliver Weide is investigating (for his PhD project) the integration of the aircraft routing and pairings problems for airline scheduling. This approach will allow cost reduction as well as improvement of recovery from disruptions in operation. Oliver is implementing an iterative approach to this problem.

Professor Jesper Larsen (Technical University of Denmark), who is involved in the project of routing trains through railway stations and is an advisor for Richard Lusby’s PhD thesis, visited from August to October 2006, after Richard spent four months visiting the DTU earlier in the year.

Two significant awards were made to programme members in 2006 by the Operations Research Society of NZ: Andy Philpott won the Hans Daellenbach Prize for excellence in operations research, awarded at the NZ Science Honours Dinner), and Richard Lusby won the Young Practitioners Prize (at the 41st Annual Conference of the ORSNZ).

- **Hidden Markov Models** – Emeritus Professor David Vere-Jones (Victoria University of Wellington), Dr Roger Littlejohn (AgResearch), Dr Peter Thomson (SRA), et al

Hidden Markov models (HMM) form a remarkably general and elastic framework for modelling systems through data that do not directly reflect the underlying dynamics. One of the main aims of this programme (which commenced mid-2005) has been to bring together NZ-based researchers who use hidden Markov models in a range of contexts, to share their own expertise and to learn from overseas experts about recent developments.

Two postdoctoral fellows have been engaged, as follows:

- Dr Pierre Ailliot was appointed for a 9-month period (January to September 2006) with co-sponsorship by NIWA, to work on HMM space-time daily rainfall models.
- Dr Junko Murakami has been working primarily on estimating the parameters in a HMM model via the posterior mean. This has several potential advantages, but until now has been generally considered to be computationally unfeasible. Junko has reduced the complexity from exponential to polynomial order, and also assisted in the exploration of particle filter methods, as an adjunct to more conventional statistical routines.

Also two postgraduate research students are involved (at PhD level):

- Shao-chuan Lv has made good progress on HMM applications to NZ earthquake data, especially data on deep earthquakes. He has successfully implemented routines for fitting simple HMM models to the deep earthquake data, with results now being interpreted.
- Ting Wang is making excellent progress on aspects of robustness for HMM estimates, with particular applications to geophysical data including well-level data from Tangshan, China.

Expert visitors in 2006 were the following:

- Professor Rick Katz (US National Center for Atmospheric Research, Colorado) visited NZ during November/December, and worked with Peter Thomson and colleagues at NIWA, as well as giving seminars at three different NZ universities.
- Dr Elisa Varini (Italian Institute of Applied Mathematics, Milan) visited for a six-week period in March/April 2006, to work with David Vere-Jones and Junko Murakami on hidden Markov models and particle filters, and their applications to earthquakes.
- Dr Takaki Iwata (Institute of Statistical Mathematics, Tokyo) visited for a three-week period in March/April 2006, to work with David Vere-Jones and geophysics researchers at Victoria University of Wellington and GNS, on earthquake models and related issues.

Being an interdisciplinary programme, this one has involved numerous interactions with researchers in a wide range of disciplines. Those most important in 2006 have been with NIWA and GNS. Weekly meetings have been held jointly with the Geophysics group at Victoria University of Wellington, GNS and Statistical Research Associates, on earthquake modelling and prediction programmes, and joint work with NIWA has been undertaken through a group of meteorologists and statistical climatologists on rainfall related risk modelling, with a particular focus on hydro-electric catchment..

Work on financial time series, agricultural monitoring, neurophysiology, and other topics involving HMMs has been continued by various participants to the programme's workshops, such as Roger Littlejohn (AgResearch) who has continued to play a role in hosting visitors and other activities.

- **Geometric Methods in the Topology of 3-Dimensional Manifolds** – Professor David Gauld (University of Auckland), Professor Vaughan Jones (University of California Berkeley and University of Auckland) and Dr Roger Fenn (University of Sussex) et al

This programme's theme is the study of 3-dimensional manifolds, and especially recent progress resulting from the use of geometry, with focus is on the techniques and consequences of recent work on Thurston's geometrisation conjecture. The programme commenced in January 2006.

Dr Richard Evans was appointed in April as a postdoctoral fellow to this programme (on the completion of his postdoctoral fellowship for the Geometry programme listed above), and worked on the "ending lamination conjecture" for hyperbolic 3-manifolds. He has now completed this project, and has taken up employment in the private sector.

Two postgraduate research students are involved, both at the University of Auckland:

- Stephen Budden is a PhD student investigating the structure of "quandles" and their relation to the classification of knots.
- Michael Brough undertook a research project on "Simple Seifert surfaces" in 2006. He completed a BSc (Hons) degree with first class honours and is continuing with a Masters degree.

The programme held three workshops during 2006:

- A popular and highly successful summer meeting was held at Taipa in January 2006. The central theme was geometric methods in the topology of 3-manifolds, and the speakers included some of the world's best in this and related fields (such as Ian Agol (Illinois at Chicago), Jeff Cheeger (NYU), Michael Freedman (Microsoft), Cameron Gordon (Texas) and Kevin Walker (Microsoft). Highlights included lectures and discussions on topological quantum field theory, techniques in knot theory, and the techniques that led to the recent resolution of the Poincaré Conjecture. Over sixty mathematicians attended, mainly from Australia, New Zealand and the USA, and these included 16 graduate students.
- A smaller, specialist workshop was held at Hahei in February, to enable the programme directors, postdoctoral fellow and one of the postgraduate students to share knowledge and ideas and improve their common understanding of research topics central to the programme
- A further workshop was held at Leigh in March, on low-dimensional topology of compact and non-compact manifolds, with a special presentation on Woodin's ideas related to the Continuum Hypothesis.

In addition to expert visitors brought in for workshops, Peter Nyikos (South Carolina) visited for three weeks in May and June, and gave a series of six lectures.

➤ **Partial Differential Equations: Applications, Analysis and Inverse Problems** – Dr Colin Fox, Professor Mike O’Sullivan and Professor Boris Pavlov (University of Auckland) et al

This programme is devoted to the development of methods for solving partial differential equations (and related “inverse problems”), and the application of these to geothermal modelling, nanotechnology, sea-ice interaction, structural vibration and acoustics. This programme commenced in late 2006, and so there is relatively little to report.

From August 2006 the programme ran a series of introductory lectures and hosted international expert visitors who gave lectures and worked with local mathematicians, as follows:

- Prof. Helcio R. B. Orlando (Federal University of Rio de Janeiro), on heat flux and sample-based methods for inverse problems in PDEs
- Prof. Pavel Exner (Czech Academy and Doppler Institute), on quantum graphs
- Prof. Richard Hall (Concordia University), on systems of identical particles and geometric spectral inversion
- Prof. Boris Altshuler (Columbia University and NEC Labs), on quantum chaos, Anderson localization, and mid-frequency acoustic propagation in complex structures.

Arrangements were made for an international meeting to take place at Waitangi in January 2007, and one or two smaller workshops at a later date.

PhD student Tiangang Cui is engaged in the programme on a project on geothermal model calibration. Other students and a postdoctoral fellow are being appointed in early 2007.

➤ **Modelling Invasive Species and Weed Impact** – Dr Jennifer Brown, Dr Alex James and Professor David Wall (University of Canterbury) et al

The main aim of this programme is the design of a mathematical and statistical framework for exploring the spread and subsequent impact of invading organisms in New Zealand ecosystems, in order to determine the optimal use of resources between the competing demands of controlling existing species and limiting new species, while maintaining biodiversity. This programme commenced in late 2006, and so there is relatively little to report

Planning was undertaken for the programme’s main meeting, to take place at Hanmer Springs in April 2007. A smaller follow-up meeting is likely to be held at the end of 2007 or early 2008. Planning for the workshop and research by PhD students and for postdoctoral fellows has involved a number of biologists; and research planning meetings and discussions have been held with representatives of Lincoln University, Landcare Research, AgResearch, and the Canterbury Regional Council.

Two postdoctoral fellows have been appointed so far:

- Dr Charles Tadjeran was engaged in the second half of 2006 on anomalous diffusion extensions of Fisher's equation;
- Dr Britta Basse is undertaking research on level set theory and metapopulation models of Tussock spread in North Canterbury, in close collaboration with AgResearch.

Additional financial support for this programme has been obtained from Landcare Research and the Miss E. L. Hellaby Indigenous Grassland Research Trust to support PhD students from 2007.

UPDATE ON EARLIER THEMATIC PROGRAMMES

This section provides an update on the first four of the NZIMA's thematic research programmes, initiated in its first year of operation.

➤ **Modelling cellular function** – Dr Nicolas Smith (University of Auckland) et al

This programme focussed on development and use of analytic and computational models to characterise, simulate and elucidate the mechanisms of cell function. Most of the programme's activity took place in 2003 and 2004, and the programme is now completed.

Research has involved the development of a hierarchical modelling approach that is consistent with the thermodynamic principles underlying energy supply and demand in the cell. This approach incorporates detailed biophysical information, while allowing simplification of the model to enable computer simulation of the heart. Another aim of this programme has been to introduce and promote CellML, a markup language, developed by a group at the Bioengineering Institute, which is used to describe mathematical models of cellular function. It is intended that CellML will provide the potential for increased involvement from the mathematical community in cellular modelling, by facilitating and accelerating the means of model exchange and reuse.

The programme generated many further research activities and provided other opportunities to develop new research relationships with groups in Chicago, Kyoto, Oxford, Queensland, San Diego, Sheffield, Sydney and Utah. Other positive outcomes have been reported previously.

➤ **Logic and computation** – Prof. Rob Goldblatt (Victoria University of Wellington) et al

The central focus of this programme involved research in the theories of computability and complexity, and the algorithmic study of randomness. Most of the programme's activity took place in 2003 and 2004, and the programme is now completed.

A major output from the programme was a collection of research papers published in a special issue of the top-ranking journal *Annals of Pure and Applied Logic* (Elsevier), guest-edited by Professors Rod Downey and Rob Goldblatt (Victoria University of Wellington). This appeared as Volume 138 of the journal in March 2006.

One of the main participants in the programme (and author of one of the above research papers), Dr Catherine McCartin, won the Hatherton Award of the Royal Society of NZ in 2006 for the best scientific paper published by a PhD student.

➤ **Numerical methods for evolutionary problems** – Prof. John Butcher (University of Auckland) et al

The principal aim of this programme was to develop numerical methods for the solution of ordinary differential equations, delay differential equations and differential-algebraic equations, and special methods for problems that evolve on manifolds, within a geometric integration framework. Most of the programme's activity took place in 2003 and 2004, and the programme is now completed.

Some of the most significant benefits of this programme have arisen directly from the appointment of Dr Helmut Podhaisky for a one-year postdoctoral fellowship in 2003/04, his

ongoing and fruitful collaboration with John Butcher, and active collaborations with others involved in the programme; these have led a growth in other activities and attracted further visitors to Auckland to work in related aspects of the research.

Further high-level research by John Butcher and his colleagues is reported later under the section “Research by co-directors and other principal investigators”.

➤ **Phylogenetic genomics** – Prof. Mike Steel (University of Canterbury) et al

This programme concentrated on the development of combinatorial methods to use new types of genomic data to infer evolutionary information. The programme’s main period of activity was in 2003/04, and it is now completed.

Research achievements of the programme have been taken further by Mike Steel and his colleague Dr Charles Semple, and former postdoctoral fellows Magnus Bordewich and Stefan Grunewald. Two of the students involved (Philip Daniel and Tobias Thierer) completed Masters degree with Distinction and are publishing papers.

Mike Steel also continues to play a key role in the organisation of the New Zealand phylogeny workshop, held annually. Further high-level research by Mike Steel and his colleagues is reported later under the section “Research by co-directors and other principal investigators”.

MACLAURIN FELLOWSHIPS

Full-year Maclaurin Fellows

- **Prof. Robert McLachlan** (Massey University) completed his 12-month tenure as a Maclaurin Fellow in early 2006. His research has focussed on a range of topics associated with his main field of expertise, namely geometric integration.

One such topic has been the study of foliations and diffeomorphism groups, in which he has developed theory of a vector field preserving the foliations induced by two or more subgroups of a Lie group action. Another has involved joint work with others on 'explicit integrators', in which he has successfully explored splitting methods for volume-preserving systems, producing many interesting new results and applications.

During 2006, he developed a new implementation of symplectic Runge-Kutta methods, and tested this extensively on 'real-life' problems like the motion of the solar system. It performs very well, and because of its simplicity, he hopes that it will lead to more widespread use of these methods. A paper describing this successful work will appear in the SIAM Journal of Scientific Computing. In another project on multisymplectic integrators (with PhD student Brett Ryland), he has shown that partitioned Runge-Kutta methods are much more widely applicable than had been thought, and furthermore, that these methods can preserve the entire dispersion relation of a multi-Hamiltonian partial differential equation, contradicting a recently-published analysis.

Robert was an invited lecturer at the New Zealand Mathematics Colloquium in December 2006, and has also received an invitation as plenary lecturer at the 2007 Scientific Computation and Differential Equations conference (SciCADE), to be held at St Malo in July 2007. He also co-edited (with Reinout Quispel) a special issue of the Journal of Physics A (volume 29 (2006)) on Geometric Numerical Integration, and has been invited to run a conference on "Applying geometric integrators" at the International Centre for Mathematical Sciences, Edinburgh, in April 2007, and to be a Senior Visiting Fellow at the Isaac Newton Institute, Cambridge, from April to June 2007.

- **Prof. Geoff Whittle** (Victoria University of Wellington) began his year as a Maclaurin Fellow in mid-2006. He has spent the first six months undertaking joint work with Jim Geelen (University of Waterloo) and Bert Gerards (CWI Amsterdam) on matroid minors, and with James Oxley (Louisiana) and Charles Semple (University of Canterbury) on matroid connectivity problems. His work with Geelen and Gerards included a 4-week visit to the University of Waterloo, where together they began developing a structure theorem for proper minor-closed classes of matroids. This is a major task, but is progressing well, and is expected to provide a powerful tool for well-quasi-ordering matroids over finite fields. The work with Oxley and Semple will help develop tools that will assist in an attack on Rota's Conjecture.

He has also been writing up a 150-page manuscript on their joint resolution of Kahn's conjecture for 4-connected matroids, which in turn proves that non-representability of matroids over a finite field can be certified in polynomial time. In addition, he has been

working with Gordon Royle (University of Western Australia) and postdoctoral fellow Dillon Mayhew on the problem of characterizing the class of binary matroids that do not contain the cycle matroid of $K_{3,3}$ as a minor, which has led to an exact structural description enabling resolution of numerous conjectures for this class.

Short-term Visiting Maclaurin Fellows

- **Prof. Hyman Bass** (University of Michigan) was appointed as a Visiting Maclaurin Fellow for a brief period in August 2006. Professor Bass is a distinguished mathematician (and former President of the American Mathematical Society) who has become a leading figure in the world of mathematics education. He spent time in Wellington and Auckland, where he gave a lecture on the rationality of the zeta-function of a finite graph, and also gave a joint Mathematics Colloquium lecture at the University of Auckland with Professor Deborah Ball entitled “A Mathematician's View of Mathematics Education”, which focussed on the need for improved two-way interaction between the teaching and learning of mathematics.
- **Prof. John Conway** (Princeton University) is John von Neumann Distinguished Professor of Mathematics at Princeton University, and is one of the world's most illustrious mathematicians. He visited New Zealand in January 2006, took part in the summer workshop on 3-manifolds at Taipa, and spent a further two weeks at the University of Auckland. He interacted with several researchers on a range of different topics (in group theory, number theory, game theory and topology), and gave a very well-attended and entertaining public lecture on “Tangles, bangles and knots”.

New Maclaurin Fellowship appointments

- We have selected Professor **Marcus du Sautoy** (University of Oxford) as a visiting Maclaurin Fellow for a 3-week period in February/March 2007. Professor du Sautoy is a talented mathematician best known not only for his work in group theory, but also for his ability in communicating and popularising mathematics. A frequent radio and TV commentator on aspects of mathematics and society, he is the author of the best-selling book on the Riemann hypothesis, *The Music of the Primes*, for which he won the Sartorius and Peano Awards.
- Also we have selected Professor **Peter Lax** (New York University) as a visiting Maclaurin Fellow for a 2-week period in 2007, at a time to be confirmed. Peter Lax is one of the world's most distinguished mathematicians, and won the *Abel Prize* when it was awarded for only the third time, in 2005, for his work in analysis and partial differential equations and their applications.
- We have appointed **Professor Graeme Wake** (Massey University) as a Maclaurin Fellow for a 1-year period beginning March 2007. Graeme Wake is an applied mathematician with strong interests in industrial applications, and experience in directing the “Mathematics-in-Industry Study Group” for the last two years. He will use his fellowship to spend a year working on functional differential equations, in collaboration with other New Zealand based mathematicians, motivated by applications such as models for cell/tumour growth.

RESEARCH BY CO-DIRECTORS AND OTHER PRINCIPALS

Directors' Research

- **Prof. Marston Conder** has been continuing his research (supported by the Marsden Fund) in combinatorial and computational group theory, with applications to the study of discrete objects with maximum symmetry. Particular highlights have been his work to determine all regular maps on orientable surfaces of genus up to 100 and non-orientable surfaces of genus up to 200, considerably extending the previous classification (which went to genus 15 and 30 respectively), and a similar computer-assisted determination of all trivalent symmetric graphs on up to 2048 vertices (extending the previous best classification, on up to 768 vertices). Both of these pieces of work have thrown up some surprising results and interesting patterns, which are leading to further discoveries and some fruitful new collaborations.
- **Prof. Vaughan Jones** has undertaken research on the Connes tensor product in quantum theory. He has been able to show that the fusion bi-module is indeed asymptotically contained in the ordinary tensor product but in a sense that is so far not entirely satisfying on physical grounds. It is a technical question of the closure of an operator algebra. On the planar algebra front his focus has shifted to the free product of planar algebras and the ensuing annular categories. This is part of a broad classification problem for the planar algebras coming from subfactors, which has already had considerable success and was his motivation for the work on intermediate subfactors. On a third front he continues to work on quantum computing, both topological and otherwise, in ongoing work with Aharonov and Landau, and discussions with Freedman and Walker at Microsoft.

Research by other Principal Investigators

Much of the research by our principal investigators is already summarised in the earlier progress reports on NZIMA thematic programmes. In addition, there are several strands of research carried out by the NZIMA's by our principal investigators that are complementary to those programmes, supported by sources other than the CoRE Fund. Here is a brief selection of these:

- **Prof. John Butcher** (University of Auckland) and his research group have been developing general linear methods for the solution of stiff and non-stiff differential equation systems, supported by the Marsden Fund. This includes the derivation of new efficient methods and also techniques for their practical implementation. Collaborators in this work include Allison Heard (Auckland), Laura Hewitt (Bath), Adrian Hill (Bath), Zdzislaw Jackiewicz (Arizona), Helmut Podhaisky (Halle) and Will Wright (La Trobe). Amongst the notable achievements of John Butcher's research programme are publication of a 100-page survey paper on General Linear Methods in the prestigious *Acta Numerica* (which publishes only invited papers), successful use of the "scale and modify" technique used in variable step-size implementations where the algorithm can adjust to changing conditions without losing stability or the integrity of local error estimation, and the proof by John Butcher of the longstanding Butcher-Chipman conjecture, on what orders are possible for various multi-value schemes which are A-stable. The last of these had been regarded as a very difficult question (which might never have been resolved) and new techniques had to be invented for

the purpose. The result itself is related to properties of certain Riemann surfaces and the method of proof makes use of a network of directed lines (known as order arrows) and homotopy theory.

- **Prof. Peter Hunter** (University of Auckland) leads the Auckland Bioengineering Institute, which is closely affiliated with the NZIMA. A major focus of this institute's work is on developing computational physiology models of all twelve organ systems in the human body. These currently include models of the heart and circulation, lungs and respiratory system, the musculo-skeletal system, the stomach and digestive system, the lymphatics and immune system, the skin and several sensory organs such as the eye; for further details, see www.bioeng.auckland.ac.nz/projects. In all cases the models are linked closely with experimental data for determining parameter values and for model validation. A major aim is to solve coupled systems of biophysically-based equations (for example, coupled electro-mechanics and blood flow in the heart) and to develop and link models across multiple spatial scales (for example, from ion channels to whole heart function). Models of cellular processes now include many aspects of cell function including ion channel electrophysiology, calcium transport, signal transduction pathways, metabolic pathways and gene regulatory pathways. To facilitate the handling of complex cell models, the NZIMA has supported the development of an XML-based markup language framework called CellML – (see www.cellml.org). This allows models of isolated systems to be developed and combined into more complex composite models. Open source software tools are being developed to allow users to run models directly from the repository of CellML models. The organ system models are being applied in clinical applications in diagnostics, surgical planning, medical devices and drug discovery, and in design projects where models can help improve interactions between the body and external devices.
- **Prof. Gaven Martin** (Massey University) undertakes research in non-linear analysis and geometry, with support from the Marsden Fund. One major highlight of his work in 2006 was his presentation with Kari Astala (Helsinki) and Tadeusz Iwaniec (Syracuse) of a solution to the 1962 conjecture of Pucci on the growth of solutions to second order elliptic partial differential equations, giving the sharp extension of Alexandrov's classical maximum principal. In addition, they were able to obtain estimates (for the first time) in the degenerate elliptic setting. A second highlight was his successful collaboration with Volker Mayer (Lille) and Kirsi Peltonen (Helsinki), which has led to strong progress on the generalized Lichnerowicz problem (the classification of rational dynamical systems on manifolds). In this work they have established an interesting rigidity theorem for locally-injective but not globally-injective rational mappings of manifolds, by showing that only euclidean space forms admit such dynamical systems.
- **Prof. James Sneyd** (University of Auckland) has continued his studies of the dynamics of calcium in a variety of cell types, with particular focus on their role in airway smooth muscle contraction, the secretion of saliva, and the control of heart beat. With Vivien Kirk he has also begun studies of the role of canards in calcium oscillations. For the next two years he will hold a James Cook Fellowship, during which time he will finish the second edition of his research textbook on mathematical physiology, as well as begin major new projects on multi-level studies of asthma and of saliva secretion. He is also developing new methods of constructing hybrid deterministic/stochastic models of calcium micro-domains, and how to

connect them to whole-cell models. He and his experimental colleagues are planning two major grant applications to the National Institutes of Health (USA) in the coming year. James Sneyd also continues to work with New Zealand Steel, and Rakon Ltd, and his work has already resulted in improved methods of crystal oscillator production.

- **Prof. Mike Steel** (University of Canterbury) directed the NZIMA's thematic programme in Phylogenetic Genomics, and later held a MacLaurin fellowship to investigate random models in evolutionary biology. These projects have led to much further work by his biomathematics group into information-theoretic approaches in molecular genetics, early evolution, and models of speciation and extinction. His work has also moved into another area of biology, namely biodiversity conservation and ecology in the 'Noah's Ark problem' (how to best allocate resources to maximize expected future biodiversity). This is part of a \$500,000 Marsden-funded project (2007–2009) with Dr Charles Semple, PhD students Beata Faller and Klaas Hartmann, and overseas colleagues and visitors. In addition, Mike Steel has co-edited (with Olivier Gascuel) a book *Reconstructing Evolution: New Mathematical and Computational Advances*, which is about to be published by Oxford University Press. Later this year Mike Steel is co-organising a 4-month workshop at the Isaac Newton Institute for Mathematical Sciences (Cambridge, UK) on phylogenetics, which will bring together leading experts in this area of computational biology, along with their students and postdocs. He is also helping to organise the annual Evolution meeting to be held for the first time outside of North America, in Christchurch, June 2007, with approximately 900 participants expected.
- **Dr Graham Weir** (Industrial Research Ltd) has been considering how geometry can provide new insights into the transfer of angular momentum between non-spherical particles, in the context of granular flows in particular, and plasticity in general. One of his main discoveries in 2006 concerned conjugate points and separating surfaces. The motivation for this research is simple: in the plane, for example, two curves typically intersect in distinct points, but if these two curves are thought as being the outline of 2-dimensional deformable bodies, then separating lines should exist between the distinct points of intersection, with one body being wholly on one side of this separating curve, and the other body wholly on the other side. How one constructs such separating lines, and then determining when these lines are straight, depends on the nature of the bodies. For very early times of intersection, and when the two bodies are rigid-plastic bodies, there is an answer that is wholly geometrical, and depends on the curvature of the bodies about the initial region of overlap. Here the initial lines of separation are straight lines when the curvatures of the two intersecting curves are equal. The points of intersection which produce planar separating surfaces are defined as conjugate points, and are those sets of points having the same curvatures at the initial intersection points. These results generalise easily to three dimensions.

RESEARCH BY POSTDOCTORAL FELLOWS

The following postdoctoral fellows were engaged on NZIMA thematic programmes in 2006, in many cases with partial or total support from other sources:

- Dr Pierre Ailliot, on the Hidden Markov Models programme, from January to September 2006, working on HMM space-time daily rainfall models
- Dr Britta Basse, on the Modelling Invasive Species programme, from August to November 2006, with support from the University of Canterbury, working on level-set theory and metapopulation models of Tussock spread in North Canterbury
- Dr Richard Evans, on the Geometry and 3-Manifolds programmes, working on the ending lamination conjecture for hyperbolic 3-manifolds and other questions in geometry and topology
- Dr Takaki Iwata, on the Hidden Markov Models programme, for a short period in 2006, with support from the Institute of Statistical Mathematics in Tokyo, working on earthquake models and related issues
- Dr Junko Murakami, on the Hidden Markov Models programme, for all of 2006, and co-sponsored by NIWA, working on estimating the parameters in a HMM model via the posterior mean, and on particle filter methods as an adjunct to more conventional statistical routines
- Dr Bart Oldeman completed his 2-year term on the Dynamical Systems programme in July 2006, working on several projects in numerical bifurcation theory, and also installing, maintaining, and troubleshooting the AUTO software package for numerous students and other researchers at three NZ Universities and one in Australia
- Dr Charles Tadjeran, on the Modelling Invasive Species programme, from August to November 2006, working on anomalous diffusion extensions of Fisher's equation
- Dr Elisa Varini, on the Hidden Markov Models programme, for a short period in 2006, with support from the Italian Institute of Applied Mathematics (Milan), working on HMM models and particle filters, with applications to earthquakes.

RESEARCH BY POSTGRADUATE STUDENTS

- Each of our **thematic programmes** has a number of postgraduate research students engaged in it, and their research is reported earlier under “Thematic programmes”.
- Typically, each programme involves up to three Masters or PhD students, some of whom hold Top Achiever Doctoral Scholarships or other scholarships, alongside others who are supported by the NZIMA, and many more who take part in the programme’s main conference or workshop.
- In addition, the following postgraduate research students and their projects were supported by the NZIMA in 2006, on a merit basis:
 - Jae-Hoon Chung (University of Auckland), project in *modelling of breast deformation during X-ray (mammographic) and MRI imaging*
 - Tiangang Cui (University of Auckland), PhD in *Bayesian inference for geothermal model calibration*
 - Jean Zhaojing Gong (University of Canterbury), PhD in *medical statistics*
 - Jack Lee (University of Auckland), project in *modelling vasoregulatory mechanism*
 - Garry Nathan (University of Auckland), PhD in *mathematics education*
 - Steven Niederer (University of Auckland), project in *modelling whole heart ischemia*
 - Kim Noakes (University of Auckland), Masters in *bioengineering*
 - Dion O'Neale (Massey University), PhD in *geometric numerical integration*
 - Josef Silhan (University of Auckland), PhD in *differential geometry*
 - Adam Smith (University of Auckland), Masters project on the *statistical validation of the NZ Marine Environment Classification*
 - Kirk Spragg (University of Waikato), project in *metallurgic applications of magnetohydrodynamics*.
- In 2006, we decided to support also the following students in 2007 and onwards:
 - Robin Averill (Victoria University of Wellington), for a PhD in *Mathematics Education*
 - Maarten Jordens (Massey University), for a PhD on *Minimisers of distortion functionals and the calculus of variations*
 - Xinshan Li (University of Auckland), for a PhD on *Modelling childbirth*
 - Yang Wang (University of Auckland), for a PhD on *Modelling of Left Ventricular Disease using cardiac MRI*
 - Oliver Weide (University of Auckland), for a PhD on *Integrated crew pairing and aircraft routing*.

Of particular note is Robin Averill’s PhD project, which is exploring the importance of effective teacher-student relationships for mathematics learning, especially for Maori and Pacific students.

VISITING EXPERTS

The local scientific community benefitted from the visits by the following expert visitors brought to New Zealand by the NZIMA's activities in 2006:

- Professor Ian Agol (University of Illinois at Chicago)
- Professor Boris Altshuler (Columbia University), *winner of the Oliver E. Buckley Condensed Matter Prize of the American Physical Society in 2003*
- Professor Hyman Bass (Michigan), *Visiting Maclaurin Fellow*
- Professor Jeff Cheeger (Courant Institute of Mathematical Sciences, New York)
- Professor John Conway (John von Neumann Distinguished Professor, Princeton University), *Visiting Maclaurin Fellow*
- Dr Patrick Dehornoy (Université de Caen, France)
- Professor Pavel Exner (Czech Academy of Sciences and Doppler Institute)
- Dr Roger Fenn (University of Sussex)
- Dr Michael Freedman (Microsoft Research), *Fields Medallist*
- Professor Paul Gartside (University of Pittsburg)
- Professor Cameron Gordon (University of Texas at Austin)
- Dr Georg Gottwald (University of Sydney)
- Professor Richard Hall (Concordia University, Montreal)
- Professor Richard Hamilton (Columbia University)
- Dr Adrian Hill (University of Bath)
- Dr Takaki Iwata (Institute of Statistical Mathematics, Tokyo)
- Professor Rick Katz (US National Center for Atmospheric Research, Colorado)
- Professor Louis Kauffman (University of Illinois at Chicago)
- Professor Bernd Krauskopf (University of Bristol)
- Professor Jesper Larsen (Technical University of Denmark)
- Professor Peter Nyikos (University of South Carolina)
- Professor Helcio Orlando (Federal University of Rio de Janeiro)
- Dr Hinke Osinga (University of Bristol)
- Professor Bruce Richter (University of Waterloo, Canada)
- Professor Dale Rolfsen (University of British Columbia)
- Professor Hyam Rubenstein (University of Melbourne)
- Dr Brian Sanderson (University of Warwick, UK)
- Professor Bjorn Sandstede (University of Surrey)
- Dr Christoph Stark (Technical University of Clausthal, Germany)
- Professor Emily Stone (University of Montana)
- Dr Elisa Varini (Italian Institute of Applied Mathematics, Milan)
- Dr Kevin Walker (Microsoft Research)
- Dr Martin Wechselberger (University of Sydney)

CONFERENCES, PUBLIC EVENTS AND OTHER ACTIVITIES

➤ We used the NZIMA's CoRE funding and status to lend support to the following **conferences held in New Zealand** in 2006:

- “*Statistical Connections*”, a **joint conference of the Statistical Society of Australia and the New Zealand Statistical Association** (ASC/NZSA 2006) was held at Sky City, Auckland, the week 3-7 July 2006. The aim of this conference was to bring together statisticians from Australia and New Zealand, offering a rich programme of invited and contributed talks, led by top-class keynote speakers. The conference attracted 290 participants, including 46 students and 50 participants from outside Australasia. Special workshops were held on Distance Sampling, the “R” system, and Stochastic Processes.
- An **international workshop** on “Analytic Topology and Applications” was held at Rotorua the week 10–14 July 2006. The conference attracted 30 participants from around the world, including delegates from Australia, Bulgaria, China, Japan, Poland, Slovakia, Spain and the USA, and well as New Zealand. Research papers from the conference will be published in a special issue of the New Zealand Journal of Mathematics.

➤ Public events:

- The NZIMA sponsored a public lecture in January 2006 by its **Visiting Maclaurin Fellow, John Conway** FRS (who is John von Neumann Distinguished Professor of Mathematics at Princeton University, and one of the world's most illustrious mathematicians). John entertained a large audience with his lecture on “Tangles, bangles and knots”. He visits New Zealand again in January 2007 and January 2008.
- Vaughan Jones (Co-Director of the NZIMA) gave two public lectures as Massey University's **Sir Neil Waters Distinguished Lecturer** in March 2006, at Albany and Palmerston North.
- In June the NZIMA organised a **special event at Victoria University of Wellington** to celebrate the appointment of Prof. Geoff Whittle to a Maclaurin Fellowship for 2006. The evening included a brief account by Sir Ian Axford (Chair of the NZIMA's Governing Board) about Maclaurin, and a showing of the MSRI video “Porridge, Pulleys, Pi: two mathematical journeys” (featuring Vaughan Jones and Hendrik Lenstra and offering insights to their work, their backgrounds, their personalities and interests, and the impact of their research in mathematics, physics, cryptography and molecular biology). Also Dr Peter Thomson (from Statistical Research Associates) gave an interesting account of progress in the NZIMA's programme on Hidden Markov Models, describing projects by the postdoctoral fellows, students and others on GDP growth rates, rainfall modelling, earthquake and other geophysical modelling. Some of these are being co-sponsored by NIWA, AgResearch, SRA and Victoria University of Wellington.
- Origami Master Jonathan Baxter and mathematics educator Hugh Gribben toured New Zealand in August, presenting an hour-long show titled “The Great Origami Maths and Science Show”. This show explores the laws of origami, origami in nature, problem-solving using the power of origami, and the application of intricate folding techniques to industrial design and engineering (ranging from safer air-bags to the deployment in outer space of giant telescopes). The NZIMA co-sponsored the production and distribution of

10,000 flyers to schools around the country to promote the tour. A companion manual tailored to the NZ curriculum includes step-by-step instructions on making the models, hands-on activities and additional classroom resources.

- Complementary to our Visiting Maclaurin Fellows and visiting experts engaged on NZIMA programmes, the NZIMA also sponsored the following additional *visitors to New Zealand*:
- Dr David Borchers (St Andrews), in the first half of 2006. Dr Borchers is an expert on *statistical ecology*. He spent time at the University of Canterbury, where he gave lectures and interacted with members of the Biomathematics Research Centre. In particular, he and Dr Jennifer Brown collaborated on two research projects, on removal method estimates for animal population size, and estimating animal abundance from surveys that only detect animal presence or absence. The first of these involved some joint activity with Landcare Research.
 - Professor Bill Newman (UCLA), in July 2006. Professor Newman is an expert on *cellular automata and complex systems*, which have wide-ranging applications to other fields of research including earthquake modelling, the spread of forest fires, and the study of urban gang behaviour. Professor Newman gave lectures and established and renewed contacts with colleagues at the University of Auckland and the University of Canterbury.

AWARDS AND HONOURS

The following is a selection of awards and honours won by NZIMA people in 2006:

- Dr Robert Aldred (University of Otago), a key member of our programme on Combinatorics, was joint winner of the *New Zealand Mathematical Society's Research Award* for 2006.
- Prof. Marston Conder (NZIMA Co-Director) has been elected to New Zealand's new 12-person *National Science Panel*, established by the Royal Society of NZ in November, and began a 3-year term as *President of the Academy of the Royal Society of NZ* in December.
- Prof. Rod Downey (our first Maclaurin Fellow) gave an *invited lecture at the International Congress of Mathematicians* (ICM) in Madrid in August; this is the first time ever that a New Zealand based mathematician has been invited to speak at the ICM.
- Elan Gin, Erin Higgins, Eyal Loz and Inga Wang, four students associated with NZIMA programmes, won *Top Achiever Doctoral Scholarships* in 2006.
- Prof. Jeff Hunter (Massey University), who has hosted NZIMA-sponsored visitors and ran an NZIMA-sponsored workshop on Matrices and Statistics, won the *Campbell Award* for 2006 from the NZ Statistical Association.
- Prof. Peter Hunter (member of our Governing Board and of our programme on Modelling Cellular Function) was elected a *Fellow of the Royal Society of London*, and as a member of the Council of the Academy of the Royal Society of NZ.
- Prof. Jerry Marsden (a member of our International Scientific Advisory Board and participant in our programme on Dynamical Systems and Numerical Analysis) was elected a *Fellow of the Royal Society of London* in 2006.
- Dr Catherine McCartin (who was a student involved in our programme in Logic and Computation in 2003/4, and now a Senior Lecturer at Massey University) won the *Hatherton Award* from the Royal Society of New Zealand for 2006.
- Prof. Gaven Martin (Massey University), co-director of our programme on Geometry and its Interactions, was re-elected as representative of the mathematical and information sciences on the *Council of the Royal Society of NZ*, and represented New Zealand at the quadrennial meeting of the International Mathematical Union (IMU) held in Spain in August.
- Prof. Andy Philpott (co-director of our programme on Transportation Modelling) won the *Hans Daellenbach Award* from the Operations Research Society of NZ for 2006.
- Prof. Cheryl Praeger (a member of our International Scientific Advisory Board) was elected to the *Executive Committee of the International Mathematical Union* (IMU) in August.
- Prof. Mick Roberts (Massey University), an active participant in our programme on Dynamical Systems and a key member of our programme on Modelling Invasive Species, was joint winner of the *New Zealand Mathematical Society's Research Award* for 2006.
- Prof. Alastair Scott (member of our Governing Board) won the *Waksberg Award* for 2006 from the American Statistical Association and the Statistical Society of Canada.
- Prof. James Sneyd (a member of the NZIMA's Governing Board and a key member of the NZIMA programme on Modelling Cellular Function) won a 2-year **James Cook Fellowship**, in biological sciences, in December 2006.
- Prof. Matt Visser (one of our three new principal investigators in 2006) was elected a *Fellow of the Royal Society of NZ* in 2006.

INTERNATIONAL LINKAGES

- The NZIMA is a member of the *International Mathematical Sciences Institutes (IMSI)*, an international consortium of research institutes in the mathematical sciences that run thematic programmes and have large visitor programmes, and is listed on the IMSI website
<http://www.fields.utoronto.ca/aboutus/IMSI.html>
- The NZIMA is also a founding member of the new *Pacific Rim Mathematical Association* (otherwise known as ‘PRIMA’), established at the end of 2005 with the aim of promoting and facilitating the development of the mathematical sciences throughout the Pacific Rim region. This new consortium of mathematical sciences institutes will involve improved networking, coordination of activities, training (including summer schools), infrastructural assistance, sharing of expertise, and pooling of resources. Marston Conder is a member of PRIMA’s Liaison Committee. More information about PRIMA and its intended activities can be now be found on its website <http://www.primath.org/>. One forthcoming initiative is a Pacific Rim Mathematical Congress, to be held in Sydney Australia in July 2009.
- Communication linkages with institutes overseas have been set up through *visits* by one or both of the two Co-Directors (often while attending other conferences). These include the Fields Institute in Ontario, the Mathematical Sciences Research Institute (MSRI) in California, and the Pacific Institute of Mathematical Sciences (PIMS) in British Columbia.
- In February 2006 Marston Conder met with Sir David Wallace CBE FRS FREng, the incoming new Director of the Isaac Newton Institute, when he visited Auckland briefly. This has the potential to be a valuable contact in the future.
- Very strong international linkages have been developed by the NZMRI through its earlier *programme of annual summer workshops*, and these are being taken further by the involvement of *invited overseas experts* in NZIMA programmes and as visiting Maclaurin Fellows — see earlier page on Visiting Experts.
- In 2006 the NZIMA has established another international linkage, this time with the *Atlantic Association for Research in the Mathematical Sciences* (AARMS), which helps coordinate research activities in the four eastern-most provinces of Canada. We will be looking at ways in which we can facilitate participation by students in each other's summer schools and workshops, and encourage other joint activity.
- The NZIMA’s *website*, the *quarterly e-mail newsletter* and our new *NZ-IMAgEs bulletin* (sent to a large number of people overseas) are proving useful devices for maintaining and enhancing international contacts.
- Strong and productive international linkages are also being maintained through the NZIMA’s *International Scientific Advisory Board*, which includes a number of representatives from other members of the IMSI (such as the CMA, MSRI and PIMS), as well as prominent New Zealand-born mathematical scientists and others resident overseas.

PUBLICATIONS

The following give a selection of publications by researchers either supported or stimulated by (or otherwise involved with) the NZIMA's activities during 2006.

Special Issues of Journals Edited

Downey, Rod; Goldblatt, Robert (eds): Special issue on New Zealand Institute of Mathematics and its Applications: Logic and Computation Programme. *Ann. Pure Appl. Logic*, vol. 138, issues 1-3, 2006, 220pp.

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FINANCIAL REPORT

This report covers only the activities supported by the award to the NZIMA from the Centres of Research Excellence (CoRE) Fund.

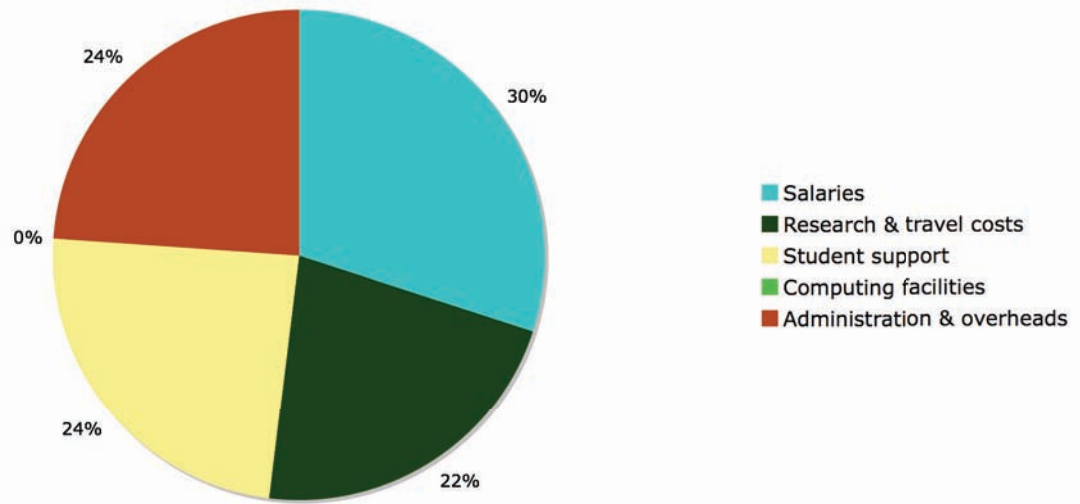
Statement of Financial Performance for the 2006 year

Income	Actual	Budget	Variance
CoRE Funding	\$ 1,631,111	\$ 1,631,111	\$ 0
Host/Partner Support	40,953		40,953
Total Income	\$ 1,672,064	\$ 1,631,111	\$ 40,953
Expenditure	Actual	Budget	Variance
<i>Salaries</i>			
Director & Principal Investigators	\$ 67,766	\$ 78,750	\$ 10,984
Associate Investigators	120,481	191,900	71,419
Postdoctoral Fellows	162,535	210,000	47,465
Research/ Technical Assistants	0	0	0
Others	36,969	23,625	(13,344)
<i>Total Salaries (a)</i>	<i>\$ 387,751</i>	<i>\$ 504,275</i>	<i>\$ 116,524</i>
<i>Other Costs</i>			
Project Costs	\$ 171,519	\$ 110,250	\$ (61,269)
Postgraduate Student Support	306,656	321,311	14,655
Travel	114,067	105,000	(9,067)
Indirect Costs: Overheads	318,911	504,275	185,364
Equipment depreciation	0	0	0
Rental - equipment	4,220	65,000	60,780
Subcontractors	0	0	0
Extraordinary expenditure	0	21,000	21,000
<i>Total Other Costs (b)</i>	<i>\$ 915,373</i>	<i>\$ 1,164,826</i>	<i>\$ 211,463</i>
Total Expenditure	\$ 1,303,124	\$ 1,631,111	\$ 327,987

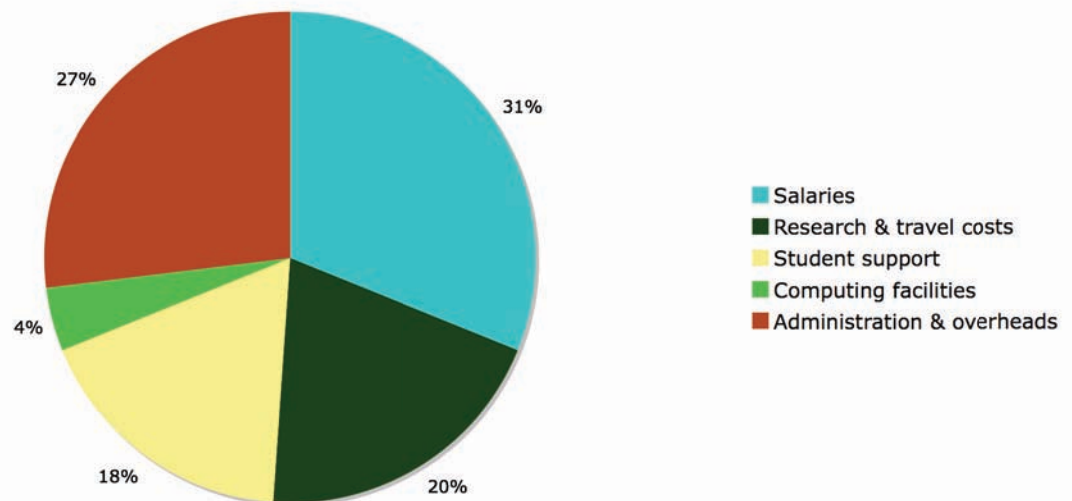
Statement of Financial Position as at 31 December 2006

	Previous total	Current year	Nett total
<i>Funds committed but not yet spent</i>	<i>\$ 1,018,055</i>	<i>\$ 327,987</i>	<i>\$ 1,386,995</i>
<i>Represented by</i>			
Thematic programmes 2005/06/07			\$ 863,505
Maclaurin fellowships 2006/07			89,000
Postgraduate scholarships 2006/07/08			434,490
<i>Total commitments going forward</i>			<i>\$ 1,386,995</i>

NZIMA Expenditure 2006



NZIMA Expenditure To Date



CONTACT DIRECTORY

Chair of the NZIMA Governing Board

Sir Ian Axford *PhD (Manchester) Hon DSc (Cantab, Victoria) FRS FRSNZ*
2 Gladstone Rd, Napier, New Zealand
Email: ian@axford.org

Co-Directors

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Research Manager

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NZIMA Website

URL: <http://www.nzima.org>

APPENDIX 1: AIMS AND STRUCTURE OF THE NZIMA

The New Zealand Institute of Mathematics and its Applications (NZIMA) was established in 2002 as one of the five Centres of Research Excellence selected by the New Zealand government in March 2002. It is hosted at the University of Auckland and headed by Fields Medallist and Distinguished Alumni Professor Vaughan Jones *DCNZM DSc FRS FRSNZ* (Berkeley) and Professor Marston Conder *DSc FRSNZ FTICA* (Auckland), with involvement of many of the best pure and applied mathematicians and statisticians from across the country.

The principal aims of the NZIMA (updated in 2006) are to

- sustain and develop a critical mass of researchers in concentrations of excellence in mathematics and statistics and their applications,
- act as a facilitator of access to new developments internationally in the mathematical sciences,
- provide a focus on a source of high-level quantitative expertise in NZ across a range of areas,
- assist and promote the engagement and application of mathematics and statistics, to other research disciplines and to NZ business, industry and local government, and
- foster the development of knowledge and skills in the mathematical sciences in NZ, through encouragement, inclusion and support of students and early-career researchers, and outreach to schools, teachers and the general public.

The NZIMA is modelled on similar mathematical research institutes in other countries, notably the Fields Institute (Canada), MSRI (Berkeley), and the Newton Institute (UK). In particular, we place considerable emphasis on world-class research in fundamental areas of the mathematical sciences and the use of high-level mathematical techniques in modern application areas such as bioengineering, bioinformatics, medical statistics, operations research, and risk assessment.

Our key activities include

- the organisation of 6-monthly programmes on themes drawn from a range of fields of significant interest
- associated workshops held at various locations around NZ
- establishment of postdoctoral fellowships in the theme areas
- establishment of PhD and/or Masters degree postgraduate scholarships in the theme areas
- establishment of a small number of merit-based open scholarships for research students (from New Zealand or worldwide) in unrestricted areas of the mathematical sciences
- establishment of annual Maclaurin Fellowships (*), to enable mathematical scientists from NZ or worldwide to take time out from their usual occupations and undertake full-time research in New Zealand (or partly overseas if based in New Zealand).

(* Richard Cockburn Maclaurin was a graduate of Auckland University College who went on to study at Cambridge, where he won the Smith Prize in Mathematics and Yorke Prize in Law, and was appointed as Foundation Professor of Mathematics at Victoria University College in 1899, and later Dean of Law and Professor of Astronomy. In 1908 he was invited to become President of the Massachusetts Institute of Technology (MIT), and helped transform that institution into the world-class research-based technological university it is today.)

The NZIMA was formally established in June 2002 as a partnership between the University of Auckland (its host) and the NZ Mathematics Research Institute (NZMRI). The NZMRI is an incorporated society, which for the last ten years has organised summer meetings in New Zealand on particular topics of contemporary significance in mathematics, with support from the Marsden Fund and contributions by individuals (from NZ and overseas) and by mathematics and statistics departments at NZ universities. The NZIMA is building on this activity.

Governing Board

The NZIMA is overseen by a *Governing Board*, with seven members appointed by each of the University of Auckland and its partner organisation the NZMRI (Inc.), and has an independent chairperson. The Governing Board's responsibilities are to oversee the Institute's activities and finances and ensure that it is meeting its responsibilities under the terms of the joint venture agreement and those of the Centres of Research Excellence Fund.

In particular, the Governing Board helps formulate the research strategy of the NZIMA, the method by which its research programmes and projects are developed, and the strategy and responsibility for the recruitment, education and ongoing development of students and other new researchers. The Governing Board also has responsibility for appointing an International Scientific Advisory Board (see below) and an Executive Committee (see below), approving annual budgets and financial accounts prepared by the Co-Directors and the Executive Committee, and ratifying contracts and fellowships that are let by the NZIMA. The Governing Board normally meets twice yearly, in person (or occasionally by audio-conference).

The current membership of the NZIMA Governing Board is as follows:

Chair of Board

- Sir Ian Axford *DSc FRS FRSNZ*

Members appointed by the University of Auckland:

- Professor Philippa Black (University of Auckland)
- Emeritus Prof. John Butcher (University of Auckland)
- Prof. Peter Hunter (University of Auckland)
- Dr John Kernohan (Auckland UniServices Ltd)
- Prof. David Ryan (University of Auckland)
- Prof. Alastair Scott (University of Auckland)
- Prof. James Sneyd (University of Auckland)

Members appointed by the NZMRI (Inc.):

- Prof. Rod Downey (Victoria University of Wellington)
- Prof. Mike Hendy (Massey University)
- Prof. Gaven Martin (Massey University)
- Prof. Mike O'Sullivan (University of Auckland)
- Prof. Andy Philpott (University of Auckland)
- Emeritus Prof. David Vere-Jones (Statistical Research Associates)
- Dr Graham Weir (Industrial Research Ltd).

Co-Directors (ex officio):

- Prof. Marston Conder (University of Auckland)
- Prof. Vaughan Jones (University of Auckland and University of California Berkeley).

International Scientific Advisory Board

The NZIMA seeks advice and guidance on its research programmes from an *International Scientific Advisory Board*, which is made up of prominent New Zealand mathematical scientists resident overseas, representatives from similar organisations (such as the CMA, MSRI and Fields Institute), and other notable individuals with a positive record of contact with the New Zealand mathematical sciences community. The composition of this advisory board is arranged to ensure balanced representation across the various disciplines of the mathematical sciences.

Members of the International Scientific Advisory Board are invited to review proposals for NZIMA programmes and applications or nominations for Maclaurin Fellowships, and to recommend new themes, suitable visitors and workshop speakers. This advisory board will meet virtually, by electronic mail, however the NZIMA plans to invite one of two members each year to visit New Zealand and take part in some of the NZIMA's activities.

Current members of the NZIMA's International Scientific Advisory Board are as follows:

- Prof. Sir Michael Berry (University of Bristol)
- Prof. Andreas Dress (Universität Bielefeld)
- Prof. Peter Hall (CMA, Mathematical Sciences Institute, Australian National University)
- Prof. Gus Lehrer (University of Sydney)
- Prof. Jerrold Marsden (California Institute of Technology)
- Prof. Hugo Rossi (Mathematical Sciences Research Institute, Berkeley, California)
- Prof. Cheryl Praeger (University of Western Australia)
- Prof. Dale Rolfsen (University of British Columbia)
- Prof. Mike Saunders (Stanford University)
- Prof. Bruce Weir (North Carolina State University)
- Prof. Keith Worsley (McGill University, Montreal)
- Prof. Margaret Wright (Courant Institute, New York University).

Co-Directors and Executive Committee

Management of the NZIMA's activities is the responsibility of the two *Co-Directors* and an *Executive Committee* appointed by the Governing Board. The Co-Directors and Executive Committee have delegated authority to manage the affairs of the NZIMA in accordance with the policy of the Governing Board.

The main responsibilities of the two *Co-Directors* are to:

- recommend policy to the Governing Board
- carry out the directions of the Governing Board
- convene meetings and discussions of the Executive Committee and other sub-committees
- maintain financial oversight of activities, staffing, and resources
- coordinate administrative matters with the host and partner organisations (the University of Auckland and the NZMRI), the CoRE Fund administrators, and other funding agencies

- coordinate collaboration with other organisations involved in research in the mathematical sciences in New Zealand (such as the NZ Mathematical Society (NZMS), the NZ Statistics Association (NZSA), the Operations Research Society of NZ (ORSNZ), and the NZ branch of Australia & New Zealand Applied Mathematics (ANZIAM))
- maintain and further promote linkages with other mathematical research institutes overseas.

The Executive Committee consists of the two Co-Directors (ex officio) plus three other members (each appointed for a 2-year term), with assistance from an Research Manager. Appointments to the Executive Committee will be on a rotating basis, with the aim of ensuring balanced representation both in terms of pure/applied focus and affiliation.

The main responsibilities of the Executive Committee are to assist the Co-Directors in:

- developing policy for and carrying out the directions of the Governing Board
- selecting (preliminary) proposals for NZIMA programmes to be developed into full proposals for consideration by the Governing Board
- selecting candidates for Maclaurin Fellowships, postdoctoral fellowships, student scholarships, and other activities for NZIMA support
- appointing programme directors and committees
- setting programme budgets and reviewing reports if required.

The *Executive Committee* considers such matters in consultation with the two Co-Directors on a regular basis, either in person, or by electronic mail, or by audio-conference.

Programme Committees and Programme Directors

All special thematic programmes run by the NZIMA are organised by *Programme Committees*, each convened by a Programme Director.

Each Programme Committee is charged with the responsibility of organising the programme (or theme) as approved by the Governing Board, and includes the Programme Director plus at least one member appointed by the NZIMA Executive Committee. The main responsibility of the programme committee is the organisation of the programme, including conferences/workshops, and selection and appointment of visiting experts, postdoctoral fellow and postgraduate scholars.

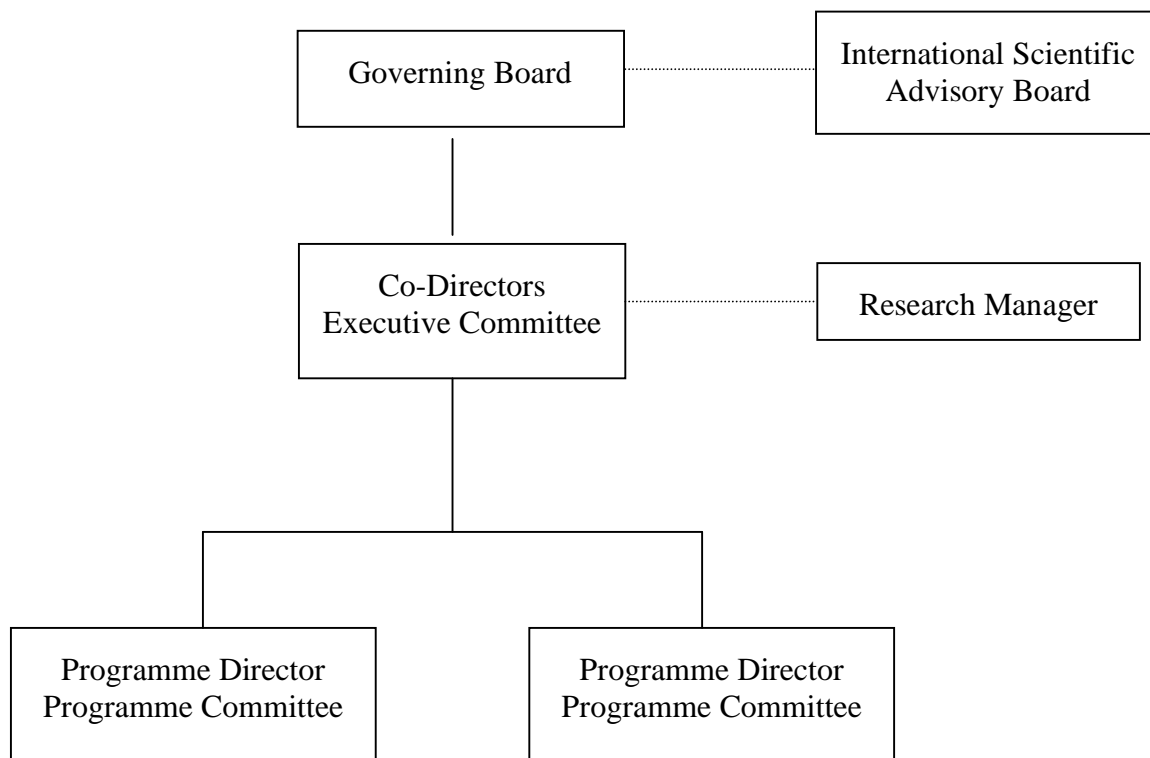
Each Programme Director is expected to provide written interim and final reports through the Executive Committee to the Governing Board, on both scientific activity and financial arrangements. These reports include a final financial statement for the entire programme, a list of all persons involved, and a list of scientific publications and other research outputs resulting from the programme.

Research Manager

The main responsibilities of the *Research Manager* are to:

- provide HR, financial and other administrative assistance to the Executive Committee and Co-Directors
- help coordinate workshop and conference organisation for each programme committee
- liaise with Programme Directors, Maclaurin Fellows and scholarship holders
- maintain correspondence for the NZIMA
- prepare and disburse publicity material on the activities and outputs of the NZIMA.

Organisational Chart



Host and partner arrangements

Office accommodation is provided by the host organisation (the University of Auckland) for the NZIMA Co-Directors and Research Manager, along with support services for administrative functions, including human resource and management accounting services. The costs of these are covered from overhead funding in the NZIMA's CoRE Fund budget. A partnership agreement between the host organisation and the partner organisation (the NZMRI) has been negotiated to ensure appropriate division of responsibilities, revenue and expenses (including allocation of overheads).

Arrangements are made for subcontracting services (including programmes and Maclaurin Fellowships as necessary) through the University of Auckland's Research Office. Arrangements will be made as necessary for commercialisation of NZIMA-funded research and protection of intellectual property through Auckland UniServices Ltd, which has a wealth of experience and a track record of success in this area.

The NZIMA offices are housed at the University of Auckland, on Floor 3 of the same building in which the Departments of Mathematics and Statistics are housed (Building 303), on the corner of Princes and Wellesley Streets, Auckland.

APPENDIX 2: PROFILES OF BOARD AND EXECUTIVE

Chair of the NZIMA Governing Board

Sir Ian Axford DSc FRS FRSNZ is a distinguished scientist who recently retired from his position as Director of the Max-Planck Institute für Aeronomie in Germany. He was named New Zealander of the Year in 1995, in recognition of his distinguished international career in the field of space science. His work placed him at the forefront of near-Earth and Solar System research. He was closely involved with the Voyager 1 and Voyager 2 planetary explorers, the Giotto space-probe, and the Ulysses galaxy explorer. He has made a lifelong commitment to excellence in research and also to the growth and popularisation of science. He previously held positions as a professor at Cornell University (New York) and at the University of California at San Diego, Vice-Chancellor of Victoria University of Wellington, and Chair of the Marsden Fund. He is a Fellow of the Royal Society of London and an Honorary Fellow of the Royal Society of New Zealand, and has an Honorary Doctorate from Victoria University of Wellington.

Governing Board Members

Philippa Black FMSAm FRSNZ is a Professor of Geology at the University of Auckland, where she has also served as Dean of Graduate Studies and Associate Deputy Vice-Chancellor (Research). She is a former President of the Royal Society of New Zealand, and also formerly chair of the University of Auckland's Postgraduate & Scholarships Committee. She has considerable experience and wisdom in dealing with academic and research matters.

John Butcher DSc FRSNZ is an Honorary Research Professor of Mathematics at the University of Auckland, having previously been Head of the Applied and Computational Mathematics Unit, Head of the Computer Science Department, and Head of the Mathematics Department during his distinguished career. He is a world authority on the numerical solution of ordinary differential equations, won the NZ Mathematical Society's annual Research Award in 1991, and won the Hector Medal (of the Royal Society of NZ) in 1996.

Rod Downey FRSNZ has a personal chair in Mathematics at Victoria University of Wellington, is one of the five (voluntary) directors of the NZMRI, and was President of the NZ Mathematical Society for the last two years. He won the Hamilton Award of the Royal Society of NZ in 1990, the NZ Mathematical Society's annual Research Award for 1992, the NZ Association of Scientists' Research Medal in 1994, and has won numerous other awards for his work in logic and computational complexity.

Michael Hendy FTICA FRSNZ holds a personal chair in Mathematical Biology at Massey University, and is Co-Director (with David Penny) of the Allan Wilson Centre (one of the other Centres of Research Excellence in NZ). He has been Head of the Mathematics discipline group in the Institute of Fundamental Sciences at Massey University and Assistant Editor of the journal *Molecular Biology and Evolution*.

Peter Hunter FRSNZ is a Distinguished Professor at the University of Auckland, and is Director of its Bioengineering Institute. He was awarded a James Cook Fellowship in 1991, and was elected a Fellow of the American Institute for Medical and Biological Engineering in 2001. He has also been Chair of the Physiome Commission of the International Union of Physiological Sciences and a member of the Scientific Advisory Board of Physiome Sciences Ltd.

John Kernohan is the retired Chief Executive Officer of Auckland UniServices Ltd, which is responsible for commercial research and consultancy partnerships, forming new business ventures based on University research, and developing intellectual property. With a PhD in Chemistry, he spent some years in R&D management for General Electric and as CEO of several businesses for ICI New Zealand Ltd. He was appointed UniServices' founding CEO in 1988, and helped it grow from small beginnings to a significant entity with annual revenue of \$70m pa.

Gaven Martin FRSNZ is a Distinguished Professor of Mathematics at Massey University (Albany), and is one of the five (voluntary) directors of the NZMRI. He won the NZ Mathematical Society's annual Research Award for 1994, held a James Cook Fellowship from 2001 to 2004, and has also won several other prestigious awards, prizes, fellowships and visiting positions overseas. He is joint author of a recent book *Geometric function theory and non-linear analysis* published by Oxford University Press. He is currently serving as the chair of the Royal Society of New Zealand's Standing Committee for Mathematical and Information Sciences

Mike O'Sullivan FIPENZ has a personal chair in Engineering Science at the University of Auckland, and is a former Head of the Department of Engineering Science. His speciality is mathematical and computational modelling of geothermal fields, and has been involved as a consultant for over 20 geothermal projects in Indonesia, Japan, Kenya, New Zealand, USA and Mexico. He is Associate Editor of the journal *Geothermics*, and has supervised over 40 postgraduate research students at Masters and PhD level.

Andy Philpott has a personal chair in Engineering Science at the University of Auckland, where he is currently Head of the Department of Engineering Science. He is also a former chair of the Royal Society of New Zealand's Standing Committee for Mathematical and Information Sciences. His research interests are in stochastic optimisation and operations research. He won the Hans Daellenbach Prize of the Operations Research Society of NZ in 2006.

David Ryan FIMA FIPENZ FRSNZ is a Professor of Operations Research at the University of Auckland, a former Head of the Department of Engineering Science, and is currently Deputy Dean of the Engineering Faculty. He is well known internationally for his work on developing methods for solution of large-scale linear programming problems, especially in the context of scheduling. He won the Engineering Excellence Award in Information Technology from the Institution of Professional Engineers New Zealand (IPENZ) in 1999, and won the Hans Daellenbach Prize of the Operations Research Society of NZ in 2001.

Alastair Scott FASA FIMS FRSNZ FRSS is a recently-retired Professor of Statistics at the University of Auckland, and was previously Head of the Departments of Mathematics and Statistics. He has a worldwide reputation for his research on sample survey statistics, and has been appointed to many editorships, fellowships of professional societies, and visiting positions at universities and laboratories overseas. His expertise has also been recognised by appointments to government and professional bodies (such as the NZ Environmental Risk Management Authority).

James Sneyd FRSNZ is Professor of Applied Mathematics and Head of the Applied Maths Unit at the University of Auckland. He is best known for his work in physiological modelling, and was joint winner of the American Association of Publishers' Award in 1998 for Best New Title in Mathematics, for his book *Mathematical Physiology* (co-authored with J. Keener). He is also closely involved with programmes at the Mathematical Biosciences Institute (in Ohio).

David Vere-Jones FRSS FRSNZ is an Emeritus Professor at Victoria University of Wellington, and a director of Statistical Research Associates (a private consultancy firm). He specialises in mathematical and statistical modelling, with particular interests in geophysics and in statistics education. He won the International Statistical Institute's Henri Willem Methorst Medal in 1995, and the Royal Society of New Zealand's Rutherford Medal in 1999, and has won a significant number of other grants and awards and distinctions.

Graham Weir DSc FRSNZ is leader of the Applied Mathematics group at Industrial Research Ltd, and is currently chair of the NZ Branch of the professional organisation ANZIAM (Australia and New Zealand Applied Mathematics). He specialises in the mathematical modelling of physical systems. He won a Ministerial Award for Excellence in Science in 1987, a Royal Society of NZ Science and Technology Medal in 1996 and the NZ Mathematical Society's annual Research Award for 2000. He has also served on several key committees.

Co-Directors

Marston Conder DSc FRSNZ FTICA is a Professor of Mathematics at the University of Auckland, best known for his work on the application of combinatorial and computational group theory to the analysis and construction of discrete objects with maximum symmetry. He obtained his doctorate from the University of Oxford, where he won the Senior Mathematical Prize and Johnson Prize in 1980. He held a postdoctoral fellowship at the University of Otago in 1981, followed by a Royal Society (UK) Research Fellowship at the University of Tübingen (Germany) in 1982, and a Fellowship from the Alexander von Humboldt Foundation in 1987. He won the NZ Mathematical Society's annual Research Award for 1993, was elected a Fellow of the Royal Society of NZ in 1998, and awarded a DSc by the University of Oxford in 1999.

He was President of the NZ Mathematical Society from 1993 to 1995, co-founder and initial convenor of the NZ Mathematical and Information Sciences Council (now a standing committee of the RSNZ) in 1994, and is a co-founding Director of the NZMRI (Inc.). He participated as a lead expert in the MoRST Review of New Zealand's Scientific Knowledge Base in 1996, was a member of the TEAC Research Working Group (2000–2001), and in 2002 chaired the NZ Ministry of Education's Working Group that developed recommendations for a Performance Based Research Fund (PBRF) for tertiary education institutions in NZ. At the University of Auckland he was Head of the Department of Mathematics from 1996 to 1998, and served a term as Deputy Vice-Chancellor (Research) from 1999 to 2001. He is a member of the Editorial Board of the *NZ Journal of Mathematics*, was a member of the Marsden Fund Council (and convenor of its Mathematical & Information Sciences panel) from 2002 to 2005, and is currently President of the Academy of the Royal Society of New Zealand and a member of the National Science Panel.

Vaughan Jones DCNZM DSc FRS FRSNZ is a Professor of Mathematics at the University of California at Berkeley and Distinguished Alumni Professor of the University of Auckland. After obtaining a Masters degree with first class honours at Auckland in 1973, he won a Swiss Government Scholarship and an FWW Rhodes Memorial Scholarship to study for a doctorate at the University of Geneva. In 1979 he was awarded the degree of *Docteurs Sciences (Mathematique)*, and the following year the Vacheron Constantin Prize for his doctoral thesis. He held postdoctoral positions at the University of California at Los Angeles (UCLA) and the University of Pennsylvania. During the 1980s his research focussed on von Neumann algebras,

and in the course of this work he discovered a new polynomial invariant for knots which led to surprising connections between apparently quite different areas of mathematics.

He was awarded a Fields Medal at the 1990 International Congress in Kyoto (Japan) for his remarkable and beautiful mathematical achievements, and until 2006 was the only person from Australia or New Zealand ever to have won this prestigious award. Since then he has gone on to receive numerous awards and honours, including a Guggenheim Fellowship in 1986, Fellowship of the Royal Society (of London) in 1990, the Rutherford Medal in 1991, honorary doctorates from the University of Auckland in 1992 and the University of Wales in 1993, membership of the US National Academy of Sciences in 1999, the Onsager medal of Trondheim University (Norway) in 2000, foreign membership of the Norwegian Royal Society of Letters and Sciences 2001, and a Distinguished Companionship of the Order of New Zealand in 2002.

He has been invited to lecture at numerous international congresses, and has served as editor or associate editor of many top international journals, including the *Transactions of the American Mathematical Society*, *Reviews in Mathematical Physics*, and the *Journal of Mathematical Chemistry*. Also he has been a member of the Scientific Advisory Boards of the Fields Institute for Mathematics (Canada), the Erwin Schrödinger Institute for Mathematical Physics (Vienna, Austria), the Mathematical Sciences Research Institute (USA), the Center for Communications Research (USA), and the Institut Henri Poincaré (Paris, France). He is also currently a Vice-President of the American Mathematical Society.

He is founder and principal director of the NZMRI, a role in which he has been instrumental in attracting some of the world's best mathematicians to NZ. His own style of working is informal, encouraging the free and open interchange of ideas, and this has rubbed off on many others. His efforts have made it possible for graduate students to gain first-hand knowledge of developments at the leading edge of their discipline, here in NZ.

Research Manager

Margaret Woolgrove MBA has a background in research project management, both in New Zealand, where she worked for the Health Research Council from 1997 to 1999, and in the USA and Britain. She spent three years with the Michigan Public Health Institute, and has worked for both the University of Auckland and Massey University since she returned to New Zealand in 2002. Margaret gained her MBA degree (with Distinction) from Massey University in 2005, and the findings of her MBA research project (on development of business skills) were reported in the *NZ Management* magazine and in *NZ Education Review*.