MATHEMATICS AND STATISTICS:

CRITICAL SKILLS FOR AUSTRALIA'S FUTURE

THE NATIONAL STRATEGIC REVIEW OF MATHEMATICAL SCIENCES RESEARCH IN AUSTRALIA

DECEMBER 2006
www.review.ms.unimelb.edu.au

"Australia's distinguished tradition and capability in mathematics and statistics is on a truly perilous path. The decline has already taken its toll: the university presence has been decimated, in part by unanticipated consequences of funding formulas and by neglect of the basic principle that mathematics be taught by mathematicians, and the supply of students and graduates is falling short of national needs."

"The mathematical sciences skill base in any country is too important for its future prosperity to let short-term market mechanisms act alone. We sincerely hope that leaders in Australian Government, academia and industry will collaborate with the mathematics and statistics community to develop an appropriate vision, and spark an Australian renaissance in our field."

— From the foreword by the international reviewers.

ISBN 0 85847 234 1

www.review.ms.unimelb.edu.au

FOREWORD BY THE INTERNATIONAL REVIEWERS

URGENT ACTION NEEDED TO AVERT 'FATAL COURSE' OF MATHEMATICAL SCIENCES IN AUSTRALIA

Mathematics and statistics permeate the complex fabric of developed societies, and mathematicians distinctively shape its texture.

At once a domain of knowledge in itself and the quantitative language for other fields, mathematics constantly evolves through research driven by the interplay of internal and external questions. As but one example, mathematicians give form and voice to ideas that help structure and deploy the flood of information transforming all of commerce, technology, medicine and daily life.

The ever-expanding role of the mathematical sciences, and the strategic need for support of the associated research and training work, has been well recognised in our home countries and in other vibrant and developing economies.

From documents submitted during the Review, we quickly saw that a destructive process was presently under way in Australia. Ten days of visits across Australia convinced us much more is at stake.

Indeed, we found the nation's distinguished tradition and capability in mathematics and statistics to be on a truly perilous path.

The decline has already taken its toll: the university presence — the essential foundation for future success — has been decimated, in part by unanticipated consequences of funding formulas and by neglect of the basic principle that mathematics be taught by mathematicians. In parallel, the supply of students and graduates falls short of national needs: despite the demonstrated value of mathematics in commerce, technology and scientific research, it is understandable that bright young people choose to enter curricula that are less demanding or more visibly endorsed.

Immediate and resolute action is required to reverse this fatal course. It will take time and thoughtful measures to achieve results.

Facing this crisis, the report outlines a national strategy to, over time:

- Rebuild a vigorous community of mathematicians and statisticians in Australia that is internationally engaged — vital in a world 'without borders' — and that partners local industry in both research and training
- Restore and further improve the nature and delivery of tertiary instruction by mathematicians to specialist and many more non-specialist students alike
- Increase the exposure of high school students to mathematics at various levels, through support for development of properly trained and recognised teachers and curricula.

The mathematics skill base in any country is too important for its future prosperity to let short-term market mechanisms act alone.

We sincerely hope leaders in Australian government, academia and industry will collaborate with the mathematics and statistics community to develop an appropriate vision, and hence spark an Australian renaissance in our field.

Measurable changes must occur very soon or the point of plausible return will pass.

International reviewers, National Strategic Review Of Mathematical Sciences Research In Australia:

Professor Jean-Pierre Bourguignon, Director, Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France

Dr Brenda Dietrich, Director, Mathematical Sciences, IBM Thomas J Watson Research Center, Yorktown Heights, New York, US

Professor Iain M Johnstone, Department of Statistics, Stanford University, Stanford, California, US

CONTENTS

SCOPE OF REVIEW

The National Strategic Review of Mathematical Sciences Research in Australia was conducted by a Working Party appointed by the National Committee for the Mathematical Sciences of the Australian Academy of Science. The Terms of Reference are listed at Appendix Three.

The Review was funded by the Australian Research Council Special Research Initiatives Scheme (project number SR059001) with additional support from the Australian Mathematical Sciences Institute, the Australian Mathematical Society, Inc. and the Statistical Society of Australia, Inc.

The views expressed herein are those of the Working Party for the Review and are not necessarily those of the Australian Research Council.

EXECUTIVE SUMMARY

KEY FINDINGS AND RECOMMENDATIONS OF THE NATIONAL STRATEGIC REVIEW OF MATHEMATICAL SCIENCES RESEARCH IN AUSTRALIA

THE FUTURE OF MATHEMATICAL SCIENCES IN AUSTRALIA IS IN JEOPARDY...

"The mathematics skill base in any country is too important for its future prosperity to let short-term market mechanisms act alone. We sincerely hope that leaders in Australian government, academia and industry will collaborate with the mathematics and statistics community to develop an appropriate vision, and spark an Australian renaissance in our field."

— Professor J P Bourguignon, Dr B Dietrich, Professor I M Johnstone*

"Australia's distinguished tradition and capability in mathematics and statistics is on a truly perilous path. The decline has already taken its toll: the university presence has been decimated, in part by unanticipated consequences of funding formulas and by neglect of the basic principle that mathematics be taught by mathematicians, and the supply of students and graduates is falling short of national needs."

— Professor J P Bourguignon, Dr B Dietrich, Professor I M Johnstone*

THE CRITICAL NATURE OF MATHEMATICAL SCIENCES[1]

The mathematical sciences are fundamental to the well-being of all nations.

They drive the data analysis, forecasting, modelling, decision-making, management, design, and technological principles that underpin every sector of enterprise. Their influence extends beyond science related disciplines to financial services, the humanities, arts and the social sciences.

They are vital to research, development and innovation in business and industry, science and technology, national security and public health.

Worldwide demand for new mathematical solutions to complex problems is unprecedented and has led to an appreciation of the power of cross-disciplinary research within the mathematical sciences and with other disciplines.

The result is international competition for mathematical talent. This presents challenges for Australia. We need a strong base in the mathematical sciences. If we don't have it, our options for solving complex problems, adding intellectual value to new technologies, spearheading innovation and continuing to compete globally will be severely hampered.

Australia has a reputation for world-class and innovative mathematical research, which can only be maintained through increased backing from governments, universities and industry. While this country cannot develop research expertise in all branches of the mathematical sciences, it must cultivate the depth needed to remain at the leading edge of key areas of innovation and the breadth to adapt new technologies to national benefit.

Australia is a big country, with a dispersed population. Ensuring a mathematical sciences base that supports teaching, research, and industry in remote and rural areas as well as the major population centres is a challenging task.

With sufficient will it can be done.

If Australia is to maintain its place in the technological world, it needs greater investment in its fundamental mathematical sciences infrastructure.

---

[1] The term 'mathematical sciences' is used to encompass mathematics, statistics and the range of mathematics-based disciplines.

* ***International reviewers, National Strategic Review Of Mathematical Sciences Research In Australia***

Professor Jean-Pierre Bourguignon, Director, Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France

Dr Brenda Dietrich, Director, Mathematical Sciences, IBM Thomas J Watson Research Center, Yorktown Heights, New York, US

Professor Iain M Johnstone, Department of Statistics, Stanford University, Stanford, California, US

...AND THIS MATTERS

1 Mathematical research in Australia is becoming increasingly narrowly focused.

At a time when, internationally, the major scientific advances are being made through collaborations between different branches of mathematics and other scientific disciplines, and by countries that invest heavily in mathematical research and education, Australian mathematicians and statisticians are becoming increasingly isolated and under-resourced.

Across most fields of mathematics and statistics, research output in Australia has become dependent on a small number of highly productive individuals working more or less in isolation.

Inadequate resources are available for fostering vital collaborative links between mathematicians and statisticians in research, academia, industry and education.

The loss of a small number of key mathematical scientists puts Australia at risk of a major collapse in research capability. Excessive reliance on a small number of scientists with specialised interests is eroding the broad skills base needed for a robust and adaptable research community.

2 The number of mathematics and statistics students and lecturers at Australian universities is critically low.

In the past decade, mathematical science departments in the Group Of Eight universities have lost almost a third of their permanent academic staff.

Mathematics departments in smaller universities have disappeared, and a number of formerly strong departments have halved in size.

Relative funding of mathematical sciences departments in universities is inadequate and does not reflect either their crucial importance or the real cost of delivering quality training of students.

In 2003, the Organisation for Economic Co-operation and Development (OECD) Education At A Glance report showed that only 0.4% of Australian university students graduated with qualifications in mathematics or statistics, compared with the OECD average of 1%.

There is clear evidence that the current supply of trained mathematicians and statisticians is inadequate and decreasing.

The nation's capacity to support research, research training and advanced education in mathematics and statistics is diminishing rapidly. The concentration of mathematical and statistical expertise in only a few universities undermines access to quality research, research training and undergraduate education in the mathematical sciences. As a result, Australian universities are unable to meet the demands of business, industry, government and the school sector for mathematically trained graduates.

The Review had four key findings

KEY FIND

3

Mathematicians and statisticians are not teaching all the university courses in mathematics and statistics. Many university courses such as engineering that should include a strong mathematics and statistics component, no longer do.

As well as ensuring an adequate supply of properly trained mathematics and statistics specialists, the Australian university system needs to ensure that students from other disciplines, such as economics, education, engineering, and the biological and medical sciences, receive appropriate training in mathematics and statistics.

Mathematical and statistical material taught to students in other disciplines — service teaching — needs to be up-to-date, accurate and presented in a way that meets the present and emerging needs of these disciplines. Such teaching is best delivered by mathematicians and statisticians.

Competition for scarce funds available for teaching leads to the transfer of service teaching from university mathematical sciences departments to non-specialists in other departments.

The transfer of mathematics and statistics service teaching to other departments delivers a poorer educational outcome. It is a major cause of the erosion of the national mathematical sciences infrastructure.

4

Not enough trained mathematics teachers are entering the high school system. Australian students are abandoning higher-level mathematics in favour of elementary mathematics.

Increasingly, high school mathematics is being taught by teachers with inadequate mathematical training.

Nationally, the percentage of Year 12 students taking higher level — advanced and intermediate — mathematics fell from 41% in 1995 to 34% in 2004. This is limiting the level of training that can be supplied in undergraduate degree programs such as commerce, education, engineering and science.

Australian universities are lowering mathematics prerequisites and this is undermining enrolments in high school mathematics.

Australia will be unable to produce the next generation of students with an understanding of fundamental mathematical concepts, problem-solving abilities and training in modern developments to meet projected needs and remain globally competitive.

INGS

Australia needs its own mathematical sciences infrastructure and supply of properly trained mathematicians and statisticians.

Without these, Australia's existing industries will become less competitive, and the ability to participate at the cutting edge of scientific research and commercial innovation, or even to be aware of developments, will be compromised.

Mathematicians and statisticians take a long time to train and need local experts to train them. There is global competition for mathematical sciences expertise.

Without supporting infrastructure and a vibrant local mathematical sciences community, Australia cannot properly train enough mathematical scientists, the best of those who are trained will not stay, and Australia will be unable to attract replacements.

Outsourcing research to offshore providers is not a viable solution. International competitors will not sell cheaply the intellectual property Australia needs to become more competitive. For example, defence-related research and highly confidential commercial research and development cannot be safely outsourced.

INFRASTRUCTURE AND PERSONNEL FOR PRESENT AND FUTURE NEEDS MUST BE SUPPORTED

- The health of mathematics and statistics rests with the nation's universities, where the researchers and teachers of the next generation are trained, and where the fundamental mathematics and statistics that underpin future applications are developed.
- A critical mass of mathematicians and statisticians, within a distinct mathematical sciences department or school, is essential to keeping a core of research and teaching expertise intact and supporting flexible and evolving interdisciplinary links.

NETWORKING AND COLLABORATION ARE CRITICAL TO SOLVING NEW TECHNOLOGICAL PROBLEMS

- There are significant, proven benefits in bringing together mathematical scientists and research experts, and clients in other scientific disciplines and from business, industry and government, to work on joint projects.
- An appropriate balance between core discipline training and applications is needed for effective interdisciplinary collaboration.
- Collaborative national and international research networks are a cost-effective and essential way of maintaining vibrant, adaptable and up-to-date research capacity. Networks need long-term support.
- Mathematical sciences institutes are an effective way of supporting national and international collaboration and providing access to new ideas in a timely and cost-effective manner.

THE WAY FORWARD

AUSTRALIAN MATHEMATICAL SCIENTISTS MUST RESPOND TO NEW CHALLENGES AND CHANGING CIRCUMSTANCES

- Mathematical scientists must promote the intrinsic value of mathematics and statistics to all Australians.
- Industry, teachers, researchers and academics must work cooperatively to improve support for the mathematical sciences and encourage greater numbers of students to pursue mathematics and statistics.
- Mathematical scientists of most value to the nation in the near future will have:
  - Sound fundamental understanding of deep mathematical and statistical concepts;
  - Facility with theoretical analysis;
  - Competence in operating research-level computer software;
  - Experience with mathematical or statistical modelling and in group collaborations; and
  - Excellent written and oral communication skills.
- Educational programs in universities must recognise and nurture these attributes.

A cross-section of Australian CEOs and senior executives from listed companies reported that they needed to add intellectual value to their products and innovations through skills in commercialisation, communication, computing, hardware and software development, optimisation, risk analysis, modelling and engineering disciplines.

They had a general expectation that graduates from science, engineering and allied degrees should have the requisite mathematics skills. Almost all preferred to, and did, source their graduates from Australian universities.

However, for most, their links with universities were either informal, limited to one university that met their particular needs, or with science or engineering departments rather than mathematics departments.

While most thought their graduates were adequately skilled on job entry, some put graduates through introductory, catch-up or specific on-the-job training. Most emphasised the need for government to drive a new thinking about mathematics, science and technology in the community, to improve the perception and popularity of science-based education.

AUSTRALIAN INDUSTRY NEEDS MATHEMATICALLY TRAINED GRADUATES

"I'd like to see Australia positioned as a globally recognised developer of new technology and technology products — not necessarily in production of those products — and in commercialisation and ownership of new technologies, electronic engineering and software development skills".

— **Graham Davie**
CEO, Redflex

"Mathematics skills... are very important because they appear in every facet of every job nowadays. Finance, research, statistics, money management, presenting information — maths is endemic. The sooner people acquire these skills, the better equipped for life they are."

— ***Damian Lismore,***
Chief Financial Officer, Biota

"Our hopes for delivering and maintaining a well-skilled country must be linked to rebuilding the infrastructure of the mathematical and other enabling skills through our education system."

— ***Peter Taylor,*** *Chief Executive, Engineers Australia*

KEY RECOMM

The mathematical sciences in Australia require an immediate and substantial capital injection to build a critical mass of research, education, industry and government interaction, and ensure we maintain our technical and problem-solving capability.

This must be followed up with significant annual funding to maintain a healthy mathematics and statistics infrastructure for national benefit.

A capital injection and ongoing funding will build, maintain and enhance:

- University mathematics and statistics departments essential to building core expertise
- Networking and collaboration to get the best value from widely geographically distributed departments in Australia
- Networking and collaboration with the best overseas mathematicians and statisticians.

1 Significantly increase the number of university graduates with appropriate mathematical and statistical training

1a. RE-BUILD and/or **MAINTAIN** mathematical sciences departments in every Australian university, to provide a mutually supportive core informed by fundamental developments in the mathematical sciences. This is essential both for the specialist training of mathematicians and statisticians, and for appropriate training of other users of mathematics and statistics.

1b. ENSURE service teaching of mathematics and statistics is performed by mathematicians and statisticians, to provide up-to-date, soundly based courses.

1c. PROVIDE every university with the appropriate mathematical and statistical consulting infrastructure to ensure that research undertaken by staff and students is efficiently planned and the results validly assessed. This infrastructure is best provided from within a mathematical sciences department, rather than by relying on dispersed individual consultants with inadequate peer support.

2 Broaden the mathematical sciences research base

2a. RE-ESTABLISH the critical mass for mathematical sciences research by rebuilding the numbers of permanent academic staff in mathematical sciences departments and providing career paths in Australian universities for talented early-career mathematicians and statisticians.

2b. PROVIDE new, additional and ongoing funding for Australia-wide networking to increase the strength of the national research enterprise.

2c. ENCOURAGE interdisciplinary work, especially in biological and medical sciences and in newly emerging areas. Ensure that such work is properly valued in research assessments and by granting agencies.

2d. Since 2002, the Australian Mathematical Sciences Institute (AMSI) has supplied strong, unifying support for mathematical research, education and industry liaison. **PROVIDE** funding for AMSI that supports its critical role in providing national infrastructure for national and international collaboration.

MENDATIONS

3
Identify, anticipate and meet industry needs for a pool of tertiary-trained expert mathematicians and statisticians

3a. CREATE internship programs for undergraduates, research students and academic staff to spend time in industry and provide opportunities for industry-based mathematical scientists to contribute to teaching and research within universities.

3b. ENCOURAGE and **SUPPORT** applications for Linkage Grants and other schemes that bring together government, university and private resources for commercial and strategic collaboration.

3c. BUILD on existing structures and collaborations with international networks.

3d. INCREASE the engagement of mathematical scientists with the wider university community by joint appointments with other departments, interdisciplinary projects and shared supervision of research students and post-doctoral fellows.

3e. DEVELOP short courses and post-graduate programs to meet current and emerging needs of business and industry.

4
Ensure that all mathematics teachers in Australian schools have appropriate training in the disciplines of mathematics and statistics to the highest international standards

4a. ENSURE future teachers of mathematics in schools acquire adequate discipline knowledge — appropriate to the teaching level — provided by mathematical sciences departments, as well as education in the practicalities of teaching school mathematics. Faculties of education and mathematical sciences departments need to cooperate to ensure that both these aspects of the training of teachers are properly addressed.

4b. DEVELOP national accreditation standards for teachers of mathematics at all levels of schooling, to ensure that the mathematics training expected of teachers aligns with international best practice; and develop appropriate education programs to ensure that future teachers meet these standards.

4c. DEVELOP appropriate mathematics courses for trainee teachers, teachers requiring re-training, and those in the process of changing careers. **PROVIDE** relevant professional development in mathematical content for all mathematics teachers.

5
Encourage greater numbers of high school students to study intermediate and advanced mathematics

5a. In liaison with tertiary representatives, state and territory education departments, **DEVELOP** secondary mathematics syllabuses to take appropriate account of the legitimate needs of post-school education, in terms of topics covered and the level of understanding developed.

5b. PROMOTE the vast — and increasing — range of rewarding careers available through studying mathematics and statistics.

5c. REWARD students for taking intermediate and advanced mathematics at high school by including scaling or bonus mechanisms when computing the Equivalent National Tertiary Entrance Rank (ENTER) or other tertiary entrance scores.

"In this ever more competitive global economy, Australia's science, engineering and technology skills need to match the best in the world."

— Prime Minister John Howard, speech in Sydney, 18 September 2006

Chapter One:

THE CRITICAL NATURE OF MATHEMATICAL SCIENCES

This chapter examines the fundamental contribution of mathematical sciences to Australia, and indicates the breadth and depth of mathematical and statistical research capacity needed for a modern society to flourish.

Chapter One

"… in the real world there is need for both pure and applied mathematics."

– Dr Warren Marwood, Defence Science Technology Organisation[1]

The Critical Nature Of Mathematical Sciences

Summary

- **The mathematical sciences are fundamental to the well-being of all nations. They drive the data analysis, forecasting, modelling, decision-making, management, design, and technological principles that underpin nearly every sector of modern enterprise.**
- **Mathematics is the pre-eminent 'enabling science' that empowers research, development and innovation in business and industry, science and technology, national security and public health. Enabling sciences are, by their nature, often invisible to the wider community but without them, modern societies would cease to function.**
- **Worldwide demand for new mathematical solutions to complex problems is unprecedented and has led to an appreciation of the power of cross-disciplinary research within the mathematical sciences and with other disciplines.**
- **Australia needs to develop and maintain its own expertise and infrastructure across a broad spectrum of mathematical sciences to meet the needs of industry and research, capitalise on emerging areas, and remain at the forefront of scientific innovation.**

"The value of research and knowledge in all areas cannot be underestimated. Knowledge, as part of information exchange with our Allies, is one of the few commodities that can be traded for political leverage."

– Dr Warren Marwood, Defence Science Technology Organisation[2]

1 DSTO Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

2 DSTO Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

The mathematical sciences now reach far beyond the natural and physical sciences and engineering, to every other application that needs quantitative analysis, often in unexpected ways.

The mathematical sciences — mathematics, statistics and related disciplines — are tightly intertwined with other disciplines and the life of a nation. Their pervasiveness is often not recognised, yet they are the essential enabling sciences underpinning research, development and innovation.

Technological and intellectual advances have increased, rather than decreased, the importance of mathematical sciences. This is especially true of basic theoretical research in mathematics that can lead to quite unanticipated applications. In the world of modern mathematical sciences, the boundaries of pure and applied mathematics and statistics have become blurred.

The mathematical sciences underpin society

Mathematical sciences are central to engineering and technology, environmental and biomedical sciences, public health, and finance and economics. They play a major role in research, development, innovation and efficiency in existing commerce and industry. They are essential to the research and development infrastructure for newly emerging technologies and industries including nanotechnology, drug discovery and biomedical engineering, and assessment of environmental and commercial risk.

Mathematical sciences are pivotal for financial institutions, the insurance industry and national security, providing tools that guarantee secure electronic data transfer and communications. These industries require a considerable pool of highly qualified, locally based mathematicians — it is not in the national interest for these industries to conduct their operations offshore.

Collaboration between scientific disciplines is essential

New developments in mathematical sciences often result from interaction between different sub-disciplines or with other disciplines. It is no longer enough to have strengths in only a few areas to meet demand for mathematical expertise.

Expertise and infrastructure across a broad spectrum of mathematical science disciplines is needed to ensure Australia can meet the needs of established industries and research, and the challenges of emerging areas, some of which are as yet unknown. There must be a critical mass of expertise available in this country, as well as the ability to call on international expertise not locally available.

Mathematics and statistics are intrinsic to national research priority areas[3].

In 2002 the Prime Minister announced Australia's national research priorities. Accordingly, the Australian Research Council (ARC) in its national competitive grants program, gives precedence to research in these areas. Almost all of these can benefit from significant contributions by mathematical scientists.

Mathematical scientists can play a key role in achieving goals in ARC priority areas for 2004 – 2006:

- **An Environmentally Sustainable Australia**
  Water use, transforming resource-based industries, managing biodiversity, deep earth resources, responding to climate change and variability
- **Promoting and Maintaining Good Health**
  A healthy start to life, preventive healthcare
- **Frontier Technologies for Building and Transforming Australian Industries**
  Advanced materials, smart information use

3 http://www.arc.gov.au/grant programs/priority areas.htm

> *"Minerals and energy production and processing are now relatively larger in the Australian economy than at any time since federation."*
> – Alan Wood, Economics Reporter, *The Australian*[6]

- Safeguarding Australia
  Protecting Australia from invasive diseases and pests, protecting Australia from terrorism and crime, transformational defence technologies

Recently, the Australian Government funded two centres of excellence involving mathematical scientists. The Centre of Excellence for the Mathematics and Statistics of Complex Systems (MASCOS)[4] contributes to priority areas requiring mathematical and statistical modelling of complex systems. The Australian Centre of Excellence for Risk Analysis (ACERA)[5] contributes to the priority areas of an Environmentally Sustainable Australia and Safeguarding Australia.

Establishment of these centres and the ARC funding focus show interdisciplinary work of national significance.

Australia needs its own strong mathematical sciences skills base

Without its own mathematical sciences infrastructure and supply of properly trained mathematicians and statisticians, Australia will become less competitive and its ability to participate at the cutting edge of scientific research and commercial innovation, or even be aware of developments, will be compromised.

Without supporting infrastructure and a vibrant local mathematical sciences community, Australia cannot properly train enough mathematical scientists and the best will not stay. There have been several recent appointments of overseas mathematicians, who have left Australia within a year, as their expectations were so different to the situation they found here.

Outsourcing research to offshore providers is neither viable nor desirable. International competitors will not sell cheaply the intellectual property this country needs to become more competitive, and defence-related research and highly confidential commercial research and development cannot be safely outsourced.

Examples and case studies providing a snapshot of the contribution mathematical sciences make to Australia are given below.

Mathematics, mining and resources

Australia's mining and resource sectors are undergoing a worldwide boom. In 2005 – 06, export earnings from the minerals and energy sector leapt 32% to a record $90.5 billion[7].

Modern mining relies heavily on mathematics at all production stages.

While Australia's mining operations are among the most efficient, they require constant technological input to remain competitive. Efficiencies have been achieved through an ability to adapt overseas technological developments to local needs as well as our own research and development.

BHP Billiton, the world's largest diversified resources company, considers recruiting competent and well-skilled mathematical scientists vital to its competitive position. It values specialist optimisation skills and systems modelling technologies as integral to its intellectual capital and advantage. These high-end mathematical skills contribute in tangible, measurable ways, helping the company to:

- substitute physical capital with intellectual capital through smarter and optimal planning
- maximise the life and value of non-renewable resources such as mines and oil fields
- make better informed mergers and acquisition decisions
- account for uncertainty in predictive modelling of all operations.

A University of Melbourne mathematics and engineering team has developed software that optimises the location and depth of new mineshafts,

4 http://www.complex.org.au/
5 http://www.acera.unimelb.edu.au
6 *The Australian*, 20 May, 2006 – Newspaper report on an address to Treasury by Ross Garnaut, Economics Professor, Australian National University
7 Australian Bureau of Statistics, http://www.abs.gov.au

"Mathematics is biology's next microscope, only better; biology is mathematics' next physics, only better."

– Joel Cohen, Rockefeller University[8]

"Today, the role of biotechnology is all-pervasive. Its applications extend from food to medicine, from energy to the environment. We are living through the genomics revolution."

– Queensland Chief Scientist, Professor Peter Andrews[9]

declines, ramps and tunnels — which can cost up to $100 million to construct — saving mining companies up to 10% over the life of a mine.

The software is now being used in more than 10 Australian mines. Underpinning it is mathematical research that has led to significant theoretical advances in construction of three-dimensional networks with gradient and turning circle constraints, such as encountered in underground operations. Companies including Newmont Australia Limited, BHP Billiton and MPI Mines have supported this work.

Mathematics and biotechnology

The impact of mathematical sciences in biotechnology and genomics is already immense, but their most striking global biological impact is likely to be found in medicine.

From solving questions about genetic differences between life forms to practical applications such as developing new drugs and early intervention for diseases, mathematics has potential to change the face of modern medicine and biological science.

In 2002 the US National Institute of General Medical Sciences and the National Science Foundation pledged to spend $US24 million on projects specifically in mathematical biology over five years[10]. Launching the initiative, then acting director of the institute, Dr Judith Greenberg, said: "Advances in biomedical research in the 21st century will be critically dependent on the collaboration between biologists and scientists in other disciplines, such as mathematics."

Mathematician and genome researcher Professor Eric Lander co-founded the Broad Institute[11], a collaboration between Massachusetts Institute of Technology (MIT), Harvard University and the Whitehead Institute for Biomedical Research, with private funding, in 2004. His training in mathematics and statistics has been instrumental in designing genome classification and pattern recognition systems that have helped discover links between genetics and disease. He and his team have identified a unique, third class of leukaemia, distinct from the two classes described in medical textbooks. This newly discovered class affects around a third of patients but is highly treatable. The team's discovery will help early diagnosis and successful treatment of this new leukaemia[12].

In Australia, pharmaceutical companies increasingly rely on the combined expertise of biologists and mathematicians to research and develop new technologies in drug discovery and DNA sequencing.

Professor Peter Adams and Dr Darryn Bryant at the University of Queensland's Department of Mathematics are applying mathematical techniques to bioinformatics and nanotechnology. Their patented work underpins the Intellectual Property of startup companies working in drug discovery, DNA sequencing technologies and combinatorial chemistry. Outcomes of their research include co-invention of colloidal bar-coding, which will make possible high throughput screening in drug testing and medical diagnostics, and techniques for innovative drug design, for potential discovery of new medicines.

8 PLoS Biology 2 (12) (December 2004), pp. 2017 – 2023; available online at http://www.plosbiology.org

9 Making Money out of Molecules; speech at the School of Biomedical Sciences Awards and Prizes Ceremony for the Institute for Molecular Bioscience, University of Queensland, May 2005

10 http://www.nigms.nih.gov/News/Results/NIGMSNSFGrantsJoinMathBiology.htm

11 http://www.broad.edu

12 http://www.broad.mit.edu/cgi-bin/cancer/publications/pub_paper.cgi?mode=view&paper_id=63

"The vast amounts of data made available through mapping of the human genome have meant biologists have turned to mathematicians to be able to understand gene sequences. Biology is at a stage where help from mathematicians is becoming vital."

– Conrad Burden, The Australian National University Centre for Bioinformation Science, 2004

Mathematics, statistics and finance

Banks employ highly qualified mathematicians and statisticians to manage foreign exchange transactions, price financial options and other financial derivatives, and analyse effects of changes. Changes include interest rate fluctuations affecting the bank's profitability and financial risks. For example, sophisticated calculus and statistical techniques are needed to estimate loss distribution on a retail bank's portfolio of assets — mainly loans — over 12 months and estimate loss probabilities from default on its assets.

A bank needs this information to show to ratings agencies that there will be only a low probability of default on its liabilities. This is critical to maintaining and improving its credit rating and funding loans through wholesale financial institutions.

High-level mathematics has a long history in insurance, where mathematicians are employed as actuaries to calculate premiums, reserves and dividends, and insurance, pension and annuity rates. Actuarial training involves extensive training in mathematics and statistics, and modern actuarial research requires sophisticated mathematical knowledge. In Australia, this training and research is shared between mathematical scientists and professional actuaries.

Mathematics, environmental risk assessment and biosecurity

Primary industries, including agriculture, fisheries and forestry, are vital to the Australian economy. About two-thirds of total rural production is exported, and in 2004 Australia accounted for 2.8% of global agricultural exports[13].

In 2005, agricultural exports alone — excluding fishery, forestry and rubber products — were valued at more than $26 billion[14].

Mathematicians and statisticians play major roles in maintaining the international disease-free status and high quality reputation of these industries, and provide tools to assess and manage risks, particularly in biosecurity (protecting a nation's food supply and agricultural resources from accidental or deliberate contamination). In 2006, the Department of Agriculture, Forestry and Fisheries funded the Australian Centre of Excellence in Risk Analysis (ACERA) at the University of Melbourne. ACERA is an interdisciplinary centre involving leaders in mathematics, statistics, biology, physical science, epidemiology, socioeconomics, natural resource management and risk management. Its mandate is to develop tools and systems to improve risk analysis, particularly around biosecurity.

13 Department of Foreign Affairs and Trade, http://www.dfat.gov.au

14 Department of Foreign Affairs and Trade, http://www.dfat.gov.au

"Mathematics is pivotal to understanding and analysing commercial risks in banking."
– Kari Stuart, Balance Sheet Analyst, Bank of Queensland, 2006

Complex mathematics is behind prediction and assessment of world and local climate change, weather forecasting and modelling natural disasters. The latter include earthquakes, fires and floods, as well as spread of weeds, pests, genetically modified organisms and infectious diseases (such as 'bird flu') spread by migrating wildlife.

Accurate data analysis and modelling enable policy-makers to plan for different scenarios and move quickly to protect people and assets, allocate resources appropriately and deploy capital-intensive infrastructure optimally. For example, in November 2004, correct prediction of the height of a tsunami approaching Hawaii cancelled a warning in time to avoid statewide coastal evacuation, saving an estimated $US68 million.

The Indian Ocean tsunami disaster of December 2004 focused world attention on the problem of developing accurate tsunami warning systems. Australia's highest risk area is the northwest coast, which while sparsely populated, has major oil and gas fields and iron ore export industries that depend on local port facilities.

Professor John Dennis of Rice University, Houston, US, is using complex equations and a computer algorithm to pinpoint the most effective areas in the Pacific Ocean to locate buoys that detect and warn authorities of an impending tsunami with maximum notice and accurate prediction of its severity. His work has potential to be employed throughout the world's tsunami risk areas, giving authorities enough warning to minimise impacts, improve clean-up efficiency and, potentially, save lives.

Mathematics, manufacturing and trade

When applied to modern manufacturing, production, transport and trade, operations research analysis — using electronic computing based on complex mathematics — contributes billions of dollars a year to the global economy through improved efficiencies.

Operations research analysis allows enterprises to coordinate vast numbers of variables such availability of raw ingredients and materials, and efficient scheduling of machinery maintenance, repairs and equipment upgrades. Food manufacturers and distributors (e.g. Kelloggs), electronics and information technology companies (e.g. Hewlett-Packard) and major airlines are among many industries employing this technology.

Operations research analysis has helped streamline shipping container movements at NSW's Botany Bay, a key international trade port. University of NSW mathematician, Dr Gary Froyland, has worked with Patrick Corporation on a new container terminal design which has reduced the number of movements needed to free up containers and saved hundreds of thousands of dollars every year.

Australia's $27 billion-a-year[15] automotive industry needs high-end engineering and mathematical skills for activities ranging from manufacturing raw products such as iron, steel, rubber and glass to digital design, logistics and simulation. These same skills sustain other manufacturing industries such as building and servicing ships, submarines, aircraft and defence-related equipment.

15 Australian Industry Group. Federal Chamber of Automotive Industries website, August 2005

Mathematics and the myriad of other applications

Mathematics and statistics invade our lives in unexpected areas. An example comes from ANU statistician, Ross Cunningham, whose mathematical methods for cluster analysis discovered a new species of Australian possum. Genetic analysis confirmed the results of his statistical research.

An economically and strategically crucial area is communications. In mobile phone use, efficient placement of base stations is an operations research problem. Signal processing relies on complex algorithms we take for granted.

Public key cryptography and secure communication on the internet and development of the internet all demand high-level mathematics.

Health care benefits when operations research mathematicians analyse complicated work and management practices for possible efficiencies. Recently at Massachusetts General Hospital, US, a Russian mathematical émigré located bottlenecks in management of emergency cases, eliminated costly delays and rescheduled procedures, saving considerable resources, using operations research techniques.

Mathematics and statistics play an important, and often ignored, role in society. Areas include modelling social networks to study linguistic change, mobilising and organising massive relief efforts and even scheduling large sporting events such as the Olympics.

In short, Australia risks losing sophisticated efficiencies, operational opportunity, modelling, jobs and know-how in unanticipated but crucial areas if its mathematical sciences continue to decline.

Conclusion

Mathematical sciences drive data analysis, forecasting, modelling, decision-making, management, design and technological principles that underpin every sector of society.

Their influence extends beyond science-related disciplines to financial services, the humanities, arts and social sciences.

Worldwide demand for new mathematical solutions to complex problems is unprecedented and has led to an appreciation of the power of cross-disciplinary research within the mathematical sciences and with other disciplines.

Australia has a reputation for world-class and innovative mathematical research. To retain its seat at the international table on matters related to sophisticated science and technology, this country must maintain its own high-level expertise.

New scientific developments are revealed at research conferences and through collaborative networks. In areas where Australia has no involvement, these developments will only be available to Australian industry and government long after the event.

While it cannot develop research expertise in all mathematical science areas, this country must cultivate the depth needed to remain at the leading edge of key areas of innovation and the breadth to adapt new technologies for national benefit.

If Australia is to maintain its place in the technological world, it needs increased backing from governments, universities and industry as well as greater investment in its fundamental mathematical sciences infrastructure.

Chapter Two examines the parlous state of Australia's mathematical sciences skills base.

"Over the past few years it has been difficult for us to recruit top class graduates in specific areas of the mathematical sciences from Australian universities. We have sought to recruit operations research and optimisation specialists from the US and Europe because of the difficulty of recruiting (them)… within Australia."

– BHP Billiton[16]

Chapter Two:

REVIEW FINDINGS: AUSTRALIA'S MATHEMATICAL SKILLS BASE IS ERODING

This chapter analyses the current state of Australia's mathematical sciences skills base.

16 BHP Billiton questionnaire submitted to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

Chapter Two

REVIEW FINDINGS: Australia's mathematical skills base is eroding

Summary

- Australia is facing a serious, chronic shortage of highly skilled, mathematically trained graduates.
- The situation for statisticians is already dire, with major sectors such as medical research and development now unable to recruit appropriately trained statisticians within Australia.
- The nation's capacity to support research, research training and advanced education in mathematics and statistics is diminishing rapidly.
- Key government agencies, industries and listed companies are encountering major difficulties recruiting the mathematically skilled graduates needed to remain globally competitive and locally viable.
- The Australian education system — from schools through to universities and professional societies — is failing to deliver the breadth and depth of mathematical skills, and numbers of highly skilled graduates, needed to fulfil current and anticipated needs.
- Concentration of mathematical and statistical expertise in only a few universities undermines access to quality research, research training and undergraduate education in mathematical sciences. As a result, Australian universities are unable to meet the demands of business, industry, government and the school sector for mathematically trained graduates.

"It has become quite difficult for us to recruit suitable staff. A lack of suitable senior appointees has hampered our growth opportunities with industry and is seriously inhibiting further investment by CSIRO."

– CSIRO Mathematical and Information Sciences[24]

Australia's mathematically skilled workforce is shrinking

By all measures, Australia's mathematical skills base has deteriorated in the past decade to the point where it is now failing to produce the mathematical and statistical scientists needed by government, industry and universities.

Australia's skilled workforce is ageing, and insufficient numbers of young mathematicians and statisticians are coming up through the ranks.

Unless urgent action is taken, this alarming trend will be extremely difficult to reverse.

In 2001, more than 3,200 Australians were employed as mathematicians, statisticians and actuaries[17], and almost 22,000 reported in the Census that they had post-school qualifications in mathematics, statistics or the mathematical sciences[18].

However, more than half with post-school qualifications were over 40 and fewer than 250 students a year now graduate from universities with honours degrees or higher-level qualifications in these areas[19]. In 2003, only 0.4% of Australian university students graduated with mathematics or statistics qualifications, compared with the Organisation for Economic Cooperation and Development (OECD) average of 1%[20].

A 2006 study showed that Australian high school students are abandoning higher-level mathematics in favour of elementary mathematics[21].

Not enough trained mathematics teachers are entering the system and, increasingly, high school mathematics is being taught by teachers with inadequate mathematical training[22].

In the past decade, mathematical science departments in the 'Group of Eight' universities(Go8)[23] — which dominate the local higher education sector in terms of research and research training — have lost almost a third of their permanent academic staff. Mathematics and statistics departments in some smaller universities have disappeared, and a number of formerly strong departments have halved in size.

Australian industry is now beginning to feel the pinch. Industry leaders are increasingly concerned about the dearth of mathematically trained graduates and lack of adequately trained mathematicians and statisticians.

17 DEST Science, Engineering & Technology Skills Audit, July 2006, http://www.dest.gov.au/sectors/science _ innovation/policy _ issues _ reviews/key _ issues/setsa

18 The Australian Census, 2001

19 Data of P Petocz & P Johnston, http://www.cit.gu.edu.au/maths, collected from university departments. Data refers to successful completions in the calendar year

20 Organisation for Economic Co-operation and Development (OECD) Education At A Glance report, 2004

21 Participation In Year 12 Report, ICE-EM, 2006. See http://www.ice-em.org.au/pdfs/Participation%20in%20Yr12%20MathsFinal.pdf

22 Deans of Science report, 2006. See http://www.acds.edu.au/

23 See Appendix 2 for an explanation of university groupings

24 CMIS Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

Government departments

Key government employers of graduates with mathematical skills include the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Defence Science Technology Organisation (DSTO), Australian Bureau of Statistics (ABS) and Australian Antarctic Division (AAD)[25].

These organisations require graduates with a range of high-end pure and applied mathematical skills such as:

- Algebraic geometry
- Coding theory
- Combinatorics
- Complexity theory
- Computational algebra
- Computational complexity
- Cryptography
- Data mining
- Evolutionary algorithms
- Machine learning
- Optimisation of algorithms
- Operations research and analysis
- Number theory
- Quantum information processing
- Signal and image processing
- Statistics
- Stochastic processes

However, all four organisations have reported increasing difficulties in recruiting suitable candidates[26], hampering growth opportunities and inhibiting further investment in research and development.

These organisations cannot source the quality and quantity of graduates required to fulfil current demand, much less meet future predicted growth.

The ABS summarised the dilemma it and other government departments face:

"In recent years, of all the applications received, only 10 to 20 have been considered to be of a standard acceptable to the ABS. This is becoming uncomfortably close to the number that we require. While some of the applicants were unsuccessful due to a lack of sufficient communication and interpersonal skills, most lacked the conceptual and technical skills required. This reinforces the need for courses that encourage strong conceptual skills, a good understanding of theory and the extension of that theory into practical applications." — Australian Bureau of Statistics[27].

"CMIS has been unable to fill a substantial number of the positions that have been advertised. A lack of suitable senior appointees has hampered our growth opportunities with industry and is seriously inhibiting further investment by CSIRO. The difficulty in recruiting appropriate staff is due, at least in part, to the decreasing number of high quality graduates and postgraduates from Australian universities over the last couple of decades."

– CSIRO Mathematical and Information Sciences[28]

25 CSIRO, DSTO, ABS and AAD were consulted during, and made submissions, to this Review

26 Submissions to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006, and meetings with the Working Party

27 ABS Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

28 CMIS Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

"The US National Security Agency is the single largest employer of mathematicians in that country."

– Dr Warren Marwood, Defence Science Technology Organisation[29]

CSIRO Mathematical and Information Sciences (CMIS)

CMIS is a substantial multi-site division of CSIRO, employing about 110 researchers with training in mathematics, statistics, computer science or engineering. Most, around 70, hold a PhD degree.

Its headquarters are at Macquarie University, Sydney, with other sites in five capital cities and Canberra.

CMIS currently prospers relative to universities. Its 2005 – 06 funding comprised about $15.4 million from the Australian government and $8 million in external funding from industry and various arms of government through competitive contracts and grants.

Its research and consulting, largely multidisciplinary, is valued highly by CSIRO. Based on recent performance and current opportunities, appropriation funding in 2006 – 07 for CMIS is forecast to increase by 17.3%, providing suitable staff can be found.

Examples of the important collaborative work conducted by CMIS with other CSIRO Divisions and organisations, include:

- **Development of the National Carbon Accounting Scheme with the Australian Greenhouse Office.** This scheme estimates the total carbon captured in Australia's vegetation, which enables on going assessment of Australia's performance against Kyoto protocols. A cost/benefit study by the Centre for International Economics identified about $100 million in national benefit from the mathematics contribution.
- **Estimation of populations in commercial fisheries.** Working with CSIRO fishery biologists, mathematicians have identified fish populations under threat and recommended actions needed to guarantee sustainable populations.
- **Breakthroughs in image analysis.** CMIS work has led to world-first development of a device for recognising melanomas, and technology to measure road damage — in real time, at 100kph.
- **Lens design software.** Developed by CMIS, the software allowed Australian optical products company, SOLA Optical, to improve their progressive lenses, giving clearer, more comfortable vision to millions.

However, despite an ongoing commitment by CSIRO, industry and the government to CMIS, CMIS has raised serious concerns about its ability to "recruit people of the requisite calibre in sufficient numbers to support our planned growth".

Defence Science Technology Organisation (DSTO)

With an annual budget of more than $300 million, DSTO is charged with applying science and technology to protect and defend Australia and its national interests. As such, it must be able to source an adequate supply of appropriately prepared mathematical sciences graduates.

In 2005 DSTO had 2223 staff, about 650 with PhD degrees, based mainly at its Canberra headquarters and largest research site in Adelaide.

Pure and applied mathematical skills are valued equally highly by its Secure Communications Branch of the Intelligence, Surveillance and Reconnaissance Division, which states that it deals with "pure mathematics that can be applied to real problems… abstract mathematics for information security processing".

DSTO favours graduates from universities that support abstract and theoretical studies, teach advanced mathematics and statistics, and link theory and applications.

29 DSTO Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

"More than any area, this places high demands on mathematicians' abilities to collaborate with others within structures, teams and organisations to meet corporate, rather than individual, goals."

– Dr Garry Newsam, Signals Analysis, Defence Science Technology Organisation

In the next 25 years, Head of Signals Analysis, Dr Garry Newsam, predicted the organisation would need staff who would be : "… asked not only to analyse problems, but use and develop sophisticated software codes to solve or simulate problems in these domains". He outlined the particular skills sought:

- A declining, but nevertheless enduring and fundamental, need for mathematical skills to analyse and model classical and applied problems in optics, electro-magnetics, fluid and structural dynamics and explosives.
- A need that has peaked, but will also endure, for sensor processing skills, e.g. in signal and image processing. The range of skills needed will also steadily expand, due to increasingly sophisticated sensors and pressure for more advanced applications in tracking, sensor fusion and information exploitation.
- A still-growing need for guidance and control in areas such as robotics and autonomous vehicles, and one that is expanding into the need to develop strategies for guiding the behaviour of general autonomous agents (e.g. independent agents within simulations, or web crawlers).
- An ill-defined but expanding need to support an increasing range of interdisciplinary activities such as operations research, systems engineering, simulation and wargaming, and psycho-physics.
- An further ill-defined but expanding need for the ability to analyse ever-growing volumes of data collected by organisations, in particular to support business process re-engineering by optimising organisational performance.

The Review notes in particular his vision to increase employee sophistication and ability or potential to participate in software development and other generic team-based skills, as well as having appropriate, strong mathematical skills.

Australian Bureau of Statistics (ABS)

ABS is a Canberra-based statutory government body providing statistics to inform decisions, research and discussion within the community and government.

It has about 3,300 employees, of whom about 250 have advanced training, that is an undergraduate major or higher (such as an honours or masters degree) in mathematical sciences. Typically about five employees hold mathematical sciences PhDs.

ABS is the largest employer of mathematical statisticians in Australia. Some recruits have substantial specific statistical expertise. Others are trained in-house in relevant statistical techniques. Most of its statisticians are employed in the Methodology Division.

In fulfilling its statutory obligations, ABS is critically dependent on its ability to recruit staff of high mathematical ability. In its submission to the Review, the ABS made the following important observations on the types of graduates it requires:

"Not all graduates with training in mathematical statistics are suitable for the ABS. We, like many other employers, are interested in graduates with strong conceptual skills supported by good communication and interpersonal skills, plus a strong understanding of underlying statistical theory. Such a graduate is able to conceptualise the task, understand the underlying assumptions, extend techniques as required and communicate the results of their analyses.

The demand for these staff will increase, not decrease, in the future.

"The AAD has been unable, for three years, to fill mathematics and statistics positions in the modelling area."
– Australian Antarctic Division[31]

We have noted a disturbing trend where some universities are placing too much emphasis on the practical application of statistical techniques (particularly in specialist fields such as finance) and leaving the student without a proper understanding of the underlying statistical principles. This leads to graduates who lack sufficient theory to understand the assumptions and limitations of the various techniques and hence are unable to extend the theory or apply it in new situations as required.

Therefore the ABS is strongly supportive of universities offering both base degrees and honours degrees that are soundly based in theory. At the same time they should provide the practical applications that interest students by assisting them to see the direct relevance of their studies, but not at the expense of a proper background in theory. This is considered essential to remain responsive to the needs of industry[30]."

A significant fall in applications from graduates after 2000 is evident in Table 1.

Table 1: Annual ABS recruitment statistics for mathematical scientists 1998 – 2005

	Applications		Recruited	
Intake year	Cadet	Graduate	Cadet	Graduate
2005	21	142	5	7
2004	38	172	2	5
2003	n/a	n/a*	4	6
2002	11	120	3	4
2001	18	159	5	5
2000	25	235	2	13
1999	39	242	3	9
1998	28	235	2	9

** The number of applicants for the 2003 intake is not available.*

Australian Antarctic Division (AAD)

The Australian Antarctic Division (AAD), part of the Department of Environment and Heritage, employs more than 300 permanent staff at its Hobart headquarters and Antarctic and sub-Antarctic bases.

Some vital AAD research in the past 12 years involves numerical modelling, an example of which is simulation of ice sheets, conducted with the Cooperative Research Centre for Antarctic Climate and Ecosystems (ACE). Ice flow in ice shelves is of global interest, given the effects on ice shelves of climate change. Increasingly elaborate mathematical models of ice shelves are needed to give precise predictions of ice flow.

Evaluation of management systems for fish stocks involves modelling at microscopic and macroscopic levels. The Review was advised by AAD personnel that it has been unable, for three years, to fill mathematics and statistics positions in modelling. They have been forced to hire instead people without mathematics training.

The AAD has tried offering internships for school students without success. Students often need intensive training and usually do not stay on after the internship ends.

Tasmania has a small local recruitment base and the AAD is trying to recruit in high demand areas. It seems unlikely their needs will be met until a skilled people pool is more available. This will be difficult locally as Tasmania's Year 12 participation rate in advanced mathematics courses is among Australia's lowest and has been for many years.

Australia's significant responsibilities under the 1959 Antarctic Treaty[32] involve science that requires mathematical expertise.

That the AAD cannot find the mathematical expertise it needs is of national concern.

30 From the ABS Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

31 From the AAD meeting with the Review Working Party, 2006

32 http://www.aad.gov.au

"Ideally I would like to recruit between 10 and 30 (mathematically trained) people over the next two years. Realistically this is unlikely to be possible due to the (low) number of good graduates available…"

– John Henstridge, Data Analysis Australia[39]

"Over the past few years it has been difficult for us to recruit top class graduates in specific areas of the mathematical sciences from Australian universities. We have sought to recruit operations research and optimisation specialists from the US and Europe because of the difficulty of recruiting (them)… within Australia."

– BHP Billiton[36]

Other government departments

Other important government departments recruiting mathematicians and statisticians include the Bureau of Meteorology, and Treasury and Finance.

The Bureau of Meteorology has strong interest in graduates with a strong foundation in mathematics and part funds a Chair in the School of Mathematics at Monash University.

Axiss Australia[33] produces materials that provide detailed information on Australia's financial services industry. They were major sponsors of the International Congress of Industrial and Applied Mathematics (ICIAM) held in Sydney in 2003. The Invest Australia web site[34] lists a range of industries that need mathematics and statistics. The Australian Treasury specifically mentions mathematics as a category under Graduate Careers[35].

The need for mathematical expertise at Australian Government level is replicated in State Governments. State departments responsible for agriculture and public health have a special need for statisticians, and suitably trained statisticians are in short supply.

Need for mathematically trained graduates in education is discussed elsewhere in this report.

Australian industry — the private sector

More than ever, Australian industry needs high-end skills in mathematical sciences. However, finding these skilled graduates is increasingly difficult. The 2006 Graduate Careers survey[37] shows an increase of employers (6% to 18%) reporting difficulties in recruiting mathematicians, statisticians and scientists.

Industry leaders consulted during the Review noted that mathematical scientists of most value to Australia in future would have:

- Sound fundamental understanding of deep mathematical and statistical concepts;
- Facility with theoretical analysis;
- Competence in operating research-level computer software;
- Experience with mathematical or statistical modelling and in group collaborations; and
- Excellent written and oral communication skills.

In an Australian Industry Group survey of more than 500 employers, World Class Skills for World Class Industries 2006[38], more than 74% of respondents cited the inability to secure skilled staff, including engineers, as their biggest potential barrier to success — ahead of competitive pressures at home and abroad.

33 http://www.axiss.gov.au

34 http://investaustralia.hyperlink.net.au

35 http://www.treasury.gov.au

36 BHP Billiton questionnaire submitted to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

37 http://www.graduatecareers.com.au

38 World Class Skills for World Class Industries: Employers' perspectives on skilling in Australia, Report to the Australian Industry Group, May 2006

39 Data Analysis Australia Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

"… all the evidence suggests that the shortage (of skilled mathematicians), as in other technical areas, is going to continue and get worse." – Tony Gibb, Sydac[42]

"It is a major limit on our growth." – John Henstridge, Data Analysis Australia[43]

BHP Billiton is a comprehensive mining and resources multinational corporation, with 37,000 employees worldwide. There are 220 researchers, of whom 60 have PhDs or equivalent degrees, eight are specialist mathematical scientists and 60 computer scientists or engineers, many with substantial mathematical sciences training. BHP Billiton also employs about 16 mathematical sciences honours graduates and 60 scientists with mathematical sciences majors in their undergraduate degree.

In its submission to the Review, BHP Billiton clearly spelled out the importance of mathematical scientists to its business:

> "Mathematical scientists play a significant role in our technology development, planning, and financial and business modelling/analysis functions. These roles are important in defining the strategic direction of the company and in optimising the company's operations through the most efficient use of capital and people.
>
> We have generally been satisfied with the standard of training of mathematical scientists that we have recruited in the past. However, over the past few years it has been difficult for us to recruit top class graduates in specific areas of the mathematical sciences from Australian universities. In particular, we have sought to recruit operations research and optimisation specialists from the US and Europe because of the difficulty of recruiting mathematicians with these specialist skills within Australia."
> — BHP Billiton[40]

While large multinationals like BHP Billiton can exploit mathematical science research outside Australia, smaller Australian companies do not have those resources and are therefore placed at a competitive disadvantage.

Maintenance of a viable Australian research and research training capacity in mathematical sciences would enable companies to compete more effectively in global markets, minimise waste and use infrastructure more effectively.

Small to Medium Enterprises (SMEs) that depend on employing mathematical scientists with postgraduate qualifications for growth appear to encounter similar recruiting difficulties, even if recruiting in major cities.

However, they are unable to compete with large companies for skilled recruits and — based on the few SME submissions to the Review — compromise by making do with what they can find.

Medical research and public health

Major medical institutes and large teaching and research hospitals employ full-time statisticians, often a significant group, to help design and analyse experiments.

Examples are use of the twins data base in medical research, requiring statistical analysis[41]. The Peter MacCallum Cancer Institute and Walter and Eliza Hall Institute are examples of well-known medical research institutes employing mathematical scientists. Replacing retirees at both institutes is likely to prove problematical since few statisticians are now being trained in universities. A worldwide shortage of statisticians has led the US to attract many outstanding statisticians from Australia. Berkeley, Stanford, Georgia Institute of Technology, Colorado State University, Carnegie-Mellon University, Harvard and the University of California medical schools all have leading former Australian statisticians on staff.

Several large pharmaceutical companies have expressed concern about the difficulty of running drug trials in Australia, due to a shortage of statisticians to help design trials and data analysis tasks. Australia's reputation as a leader in medical research and multi-million dollar contracts are jeopardised if we are not able to host such trials.

40 BHP Billiton questionnaire submitted to the National Strategic Review of Mathematical Sciences Research in Australia, 2006

41 http://www.twins.org.au

42 Sydac Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006. Sydac is a leader in the application of simulation technology to optimise the performance of business assets, and is based in Adelaide, SA

43 Data Analysis Australia Submission to the National Strategic Review Of Mathematical Sciences Research In Australia, 2006

"(There has been) a decline of some 25% in staff since 1995, a brain drain of both experienced and new researchers, marginalised or restructured departments, fewer applications for research grants, few if any new...

Universities

Assessing the capacity and performance of mathematical sciences in Australian universities requires careful attention to the status quo and long-term trends in three key areas: staff, research training and research output.

Staffing in mathematical sciences departments

There have been drastic changes in academic staff numbers and profiles in mathematical sciences departments since the previous review of mathematical sciences in 1995[44].

The tertiary sector as reformed in the late 1980s and early 1990s included growth in numbers of universities — largely by converting former Colleges of Advanced Education into universities — and introduction in 1989 of the Higher Education Contribution Scheme (HECS)[45]. A relative funding model (RFM) was constructed based on historical data relating to teaching costs (see explanatory note, Appendix 2).

While the 1995 Review found that the mathematical sciences profession in Australia faced several challenges, it did not envisage any serious contraction of mathematical sciences in universities.

It did note that age distribution was skewed by growth in the profession in the late 1960s and 1970s, but expected retirements were also seen as opening up opportunities for new appointments.

The 1996 Federal budget heralded a decade of dependence on student numbers to maintain departments and aggressive competition for full fee paying international students.

Prerequisites fell from favour as imposition of school subject prerequisites for university courses came to be seen as restricting market potential. This increased the diversity of the enrolling cohort and the cost of teaching. It has had other unintended consequences. The low RFM for mathematics and statistics has encouraged teaching of these subjects by other departments and faculties. It has led to students requiring fewer mathematics or statistics subjects to complete as part of their degrees.

The 2005 Review of Statistics[46] was unequivocal about RFM's effect on statistics and recommended to the Federal Minister for Education, Science and Training:
As a matter of urgency, to reconsider the Relative Funding Model to ensure a more equitable funding arrangement for statistics in universities, bringing funding for statistics courses into line with the current funding levels for computer science courses.

Traditionally mathematicians and statisticians in mathematical sciences departments have taught their specialties to students in other departments and faculties — a practice known as service teaching. However, competition for scarce funds for teaching has led to transfer of service teaching from university mathematical sciences departments to non-specialists in other departments, which delivers a poorer educational outcome and is a major cause of erosion of the national mathematical sciences infrastructure.

The impact on mathematical sciences departments across Australia has been profound.

Permanent academic staff normally occupy 'teaching and research' positions reflecting their dual responsibilities. Between 1995 and 2005, the Group of Eight (Go8) university mathematical sciences departments have lost 30% — almost

---

44 Mathematical Sciences: Adding To Australia, National Board of Employment, Education and Training, Australian Research Council & Discipline Research Strategies, 1995

45 http://www.aph.gov.au/library/intguide/SP/HECS.htm

46 Statistical Society of Australia Inc, Statistics at Australian Universities: An SSAI-sponsored Review, December 2005

…appointments, difficulties in making appointments in key areas such as financial mathematics and statistics, and some universities are no longer offering a three year degree majoring in mathematics or statistics.”

– Federation of Australian Scientific and Technological Societies (FASTS), 2000[47]

a third — of their teaching and research staff, as shown in Table 2. The number of academic staff designated as ‘teaching only’ was small in 1995 and remains so, as in shown in Table 3. In the same period, little overall change occurred in numbers of technical support staff – mainly Information Technology – but 37% of administrative staff left.

There has been a partly compensating increase in research-only staff at some institutions. However, most research-only staff are on fixed-term contracts with limited prospects for long-term employment in Australian universities.

The severe staff losses across universities — which have seen some formerly strong departments halve in size and other small departments disappear — have seriously compromised mathematical science experts’ ability to maintain standards in statistics and mathematics teaching and practice on campus. The talent pool within universities available for consulting work or collaboration with industrial partners is also shrinking.

As a consequence, several major departments are vulnerable to further serious decline in response to present or imminent budget deficits.

The problem of erosion of mathematical sciences capability in regional universities is particularly acute. Departments are typically small and any loss of staffing has immediate effects on research and teaching diversity. Where a single institution services the mathematics and statistics needs of a region, decay or disappearance of the only local mathematical sciences department degrades the entire region’s capacity. Moreover, many regional campuses provide teacher training programs, and loss of mathematical sciences capacity weakens the institution’s ability to train future mathematics teachers properly in the discipline.

The updated 2002 FASTS paper showed a continuing brain drain[48]. It also showed that some gains translated into losses in a very short time. There appeared to be a dearth of new appointments although a number of retirements and other losses occurred.

Table 2: ‘Teaching and research’ staff (normal academic staff) in mathematical sciences departments in the Group of Eight universities 1995–2005: statistics gathered from questionnaires returned by the departments.* Staff whose positions are classified as ‘teaching only’ or ‘research only’ are not listed here.

	1995			2005			change 1995 to 2005	
Teaching & Research	male	female	total	male	female	total	number	percent
Adelaide	33	9	42	18	6	24	–18	–42.9%
Melbourne	34	3	37	29.5	5	34.5	–2.5	–6.8%
Monash	46	5	51	21.6	4.5	26.1	–24.9	–48.8%
NSW	61	6	67	40.23	9.1	49.33	–17.67	–26.4%
Sydney	60	4.5	64.5	33.08	5.33	38.41	–26.09	–40.4%
WA	33.1	2	35.1	22.5	2	24.5	–10.6	–30.2%
Queensland	26.83	1.6	28.43	22.8	5.05	27.85	–0.58	–2.0%
ANU Mathematics	12.5	0.5	13	8	3	11	–2	–15.4%
ANU FAS	19	1	20	12	1	13	–7	–35.0%
Total Go8	325.43	32.6	358.03	207.71	40.98	248.69	–109.34	–30.5%

* *Except for two Monash university staff transferred to other departments and several econometricians from ANU transferred to other departments, all losses represent genuine loss of employees from the university. Staff from the ANU Department of Finance and Applied Statistics whose expertise is in finance rather than statistics are excluded to avoid misleading data arising from department restructuring.*

47 FASTS Occasional Paper, 2000. http://www.austms.org.au/AustMath/lookfuture.pdf.

48 http://www.austms.org.au/AustMath/braindrain _ 2002.pdf

Table 3: 'Teaching-only' staff in mathematical sciences departments in the Group of Eight universities 1995–2005: statistics gathered from questionnaires returned by the departments. Departments that had no mathematical sciences staff classified as 'teaching only' are not listed.

Teaching Only	1995			2005			change	
	male	female	total	male	female	total	number	percent
Adelaide	1	2	3	2	1	3	0	
Melbourne	3.8	4	7.8	3	5	8	0.2	2.6%
WA	0	0	0	0	1	1	1	
Queensland	3	0	3	0	0	0	–3	–100%
ANU Math	1	0	1	0.5	0	0.5	–0.5	–50%
Total Go8	8.8	6	14.8	5.5	7	12.5	–2.3	–16%

Table 4: Departures (October 2004 to March 2006)

	A	B	C	D	E	Total	Total C or above
Statistics	4	7	7	7	3.8	28.8	17.8
Pure	1	8	10	4	3.5	26.5	17.5
Applied	1	4	5	2	2	14	9

Table 5: Advertisements—ongoing, academic positions in mathematical sciences departments (October 2004 to March 2006)

	C	D	E	Total
Statistics	5	1	4	10
Pure	1	–	1	2
Applied	3	–	–	3

Academic vacancies advertised in the Higher Education section of *The Australian* have been compared with numbers leaving university mathematical sciences departments from October 2004 to March 2006. These show few opportunities for new ongoing, academic positions in mathematical sciences departments, while the considerable loss of existing academic staff continues.

About 65 positions were advertised that could be classified as an academic position for a mathematical scientist. However, many were for positions in medical research institutes or similar and well over half specified statistics or a related field. Only 15 of the advertisements were ongoing academic positions in a mathematical science department at level C (senior lecturer) or above; levels that might attract overseas applicants.

Tables 4 and 5 indicate both the continued contraction of the mathematical sciences base in universities and lack of opportunity for new applicants.

Statistics

One of Australia's leading academic statisticians, whose department is responsible for training both actuarial and statistics students, has reported that demand for statisticians is so great that their average starting salaries exceed those for actuarial science graduates.

Of the 65 higher education positions advertised, well over half required statistics or a related field, reflecting the demand for statistics academics.

In spite of demand for statistics graduates, impact of the RFM and loss of service teaching, compounded by the difficulty of attracting international students, have impacted adversely on the number and standard of research-trained statisticians in Australia. Sizes of some once-major statistics groups have fallen to such low levels, it is virtually impossible for them to mount a viable research-training program.

Costs of delivering statistics and mathematics courses are not met by funding paid through the RFM. This is particularly true of the more theoretical courses, for example those in the third and final years of Honours degrees, that form the basis of research-training programs.

Research training

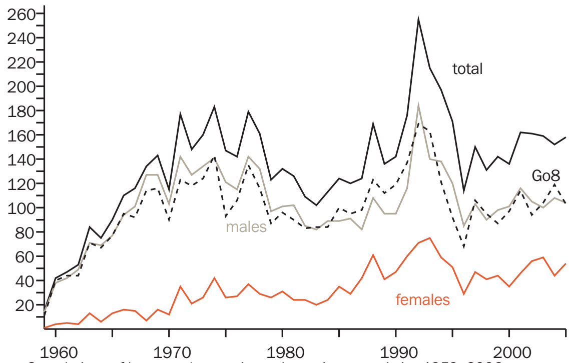
The current Australian research training model[49] consists of a:

- three-year undergraduate degree
- one-year program of advanced coursework and research or project work (the honours year)
- fully research-based higher degree, either at masters level — nominally two years —or at doctoral (PhD) level, nominally three years.

Supply of research-capable staff to business, industry and academia has a long lead time. Any changes to the secondary school mathematics experience or undergraduate enrolment patterns affect the future supply of researchers.

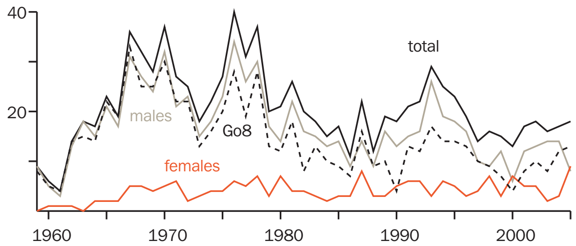
A natural way to assess the rate of production of research-ready graduates is to consider numbers of students successfully completing honours degrees or research higher degrees (MSc by Research or PhD). This data, collected since 1959, is summarised in Figures 1 to 3[50].

Figure 1: Australian honours completions in mathematics or statistics 1959–2003



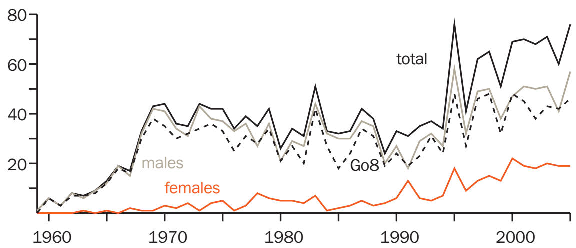
Completions of honours degrees in mathematics or statistics 1959–2006 (Johnston–Petocz data, with small corrections for 2004 and 2005). The solid curves give total numbers (black), total males (gold) and total females (red). The broken curve corresponds to total completions from the Group of Eight (Go8) universities.

Figure 2: Australian research masters degree completions[51] in mathematics or statistics 1959–2003



Completions of research masters degrees in mathematics or statistics 1959–2006 (Johnston–Petocz data, with small corrections for 2004 and 2005). The solid curves give total numbers (black), total males (gold) and total females (red). The broken curve corresponds to total completions from the Group of Eight (Go8) universities.

Figure 3: Australian PhD completions[51] in mathematics or statistics 1959–2003



Completions of PhD in mathematics or statistics 1959–2006 (Johnston–Petocz data, with small corrections for 2004 and 2005). The solid curves give total numbers (black), total males (gold) and total females (red). The broken curve corresponds to total completions from the Group of Eight (Go8) universities.

49 This is about to change at the University of Melbourne and others may follow, but the total training time will not decrease

50 Data of P Petocz & P Johnston, http://www.cit.gu.edu.au/maths, collected from university departments. Data refers to successful completions in the calendar year

51 Numbers represent degrees awarded in that year. In some cases, students will have submitted their theses in the preceding year

"There seems to be an increasing expectation that a senior researcher will accomplish research through graduate students and post-doctoral fellows, but the average quality of students going into the mathematical sciences appears to have declined and so research conducted by them is likely to be of lesser quality."

– CSIRO Mathematical and Information Sciences

From this data, the Review concludes:

- There has been some encouraging growth in female enrolments, but further efforts are needed if the mathematical talents of half of the nation's population are to be properly developed.
- Despite a brief period of high enrolments in honours programs in the early 1990s, total production per year is now back to the level of the early 1970s.
- The peak in honours completions in 1992 is reflected in a peak in PhD completions in 1995. The subsequent recovery in PhD graduations after the drop in 1996 is partly offset by a decline in MSc by Research graduations.
- Research training is strongly concentrated in the Go8 universities. The contribution of the rest of the sector is dominated by the output of a small number of institutions.

Although PhD completions in recent years have held up, this reflects the disappearance of the research masters degree, with PhD now becoming the research higher degree of choice. Current arrangements for the Research Training Scheme (RTS) favour university departments having students in PhD programs rather than research masters. This may prevent students from completing masters by either research or coursework that would prove attractive to business and industry.

Total higher degree completions (MSc and PhD combined) have stalled. Previously, several major departments had high masters student numbers, either as a requirement for higher level roles in industry or for doing a PhD in the US or Europe.

Some departments that had healthy numbers in honours and postgraduate training are now so depleted that they have essentially no higher degree students.

Improving honours and postgraduate student numbers depends on rebuilding mathematical sciences departments and improving flow of students with a major in mathematics or statistics. To achieve this requires action in schools and universities.

Membership of key professional societies is declining

Professional society membership, an indicator of the health of a profession, has declined significantly in the past decade across four key mathematical and statistical societies — the Australian Mathematical Society (AustMS), the Australian and New Zealand Industrial and Applied Mathematics division of the Australian Mathematical Society (ANZIAM), the Australian Society for Operations Research (ASOR) and the Statistical Society of Australia, Inc (SSAI).

This is despite strong demand for mathematical modellers and the chronic shortage of highly trained statisticians.

Decline in membership of the four key professional societies was a recurring theme in meetings between the Working Party and stakeholders in February 2006.

The only professional society for mathematicians experiencing membership growth is the Combinatorial Mathematics Society of Australasia (CMSA), but this is a smaller society with a narrower focus and large membership outside Australia.

Some of these professional societies also provide accreditation but uptake has been low — about one in every nine members of the AustMS for example.

While most AustMS members are employed in universities, the employment profile of SSAI members shows a wide distribution of mathematical scientists throughout the Australian workforce: 17% with private employers, 27% in government (including CSIRO), 33% working in universities, 6% students; the remaining 17% of members have not disclosed an employment status to SSAI.

Membership growth in the Institute of Actuaries of Australia (IAA) reflects the growing sophistication of the Australian finance sector.

Table 6: Membership of Australian mathematical sciences professional societies 1995 – 2005

	Current profile		Total membership		
Society	Australia	female	2005	1995	trend 1995 – 2005
AustMS	82%	n.a.	873	c.1100	21% decrease
ANZIAM	80%	≥12%	450	c. 500	10% decrease
ASOR	n.a.	n.a.	180	430	58% decrease
CMSA	29%	18%	204	c. 130	50% increase
SSAI	99.5%	30%	778	c. 910	17% decrease
IAA	79%	28%	2988	1633	83% increase

Conclusion

Australia is in danger of becoming irrelevant in the advanced mathematical sciences, and mathematics and statistics may become imported skills that are increasingly hard to obtain in a globally competitive labour market.

There is no evidence to suggest that these worrying trends will cease without remedial action.

The long lead time in research training means that damage sustained by the sector will take years to repair, and makes action to arrest and reverse the decline urgent.

The Review notes that the university mathematical sciences sector generally, and the most stressed departments in particular, are placed in a very awkward position. A frank disclosure of the fragility of their situation is necessary to convince stakeholders of the need for assistance.

However, such frank admissions may be counterproductive, eroding staff and student morale, reducing public esteem, and perhaps convincing influential people that the situation is beyond repair and that many departments should simply be shut down completely.

The next chapter documents the decline in Australia's mathematical sciences research base.

The 1995 review[52] commented on the ageing profile of University Mathematical Sciences Departments. The situation has deteriorated since then due to the very small number of appointments being made as mathematics and statistics departments have shrunk.

Chapter Three:

REVIEW FINDINGS: OUR MATHEMATICAL RESEARCH BASE IS NARROWING

This chapter documents the decline in Australia's mathematical sciences research base.

52 Mathematical Sciences: Adding To Australia, National Board of Employment, Education and Training, Australian Research Council & Discipline Research Strategies, 1995 (www.review.ms.unimelb.edu.au/95Review.pdf)

Chapter Three

REVIEW FINDINGS: Our mathematical research base is narrowing

Summary

- Mathematical research in Australia is becoming increasingly narrowly focused.
- Across most fields of mathematics and statistics, research output in Australia has become dependent on a small number of highly productive, older individuals working more or less in isolation. Losing them would put Australia at risk of a major collapse in research capability.
- There are almost no permanent mathematics and statistics academic staff aged under 30 and very few under 40. Research leaders in mathematics and statistics are close to retirement and there is a serious shortage of capable younger people to replace them, due to the brain drain and shrinkage of university departments of mathematics and statistics in the past decade.
- Excessive reliance on a small number of mathematical scientists with specialised interests is eroding the broad skills base needed for a robust and adaptable research community.
- Inadequate resources are available to foster vital collaborative links between mathematicians and statisticians in research, academia, industry and education.

The mathematical sciences research base in Australia must meet a range of needs:

- research training to ensure supply of suitable mathematical sciences graduates — honours and above — needed for business and industry, government agencies, research institutes and the universities
- fundamental research that is not yet able to attract substantial application-specific industrial or government funding
- support for research across the universities through appropriate use of statistics and mathematics
- applied and interdisciplinary research involving industry and university collaboration
- research informed teaching of undergraduate students

When internationally, the major scientific advances are being made through collaborations between different branches of mathematics and other scientific disciplines, and by countries that invest heavily in mathematical research and education, Australian mathematicians and statisticians are becoming increasingly isolated and under-resourced.

The diverse nature of mathematical sciences research — the fact that it encompasses many fields of science, not just mathematics or statistics alone — means it is difficult to measure the extent and quality of research being conducted.

However, through the latest statistical data on performance of mathematical scientists in specific research areas, and international research benchmarks, the Review was able to draw some broad conclusions consistent with anecdotal evidence and observations made during its consultation process:

- Australia's research output has not grown enough to maintain its position relative to rapidly developing economies in Asia and established economies in peer countries.
- Capacity in areas where Australia has been previously 'punching above its weight', such as probability and statistics, is now in serious decline.
- Across most fields of mathematics and statistics, research output in Australia has become dependent on a small number of highly productive individuals working more or less in isolation, leading to vulnerability and loss of flexibility.
- Research capacity increasingly depends on research-only staff in insecure employment circumstances, as workloads of diminishing numbers of teaching and research staff grow.
- Research capacity is being eroded in rural and regional universities. This reduces both total national research capacity and the capacity to address problems of particular significance to rural and regional communities.
- Inadequate resources are available to foster vital collaborative links between mathematicians and statisticians in research, academia, industry and education.

The consequences for mathematical sciences research in Australia are dire.

Research active and research capable mathematicians in Australia are dwindling

Data on movement of mathematicians and statisticians in and out of Australia shows a serious brain drain of experienced and younger researchers[53]. Recent data highlights the continuing loss of academic teaching and research staff. Lack of advertisements for such positions indicates staff are not being replaced.

This is particularly true of pure mathematics and, to some extent, applied areas. Advertised statistics positions are hard to fill and senior positions are typically filled from within Australia.

The overall result is a dwindling research base that is narrowing around a few individuals at a time when it should be expanding to take advantage of vibrant mathematical sciences activity in other nations.

Research productivity across Australia is maintained by a small key leadership group, almost all in their late 50s or early 60s. There are almost no mathematics and statistics teaching and research staff under 30 and few under 40 coming up through the system to replace the retirees.

This is especially true in traditional areas of strength such as analysis, numerical computation and statistics.

Seven of the Group of Eight (Go8) universities provided age-distribution data to the Review, revealing that only 1.1% of effective full time teaching and research staff (permanent academic staff) were aged 30 or less. In contrast, 11.6% were aged 61 or above. This shows the paucity of career paths into normal academic staff positions for young staff in the critical age bracket where secure employment is needed to buy a house or begin to raise a family.

It is proving extremely difficult to fill chairs at Go8 universities in areas such as statistics and operations research (OR). At Melbourne University, it took three years to fill the vacant Chair of Statistics. Without action, within several years Australia may well vanish in terms of research relevance in mathematics and statistics.

The 1995 review[54] commented on the ageing profile of university mathematical sciences departments. The situation has deteriorated since then due to the very few appointments being made as mathematics and statistics departments have shrunk. As many departments are struggling financially, there is no guarantee of replacement when people retire, a situation highlighted by the lack of positions advertised compared with retirements as already highlighted.

Australia is in imminent danger of slipping in its international rankings for research output

The American Mathematical Society's MathSciNet database lists papers published in recognised international scientific journals with 'significant mathematical content', providing a measure of the total size of the mathematical sciences research sector in each country.

53 http://www.austms.org.au/AustMath/braindrain _ 2002.pdf

54 Mathematical Sciences: Adding To Australia, National Board of Employment, Education and Training, Australian Research Council & Discipline Research Strategies, 1995 (http://www.review.ms.unimelb.edu.au/95Review.pdf)

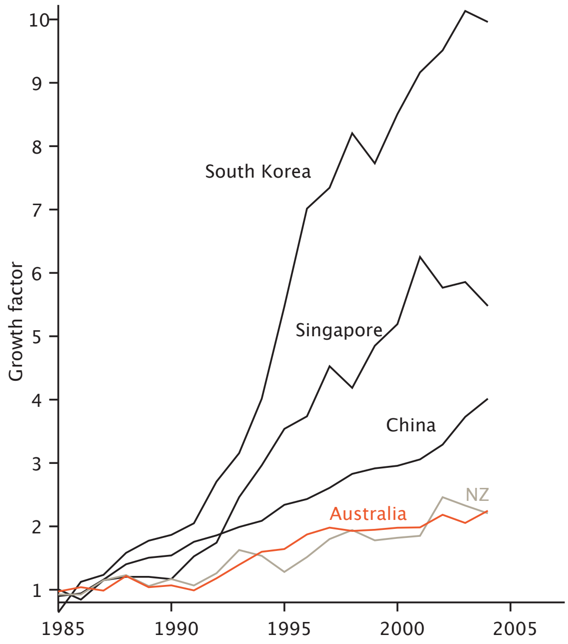
Table 7: MathSciNet database — papers published in recognised international scientific journals with 'significant mathematical content' (by country), 1985 – 2004

Year	Singapore	Korea	New Zealand	Australia	China
1985	56	70	91	541	2048
1990	65	204	115	595	3507
1995	197	598	126	914	5325
2000	289	930	179	1101	6726
2002	321	1040	242	1215	7487
2004	305	1089	217	1250	9136

Data for five countries is shown in Table 7, comparing Australia with New Zealand, and three Asian countries, Singapore, South Korea and the People's Republic of China[55]. In 1985, by this indicator, neither Singapore nor Korea had a large output — both were less productive than New Zealand. Within five years, Korean output had already outstripped New Zealand and Singapore overtook New Zealand in less than a decade. Modest additional growth would place Korea ahead of Australia in the near future. Growth in China has been spectacular.

Figure 4 shows papers published, scaled against each country's baseline performance in the mid 1980s. (Downward trends from 2004 to 2005 reflect the time taken for 2005 papers to be incorporated in the MathSciNet database.)

Figure 4: Productivity improvement in mathematical sciences research publication numbers



The ascendance of the Asia Pacific region is apparent in reports from Science Watch. In its 1997 report Science Watch noted that, in the mid–1990s, the sliding US share of world scientific paper output had intersected that of the ascendant EU.

In its 1990 – 2004 report, it noted a continuing trend, but with EU share seeming to level off in recent years.

This report also noted the striking rise of the Asia Pacific share, which, if current trends continue, will likely outstrip that of the US within six or seven years[56].

55 Papers from Hong Kong prior to its integration into the People's Republic of China are included under China for the appropriate year

56 http://www.sciencewatch.com/july-aug2005/sw _ july-aug2005 _ page1.htm

For probability and statistics, data on national productivity is provided in the World Rankings in Probability and Statistics Research report for 1986 – 2000, based on publications in 25 international refereed journals[57].

Australia has ranked highly in the world in probability research. Its position of fourth in statistics 1986 – 2000 has been maintained consistently. But rankings can change quickly. Japan, eighth overall in both probability and statistics from 1986 – 2000 went from sixth in 1991 – 95 in probability to twelfth in 1996 – 2000, and from fifth in statistics in 1986 – 90 to 11th in 1996 – 2000. For productivity scaled against population, Australia rates a creditable sixth in probability and first in statistics.

However, Australia's rankings for total output and output scaled against population are expected to fall rapidly due to academic staff losses and retirements. Ratings in statistics reflect strengths in the late 1990s.

In the general field of mathematics, Australian research and research training has generally been well regarded for its quality. This is reflected in the way both younger and experienced researchers find positions in top universities across the world and in individuals who hold prominent positions in the international community. The current president of the International Council for Industrial and Applied Mathematics (ICIAM) is Professor Ian Sloan of The University of NSW. Professor Cheryl Praeger from The University of Western Australia was recently elected to the Executive Committee of the International Mathematical Union (IMU).

Australia's reputation is greatly enhanced by its expatriates' standings. At the recent International Congress of Mathematicians, two plenary speakers were expatriate Australians, including Professor Terence Tao, winner of the 2006 Fields Medal.

Australia-wide research output is vulnerable

The Review found that, overall algebra, and geometry and topology grew significantly from 1985 to 1995, but not since.

Growth in analysis was sustained for longer (to around 2000) but now appears to have stalled. The apparent success of analysis conceals significant vulnerability related to the large output of published papers by one individual as author or co-author[58].

The sensitivity of national publication levels to the activities of a small number of highly productive individuals is obvious in the statistics area. Of 1,933 papers in statistics for the years 1995 to 2005 (listed in MathSciNet up to May 2006), 307 or almost one sixth had one individual as author or co-author[59].

This raises two particular concerns:

- The loss of a small number of highly active individuals could lead to a major collapse in overall productivity.
- Excessive reliance on a small number of individuals or groups with narrowly focused interests may erode the broad skills base necessary for a robust and adaptable mathematical sciences research community.

The American Mathematical Society's MathSciNet data does not directly measure the health of particular departments at a given university. However, it is a useful indicator of changes over time in departmental research health. In particular, little progress in papers or fewer papers produced can indicate stagnation or decline in productivity, especially in fundamental mathematical sciences research.

57 For ranking methodology and criteria see C Genest and M Guay, Worldwide research output in probability and statistics: an update, Canadian Journal of Statistics, 30 (2002), 329-342

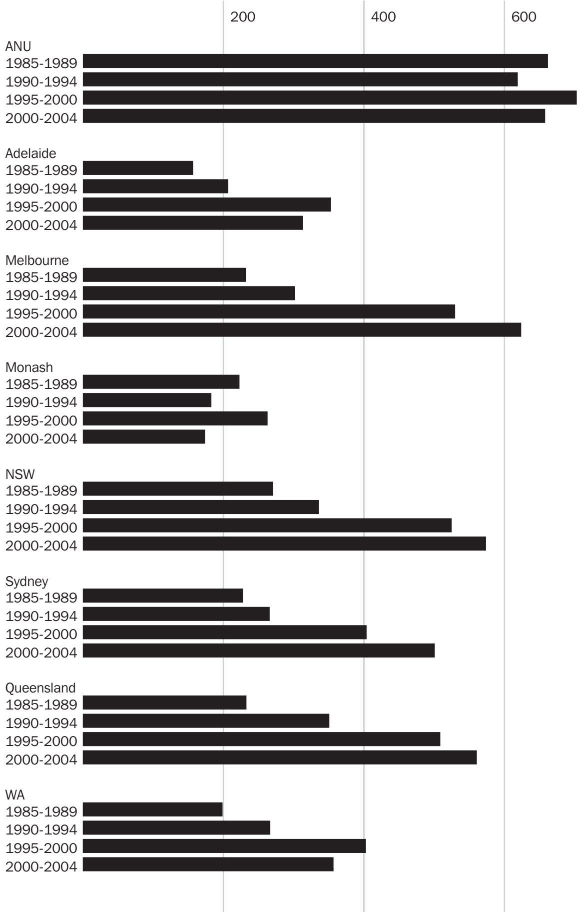
58 Professor S S Dragomir, Victoria University

59 Professor P G Hall, Australian National University

With these caveats, the performance of individual universities from two national networks, the Go8 and Innovative Research Universities of Australia (IRUA), are considered. Both groups consist of comprehensive universities with large pure science programs and professional disciplines in which mathematical sciences play a significant role.

Figure 5 shows numbers of papers associated with the Go8 universities. Over twenty years, The Australian National University has been important and from 1985 – 95 dominant over its seven state-based peers. Its unique structure, with research schools free from undergraduate teaching obligations, makes its pre-eminence easy to understand.

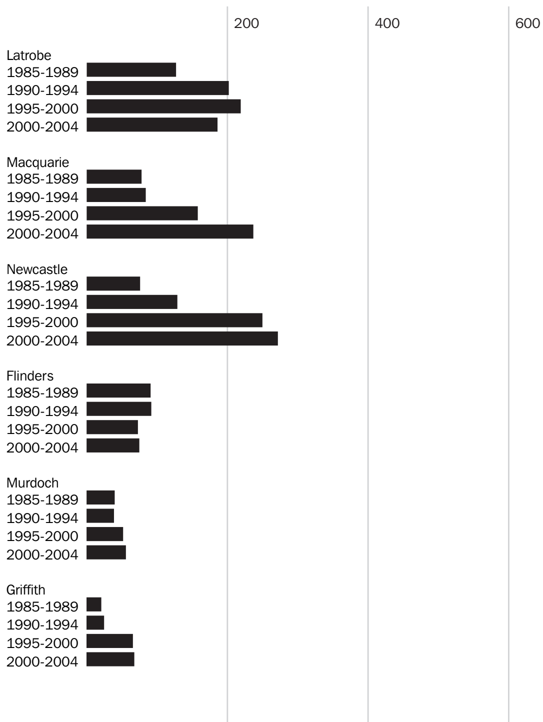
Figure 5: Papers indexed in MathSciNet from Go8 universities



However, from 1996 to 2004, the Universities of Sydney, NSW, Melbourne and Queensland markedly increased productivity relative to the Australian National University and by 2004, these five Go8 universities in the eastern States had comparable impact. Monash University, the University of Adelaide and the University of Western Australia each peaked in performance somewhere between 1996 and 1998, and have since declined in output. This is occurring at a time when WA has unprecedented needs for mathematical expertise to support its booming resources industry and SA has major defence needs.

Similar MathSciNet data are given in Figure 6 for the six IRUA universities. The strongest overall performers are the University of Newcastle, Macquarie University and Latrobe University.

Figure 6: Papers indexed in MathSciNet from IRUA universities



Productivity at Latrobe University peaked in 1996 and has since declined. Griffith and Murdoch Universities have been unable to grow substantially. Flinders University in SA, once relatively important, is in decline and no longer offers an honours program.

The brain drain has increased substantially in recent years. It has become very difficult for departments to maintain or develop a critical mass of researchers in areas of strong demand in mathematics and statistics.

Our top young graduates are now in tenured or tenure track appointments in leading US and European universities and it is a great challenge to convince them to come back to departments with few active young staff members.

Well-publicised teaching and administrative loads above what is expected in other countries and the lack of positions are not attractive to potential candidates.

Government agencies and research

The Review recognises the positive contribution of government agencies to mathematical sciences research.

For example, CSIRO Mathematical and Information Sciences (CMIS) provides a vacation scholarship scheme for third-year students, top-up scholarships for PhD students, and shared support for post-doctoral fellows and visitors. Research at CMIS is likely to increase with the proviso that they have had difficulties filling advertised positions.

Statutory bodies have in the past undertaken significant research and provided research and training that not only benefited their own activities, but also the Australian community. Uniquely Australian problems that would not receive attention from offshore researchers have been addressed.

One unintended consequence of the break-up and commercialisation of former government utilities may be the loss of research infrastructure, including key resources in mathematical sciences. For example, the former Postmaster General's Department established research laboratories in 1923. The laboratories contributed greatly to telecommunications research and development, dealing with specific Australian problems and problems of wider import. In January 2006, what had become the Telstra Research Laboratories, one of the largest research and development organisations outside the university sector, was closed.

Given the increasing role of mathematical modelling and operations research in telecommunications, the loss of the Telstra Research Laboratories is seen by many as a serious loss to mathematical sciences.

National investment in mathematical sciences research is already low, and further decreasing

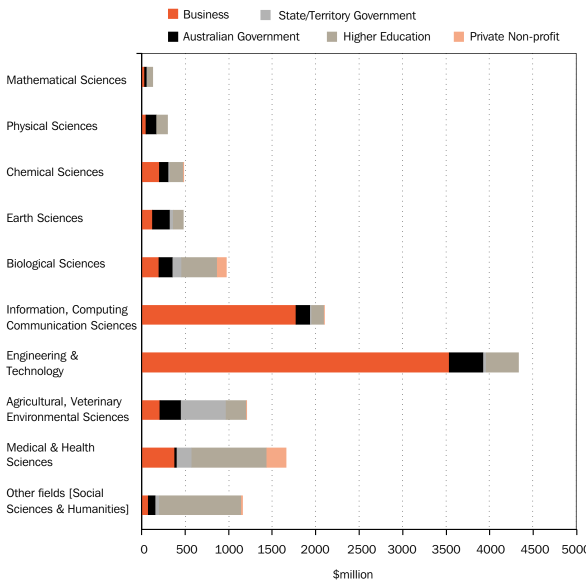
The decline in the research base has occurred at a time when an already low investment in mathematics and statistics has contracted relative to other discipline areas.

ABS data on distribution of Higher Education Expenditure on Research and Development (HERD) in 1992 and 2002, and Gross Expenditure on Research and Development (GERD) in 2002 – 03 is telling — of the nine key research areas, **mathematical sciences received the least funding from all sources** (business, government, higher education and non-profit organisations).

The physical, chemical, earth, biological, IT, engineering, agricultural and medical sciences were all funded at more than twice the level of mathematical sciences.

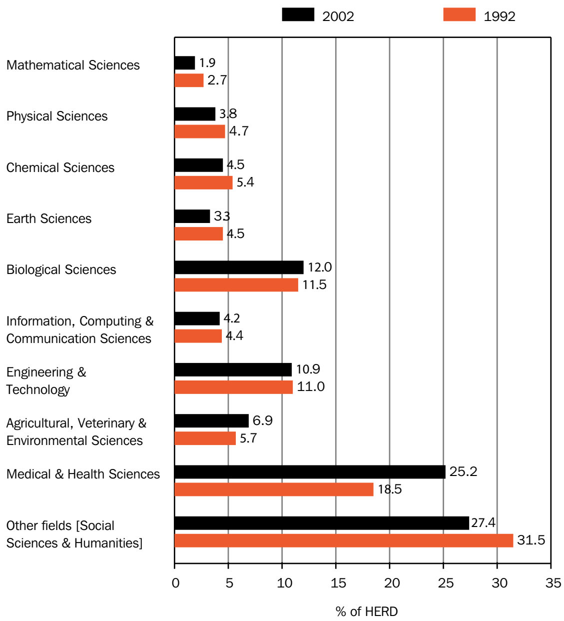
And while the proportion of Higher Education Expenditure on medical, agricultural and biological sciences R&D grew from 1992 – 2002, mathematical science investment slumped from 2.7% to 1.9% of total spending on higher education research and development.

Figure 7: GERD by sector of performance — by field of research 2002 – 03



Gross expenditure on research and development in 2002 – 03 by field of research. From the DEST publication "Australian Science and Technology at a Glance 2005" (Chart 17, based on unpublished ABS data).

Figure 8: Distribution of HERD — by field of research, 1992 and 2002



Distribution of higher education expenditure on research and development, 1992 and 2002. From the DEST publication "Australian Science and Technology at a Glance 2005" (Chart 30, based on unpublished ABS data).

Private enterprise R&D

Australia's private sector has increased its expenditure on science and innovation but it is still considerably below the OECD average.

The value of mathematical sciences to BHP Billiton has led it to forge links with the global mathematical sciences community, including ARC Linkage Grants with the Universities of Newcastle, NSW and Melbourne, sponsored research in mixed-integer-linear programming at Columbia University, US and sponsorship of a chair in mine planning optimisation at McGill University in Canada.

Investment in the operations research area of mathematical sciences outside Australia is significant.

Mathematical scientists around Australia are engaged in considerable consulting and research work with industry. Examples are in mining, manufacturing, health services and the finance sector. There are a number of industrial consulting centres based at universities, such as Curtin, University of South Australia, University of Adelaide, University of Ballarat, University of Melbourne and several statistical consulting centres. Such centres provide a useful, but small source of income for university departments. They also provide opportunities for students and staff to gain invaluable experience in real world problem solving.

Conclusion

Research output has not grown adequately to maintain Australia's position relative to rapidly developing economies in Asia.

Capacity in areas where Australian has been 'punching above its weight', such as probability and statistics, is in serious decline.

Research capacity is becoming narrowly focused around a few highly active individuals or groups, leading to vulnerability and a loss of flexibility.

There is a chronic shortage of mathematics and statistics teaching and research staff under 40.

Research capacity increasingly depends on research-only staff in insecure employment circumstances, as workloads of diminishing numbers of teaching and research staff grow.

Research capacity is being eroded in rural and regional universities. This reduces the total national research capacity and rural and regional research capacity.

While valuable research is conducted in government agencies and other enterprises, it depends on a supply of suitable graduates from the universities.

The narrow base of research in Australian universities compromises their ability to produce the graduates needed now and in the future. Australia's mathematical scientists have performed well in recent Australian Research Council grants, especially Discovery grants in recent years, reflecting increased funding available through the ARC. However, this is not enough to maintain the research base Australia needs, nor does it necessarily lead to strengths being developed in new areas.

In this regard, possible implementation of the Research Quality Framework (RQF) has potential to contract research into areas of existing strengths and this would not be in the interests of Australian mathematical sciences at this time.

"Australia's mathematical skills base can only be improved by a concerted effort to improve participation in the mathematical sciences from primary schools to advanced level research."

Chapter Four:

THE WAY FORWARD: AUSTRALIA MUST IMPROVE THE FLOW OF MATHEMATICALLY TRAINED STUDENTS

This chapter highlights the need to increase the numbers and quality of mathematically trained students and teachers throughout the education system.

Chapter Four

"While Australian Year 8 students, overall, perform above the international average (for mathematics)… the long tail of underachievement and small percentage reaching advanced level are cause for concern."

THE WAY FORWARD: Australia must improve the flow of mathematically trained students

Summary

Australia must improve its percentage of university graduates with a mathematics or statistics major, from the current 0.4% p.a. to at least the OECD average of 1% p.a. This target cannot be achieved without improving school mathematics education and providing greater opportunities within the university sector.

While international studies show that, overall, Australian mathematics students perform well, the long tail of underachieving and small percentage reaching advanced levels are cause for concern.

Mathematical sciences are not cheap to teach, and the current funding model is driving educational practice in detrimental ways. Changes to the funding model are needed urgently.

The annual Organisation for Economic Cooperation and Development (OECD) *Education At A Glance* report provides key indicators on the performance of education systems across the world[60].

A nation's educational performance, as measured in the OECD report, is a key measure of its ability to produce skilled graduates to meet its needs for technological growth and development.

In 2003, when university mathematics and statistics graduation figures were most recently compiled, only 0.4% of Australian university students graduated with qualifications in mathematics or statistics compared with the OECD average of 1%.

Australia must aim to more than double this percentage of graduates and reach at least the OECD average, as a matter of urgency, if it is to continue to support teaching, research and industry needs, and compete internationally.

This can only be achieved by improving the flow of mathematically trained students through the entire system — from primary schools to advanced level research.

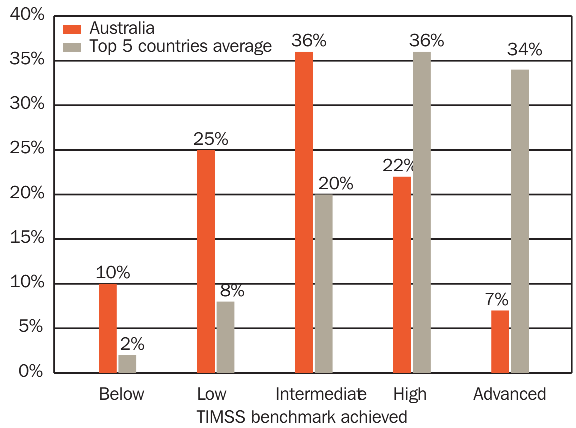
School mathematics

Disturbing picture emerging from international comparison

While Australian students achieve better than the international average, their spread across achievement levels is too wide. When Australian Year 8 students are compared against averages for the top five countries, there is extensive underachievement and small numbers reaching advanced levels. This affects the number of students with adequate background to pursue advanced or intermediate mathematics courses at Year 12.

Australia can, and must, do better.

Figure 9: Comparison of the percentage of Australian Year 8 students reaching the TIMSS international benchmarks (2002/2003) with average of top five countries[61].



The poor performance of Year 8 students indicates problems with mathematics teaching in primary schools. In part this reflects a problem with preparation of primary teachers discussed below.

Fewer Year 12 students graduating with adequate mathematics

A critical issue is the number of students completing Year 12 with enough mathematics for tertiary courses.

A study[62] published by the International Centre of Excellence for Education in Mathematics (ICE-EM) in June 2006, documented a marked decline in the percentage of Year 12 students taking higher-level mathematics. The study found that over the past decade, there has been a movement by Australian Year 12 students into elementary mathematics at the expense of advanced and intermediate subjects. See Table 8.

60 Education At A Glance – OECD Indicators, Organisation for Economic Co-operation and Development (OECD), 2004 http://www.oecd.org/

61 See Appendix 2 for an explanation of TIMSS benchmarks

62 Participation in Year 12 Mathematics Across Australia, F Barrington, May 2006, http://www.ice-em.org.au/pdfs/Participation _ in _ Yr12 _ Maths.pdf

"We have been on record many times expressing concerns about the decline in the number and quality of teachers in the enabling sciences and mathematics."

– Dr John Dodgson, Chief Executive Officer, Australian Academy of Technological Sciences and Engineering[65]

Table 8: National participation by Year 12 students in advanced and intermediate mathematics in 1995 and 2004. Students are classified according to the highest level mathematics subject that they take.

Advanced mathematics students, as a percentage of Year 12

	NSW	VIC	QLD	WA	SA	TAS	ACT	NT	(AUS)
1995	18.9	11.4	12.6	12.6	11.8	4.6	12.2	5.8	(14.1)
2004	15.0	12.6	8.4	8.2	9.1	5.5	11.9	3.2	(11.7)

Intermediate mathematics students, as a percentage of Year 12

	NSW	VIC	QLD	WA	SA	TAS	ACT	NT	(AUS)
1995	30.0	24.4	33.7	18.8	23.6	15.3	27.6	9.7	(27.2)
2004	20.1	24.2	31.7	13.4	16.0	14.3	28.0	9.9	(22.6)

Not only does this trend limit the level of training that can be supplied to students in undergraduate degree programs such as commerce, education, engineering and science, but it also poses a serious threat to the nation's future high-end skills capability.

This trend can be attributed to several factors including wide differences in mathematics teaching between the States, the trend by universities towards lowering prerequisites to attract greater enrolments and lack of reward for taking more advanced subjects in university entry procedures.

In 2005, an ICE-EM study of Year 12 mathematics curricula across the States revealed major disparities in syllabuses and assessment, and described the situation as 'chaotic'[63]. While recommendation of possible solutions was outside the study's scope, it—and the 2006 Participation Rates study—suggests that providing challenging courses with appropriate scaling would encourage students to continue with more advanced level courses. An associated issue is that only 64% of high schools now offer advanced mathematics — and this is likely to contract further in the current climate[64].

Australia is reaching the stage where it is unable to produce the next generation of students with an understanding of fundamental mathematical concepts, problem-solving abilities and training in modern developments to meet projected needs and remain globally competitive.

Australia must produce greater numbers of adequately trained mathematics teachers

A key to solving the problem of underperformance in school mathematics is ensuring supply of adequately trained mathematics teachers from primary to secondary.

"... Only four out of 31 Australian universities require Year 12 mathematics as a prerequisite for Bachelor of Education courses, eight require Year 11 mathematics and the remaining 19 do not have or do not specify any mathematics as an entry requirement. Worse still, many of these courses contained very little mathematics content." — AMSI/ICE-EM Joint Submission to the House of Representatives Standing Committee on Education and Vocational Training[66].

Problems with teacher training and teacher supply

The lack of mathematical content in courses for primary teachers documented in the AMSI/ICE-EM submission to the House of Representatives Standing Committee on Education and Vocational Training[66] is cause for serious concern. The study behind the submission also found evidence that courses for teaching the middle years — upper

63 Comparison of Year 12 Pre-tertiary Mathematics Subjects 2004-2005, F Barrington & P Brown, October 2005 http://www.ice-em.org.au/year12maths.pdf

64 K L Harris and F Jensz, The Preparation of Mathematics Teachers in Australia. Report prepared for Australian Council of Deans of Science, Centre for the Study of Higher Education, The University of Melbourne, July 2006, www.acds.edu.au/Prep _ Math _ Teach _ Aust.pdf

65 Submission to the Review

66 http://www.aph.gov.au/house/committee/evt/teachereduc/subs/sub058.pdf

"In the enabling sciences we… have a high proportion of teachers who are manifestly unprepared to be able to teach at a world's best practice level at Year 12."

– Professor Tim Brown, President, Australian Council of Deans of Science[67]

primary, early secondary-lack discipline-specific studies, so early — year secondary students are increasingly likely to encounter a trained middle years teacher who actually has little mathematics discipline background.

The submission concluded, "… teacher education courses should be concerned with mathematical content knowledge appropriate to the level at which teachers are going to teach and separate courses about the pedagogical skills related to that knowledge. Course descriptions should reflect this and be written in clear and unambiguous language."

In October 2006 the Deans of Science released a report focusing on secondary mathematics teachers[68].

They warned that: "… One in four teachers of senior mathematics (do not undertake) any third year mathematics study at university. Further, it could well be that a proportion of those with third year mathematics did not have a full major. Even more worrying, one in twelve of all mathematics teachers studied no mathematics at university and one in five of all mathematics teachers studied no mathematics beyond first year."

The Deans concluded these problems would only worsen because fewer students were studying mathematics at school at advanced levels and retirements were increasing.

The Review believes there is insufficient mathematical depth in most educational faculties for this issue to be properly addressed. As with all mathematics and statistics service teaching, it recommends strongly that this teaching be the province of mathematical sciences departments for primary and secondary courses.

The Review recommends mathematics teacher courses:

- be developed in conjunction with education faculties
- provide content appropriate to the year level at which they will be teaching
- be linked to accreditation, with ongoing professional development.

Supply of mathematics teachers for secondary schools will remain problematic until numbers of students completing mathematics and statistics majors[69] improve. Meanwhile, support is needed for career change professionals and teachers teaching out of their field to upgrade their qualifications.

The Review also supports the Royal Australian Chemical Institute's recommendation that anomalies in Higher Education Contribution Scheme (HECS) type fees be resolved[70].

Starting salaries need to take account of the additional debt incurred by high school science and mathematics teachers compared with, for example, a primary teacher. Special incentives are needed to encourage students with honours in mathematical sciences to enter teaching. Teachers with this depth of discipline knowledge are needed to give leadership and maintain contact with university, business and industry mathematics and statistics experts.

University mathematics and statistics — learning and teaching

The current funding model does not reflect the real cost of teaching mathematical sciences relative to other disciplines.

The health of mathematics and statistics rests with the nation's universities, where the researchers and teachers of the next generation are trained, and fundamental mathematics and statistics knowledge is developed.

67 Quoted in newspaper articles: Science teachers don't make grade: study, E Bellamy, Education Reporter, Canberra Times, 20 April 2005 and Teachers working with inexact science, Louise Perry, *The Australian*, 20 April 2005

68 K L Harris and F Jensz, The Preparation of Mathematics Teachers in Australia. Report prepared for Australian Council of Deans of Science, Centre for the Study of Higher Education, The University of Melbourne, July 2006, http://www.acds.edu.au/Prep _ Math _ Teach _ Aust.pdf

69 Defined as half the third year of a standard three-year degree.

70 Royal Australian Chemical Institute (2005). Future of Chemistry Study, p25. http://www.raci.org.au/future/Future%20-20Final%20Report%202005-09-22.pdf

Undergraduate degrees need to be strengthened

The standard entry point to university for future mathematical scientists has been the Bachelor of Science, a three-year general science program within which major studies in mathematics or statistics could be taken, although a small number of Australian institutions have offered a specialist three-year Bachelor of Mathematics[71].

Reforms to Australian undergraduate education in the spirit of the US or European models may impact greatly on ultimate demand for mathematical sciences education in universities, but the nature and extent of this impact is unclear at present[72].

Combined two-degree undergraduate programs have grown in popularity. However, for students completing a combined degree, the prospect of doing additional coursework and assessment for honours in mathematical sciences can be unappealing.

A worrying development is the emergence of combined four-year degrees in science and education where the science component is only two-thirds of a normal BSc. Teachers themselves do not think this sufficient background[73].

If students are to be attracted to studying mathematics and statistics, either in their own right or as part of other degrees, then the courses must be available at universities.

These courses must cater for students who may potentially be higher degree mathematical science candidates as well as for students needing mathematical content for other degrees e.g. engineering, education, economics, biomedical sciences. While the former underpins the mathematical sciences research base, the latter contributes to the total skills base and ability to apply research.

More broadly, a weakening of the university mathematical science infrastructure reduces the quality and currency of this education in associated disciplines.

Industry and government agencies stress that modern graduates need software and programming skills, as well as teamwork experience, but not at the expense of deep mathematical and statistical understanding.

Courses must be contemporary and relevant. In the case of service teaching, courses must have relevance to the discipline concerned, be it engineering, education or agricultural science.

In many institutions, in-house non-specialists teach mathematics and statistics material in professional degrees. As a result, and because funding is tied to student load, a three-year sequence of appropriate mathematics and statistics courses is no longer offered at some universities.

Universities must provide a diverse range of exemplary mathematics and statistics courses

Universities need to provide three types of courses to cater adequately for all needs:

- students majoring in mathematics or statistics
- students requiring a generalist subject not customised for a particular audience e.g. an entry-level mathematics subject in calculus or linear algebra for science students
- students needing customised mathematics or statistics courses appropriate to other major studies e.g. engineering, commerce, biological studies or education.

This means a university mathematical sciences department must be able to offer a variety of courses, many requiring considerable liaison with other departments and faculties. There must also be some choice for potential majors at second and third year if student interests and aspirations are to be met.

---

71 Currently the University of Newcastle, the University of Wollongong and Queensland University of Technology

72 Under the present US undergraduate model, professional education is more aligned to masters level education than to stand alone undergraduate degrees. This will also be the case by 2010 in Europe under the 1999 Bologna Declaration, http://ec.europa.eu/education/ policies/educ/bologna/bologna.pdf

73 K L Harris and F Jensz, The Preparation of Mathematics Teachers in Australias. Report prepared for Australian Council of Deans of Science, Centre for the Study of Higher Education, The University of Melbourne, July 2006, http://www.acds.edu.au/Prep _ Math _ Teach _ Aust.pdf

The university funding model is driving pedagogical practice in detrimental ways

The problem of relying on the Relative Funding Model (RFM) to produce graduates with appropriate skills is illustrated by the situation in statistics, an area of critical shortage.

The cost of delivering statistics courses is not met by RFM funding. This is particularly true of the more theoretical subjects, for example those in third year and at honours level, that form the basis of research training programs.

The funding shortfall for training Australian statistics students cannot be met by charging extra fees or advertising potential salary levels to motivate increased student enrolments in statistics courses.

University statistics groups have responded to this challenge in various ways. Many have reduced and even eliminated mathematics prerequisites for statistics courses to attract more students. Thus, statistics programs have become more descriptive, more applied and more strongly motivated by computational aspects.

In many Australian universities, statistics courses today place far less emphasis on principles, on theoretical aspects or on the intuition that theory conveys, than they did fifteen or more years ago. The ABS, in its submission to the review, expressed its strong concern about this position:

“We have noted a disturbing trend where some universities are placing too much emphasis on the practical application of statistical techniques and leaving the student without a proper understanding of the underlying statistical principles. This leads to graduates who lack sufficient theory to understand the assumptions and limitations of the various techniques and hence are unable to extend the theory or apply it in new situations as required.”

A related approach, taken by some university statistics groups, has been to design less theoretical courses to attract full fee-paying foreign students rather than Australian students and redirect teaching resources to areas where full fee-paying students occur in greater numbers.

Statistics courses designed for students in social science, rather than science, put less emphasis on principles and theory than application. This may meet the needs of the social sciences and humanities, but if these courses become the norm for other students they may not give the depth required.

The most serious problem created by the RFM stems from the way funding is weighted. Laboratory-based science and engineering programs attract substantially greater government funding per student per course than programs in mathematics and statistics. So as funding has declined, it has become increasingly attractive for laboratory departments to earn money by teaching their own statistics service courses.

This loss of service-course teaching has substantially reduced, and in some cases eliminated, a critical source of income for university groups responsible for teaching statistics courses. It has led to further reductions in the relatively challenging, theoretical aspects of these courses, so as to maximise class sizes.

These reductions have also made the courses less attractive to advanced, able students who enjoy intellectual challenge and would be most likely to go on to graduate work in statistics. It is largely from this pool that the research base of future statistics groups in industry, government (e.g. CSIRO) and universities is drawn. In particular, the supply of suitable, Australian-trained statistics PhD students has largely dried up.

Moreover, PhD-enrolled students often do not have adequate undergraduate preparation, in particular, adequate exposure to basic statistical principles, theoretical arguments and use of theory to support intuition. This can mean that their research, and perhaps also the research they supervise when they become mature statistical scientists, is not always up to standards enjoyed abroad.

Similar issues arise across the mathematical sciences, particularly in areas of shortage such as operations research and financial mathematics.

The issue of service teaching, and lack of mathematics and statistics in degrees where they would be mandatory in other parts of the world, is depleting Australia's mathematical sciences capability.

In Australia, even for students enrolled in science courses, there is usually no requirement to take a generalist mathematics or statistics subject in an undergraduate degree, although particular degree programs may have a small mandatory mathematical sciences component. Funding for mathematics and statistics, and demand for student load from other faculties and departments, are driving mathematical sciences out of universities. A nationwide retreat from setting significant mathematics prerequisites for entry into science, engineering and commerce courses is compounding the problem.

Less and less mathematics and statistics is being taught in many degrees and mathematical sciences departments continue to contract. Reduced mathematical content in many degrees has seriously weakened mathematical sciences in universities and is eroding Australia's skills base.

The situation in Australian universities is in stark contrast to that in the US and Europe where it is often expected that most students will take some mathematics or statistics and it will be taught by the mathematical sciences department. At the University of Delaware, 95% of the undergraduate students take some mathematics, while at the University of Oklahoma all undergraduate students are required to take at least one mathematics subject[74]. These are typical examples of US university requirements.

Conclusion

Nurturing the health and securing the future of Australia's mathematical sciences hinges on:

- ensuring an adequate supply of properly qualified mathematics teachers for all levels of schooling
- mathematics and statistics at universities being taught by qualified mathematicians and statisticians.

The two are interlinked — the teaching of mathematics and statistics discipline knowledge needs to be conducted by mathematical sciences departments. Universities with large numbers of undergraduate teacher education students but unable to offer a three-year major in the mathematical sciences are not in the nation's interest. Neither is lack of an appropriate mathematics course in primary teacher education.

All universities should have a readily identifiable mathematical sciences department able to offer a three-year sequence with the opportunity to qualify for an honours year. These departments should be teaching mathematics to intending school teachers and in all other service courses appropriate to the particular university. This would provide the critical student numbers at first year to support smaller classes at second and third year.

Emerging technologies for sharing classes across the nation means choices should be available for students even in small, remote universities.

Industry, teachers, researchers and academics must work cooperatively to improve support for mathematical sciences and encourage greater numbers of students to pursue mathematics and statistics.

Chapter Five examines the need to rebuild the mathematical sciences research base in Australia.

74 http://www.ou.edu/admrec/gened.htm

"Technological advances are often unexpected and a strong foundation in mathematics and the fundamental sciences will provide an environment that fosters creativity and innovation."

– Australian Research Council (ARC) National Research Priorities & Associated Priority Goals 2004 – 2006

Chapter Five:

THE WAY FORWARD: STRENGTHENING THE RESEARCH BASE

This chapter looks at strategies to broaden and strengthen Australia's mathematical sciences research base.

Chapter Five

THE WAY FORWARD: Strengthening the research base

Summary

The narrowing of the research base can be addressed by:

- Improving education in mathematics and statistics from primary schools to post-graduate education
- Building up core university mathematical sciences departments to a critical mass so they have the flexibility to teach three-year minimum, and preferably four-year, mathematical sciences courses
- Revisiting the funding formula to reflect the real cost of mathematical sciences teaching
- Ensuring that service teaching is the responsibility of mathematical sciences departments
- Maintaining a statistical group that ensures research across universities, including the humanities and social sciences, is valid and uses up-to-date contemporary methods
- Providing a climate that encourages new appointments and overseas collaboration to broaden the research base
- Supporting national collaborative infrastructure to broaden student options, promote research and business links and expand national and international research opportunities

Building critical mass

The nation's universities are the source of Australia's mathematical scientists. They are where researchers and teachers of the next generation are trained. They are also where fundamental mathematics and statistics that underpin future applications are developed, and their academic staff provide a valuable reservoir of existing knowledge and experience.

Reinforcing mathematical science departments in Australian universities with adequate, well-resourced permanent teaching and research positions is key to maintaining the healthy, broadly focused and adaptable high-level research capability Australia increasingly needs.

This step alone will go a long way to restoring the core of mathematical scientists required to maintain research capability following the 30.4% decline in mathematical scientists holding permanent teaching and research positions in the Go8, and even greater decline in other universities from 1995 – 2005.

Reviewing the funding formula

Viable, active mathematical sciences departments depend on students. The unintended consequences of the Relative Funding Model (RFM), its effect on service teaching and educational practices can only be addressed by changes to the way mathematics and statistics teaching is funded.

In addition, it requires action at the individual university level to ensure service teaching is conducted by mathematical sciences departments. This includes teaching appropriate courses in mathematics and statistics to primary and secondary teachers.

A change in the RFM would also enable mathematics and statistics departments to restore tutorial services and IT laboratory work. These are crucial to retain high quality teaching programs, give students key skills that industry requires and attract students into mathematical sciences.

The problems begin in schools

States and the Australian Government must work together to ensure the mathematics curriculum matches best practice internationally. The International Centre of Excellence for Education in Mathematics (ICE-EM) school mathematics program already funded by the Australian Government could assist in this area.

Concerted strategies will improve flow of properly qualified teachers. Measures should include adjustments for the increased debt incurred by well-qualified teachers as well as HECS incentives, retraining of existing teachers and support for career change professionals.

A national awareness campaign is needed to ensure that teachers, parents and students appreciate the value to Australia of mathematical sciences as a career or as a great way to enhance career options.

A draft action plan[75] has been prepared (October 2006) from a workshop held in May 2006 where concerns about career advice and mathematical science careers were raised.

Appropriate subject scaling to ensure students are not disadvantaged in university selection by taking harder subjects, will encourage them to continue with more advanced Year 12 subjects.

Maintaining a mathematical sciences department

An increased demand for mathematics courses from a better prepared school cohort must be matched by access to university mathematics and statistics courses.

There is no reason why all universities cannot have an identifiable mathematical sciences department. This is what is expected internationally.

If smaller universities co-locate their statisticians, achieve critical load by ensuring service teaching is done by mathematicians and statisticians and appoint at least one professorial position to

75 http://www.maths.org.au

ensure leadership, they will have the critical mass to support at least three-year, preferably four-year courses. They will also have the mathematical base needed to ensure quality research across the university.

With some universities currently not offering a three-year sequence in mathematics and statistics, the pipeline into honours and subsequent research has not grown in the past five years and competition for graduates from organisations outside universities has increased.

Co-locating mathematical scientists will halt another tendency that has developed which is to appoint a single statistician, biostatistician or mathematical modeller to meet a department's or centre's needs for expertise. Such appointments lead to a lack of peer support, place unreal expectations on the breadth of expertise and create difficulties in arranging academic leave. The Review fully supports the need for such appointments but believes that such staff should be co-located in a mathematical sciences department. This will build critical mass that is more flexible and adaptive to all universities' needs.

Isolation of mathematical scientists in remote areas can be largely alleviated by ensuring they are supported to, for example, spend time at a bigger centre on a regular basis.

Honours as the precursor

The honours year is the usual precursor to becoming a mathematical sciences researcher. However, honours student numbers are unacceptably low and in turn will continue to affect higher degree student numbers unless improved considerably. This depends on raising the 0.4% graduation rate, promoting the value of an honours year per se and having a wide availability of honours year mathematics and statistics courses providing for student interests and future directions. Some once quite strong departments no longer offer honours; for example, Flinders University where Professor Tao — recent recipient of the 2006 Fields medal — received his initial training.

Core mathematical sciences groups to protect skills for other disciplines

Maintaining a core mathematical sciences group as a source of expertise in universities and large research organisations ensures a reservoir of broad expertise. It also reduces the risk of other disciplines relying on past mathematical and statistical knowledge and applying outmoded approaches to increasingly complex problems.

Interaction will work best if the core group is encouraged to create 'permeable walls' that welcome shared appointments, joint projects and shared supervision of research students and junior researchers.

Mathematical sciences play a key role in interdisciplinary work, through direct involvement of mathematical scientists and indirectly by contributing to researchers in other disciplines. The role of statisticians is particularly important, spanning sciences, engineering, humanities and social sciences research.

Permeable walls and links

Mathematical scientists working in interdisciplinary projects need to keep links with other mathematical scientists. Otherwise, highly applied work may develop in ignorance of known results or recent advances in core mathematics and statistics. Further, inadequate contact between core disciplines and applications deprives the core of the stimulus that inspires new fundamental studies.

"There is a tendency for dialogue between the core and those involved in multidisciplinary research to die away to the long-term detriment of both. In the extreme form, new sub-fields develop in isolation[76]." A submission from University of New England mathematical scientists is somewhat blunter:

76 CSIRO Mathematical and Information Sciences submission to the Review

The cognate disciplines did not adapt to the computer revolution beyond Microsoft applications and are not able to adopt the developments in mathematics (applied and theoretical) that accompanied it. Examples of techniques from the past 20 years which are under-utilised in rural and environmental sciences are (i) simulation methods such as Markov chain Monte Carlo and bootstrap, (ii) non-parametric regression, (iii) wavelets, (iv) chaos. Rather, we now notice a demand from some biologists that equal status be given to defunct techniques on the basis that they are preferred by biologists (without regard to their reliability) and it seems some journals accede to this.

Broadening options

A temporary spike in ARC funding for mathematical sciences research that flowed from the Backing Australia's Ability programs in 2002, led to research-only appointments with no job security or long-term career path in Australia. This would perhaps not be so critical if this trend had occurred when universities had an adequate core of research and teaching staff and new positions were being created as core staff left. Even with the one-third erosion of permanent department staff from universities in the past 10 years, there have been few opportunities for ongoing positions.

This situation can be reversed with a national commitment to permanent research and teaching positions in mathematics and statistics in all Australia's universities.

The mathematical sciences and ARC priorities

The Australian Government's four national research priorities in 2002[77] are reflected in ARC priorities[78].

The Review notes the specific mathematical research capabilities that have been recognised and resourced by the ARC. In 2003, the ARC Centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS) was established involving five Australian universities and AMSI[79].

MASCOS conducts research in areas such as criticality and phase change, Monte Carlo methods, statistical modelling, dynamic systems, risk modelling, and advanced computation. The research supports Australia's ability to develop advanced technology for controlling traffic flows, modelling financial systems, understanding telephone and internet traffic, meteorological and oceanographic phenomena, and the behaviour of polymers and composite materials, mathematical tools for insurance industry and national security, and predicting large-scale, long-term environmental impacts.

While MASCOS is contributing significantly to research in mathematical and statistical modelling, these are specific capabilities and do not broaden Australia's overall research capability in mathematical sciences to the extent needed. A broad base of teaching and research that can only be supplied through universities is required as well.

Loss of other ARC funding

While the increase in overall ARC funding through the Backing Australia's Ability programs has been welcome, loss of the small ARC grant scheme has significantly affected some mathematical sciences departments. Within universities, general budgetary tightness has damped down replacement schemes.

Overall, increased funding for research from both the Australian Research Council (ARC) and National Health and Medical Research Council (NHMRC) as part of the Backing Australia's Ability programs saw the success rate of grant applications improve since 2002, but decline again in 2006.

77 http://www.dest.gov.au/sectors/research _ sector/policies _ issues _ reviews/key _ issues/national _ research _ priorities/default.htm

78 http://www.arc.gov.au/grant _ programs/priority _ areas.htm

79 http://www.complex.org.au

Supporting national investment

Australia is making a major investment in infrastructure for research through the National Collaborative Research Infrastructure Strategy (NCRIS)[80]. Many of these initiatives will require mathematical and statistical infrastructure that may be difficult to find.

For example, the Integrated Marine Observing System (IMOS) will collect marine data, draw it together and make it accessible to researchers and other users. However, the AAD has not been able to attract the mathematical scientists it needs.

Mathematical sciences are essential infrastructure to maximising the outcomes of NCRIS and national investment in research.

National resourcing = high-value research

Perhaps the most transparent indicator of the reality and global perception of Australia's capability in mathematical sciences research is in the fundamental research which leads to published papers. With South Korea set to pass Australia in published papers in the near future, Australia is in imminent danger of slipping in international rankings for research output. If the perception globally is of a shrinking research base in Australia, this affects the nation's ability to keep and attract industries and services, attract overseas university students and staff, and keep and attract talented individuals in a range of fields.

The review recommends a reversal of the current low and declining national resourcing of mathematical sciences research to avert this possibility. It notes significant room for improvement exists. In 2002 – 03, of the nine key research areas, mathematical sciences research received the least funding from all sources — business, government, higher education and non-profit organisations (Gross Expenditure on Research and Development (GERD) figures).

Australia is about to introduce a research assessment framework known as the Research Quality Framework (RQF). A particular danger is that it will contribute to supporting existing pockets of excellence at the expense of the larger base needed for Australia to continue to have a place on the world mathematical stage.

Promoting excellence in research

The renowned Walter and Eliza Hall Institute (WEHI) in Melbourne has appointed high level statisticians with outstanding results. The appointment of a foremost Australian mathematical statistician and probabilist, Professor Terry Speed, for half the year—he spends the other half year as Professor at the University of California at Berkeley—has had great impact.

The whole scientific culture of the WEHI as been transformed by this appointment, in part due to the great opportunities opened up by the Human Genome Project and in particular micro array and other DNA chip technologies. The statistical and design advances that have been developed by his group have revolutionised this area and had wide application from national and international research teams.

More importantly, there has been a rapid influx of high level mathematicians and statisticians who have been attracted to work with Professor Speed in this exciting environment. This has had a ripple effect across all aspects of WEHI's biomedical research, bringing higher standards of design and analysis and opening new avenues for research.

80 http://www.ncris.dest.gov.au

Also at WEHI, innovative analysis introduced by Professor John Hopper and colleagues has had international impact. The synergy from combining high level statistical skills and thinking with new molecular and genetic technologies and creative and experienced epidemiologists has rocketed Australia to the forefront of cancer genetics and positioned its clinical and genetic scientists at the cutting edge of international research.

The need for excellence in statistics and mathematics to support research needs to be recognised and fostered.

The way forward to encourage collaborative effort

Most countries with strong mathematical sciences research communities have substantial, well-funded national mathematical sciences research institutes or centres. These are different from specialist research centres such as MASCOS with a narrower focus involving mathematical scientists.

The Australian National University's Institute of Advanced Studies

The Australian National University's Institute of Advanced Studies, which included a Department of Mathematics, was originally established as a national research institute in which permanent and fixed-term researchers supervised fundamental and strategic research and trained postgraduate students. The present structure, including the Centre for Mathematics and its Applications, reflects this history. There is a good case for maintaining some additional capacity at the Australian National University. Currently, the ANU appears to have many of the same problems as other universities, a sad reflection on the Australia-wide state of mathematics and statistics.

Broadly based National Institutes

National mathematical sciences research institutes or centres such as AMSI have a more general brief. In 2005 three US-based institutes on a ten-year funding cycle had their mid cycle review and all received increases. The institutes have been called upon to ensure participation in their programs by a broad swath of the mathematical sciences community. The US National Science Foundation sees this as a way of supporting more mathematical scientists than it can through individual grants[81]. This broader view was strongly supported by Professor Peter Kloeden, who left Australia some years ago and is now in Germany[82].

The Australian Mathematical Sciences Institute (AMSI)

AMSI was established with a Victorian Government's Sciences and Technology Innovation (STI) grant in 2002[83], with infrastructure funds for three years. Although initial funding was from the Victorian Government, support from universities in all mainland States and from several non-university stakeholders, meant that it had broad national coverage from the outset.

AMSI is modelled on two successful Canadian institutes, the Fields Institute[84] and Pacific Institute for the Mathematical Sciences (PIMS)[85]. AMSI always sought to have integrated programs across research, education and industry but the ability to mount these successfully requires more funding than the participating universities can provide. Extra funding from the Australian Government provided the first two summer schools for honours and postgraduate students. Subsequent summer schools have been supported by ICE-EM, funded by the Australian government through the Department of Education, Science and Training (DEST) and managed by AMSI.

81 Allyn Jackson, Notices of the AMS, December 2005, p. 1367

82 Submission to the Review. See http://www.review.ms.unimelb.edu.au/PeterKloeden.pdf

83 The suggestion to apply for the STI grant originated from Professor Lynn Batten of Deakin University, a former Canadian who had been involved in the Canadian Fields Institute.

84 http://www.fields.utoronto.ca

85 http://www.pims.maths.ca

Core infrastructure funding from the Australian Government would mean that AMSI can continue and enhance its work in coordinating national and international research efforts and engaging State governments, industry, schools and other stakeholders.

In the longer term, as mathematical sciences are rebuilt, Australia should aspire to a number of institutes and centres of excellence as in Canada.

Strong education program

In 2006, AMSI has a strong education program because of ICE-EM. At this time AMSI's core programs in research and industry have no government support but rely on subscriptions from members and a small income from emerging business partnerships and other grants. It is not able to participate equally in collaborative programs with mathematical sciences institutes of Britain, Europe, North America, Asia or even New Zealand. Nor is it able to devote enough time to engaging mathematical scientists on industrial problems. AMSI conducts industry forums and brokers linkage projects and consulting jobs to help industry. However, experience shows that devoted personnel are required to achieve long-term benefit[86].

AMSI plays a major role in promoting collaboration across mathematical sciences but does not currently fulfil the role envisaged for a national centre of the scope of Fields or PIMS. It has developed extensive international links that, fully exploited, have potential to greatly enhance mathematical research in Australia in universities and industry.

Collaborative approach

For example, AMSI and MASCOS have a memorandum of understanding with the Canadian network Mathematics of Information Technology and Complex Systems Network of Centres of Excellence (MITACS). Links are being forged with the Atlantic Association for Research in the Mathematical Sciences (founded 1996), a cooperative exercise of six universities in eastern Canada, supported also by the Fields Institute, Centre de Recherches Mathématiques (CRM)[87] and PIMS.

In the long term, the mathematical sciences community would expect more research-focused centres to be established. In the current climate, such a development would likely provide a haven for a select few and contribute to further problems with university teaching. Further, AMSI's experience is that it is difficult in the current Australian climate to support extended thematic programs of the type common in other institutes. Academics cannot get away from their institutions for enough time to either manage a program or participate.

The Review believes the more broadly based Canadian institutes continue to be the best model for Australia. AMSI is an established entity with membership covering most university mathematical scientists, as well as CSIRO, Australian Bureau of Statistics and the Australian Mathematics Trust. It provides a base from which to extend and grow.

Long-term commitment

Global demand for the very best mathematics and statistics talent means that to run programs in Australia using the very best people available, arrangements need to be made two to three years ahead.

In 1972 the Australian Institute of Marine Sciences (AIMS) was established as a statuary authority and continues to thrive. It is a model that could be emulated, albeit with a more modest budget as the mathematical sciences do not need ships or expensive research laboratories. However, AMSI and the mathematical sciences do need the same sense of commitment and permanence that AIMS continues to enjoy.

86 More details on AMSI and ICE-EM are available at <http//:www.amsi.org.au>

87 http://www.crm.umontreal.ca

Building on existing structures

AMSI has already established a role coordinating nationally networked activities in mathematical sciences research, research training, education and industrial mathematics, and as a sponsor of conferences and workshops, as well as individual visitors.

By sharing resources and coordinating activities, AMSI has helped bring three centres of excellence into being. The first was MASCOS and the second ICE-EM. The third is the Australian Centre of Excellence for Risk Analysis, established in 2006 with Australian Government funding by the Bureau of Rural Sciences in the Department of Agriculture, Fisheries and Forestry.

Despite its short history, AMSI's accomplishments to date clearly show the value of a dedicated national mathematical sciences institute with central infrastructure but devolved activity.

Improving student mobility

There needs to be much greater movement between universities and, ideally, PhDs undertaken in major centres of research. Larger, better resourced mathematical sciences departments make that possible. Potential higher degree candidates who cannot move from regional universities are already starting to have improved options through courses delivered via Access Grid Rooms (AGRs)[88]. AGRs are rooms allowing interaction between Australian sites or with overseas ones, and at all levels between students, lecturers and tutors. University mathematical sciences departments are being supported through ICE-EM to install AGRs. The first three shared honours courses, involving Wollongong, La Trobe and University of South Australia have been completed.

The annual national ICE-EM/AMSI Summer School for honours students has been a major success in improving course offerings and enabling students to meet their peers. These collaborative ventures can help universities maintain or restore an honours program.

Stated concerns — research training

Concerns about research training raised in the Review include a need for graduate course work, concern that the duration of Australian Postgraduate Awards makes course work components problematic, lack of mobility of graduate students encouraging 'inbreeding', and the honours year being used as training for a department's postgraduate program.

Some good practice is at risk. In comments to the Review, the Head of one mathematical sciences department said: "The department previously followed a policy of encouraging good students to consider other Australian and overseas institutions for PhD studies, possibly to its disadvantage… A significant factor in low recruitment is the lack of recommendation for students by staff at other Australian universities, especially as the pool of Australian PhD students appears to have dwindled over the past decade[89]."

Masters in mathematics and statistics

The current financial incentive for students to be encouraged to complete a PhD rather than a Masters course by either research or course work may not always be in the interests of the students. Business and industry may be better served in some cases by Masters courses and should be encouraged to support appropriate initiatives. As noted previously, some government agencies such as the Australian Bureau of Statistics and the Australian Bureau of Meteorology already do this.

Strengthening the PhD experience

The typical Australian PhD is narrowly focused on a single research project. Some involving industry partners expose students to a broader experience but there has been serious lack of the kinds of postgraduate course work options that are the norm in other parts of the world.

88 http://www.ice-em.org.au/AGR/index.html

89 Confidential comments to the Review

The ANU used to be able to provide some courses and more recently the ICE-EM Australian Graduate School in Mathematics[90] has gained praise from participants[91]. Funding for the ICE-EM program past 2007 is currently in doubt although it has started to attract overseas students.

Graduate schools have an important role to play by enhancing the PhD experience, attracting overseas students, and providing opportunities for existing academics and post-doctorates to learn about new areas of mathematics.

As an alternative to the incorporation of course work into the PhD program, students could be encouraged to take a two-year, largely course work based Masters degree in place of the now-standard honours year as their pathway into the PhD program. Current funding arrangements make the lengthening of the PhD program by incorporating course work, or the use of the Masters degree pathway into the PhD, difficult.

Encouraging Honours and postgraduates from overseas

Tuition fees in Australia are among the highest in the world[92]. Australia is competing for students in a market where it is common for scholarships and tuition waivers to be offered. This is what has kept the research training climate so healthy in the US, and why many talented young Australian mathematics and statistics graduates are now in the US.

Critical mass to cover fundamentals

No single institution in Australia currently maintains a mathematical sciences department large enough to cover comprehensively all major areas in mathematics and statistics, and even several universities in the same city considered as a single entity give patchy coverage of major discipline areas. It is essential that all major disciplines be covered in Australia, and that effective communication allows expertise to be accessed beyond the city where it is located.

Especially in smaller institutions or rural or regional areas, it may be natural to achieve depth in research by specialising in an application related to an external stakeholder. However, it is a mistake to completely remove competence or research capacity in fundamental areas. One of the international reviewers summarises the danger as follows: “Banishing pure mathematicians from departments could be said to be like wishing to grow trees without trunks.”

The lack of advertisements for pure and applied mathematicians as these academics leave is cause for grave concern. The same cautionary note applies to fundamental areas of probability and mathematical statistics on which applied statistics rest, and to more theoretical aspects of operations research.

It is possible to turn things around. The planned expansion over time at Vanderbilt University, Tennessee, US and the success of this is one example[93].

The size of mathematical sciences enterprise in Canada shows what is possible. An outstanding example is the University of Waterloo, Ontario, claimed to be the biggest mathematical group in the world[94]. Professor Chris Radford left the now struggling University of New England, NSW to head the Memorial University of Newfoundland’s Department of Mathematics and Statistics with more than 34 PhDs on staff[95]. Both UNE and Memorial University have about 17 000 students, but by late 2006 UNE had only eight mathematics and statistics staff.

Excellence in mathematics and statistics teaching does not necessarily mean large, as Harvey Mudd College in the US has shown through its programs and teaching awards[96].

90 http://www.ice-em.org.au/students.html
91 http://www.austms.org.au/Publ/Gazette/2006/Nov06/winterschool.pdf
92 OECD, Education at a Glance 2006, p.38
93 http://in-cites.com/institutions/VanderbiltUnivDepMath.html
94 http://www.math.uwaterloo.ca
95 http://www.math.mun.ca/
96 http://www.math.hmc.edu/

Enhancing industry and organisational research

AMSI and MASCOS and their emerging cooperative ventures with industry suggest an Australian MITACS could emerge from a stronger mathematical sciences base. MITACS is the Canadian industrial mathematics network. The first joint AMSI/MASCOS/MITACS workshop will take place in 2007.

AMSI is assisting member institutions in applications for ARC Linkage grants.

Industry – research interaction

Organisations working away from major population centres, such as the Australian Antarctic Division (AAD) cannot source the mathematical expertise they need. AAD recommends a postdoctoral-level mathematical modelling program to train modellers to meet the enormous demand. This will require coordination across university providers.

BHP Billiton would welcome extra support for universities to promote study of operations research and optimisation in graduate courses. It recommends higher priority being assigned to ARC Professorial and Federation Fellow appointments in these areas.

On a modest scale, several university-based research groups have created their own centres with industry partners, including the University of South Australia and Curtin University, WA. The University of Adelaide has run a very successful Teletraffic Centre for a considerable period.

The Mathematics-in-Industry Study Group (MISG) annual workshop has run in Australia and New Zealand for more than 20 years. Groups of mathematical scientists and other researchers or industry representatives collaborate on selected industrial problems for which a mathematical or statistical approach has potential merit. The Review felt MISG would work better as part of a broad industry group.

Small and medium enterprises were represented at some Review meetings. They noted that opportunities exist for consulting but it is not always done well. Interacting with university intellectual property and commercialisation arms was perceived as very difficult.

Knowledge precincts

In his meeting with the Review Working Party, the Queensland chief scientist Professor Peter Andrews stressed the importance of partnerships between government, academic enterprises and industry and is especially proud of the Queensland government's success in producing knowledge precincts. He acknowledged the role of mathematics and statistics in this new biological age. Professor Andrews also suggested forming a large grouping, including, for example, the BHP Billiton group, CSIRO, possibly some part of DSTO, on one site with AMSI. Such a grouping would need to follow from a greatly enhanced capability across Australia or it may deplete expertise, especially that available to SMEs not close to the site.

The Review shares with CMIS the view that stronger interactions with universities are highly desirable. The Australian Bureau of Statistics (ABS) is upgrading its videoconferencing facilities to AGRs. Developments such as this have potential to greatly enhance university, agency and industry research collaboration and research training.

Mathematical societies as information providers

AustMS and ANZIAM annual meetings need to be structured to ensure that industry and other stakeholders are regularly invited to explore recent theoretical developments or compelling applications.

The Review found other professional societies involving mathematical science stakeholders better connected to the wider community, but the observations about AustMS and ANZIAM still applied to a lesser extent to the Statistical Society of Australia, Inc. and Australian Society for Operations Research.

Conclusion

The nation's universities are the source of its mathematical scientists, where researchers and teachers of the next generation are trained and where fundamental mathematics and statistics that underpin future applications are developed.

The key to ensuring a strong mathematical science research future for Australia therefore lies in strengthening university mathematical sciences departments.

This means appointing and supporting permanent research and teaching staff and ensuring collaboration — within and across research institutions and with industry.

It also means support of autonomous mathematical science departments in universities to ensure strong cover of major disciplines and reduce researcher isolation. This will also broaden research options and ensure other faculties, research organisations, industry and Australia are well placed to lead critical thinking and keep abreast of new developments.

The way forward to ensure a viable core of high-level research for Australia is:

- increasing permanent staff and guaranteeing viable, autonomous mathematical sciences departments at every university
- protecting Australia's publications record by resourcing permanent teaching and research staff and autonomous departments
- reviewing funding to take into account the cost of teaching mathematical sciences to the highest international level to improve honours student numbers
- protecting fundamental mathematical science research.

The immediate way forward is to improve funding to university mathematical sciences departments. This should be supported by improved funding for national mathematical sciences infrastructure, networking and collaboration, including ongoing support for AMSI.

In the longer term, Australia should aspire to a mathematical sciences base commensurate with that of Canada. This would mean new collaborative ventures, possibly in conjunction with State governments or industrial partners to meet local needs.

Chapter 6 contains recommendations and strategies to restore the international standing of Australian mathematical sciences and ensure its future value for Australia.

"The mathematical sciences in Australia require an immediate and substantial capital injection to build a critical mass of research, education, industry and government interaction, and ensure we maintain our technical and problem-solving capability. This must be followed up with significant annual funding to maintain a healthy mathematics and statistics infrastructure for national benefit."

Chapter Six:

A BOLD PLAN: TO SECURE AUSTRALIA'S HIGH-END SKILLS BASE

This chapter commends a strong action plan for immediate implementation.

Chapter Six

A BOLD PLAN: to secure Australia's high-end skills base

The Review was charged with recommending a strategy for mathematical sciences over the next 10 – 15 years.

The Review has found immediate action is required if Australia's high-end skills and innovation base is to be maintained and expanded.

To ensure Australia maintains its technical and problem-solving capability, a critical mass of mathematical sciences research is needed that supports education, industry, business and government agencies. Across Australia and in many universities, critical mass needs to be rebuilt.

The Review identifies two linked priorities for immediate implementation[97]:

1. strengthening and rebuilding mathematical sciences departments in universities
2. providing ongoing national infrastructure support for mathematical sciences.

97 The full list of recommendations is on pages 14 – 15

"As a matter of urgency, to reconsider the Relative Funding Model to ensure a more equitable funding arrangement for statistics in universitites, bringing funding for statistics courses into line with the current funding levels for computer science courses."

– Recommendation to the Federal Minister for Education, Science and Training from the 2005 Review of Statistics[100]

Immediate priorities

Priority 1— The funding model

The present Review and a 2005 review of statistics[98] identified the Discipline Funding Model[99] as the major driver of:

- contraction of university mathematics and statistics departments and discipline groups
- poor pedagogical practices.

An immediate injection of additional, ongoing funding per student to university mathematical science departments to raise funding levels to that of computer science would have an immediate impact. The estimated cost would be $17 million a year.

Government would need to work closely with Vice-Chancellors to ensure this new money supported ongoing academic teaching and research positions in mathematical sciences. Vice-Chancellors also need to ensure that service teaching of mathematics and statistics is delivered by mathematical sciences departments and discipline groups.

This capital injection would achieve:

- three-year core mathematics courses at all universities
- maintenance of autonomous mathematics and statistics departments
- permanent academic staff appointments
- service teaching capability
- raising graduate percentages above 0.4% to the 1% OECD average
- improvements in provision of tutorials and computer laboratory work.

98 Statistical Society of Australia Inc, Statistics at Australian Universities: An SSAI-sponsored Review, December 2005

99 See Explanatory Notes, Appendix 2.

100 Statistical Society of Australia Inc, Statistics at Australian Universities: An SSAI-sponsored Review, December 2005

Priority 2— Funding for national infrastructure

National mathematical sciences institutes are recognised internationally as the most appropriate research infrastructure for mathematicians and statisticians. Mathematical scientists require only modest quantities of research equipment, but the potential value and impact of their work can only be harnessed effectively if they have a vehicle for interaction, collaboration and delivery of frontier-breaking advances to Australia.

Australia's mathematical sciences community proactively shared resources and increased the effectiveness of a necessarily dispersed enterprise. This cooperation has led to formation of the Australian Mathematical Sciences Institute (AMSI), presently funded by about thirty institutions.

The required national infrastructure could evolve from AMSI and increased ongoing funding for AMSI will preserve and expand national collaborative ventures already in place. Supporting AMSI to attain international standards would cost about $2.5 million per year.

Key, lasting outcomes would include:

- use of Access Grid Rooms to improve course offerings
- introduction of semester length theme programs to build research and teaching capability, especially in newer areas
- collaboration between the Centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS), and AMSI, the Canadian Mathematics of Information Technology and Complex Systems (MITACS)
- ongoing support for honours and postgraduate students, including summer and winter schools and workshop and conference participation
- creation of industry internships
- support for mathematicians and statisticians in promoting mathematical sciences careers
- liaison with industry users to ensure mathematics and statistics departments achieve best across-discipline outcomes
- visits by international experts
- networking with the best mathematicians and statisticians overseas.

As mathematical sciences are rebuilt, new institutes and research networks should be initiated, possibly with some State Government investment to meet local needs.

Additional concerns

The 2006 Review's main concern has been Australia's mathematical sciences research capacity. Ultimately this depends on the quality of school mathematics education.

The Review draws particular attention to the need for improved flow of well-qualified mathematics secondary school teachers. While short-term solutions must be sought at this stage, the long-term solution rests with improving university mathematical science graduate numbers.

Improvements to school mathematics subjects and student achievement levels will not only nurture future mathematical sciences researchers, but also prepare many other young Australians for careers in which mathematics and statistics play a major role.

Recap on Review recommendations

The Review's five key recommendations are outlined in the Executive Summary.

Australia must:

1. significantly increase the number of university graduates with appropriate mathematical and statistical training
2. broaden the mathematical sciences research base
3. identify, anticipate and meet industry needs for a pool of tertiary-trained expert mathematicians and statisticians
4. ensure all mathematics teachers in Australian schools have appropriate training in mathematics and statistics disciplines to best international standards
5. encourage greater numbers of high school students to study intermediate and advanced mathematics.

Implementation

Recommendations are linked to suggested actions, responsibilities and key performance indicators (KPIs) in the following pages. Some actions are short term, achievable within a year or less. Others recognise that improvements in, for example, primary education, will take years to influence outcomes at graduate and research level. There is considerable overlap; an action to address one recommendation may also address another. The relevant parts of each recommendation are therefore mapped against actions.

Responsibility for implementing key Review recommendations lies with many stakeholders, including the Australian Government and State Governments, universities, business and industry, and mathematics and statistics departments.

Immediate and concerted action is essential. The solutions are affordable. It is the failure to respond that Australia cannot afford.

Action Plan: Rebuilding Australia's mathematical sciences base

Review Recommendation	Action	Commended To	KPIs
1a 1c 2a	Change the discipline funding model (RFM) Increase permanent academic staff numbers	Australian Government Vice-Chancellors (VCs) Departments	Staff – student ratios improved More courses offered More tutorials and computer laboratory use Number of new appointments More applications from talented mathematicians and statisticians from abroad
1a 1c 2a	In smaller universities: 1. Co-locate isolated statisticians and mathematics staff 2. Ensure at least one professorial appointment 3. Use Access Grid Rooms and share resources to increase course offerings All universities: Ensure appropriate mathematical and statistical consulting infrastructure	VCs and Deputy VCs (Research) AMSI/ICE-EM and mathematical sciences departments	Number of universities with at least one professor of mathematical sciences Number of courses offered Number of universities offering 3 years of mathematics and statistics Student load in mathematics and statistics Percentage of mathematical sciences graduates
1b	Ensure service teaching of mathematics and statistics is performed by mathematicians and statisticians Ensure appropriate course offerings through liaison with service departments and collaboration between institutions	VCs and DVCs (Academic) Mathematical sciences departments	Service courses taught in mathematical sciences departments
2a 2b 2c	Adequate funding to support the research of new staff, networking and interdisciplinary collaboration Support interdisciplinary and collaborative research in emerging areas	ARC, NHMRC, other funding agencies, Vice-Chancellors	Number of national competitive grants Grants application success rate New interdisciplinary projects
2d	Fund national mathematical sciences infrastructure	Australian Government State Governments	Ongoing support for AMSI Development of other national or statewide initiatives

Review Recommendation	Action	Commended To	KPIs
2d 3a 3b 3c 3e	Improve industry support and interactions: Create internships Provide short courses	AMSI/MASCOS Mathematical sciences deptartments State Governments	Number of internships Number of linkage grants Number of short courses
3d	Increase engagement of mathematical scientists with the wider university community	Mathematical sciences departments Deans VCs	Number of departmental industry advisory committees Shared supervision of postgraduates
4a 4b 4c	Upgrading skills of existing teachers Financial and other support for career change professionals with mathematics background Incentives for mathematics graduates	Australian, State and Territory Governments	Fewer schools reporting difficulties with finding mathematics teachers More students achieving at higher levels, and fewer at very low levels (TIMSS data)
4a 4c	Appropriate course development for teachers Accreditation of school mathematics teachers at all levels	Australian, State and Territory Governments, mathematical sciences deptartments, education faculties, ICE-EM	Number of accredited teachers
5a 5b	Appropriate secondary mathematics syllabuses National campaign to promote mathematical sciences and careers	Australian and State Governments, ICE-EM Australian, State and Territory Governments in association with professional societies, ABS, CSIRO and Industry	Year 12 mathematics enrolment patterns Number of students studying tertiary mathematics or statistics
5c	Reward participation in more advanced school mathematics subjects through tertiary entrance ranks and university selection procedures	State Government authorities and universities	Number of students taking advanced mathematics in Year 12 Mathematics prerequisites for university courses

APPENDICES

Appendix One

Abbreviations and acronyms

AAD	Australian Antarctic Division
AAS	Australian Academy of Science
ABS	Australian Bureau of Statistics
ACERA	Australian Centre of Excellence for Risk Analysis
AGR	Access Grid Rooms
AMSI	Australian Mathematical Sciences Institute
AMSC	American Mathematical Society Classification
ANU	Australian National University
ANZIAM	Australian and New Zealand Industrial and Applied Mathematics, a division of the Australian Mathematical Society
ARC	Australian Research Council
ASOR	Australian Society for Operations Research
ATN	Australian Technology Network
AustMS	Australian Mathematical Society, Inc.
AVCC	Australian Vice-Chancellors' Committee
BSc	Bachelor of Science
CMIS	CSIRO Mathematical and Information Sciences
CMSA	Combinatorial Mathematics Society of Australasia
CRM	Centre de Recherches mathématiques, Montréal, Canada
CSP	Commonwealth Supported Place
DEST	Department of Education, Science and Training
DSTO	Defence Science and Technology Organisation
EU	European Union
FASTS	Federation of Australian Scientific and Technological Societies
Go8	Group of eight (universities)
GDP	Gross Domestic Product
GERD	Gross Expenditure on Research and Development
HECS	Higher Education Contribution Scheme
HERD	Higher Education Expenditure on Research and Development
IAA	Institute of Actuaries of Australia
ICIAM	International Council for Industrial and Applied Mathematics
IMU	International Mathematical Union
IRUA	Innovative Research Universities of Australia
MASCOS	ARC Centre of Excellence for the Mathematics and Statistics of Complex Systems
MITACS	Mathematics of Information Technology and Complex Systems network, Canada
NHMRC	National Health and Medical Research Council
OECD	Organisation for Economic Cooperation and Development
OR	Operations Research
PhD	Doctor of Philosophy
PIMS	Pacific Institute for the Mathematical Sciences
RFM	Relative Funding Model
RQF	Research Quality Framework
RTS	Research Training Scheme
SSAI	Statistical Society of Australia, Inc.
TIMSS	Trends in International Mathematics and Science Study

Appendix Two

Explanatory notes

University groupings

Membership of three important 'peer groups' of universities:

Group of Eight (Go8), the Innovative Research Universities of Australia (IRUA) and the Australian Technology Network (ATN)

Go8	IRUA	ATN
University of New South Wales	Macquarie University	University of Technology Sydney
University of Sydney	University of Newcastle	RMIT University
Monash University	Latrobe University	Queensland Univ. of Technology
University of Melbourne	Griffith University	University of South Australia
University of Queensland	Murdoch University	Curtin University of Technology
University of Western Australia	Flinders University	
University of Adelaide		
Australian National University		

Other public universities created before 1987:
University of Tasmania
University of New England
University of Wollongong
James Cook University

Other public universities created from 1987 onwards:

Largely capital city universities	**Essentially regional universities**
Swinburne University of Technology	Charles Darwin University
Deakin University	University of Ballarat
Victoria University of Technology*	Charles Sturt University
University of Western Sydney	Southern Cross University
Edith Cowan University	Central Queensland University
University of Canberra	University of Southern Queensland
	University of the Sunshine Coast

** Now renamed Victoria University*

Mathematics and Statistics and the Discipline Funding Model

In 1989 the institutionalised distinctions between colleges of advanced education and the 19 pre-existing universities were removed by the then Minister of Education, John Dawkins. One of their biggest distinctions was their funding levels.

Historical expenditure patterns were analysed and adjusted to give a relative teaching cost matrix that became known as the Relative Funding Model (RFM). The RFM had two main factors in its calculations: discipline groups and program levels. There were five groups and mathematics and statistics were in the second lowest level for undergraduate teaching and on the lowest for research degrees and other postgraduate courses.

Thus mathematics and statistics were funded on a historical model that took no account of the increased costs of a more diverse student population and a new development of needing to equip computer laboratories. The AVCC was apparently asked to report on the RFM in 1999 and still hasn't.

The problems inherent in the original model remain. In 2005 the Commonwealth Course Contribution Schedule replaced the RFM, which DEST confirmed was basically the old RFM.

In the present Discipline Funding Model, mathematics and statistics are weighted at 1.3 whereas computer science is weighted at 1.6. However, the actual Commonwealth course contribution to universities is close to $5,000 for mathematics and statistics as compared with $7,400 for computer science. All other sciences and engineering are weighted at $12,300 per student at 2005 rates.

The model is built on a relatively homogenous student body being taught in large lectures supplemented by tutorials. It takes no account of the laboratory component of a modern mathematics or statistics course or the need for multiple courses to cater for student with different mathematical backgrounds and diverse course needs relating to other discipline areas.

TIMSS benchmarks

The Trends in International Mathematics and Science Study (TIMSS) 2003 is the third comparison of mathematics and science achievement carried out since 1995 by the International Association for the Evaluation of Educational Achievement (IEA).[101]

The TIMSS benchmarks for student achievement are defined as follows.

- **Below –** students have not met minimum level of basic mathematical knowledge
- **Low –** students have some basic mathematical knowledge
- **Intermediate –** students can apply basic mathematical knowledge in straightforward situations
- **High –** students can apply their understanding and knowledge in a wide variety of relatively complex situations
- **Advanced –** students can organise information, make generalisations, solve non-routine problems, and draw and justify conclusions from data.

101 http://nces.ed.gov/timss

Appendix Three

Terms of Reference

The National Strategic Review of Mathematical Sciences Research in Australia was conducted by a Working Party appointed by the National Committee for the Mathematical Sciences of the Australian Academy of Science. The Review had the following terms of reference:

To prepare a strategy for the mathematical sciences in Australia over the next 10 to 15 years which will:

- Ensure an internationally competitive and sustainable research base in the mathematical sciences which values theory, application, and interdisciplinary activity;
- Stimulate mutually beneficial interactions among academia, business, industry, government, research institutions and other users of the mathematical sciences; and
- Ensure a supply of appropriately trained researchers in the mathematical sciences to fulfil the needs of business, industry, government, research institutions, universities, and other organisations.

A. Mathematical Sciences Research

To make recommendations on research in the mathematical sciences that advance those sciences and contribute to the scientific, economic and cultural welfare of Australia.

To determine the degree to which an internationally competitive fundamental research base is required in all branches of the mathematical sciences in Australia.

To identify areas of current and anticipated strength and weakness in research in the mathematical sciences in Australia, in light of Australia's strategic needs.

To evaluate the effects of participation in collaborative national and international research ventures in the mathematical sciences.

To evaluate benefits and challenges arising from interdisciplinary research involving the mathematical sciences.

To identify any factors which impinge on the quantity and quality of research in the mathematical sciences.

To recommend actions which will, now and in the next decade:

(a) provide appropriate funding for research in the mathematical sciences and for interdisciplinary research involving the mathematical sciences, and

(b) ensure the ongoing intellectual health of the mathematical sciences.

B. Provision of Advanced Mathematical Services

To make recommendations on the provision of advanced services in the mathematical sciences, including mathematical and statistical research and consulting, and advanced mathematical and statistical training, to business, industry, government, research institutions, and other users in Australia.

To examine how advanced services in the mathematical sciences contribute to other fields of endeavour, and to assess the benefits of the nation's investment in the mathematical sciences.

To determine the areas of the mathematical sciences most used by business, industry, government, and other organisations, and identify those most likely to be needed in the next decade.

To identify strengths and weaknesses in the provision of advanced services in the mathematical sciences in Australia.

To identify any factors which impinge on the provision of and demand for advanced services in the mathematical sciences.

To recommend policy and funding changes that will:

(a) enable the mathematical sciences community to offer better services to business, industry and government and other organisations,

(b) facilitate the uptake of advanced services in the mathematical sciences by organisations that may benefit from the use of these, and

(c) improve communication and mobility between the academic mathematical sciences community and business, industry and government.

C. Infrastructure

To make recommendations for structural modifications and resource allocations to implement the recommendations in A and B above.

To assess the flow of high quality students into training and research in the mathematical sciences and areas utilising the mathematical sciences.

To investigate human resource issues associated with mathematical, statistical and interdisciplinary research and the provision of advanced services in the mathematical sciences.

To assess educational programs in the mathematical sciences leading to the training of researchers and the delivery of advanced services in the mathematical sciences to business, industry and government.

To examine how computing, communications and information technology have influenced research and training and the provision of advanced services in the mathematical sciences.

To examine current government support for research and for the provision of advanced services in the mathematical sciences.

To identify any other infrastructural factors which impinge on the quality and quantity of research and the provision of and demand for advanced services in the mathematical sciences.

To make recommendations to:

(a) improve educational programs in the mathematical sciences,

(b) ensure that an adequate supply of appropriately trained people will be available to meet the nation's needs over the next ten to fifteen years, and

(c) direct future support to areas of priority, quantifying any increase in required funding.

Appendix Four

Review Personnel

A. International Members of the Working Party

Professor Jean-Pierre Bourguignon, Director, Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France

Dr Brenda Dietrich, Director, Mathematical Sciences, IBM Thomas J Watson Research Center, Yorktown Heights, New York, US

Professor Iain M Johnstone, Department of Statistics, Stanford University, Stanford, California, US

B. Local Members of the Working Party

Chair: Professor Hyam Rubinstein FAA, Department of Mathematics and Statistics, University of Melbourne

Professor Peter Hall FAA FRS, Mathematical Sciences Institute, Australian National University

Executive Director: Associate Professor Barry Hughes, Department of Mathematics and Statistics, University of Melbourne

Dr Edwin van Leeuwen, Manager, Exploration Technologies, BHP-Billiton

Ms Jan Thomas, Executive Officer, Australian Mathematical Sciences Institute

C. The Advisory Council

Chair: Professor Michael Cowling FAA, President, Australian Mathematical Society Inc., School of Mathematics, University of NSW

Dr Neville Bartlett, Past-president, Statistical Society of Australia, Inc., NR Bartlett Consulting, Baranduda, Victoria

Professor Kaye Basford, President, Statistical Society of Australia, Inc., School of Land and Food Sciences, University of Queensland

Professor Andrew Bassom, School of Mathematics and Statistics, University of Western Australia

Professor Nigel Bean, School of Mathematical Sciences, University of Adelaide

Professor Philip Broadbridge, Director, Australian Mathematical Sciences Institute

Professor Lou Caccetta, President, ASOR (Australian Society for Operations Research), School of Mathematics and Statistics, Curtin University

Dr Murray Cameron, Chief, CSIRO Mathematical and Information Sciences

Professor John Coates FRS, Centre for Mathematical Sciences, University of Cambridge, England

Professor Marston Conder FRSNZ, Department of Mathematics, University of Auckland, New Zealand

Ms Teresa Dickinson, Head, Policy Secretariat Branch, Australian Bureau of Statistics

Ms Judith Downes, ANZ Banking Group

Professor Garth Gaudry, Director, International Centre of Excellence for Education in Mathematics

Professor Nalini Joshi, School of Mathematics and Statistics, University of Sydney

Professor Peter Taylor, President, Australia and New Zealand Industrial and Applied Mathematics, Department of Mathematics and Statistics, University of Melbourne

Dr Les Trudzik, Director, The Allen Consulting Group, Melbourne

Appendix Five

Documentation

The Working Party solicited written material for the Review in two forms: questionnaires tailored for specific types of stakeholder and other written submissions.

Representatives of most organisations that submitted material, and many of the individuals who made submissions, met with the Working Party during its national tour in February 2006.

A. Questionnaires

Questionnaires for Professional Associations

Australian Computer Society Inc.

ANZIAM (Australia and New Zealand Industrial and Applied Mathematics)

Combinatorial Mathematics Society of Australasia

Institute of Actuaries of Australia

Statistical Society of Australia Inc.

Questionnaires for Research Centres

ARC Special Research Centre for Ultra-Broadband Information Networks (CUBIN)

Centre for Industrial and Applied Mathematics, University of South Australia

Questionnaires for Companies and Government Organisations

Australian Bureau of Statistics

BHP Billiton

Data Analysis Australia

Sunoba Renewable Energy Systems

Sydac Pty Ltd

Questionnaires for University Mathematical Sciences Departments or Discipline Groups

Faculty of Business & Informatics, Central Queensland University

School of Science, Griffith University

School of Mathematical Sciences, Queensland University of Technology

Discipline of Mathematics, School of Physical Sciences, University of Queensland

Department of Mathematics & Statistics, Charles Sturt University

Department of Mathematics, Macquarie University

School of Mathematical & Physical Sciences, University of Newcastle

School of Mathematics, Statistics & Computer Science, University of New England

School of Mathematics, University of New South Wales

School of Mathematics & Statistics, University of Sydney

Department of Mathematical Sciences, University of Technology, Sydney

School of Quantitative Methods & Mathematical Sciences, University of Western Sydney

School of Mathematics & Applied Statistics, University of Wollongong

School of Engineering & Information Technology, Deakin University

Departments of Mathematics & Statistical Sciences, Latrobe University (Bundoora)

School of Mathematical Sciences, Monash University

School of Mathematical & Geospatial Sciences, RMIT University

Department of Mathematics & Statistics, University of Melbourne

School of Computer Science & Mathematics, Victoria University

School of Mathematical Sciences, University of Adelaide

School of Mathematics & Statistics, University of South Australia

School of Engineering & Mathematics, Edith Cowan University

School of Engineering Science, Murdoch University

School of Mathematics & Statistics, University of Western Australia

Australian Defence Force Academy

Centre for Mathematical Analysis, Australian National University

School of Finance & Applied Statistics, Australian National University

Appendix Five continued

B. Written Submissions[102]

Professor Richard Huggins, Professor of Statistics, University of Melbourne

Professor Peter Hall, Australian National University

Dr Jane M Watson, Reader in Mathematics Education, University of Tasmania

Dr John F Dodgson, Chief Executive Officer, Australian Academy of Technological Sciences and Engineering

Centre for Mathematics and Its Applications, Australian National University

Associate Professor David Panton and others, School of Mathematics & Statistics and Centre for Industrial & Applied Mathematics, University of South Australia

Mr Will Morony, Executive Officer, Australian Association of Mathematics Teachers

Prof Dr Peter E Kloeden, Institut fuer Computerorientierte Mathematik, JW Goethe Universitaet, Frankfurt am Main, Germany

Associate Professor James Franklin, School of Mathematics, University of New South Wales

Associate Professor Albert J Gabric, Faculty of Environmental Sciences, Griffith University

Professor Rod Downey, Victoria University of Wellington, New Zealand

School of Mathematics and Statistics, University of Sydney

Professor Gus Lehrer, University of Sydney

Professor Tony Guttmann, Director, ARC Centre of Excellence for Mathematics and Statistics of Complex Systems

Dr Andrew Constable, Australian Antarctic Division

CSIRO Mathematical and Information Sciences

Professor Tony Dooley, President of the Academic Board, University of New South Wales

Professor Richard Coleman, Quantitative Marine Science Program, University of Tasmania

Dr John Louis, Department of Mathematics & Statistics, Charles Sturt University

Dr Ian Roberts, School of Engineering & Logistics, Charles Darwin University

University of New England mathematical scientists

Australian Mathematical Society

Professor John Carlin, School of Population Health, University of Melbourne

Dr Justin Sawon, State University of New York at Stony Brook, U.S.A.

Professor Nick Wormald, Department of Combinatorics and Optimization, University of Waterloo, Canada

Emeritus Professor David Lee, University of South Australia

Dr Warren Marwood, Defence Science Technology Organisation

Dr Garry Newsam, Defence Science Technology Organisation

Australian Mathematical Sciences Institute

School of Mathematics and Statistics, University of New South Wales

Professor Louis Chen, Director, Institute for Mathematical Sciences, National University of Singapore

102 Listed in order of receipt of the first version of the submission; in some cases a revised or expanded version was received later. Some of these submissions are available at http://www.review.ms.unimelb.edu.au

Edited by Wolfe Words & Sage Words **Designed by** DesignGrant **Printed by** John Herrod & Associates

"In this ever more competitive global economy, Australia's science, engineering and technology skills need to match the best in the world."
— **Prime Minister John Howard,** speech in Sydney, 18 September 2006

"Every advanced industrial country knows that falling behind in science and mathematics means falling behind in commerce and prosperity."
— **Gordon Brown, UK Chancellor of the Exchequer,** Budget speech, March 2006

CONTACTS

Review Executive Director
Associate Professor Barry Hughes,
Department of Mathematics and Statistics,
The University of Melbourne
T: +61 3 8344 5557
E: hughes@ms.unimelb.edu.au

Chair of Working Party
Professor Hyam Rubinstein,
Department of Mathematics and Statistics,
The University of Melbourne
T: +61 3 8344 5550
E: rubin@ms.unimelb.edu.au

www.review.ms.unimelb.edu.au

Australian Academy of Science