AMS Revised Academic Plan for 2005–11

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1 Maintaining and Building Excellence

Over the next five years the Department of Applied Mathematics and Statistics[1] (AMS) will help UCSC to

- strengthen the campus position as a major research university, by building on our already-recognized excellence in mathematical biology, mathematical astrophysics, control theory, and Bayesian statistics (nonparametrics, spatial-temporal modeling, and computationally-intensive methods of inference, prediction and decision-making, with applications in environmetrics, genetics, health policy, medical statistics, and computer modeling and simulation of complex phenomena);

- promote innovation and enhance academic quality at both the undergraduate and graduate levels, and substantially increase doctoral production, (a) by converting the already-functioning informal AMS graduate program to a formal program with parallel tracks in Applied Mathematics and in Statistics, and (b) by co-developing with the Department of Mathematics a new undergraduate major (and/or minor) in applied mathematics;

- substantially increase contract and grant support, by building upon existing strengths within AMS to reach out even more successfully to current research partners—at Arizona State University, Kaiser Permanente Division of Research, the Lawrence Livermore Labs, the Los Alamos National Laboratories, MIT, the Naval Postgraduate School, the National Aeronautic and Space Administration (NASA), the National Center For Atmospheric Research, the National Marine Fisheries Service (NMFS, Santa Cruz Laboratory), the Sandia National Laboratories, UC Santa Barbara, the University of New Mexico, and Universidade Federal do Rio de Janeiro—and new partners, for new and continuing funding from institutions such as the CalFed Science Program, NASA, the National Institutes of Health, the NMFS, and the National Science Foundation;

- manage the enrollment growth necessary to accommodate 2,800 new student FTE campus-wide between now and 2010–11, and improve access for the diverse population that comprises California today, by continuing the process of joint curriculum planning with existing partner Departments (Biomolecular Engineering, Computer Engineering,

[1] AMS has not yet formally applied for departmental status (we expect to do so near the beginning of the winter 2006 quarter); as a courtesy (and a kind of shorthand) the campus permits us to call ourselves a Department in the interim period, and we will use that shorthand in this document.

Computer Science, Ecology and Evolutionary Biology, Economics, Electrical Engineering, Environmental Studies, Environmental Toxicology, Mathematics, Molecular and Cell Developmental Biology, and Technology and Information Management), and extending this joint curriculum planning to new partner Departments (e.g., Psychology and Sociology), to expand existing AMS service teaching and develop new courses of greatest usefulness to the campus in both applied mathematics and statistics; and

- encourage trans-departmental and trans-divisional academic and scholarly programs, by building upon existing strengths within AMS (1) to deepen continuing collaborations with other UCSC scholars in programs such as the UCSC Center for Information Technology Research in the Interest of Society (CITRIS), the Center for Stock Assessment Research (CSTAR), the Institute for Quantitative Biomedical Research (QB3), and the STEPS Institute, and begin new collaborations, and (2) to continue planning of trans-departmental graduate programs such as the *Program in Control Theory and Applications* now under joint development between AMS, Computer Engineering, Electrical Engineering and Technology and Information Management.

2 Sustainability Within Available Resources

2.1 AMS Current Position

As elaborated in Appendix 2 (and detailed, e.g., in the 2004–05 AMS Annual Report, available at `www.ams.ucsc.edu/AMS-annual-report-2005.pdf`), the current position for AMS is as follows.

- AMS currently has 9 ladder faculty (4 in Applied Mathematics (AM), 5 in Statistics (S)), with a senior search in Applied Mathematics underway in 2005–06;
- Regarding extramural funding, applied mathematics and statistics are subjects in which it is unusual to generate large amounts of funding, because the customary awards involve summer salary, student and/or postdoctoral researcher support, and modest allocations for computing equipment and travel. Having said that, in 2004–05 the 9 ladder AMS faculty received a total of $1,163,809 in contract and grant awards, an average of $116,400 per ladder faculty member, and had research expenditures of $784,128, an average of $78,400 per ladder faculty member;
- AMS currently supervises 20 M.S. and Ph.D. students (6 in applied math, 14 in statistics), who were initially admitted to graduate study within the Departments of Computer Science, Environmental Studies, Ocean Sciences or Physics (with transfer to AMS when our graduate program is approved); and
- We expect a total of approximately 2,810 students (about 312 student FTE) from at least 25 Departments in all 5 Divisions on campus to take the 34 AMS courses offered in 2005–06.

Note that, as campus enrollment figures demonstrate, AMS has the highest workload ratio of any School of Engineering (SoE) Department at 23.7 (see Table 3 below; the SoE average is 14.9, and the campus average is 19.5).

2.2 AMS Sustainable Position in 2010–11

As the rest of this document details, the projected sustainable position for AMS in 2010–11 will be as follows.

- AMS is projected to have 15 ladder faculty (7 in applied math, 8 in statistics) in 2010–11 (the corresponding figure in 2011–12 is projected to be 16 (8 applied math, 8 statistics)); the 2010–11 figure will be a 67% increase over the 2005–06 value;
- AMS is projected to receive a total of $1,710,550 in contract and grant awards in 2010–11 (an average of $114,000 per ladder faculty member), and to have research expenditures of $1,554,700 (an average of $103,650 per ladder faculty member); the 2010–11 award figure will be a 73% increase over the corresponding 2005–06 value; and total expenditures and expenditures per ladder faculty member are expected to rise from 2004–05 by 113% and 33%, respectively;
- AMS expects to have a total of 39 graduate students in residence in 2010–11 (30 Ph.D., 9 M.S.), and to graduate 12 students that year (6 Ph.D., 6 M.S.); this means that the AMS graduate program will more than double over the next five years (total students will go up by a factor of 2.05, and students graduating by a factor of 2.17); and
- AMS expects to teach approximately 4,030 students (447.5 student FTE) in 2010–11 (3,105 lower division, 450 upper division, and 475 graduate enrollments); this will represent a 51% increase over the corresponding figure in 2005–06.

3 Future Opportunities For Investment in New Endeavors

As part of this revised planning exercise we have identified four promising future opportunities for UCSC investment in new endeavors related to AMS.

- We argue in Appendix 3, on the basis of an analysis of the size of the top 18 Departments of Statistics in the most recent (1995) National Academy Survey (NAS) of academic excellence in the U.S., that every attempt the campus can make to enable AMS to grow beyond the current target of 8 faculty in each of AM and S in 2011–12 will have significant positive impact on external reputation surveys such as the NAS ranking just mentioned. With this in mind, and with substantial intellectual support from a number

of Departments with which we collaborate in the SoE and the Divisions of Physical and Biological Sciences (PBSci) and Social Sciences (SSci),

> In the next 2–3 years AMS will propose the establishment at UCSC of a Research Institute in Applied Mathematics and Statistics (RIAMS).

(We believe that it is unreasonable to make this proposal now, because we are currently searching for a senior member of the Applied Math Group and this person should be allowed substantial input into the content of the RIAMS proposal.) This Institute, which will be funded by a combination of grant/contract support and a request to central campus for 8 new faculty lines for AMS over a 12–year period, will enable UCSC to bring together a sufficiently large critical mass of researchers in Applied Math and Statistics to tackle large, difficult and important collaborative problems—at the crucial interface between applied math and statistics—in fields such as astronomy/astrophysics, computational genomics, environmetrics, mathematical biology and robotics whose solution would not be possible without attaining the required critical mass. The Statistical and Mathematical Sciences Institute (SAMSI) in North Carolina, the only organization in the U.S. anything like RIAMS, has been highly successful both in employing postdoctoral researchers to work on problems at the applied math-statistics interface and in demonstrating that there is ample demand for a second U.S. institute with a similar theme. As the West Coast center of excellence in this highly important topic for 21$^{\text{st}}$ century science and technology, RIAMS will greatly increase UCSC's visibility in the mathematical sciences.

- It is clear from an examination of (1) funding patterns at NSF and other scientific funding agencies and (2) the importance of problems in this burgeoning field that **biophysics** is a growth area of enormous potential at the interface between Engineering and the Physical and Biological Sciences. We believe that UCSC should follow leading universities such as Princeton in making a significant investment in biophysics in the next 5–10 years. With Marc Mangel's work on the nanobiology of aging and Hongyun Wang's work on protein motors, AMS is already well positioned to make a significant contribution to the UCSC biophysics initiative, and we anticipate that future hires in the mathematical biology area within AMS—including one or more of the RIAMS new faculty lines funded by central campus—will be able to strengthen UCSC's presence in this important field.

- **Control theory** is another extremely important area in applied mathematics at the interface between Engineering and the Physical and Biological Sciences. Applications in adaptive optics, remote sensing, and robotics—involving collaboration between researchers in AMS and Astronomy/Astrophysics, Electrical Engineering, and Computer Engineering/Computer Science, respectively—are three of the many interdisciplinary and interdivisional collaborative possibilities in this crucial field. The addition of Jorge Cortés to the Applied Math Group in AMS in 2004 immediately put UCSC on the map in control theory; Cortés is now working with William Dunbar and Gabriel Elkaim

(Computer Engineering), John Musacchio and Kevin Ross (TIM), Donald Wiberg (Electrical Engineering) and others to develop a graduate program in control theory and its applications. Below we will propose that AMS be given authorization to make a second hire in control theory in 2006–07, and we believe that UCSC should further invest in this important area by allocating one or more of the RIAMS new faculty lines funded by central campus to control theory.

- UCSC has a pressing need for a **Statistical Consulting Service** (SCS), a central clearing-house of statistical advice to faculty and graduate students on design and analysis issues in projects involving data collection, modeling and interpretation. Since the founding of the Statistics Group within AMS in 2001, the number of requests for statistical consultation from UCSC faculty and graduate students has steadily risen, and is now at a point where the demand can no longer be met without central campus help in the form of release time for AMS faculty and modest support for AMS graduate students. In the next 1–2 years the Statistics Group in AMS will make a proposal to the Graduate Division for central campus line-item support to launch the SCS and yearly line-item support thereafter to maintain it and permit it to grow.

  The day-to-day running of the SCS will be based on free short consultations; when the person initiating a medium-length or long consultation has a grant to support the research giving rise to the question under study, a modest transfer of funds from the relevant grant to support the AMS graduate students who help with the consultation will be requested. In steady state we envision the demand for the SCS to be such that, for the AMS faculty member leading the SCS in any given quarter, the load would be equivalent to teaching one course. Participating in the SCS through enrollment in a course on statistical consulting will become part of the second year of the M.S. and Ph.D. degree tracks in Statistics within AMS; this will serve both to ensure sufficient graduate student staffing of the SCS and to provide a rich source of applied problems (some of which may turn into dissertation collaborations) for AMS graduate students.

4 Synergistic Graduate and Undergraduate Programs

Academic Departments in the United States do three kinds of teaching: service teaching, mainly to first- and second-year undergraduates; teaching in support of an undergraduate major, mainly to third- and fourth-year undergraduates; and graduate teaching to M.S. and Ph.D. students. A small Department does not have enough faculty to engage vigorously in all three of these teaching modes. From its inception in 2001 the AMS Department has chosen to concentrate initially on service and graduate teaching, the former because it is natural for faculty in applied math and statistics to do their part in educating all of UCSC's undergraduates in these two disciplines, and the latter because excellence in graduate teaching goes hand in hand with the kind of research excellence to which AMS is dedicated.

4.1 Graduate Programs

Through the kind cooperation of a number of other Departments (principally Computer Science but also including Environmental Studies, Ocean Sciences, and Physics), AMS has been able to build up a substantial cohort of graduate students by initially admitting these students to the cooperating Departments: from 0 such students in 2001 the incipient AMS graduate program has grown to 20 students (18 Ph.D., 2 M.S.) in 2005–06. The formal AMS proposal for M.S. and Ph.D. degrees in Statistics and Stochastic Modeling (SSM) was submitted to campus in April 2005; it received strongly positive reviews from the Graduate Council (GC) and the Committee on Planning and Budget (CPB) in October 2005, and a revised version of the proposal that responds to the suggestions of GC and CPB will be re-submitted to campus in January 2006. (VPAA Alison Galloway has predicted quick UCSC approval after this resubmission, and systemwide approval 6–12 months after UCSC approval.)

As detailed in Section 5 below, GC and CPB had two main concerns about the SSM proposal:

(1) It is vital for campus to support graduate training in statistics by quickly ramping up the faculty size in the Statistics Group within AMS, while remaining mindful of the need for balance with faculty size in the Applied Math Group, and

(2) It is equally vital to the campus research mission for there to be graduate training within AMS in applied mathematics.

We agree completely with the first of these concerns: AMS can only strengthen and enlarge the campus graduate mission, particularly doctoral education, by continuing the growth—at the fastest possible rate supported by SoE and campus growth—of the faculty in both the Applied Math and Statistics Groups. Section 5 below details the proposed AMS sustainable faculty growth plan, which is both responsive to GC and CPB concerns and consistent with the SoE and campus growth projections.

In response to the second of the GC and CPB concerns noted above, the AMS plan for graduate education, subsequent to the re-submission of the SSM proposal, is as follows.

- While the revised SSM proposal is undergoing final UCSC and system-wide approvals, we will develop an applied math track of a joint graduate program in Applied Mathematics and Statistics, and

- As soon as the SSM proposal is approved systemwide, we will request permission to relaunch the AMS graduate program with the title "graduate program in Applied Mathematics and Statistics" with parallel tracks in (i) applied math and (ii) statistics.

Table 1 below gives the actual and projected growth of the AMS graduate program from 2003–04 (the year the first AMS graduate student finished) to 2011–12. As noted in Section

Table 1: *Actual and projected growth of AMS graduate program, 2003–2012.*

Year	Ladder FTE	Graduate Students in Residence			Graduate Students Finishing		
		Ph.D.	M.S.	Total	Ph.D.	M.S.	Total
2003–04	8	13	1	14	0	1	1
2004–05	10	18	2	20	1	2	3
2005–06	9	18	2	20	6	2	8
2006–07	10	18	4	22	5	2	7
2007–08	12	21	6	27	6	3	9
2008–09	12	23	7	30	5	4	9
2009–10	14	27	8	35	2	5	7
2010–11	15	30	9	39	7	6	13
2011–12	16	33	10	43	7	7	14

Note: Figures for 2003–2006 are actual; 2006–12 figures are projections based on sustainable growth assumptions.

2.2, we expect to have a total of 39 graduate students in residence in 2010–11 (30 Ph.D., 9 M.S.), and to graduate 12 students that year (6 Ph.D., 6 M.S.); this means that the AMS graduate program will more than double over the next five years (total students will go up by a factor of 2.05, and students graduating by a factor of 2.17). This is precisely consistent with the UCSC overall plan to double the size of the graduate student cohort by 2010–11.

Early in 2001, at its inception, AMS began curriculum coordination with the Department of Mathematics in the Division of Physical and Biological Sciences; this coordination is an ongoing process at present and will continue indefinitely into the future. AMS graduate students have already begun to take graduate courses in the Department of Mathematics and vice versa, and we anticipate that the flow of AMS graduate students into Mathematics Department graduate courses will increase with the launching of the Applied Math track of the AMS graduate program.

Since 2001 AMS curriculum coordination at the graduate level has steadily grown with other Departments as well: for example, AMS 205 (Mathematical Statistics) is a required graduate course for Ph.D. students in the Department of Economics. In the next 1–2 years we look forward to developing a new graduate class on data analysis (including computing laboratory work in a widely-used statistical computing environment such as `SAS`); based on discussions with faculty in Departments such as Ecology and Evolutionary Biology; Environmental Toxicity; and Molecular, Cell and Developmental Biology, we expect this course to be extremely valuable for a wide range of graduate programs in the sciences.

Block Grant Funding. As soon as the SSM graduate proposal is approved systemwide, we will begin submitting proposals for block grants to help fund our graduate students. Three promising block grant funding possibilities for AMS students are as follows.

- The Division of Mathematical Sciences (DMS) at the National Science Foundation (NSF) runs a program called Enhancing the Mathematical Sciences Workforce in the 21st Century (EMSW21), which has two component programs of particular relevance to AMS: Grants for Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE; award size from $400,000 to $1,000,000 per year; awards granted for three years, with a two year extension possible), and Research Training Groups in the Mathematical Sciences (RTG; provides groups of researchers who have related research goals in the mathematical sciences with funds to foster research-based training and education).

- The U.S. Department of Education runs a program called Graduate Assistance in Areas of National Need (GAANN). GAANN provides fellowships in areas of national need to assist graduate students with excellent academic records who demonstrate financial need and plan to pursue the highest degree available in their courses of study. In fiscal year 2004, for example, a total of $10,015,000 was awarded to 48 recipient graduate programs; the awards ranged from $124,668 to $750,000 and averaged $208,645 in size. UCSC has a successful track record with GAANN grants; for example, the Department of Computer Science currently has a GAANN award.

- The National Institutes of Health (NIH) runs a program called Predoctoral Research Training in Biostatistics. The purpose of the program is to provide support for predoctoral training in biostatistical theory and evolving methodologies related to basic biomedical research; the goal is to ensure that a workforce of biostatisticians with a deep understanding of statistical theory and new methodologies is available to assume leadership roles related to the nation's biomedical, clinical, and behavioral research needs. The Department of Biomolecular Engineering has expressed interest in co-applying for an NIH biostatistics training grant with the Statistics Group in AMS.

4.2 Undergraduate Programs

Once AMS has reached sufficient faculty size, the initial AMS concentration only on service and graduate teaching can be augmented by the launching or enriching of two undergraduate programs, one in applied math and one in statistics (we have already established an undergraduate minor in statistics).

- **Applied Mathematics.** The AMS graduate program in applied math will serve as a research and teaching springboard for a new undergraduate program in applied math. We will develop this new major and/or minor, which is crucial for UCSC's overall health in the mathematical sciences, jointly with the Department of Mathematics. We do not expect to have sufficient faculty in the Applied Math Group to launch this program, jointly with Mathematics, until 2009–10. In addition to serving as a double major (and/or minor) possibility for a number of students on campus (e.g., in Biology, Mathematics, Physics, and all of the SoE disciplines), this program will potentially

serve as an excellent source of high-quality graduate students for AMS in both applied math and statistics.

- **Statistics.** Given the extra burden of running the *Statistical Consulting Service*, we do not expect to have sufficient faculty in the Statistics Group to launch an undergraduate major in statistics until 2011–12 at the earliest, and it is possible that we will not be able to run such a major without one or more of the additional statistics faculty to be requested in the RIAMS proposal. We expect to revisit this issue in 2008–09, by conducting a study at that time of the undergraduate statistics degree programs at the other UC campuses to assess their resource burden.

From the summary here and the discussion in Section 5 below, it should be clear that the entire program of additional faculty hiring in AMS over the next 5–10 years will both (a) strengthen and enlarge the campus graduate mission with high-quality M.S. and Ph.D. students and (b) enrich the overall UCSC academic experience and lend distinction and visibility to undergraduate programs, in AMS and campus-wide.

5 Plan for Additional Faculty FTE

It is vital for the campus to build on the early success of AMS by rapidly continuing the growth of the Department's faculty. An example of the reasoning supporting this statement is given by the AMS graduate proposal in Statistics and Stochastic Modeling (SSM), which was submitted to campus in April 2005 and received comment from the Graduate Council (GC) and the Committee on Planning and Budget (CPB) in October 2005. Both GC and CPB found the proposal to be strong and innovative:

> "We felt the overarching goals of the program ... were very strong, reflecting considerable thought and planning on the part of AMS faculty." (CPB)
>
> "... the proposal seems strong at its core. Faculty participants both within and outside of AMS are enthusiastic about the proposal, and possess an expertise that should serve the program quite well. Engineering Dean Kang is unambiguous in his support for the program. External letters are strong and encouraging. ... The [GC] feels that, at its core, this is a strong proposal that will provide great benefit to the campus." (GC)

However, both raised concerns that can only be addressed by a commitment by campus to rapid continued growth of AMS faculty:

- Both GC and CPB felt the viability of the SSM graduate program is threatened without an immediate infusion of new faculty positions in statistics; a quote from the CPB report can serve to summarize these concerns:

> "The number of faculty (statisticians and stochastic modelers) directly associated with the [SSM] program is of concern. ... With current staffing, the program sits at a knife-edge of feasibility, so a firm commitment for faculty expansion is vital to demonstrate that the program will be viable over the long term. ... We believe that the Dean's letter [of support in the revised graduate proposal] needs to incorporate explicit FTE commitments (at least two positions) and explicit, relatively short timelines that will ensure the ongoing viability of the program, while remaining mindful of the need for balance with the applied mathematics faculty." (CPB)

- CPB also clearly stated the campus strong need and strong desire for a graduate program in Applied Mathematics to supplement and complement the SSM program:

  > "CPB is strongly committed to the idea that all faculty at UCSC should have access to graduate students. Therefore, we view [the SSM] proposal, which will only train the students of statisticians and a subset of modelers within AMS, as just a first step. The campus must eventually have a graduate program in Applied Math, and it should come sooner, rather than later." (CPB)

Thus there is a pressing need, articulated forcefully by the UCSC Senate, to quickly grow both the faculty in Applied Mathematics and the faculty in Statistics.

We believe that, to fulfill the recommendations of the Graduate Council and CPB, AMS should grow at the rate of 2 positions per year (1 in applied math, 1 in statistics) for several years running, to ensure the viability of the statistics track of the AMS graduate program and to launch the applied math track. However, we are mindful that in CPEVC Kliger's memo of 16 November 2005 on faculty recruitment for 2006–07, he proposed that the entire SoE only receive authorization to make the following recruitments:

2006–07	2007–08	2008–09	2009–10	2010–11
5	6	7	7	8.9

In view of this highly restrictive growth plan for the entire SoE, we propose in Table 2 below a less rapid growth plan for AMS that is the absolute minimum necessary

(a) to ensure the viability of the statistics track of the AMS graduate program,

(b) to launch the applied math track of the AMS graduate program,

(c) to co-launch (with the Department of Mathematics) a new undergraduate major (and/or minor) in applied math, and

(d) to ensure the continued enrollment growth of the SoE through expansion of the AMS program in service teaching.

Table 2: *Proposed ladder faculty growth plan for AMS.*

Academic Year (AY)	Number of Ladder Faculty in Fall of AY			Number of New Searches in AY		
	AM	S	Total	AM	S	Total
2005–06	4	5	9	1	0	1
2006–07	5	5	10	1	1	2
2007–08	6	6	12	0	0	0
2008–09	6	6	12	0	1	2
2009–10	6	7	14	1	1	1
2010–11	7	8	15	1	0	1
2011–12	8	8	16	0	0	0

Given that the SoE has six programs and that there is a general desire to move forward as often as possible in as many of these programs as possible, CPEVC Kliger's proposal for SoE hiring breaks down naturally into a pattern of approximately 1 hire per year per program. Table 2 deviates from this pattern for AMS in two crucial places:

- It will be vital to run 2 AMS recruitments in 2006–07, one each in applied math and statistics: the applied math recruitment will be in control theory, in order to balance the three sub-groups in the Applied Math Group, and the statistics recruitment is needed to satisfy the GC and CPB recommendations and to improve the extremely low morale in the Statistics Group created by campus postponing the proposed statistics hire in 2005–06. Note that we are requesting no recruitments at all in 2007–08, so that having 2 in 2006–07 can simply be thought of as forward funding (of 1 position for 1 year) in relation to the normal pattern of 1 AMS hire per year.

- It will be equally vital to run 2 AMS recruitments in 2008–09 so that there will be enough faculty in both applied math and statistics in 2009–10 to co-launch (with the Department of Mathematics) the new undergraduate major (and/or minor) in applied math, which is so strongly needed (both as a stand-alone major/minor and a double major/minor) by many programs on campus.

Prioritized list of proposed annual faculty recruitments through 2010-11. In the disciplines of Applied Mathematics and Statistics, we have identified the following programmatic directions for research specializations of current faculty and future hires, by targeting sub-disciplines in these two fields that (a) are envisioned to be of paramount scholarly importance in the first half of the 21$^{\text{st}}$ century, (b) will lend distinction to the existing AMS faculty, and (c) are likely to promote fruitful interdisciplinary interactions[2] at UCSC. Statisticians tend to work in more than one sub-discipline, so most of AMS's existing statisticians are

[2]Abbreviations for interactions in the list on the next page: COH = Center for Ocean Health; STEPS = Science, Technology, Engineering and Policy for Society; CSTAR = Center for Stock Assessment Research;

listed below more than once, and there will be strong interactions among the research work in the three statistics sub-disciplines.

Each of the Applied Math (AM) and (S) Statistics Groups naturally breaks down in research specialization into 3 sub-groups; because each of these groups is equally important and the SoE target for AMS of 8 faculty per Group is not divisible by 3, we have anticipated the possibility of at least 1 additional hire in each Group in the future beyond 2011–12 (through a combination of increased central campus resources and/or extramural funding to support the Research Institute in Applied Mathematics and Statistics (Section 3) and/or non-RIAMS extramural funding and/or additional AMS workload), making at least 3 ladder faculty in each research subgroup.

- (**AM**) **Mathematical biology (3 faculty)** (Mangel, Wang, 1 new; SoE interactions with Bioinformatics, BME; campus interactions with COH, STEPS, CSTAR, EEB, ES, MCDB, Physics (especially biophysics, if UCSC starts a new initiative in this field));
- (**AM**) **Fluid dynamics (3)** (Garaud, 2 new; SoE interactions with EE, CE; campus interactions with OS, ES, Astronomy/Astrophysics);
- (**AM**) **Optimization/control theory (3)** (Cortés, 2 new; SoE interactions with EE, CE, CS, Bioinformatics; campus interactions with Astronomy/Astrophysics, ES, CFAO, ETox, Physics);
- (**S**) **Bayesian nonparametrics (3) (nonparametric distributional modeling, nonparametric modeling of regression surfaces, connections with machine learning)** (Draper, Kottas, Lee, 1 new; SoE interactions with CS, BME; campus interactions with CSTAR, Astronomy/Astrophysics, SCIPP);
- (**S**) **Bayesian environmetrics (3) (spatial-temporal modeling, environmental risk assessment)** (Draper, Lee, Sanso, 1 new; SoE interactions with CE, EE; campus interactions with COH, CSTAR, STEPS, ETox, OS); and
- (**S**) **Computationally-intensive Bayesian inference, prediction and decision-making (3) (Markov chain Monte Carlo methods, stochastic optimization)** (Draper, Kottas, Lee, Prado, Sansó, 2 new; SoE interactions with BME, CS, TIM; campus interactions with EEB, MCDB, SCIPP, CSTAR).

Starting in 2006–07, we propose to search for new applied mathematicians and statisticians according to the following schedule (CIBIPD = Computationally-intensive Bayesian inference, prediction and decision-making):

EEB = Ecology and Evolutionary Biology; ES = Earth Sciences; MCD = Molecular Cell and Developmental Biology; OS = Ocean Sciences; CFAO = Center for Adaptive Optics; ETox = Environmental Toxicology; SCIPP = Santa Cruz Institute for Particle Physics.

Academic Year	Area in AM	Area in S
2006–07	Control Theory	Environmetrics
2007–08	—	—
2008–09	Mathematical Biology	CIBIPD
2009–10	—	Nonparametrics
2010–11	Fluid Dynamics	—
2011–12	—	—
2012–13	Control Theory	CIBIPD

6 Plan for Enrollment FTE

The AMS plan for enrollment FTE is in three parts: lower-division (service) undergraduate, upper-division (major) undergraduate, and graduate (M.S. and Ph.D.) teaching.

- *Lower-division (service) undergraduate teaching.* As AMS has grown we have taken on an increasing burden of service teaching in the mathematical sciences on campus, and we expect that trend to continue. It is natural for AMS and the Department of Mathematics to work out an arrangement that allocates the total campus enrollments in the mathematical sciences in proportion to ladder faculty size, and to adjust the relative percentages each year based on (potentially changing) ladder faculty count in each Department; we are now in discussions with the Mathematics Department to capture this idea in a Memorandum of Understanding.
- *Upper-division (major) undergraduate teaching.* We expect this area to grow fairly slowly until 2010–11, when the undergraduate major and/or minor in applied math is launched; at that point we expect a jump followed by steady but (again) fairly slow growth.
- *Graduate (M.S. and Ph.D.) teaching.* We expect AMS graduate enrollments to increase with the Department's increasing graduate student cohort, in a manner that parallels the growth indicated in Table 1.

Table 3 below gives the actual and projected growth of AMS enrollment FTE over the period from 2000–01 through 2011–12. Note that, to accommodate the increases in service teaching, AMS will need increasing support from lecturers over time, in a manner analogous to the arrangement already approved in the original 10–year plan in 2001. The proportion of AMS projected lecturers to overall total student FTE in Table 3 is consistent with existing patterns in the SoE; for example, in 2004–05 the Computer Engineering (CE) Department used 4.41 lecturers with a total enrollment FTE of 325.4, a ratio of 73.8, whereas the corresponding projected ratio for AMS in 2011–12 will be 94.9 (higher numbers in this ratio are better because they signify higher total workload for a given lecturer budget).

Table 3: *Actual and projected growth of AMS enrollment FTE, 2000–2012.*

Year	Lower Division	Upper Division	Under-graduate Total	Graduate	Overall Total	AMS Lecturers	AMS Workload Ratio
2000–01	7.0	20.5	27.5	0.5	28.0	0.1	9.0
2001–02	77.3	6.0	83.3	7.0	90.3	0.1	17.7
2002–03	82.2	13.2	95.4	21.1	116.5	0.2	16.2
2003–04	178.4	9.8	188.2	21.6	209.8	0.5	24.7
2004–05	216.6	13.3	229.9	29.2	259.1	0.9	23.7
2005–06	270.0	15.0	285.0	30.0	315.0	1.9	28.9
2006–07	283.5	17.5	301.0	37.5	338.5	2.5	26.2
2007–08	298.0	20.0	318.0	40.0	358.0	3.0	23.9
2008–09	313.0	25.0	338.0	42.5	380.5	3.5	24.5
2009–10	329.0	45.0	374.0	47.5	421.5	4.0	23.4
2010–11	345.0	50.0	395.0	52.5	447.5	4.5	22.9
2011–12	362.0	55.0	417.0	57.5	474.5	5.0	22.6

Note: Figures for 2000–2005 are actual; 2005–12 figures are projections based on sustainable growth assumptions, and assuming that the inter-divisional (Mathematics + AMS) undergraduate major/minor in applied mathematics starts in 2009–10.

7 Plan for Extramural Research Support

AMS faculty constantly seek additional non-state funding as a high priority, and have had considerable success to date: for example, from 2000–01 through 2004–05, extramural award amounts per ladder faculty in AMS have doubled, from $58,000 to $116,400, and research expenditures per ladder faculty member have increased by a factor of 2.5, from $30,786 to $78,400. With the understanding (as noted in Section 2.1) that extramural research awards in applied math and statistics will almost never be enormous, because such awards almost always consist only of summer salary, graduate student and postdoctoral researcher support, and modest budgets for computing and travel (and almost never involve large equipment awards of the type that are more common in wet-lab fields and areas such as nanotechnology), our proposed future appointments are all in areas (Bayesian statistics, control theory, environmetrics, fluid dynamics, and mathematical biology) with abundant interdisciplinary collaborative possibilities for significant extramural funding, and we intend to hire future colleagues who are strongly interested (as we are) in competing successfully for high-quality grants and contracts that will help support AMS scholarship and graduate education.

Table 4 below gives the actual and projected growth of AMS extramural funding from 2000–01 through 2011–12. Assuming faculty growth as in Table 2, we expect to roughly double awards received from 2005–06 ($990,000) to 2011–12 ($1,838,250) and to more than double research expenditures from 2004–05 ($784,128) to 2011–12 ($1,671,300), and we expect re-

Table 4: *Actual and projected growth of AMS extramural funding, 2000–2012.*

Year	Ladder FTE	Awards Received ($)	Awards Received Per Ladder FTE ($)	Research Expenditures ($)	Research Expenditures Per Ladder FTE ($)
2000–02	3.5	203,000	58,000	107,751	30,786
2002–03	7.0	750,819	107,260	300,426	42,918
2003–04	8.0	532,314	76,045	685,059	97,866
2004–05	10.0	1,163,809	116,400	784,128	78,400
2005–06	9.0	990,000	110,000	900,000	100,000
2006–07	10.0	1,182,500	118,250	1,075,000	107,500
2007–08	12.0	1,271,200	105,900	1,155,600	96,300
2008–09	12.0	1,366,100	113,850	1,242,300	103,500
2009–10	14.0	1,468,700	122,400	1,335,150	111,250
2010–11	15.0	1,710,550	114,000	1,554,700	103,650
2011–12	16.0	1,838,250	114,900	1,671,300	104,500

Note: Figures from 2000–05 are actual; dollar figures in 2005–06, and all figures in 2007–12, are projections based on sustainable AMS growth.

search expenditures per ladder FTE to increase by about 33% from 2004–05 ($78,400) to 2011–12 ($104,500).

8 Additional Measures of Success

The measures of UCSC success detailed in previous sections to which AMS will contribute may be summarized as follows.

- Establishing high-quality new graduate degree programs of critical importance to the UCSC research mission;
- Conducting successful high-quality faculty recruitments;
- Increasing the quality and quantity of Ph.D. and M.S. production;
- Increasing the level of extramural funding;
- Establishing distinctive, high-quality new undergraduate degree programs of critical importance to the UCSC research mission; and
- Helping to increase the SoE instructional workload of senate faculty, and overall SoE enrollments.

In addition to these measures, AMS looks forward to contributing to the success of the SoE and the campus in four ways.

- *State-funded summer session:* Provided that faculty are given full freedom to choose whether or not they wish to make the summer quarter one of their three "quarters in residence" in any given year (rather than just the usual fall-winter-spring pattern), AMS supports the idea of migrating toward a model in which the summer becomes more like a regular academic quarter.
- *Off-campus sites:* AMS looks forward to increasing collaborations with the Technology and Information Management (TIM) Program (e.g., in fields such as stochastic optimization and control theory) in helping to grow the Silicon Valley Center as a major research and teaching resource for the SoE and the campus.
- *Diversity of faculty and students:* With 3 Hispanic and 2 women faculty—who take every opportunity to mentor students from underrepresented groups in Engineering and other parts of campus—among the 9 current AMS ladder faculty, and 4 Asians among our 18 Ph.D. students, we have already demonstrated a commitment to diversity which we look forward to continuing.
- *International profile of AMS faculty:* AMS has already established an international profile in both applied math and statistics (as measured, e.g., by comments from non-U.S. researchers in these fields in letters solicited through the merit review process), and we look forward to continuing to enhance the international visibility of the Department and the SoE.

Appendix 1: Founding Vision

The newly-forming Department of Applied Mathematics and Statistics (AMS) represents an interdisciplinary collaboration between two fields of study—applied mathematics (AM) and statistics (S)—both of which are vital to the research, teaching and service missions of the University of California, Santa Cruz (UCSC). Both disciplines have as their underlying approach the use of mathematical methods to solve problems in science and decision-making, but they differ in fundamental and complementary ways in how mathematical methods are brought to bear on the problems being solved.

In practice both disciplines start with a real-world process or phenomenon and develop a mathematical model capturing the salient features of this process or phenomenon. The dividing line between the two disciplines generally concerns whether *stochastic* (or *probabilistic*, or *random*) mechanisms are (S) or are not (AM) built into the model. AM models often employ *deterministic* (i.e., non-stochastic) systems of (ordinary or partial) differential equations to describe the dynamic evolution over time of the process or phenomenon under study. In contrast, statistics can be defined as *the study of uncertainty*: how to measure it (through

probability), and what to do about it (through *inference* [the process of drawing quantitative conclusions about unknown quantities on the basis of (i) known quantities and (ii) assumptions and judgments about how the knowns and unknowns are related] and *decision-making* [the process of using what is known, and partially known, to make a real-world choice, even if that choice must be made in the presence of uncertainty]).

AM models typically make deterministic predictions of observable real-world outcomes, but uncertainties often exist about (a) whether or not all relevant features of the process or phenomenon under study have been captured structurally in the model, and (b) the values of relevant inputs to such models. Thus when AM models are confronted with data on the observable outcomes, discrepancies between observed and predicted may arise. Among other purposes, statistical methods may be used (1) to help decide whether these discrepancies are too large to have "arisen by chance," which would encourage a search for more realistic structural assumptions; (2) to inferentially summarize the current state of uncertainty (given the data) about both model structure and unknown quantities of interest; and (3) to suggest how a future data-collection experiment might best be designed to maximally decrease the dominant uncertainties.

Thus a high-quality 21$^{\text{st}}$-century attempt to understand a complex real-world process or phenomenon will frequently involve a collaboration between the fields of applied mathematics and statistics. This observation is fundamental, but recognition of its truth has been slow to develop in universities where rigid boundaries between mathematics and statistics have been preserved. As Professor Bradley Efron of Stanford University (a distinguished statistician and member of the National Academy of Sciences) said in his letter of support for the April 2005 AMS proposal for graduate degree programs in statistics and stochastic modeling,

> "I read your nicely written proposal with some pangs of jealousy. Stanford, which has first-rate faculty in both [statistics and applied mathematics], does not have a favorable structure for combining them. I run Stanford's undergraduate program in applied mathematics, which is our closest approach, and many of us wish we could have similar interactions at the graduate level."

AMS was founded with the vision that UCSC can gain distinction as a major research university by co-locating leading researchers in AM and S in a single department within the School of Engineering, an environment that by its very nature fosters inter-disciplinary collaborations in science and technology.

Appendix 2: Details on AMS Current Status

- AMS currently has 9 ladder-rank faculty (4 in AM, 5 in S), with 1 senior search in AM currently underway:

- Assistant Professor **Jorge Cortés** (AM: distributed coordination algorithms; cooperative control; sensor networks; nonlinear and geometric control theory, with applications to robotics; applied computational geometry; non-smooth analysis);
- Professor **David Draper** (S: *Chair* and *Head of Statistics Group*; Bayesian hierarchical modeling; stochastic optimization; Markov chain Monte Carlo methods; Bayesian nonparametrics; model uncertainty; quality assessment in health and education; risk assessment; applications in the social and environmental sciences);
- Assistant Professor **Pascale Garaud** (AM: fluid dynamics; astrophysics (planetary formation; internal dynamics of stars); geophysics; environmental applications);
- Assistant Professor **Athanasios Kottas** (S: Bayesian nonparametric and semiparametric modeling; survival analysis; quantile regression modeling; categorical data analysis; spatial statistics; inference under probability order constraints);
- Assistant Professor **Herbert Lee** (S: Bayesian statistics, computational methods, inverse problems, spatial statistics, machine learning, model selection and model averaging);
- Professor **Marc Mangel** (AM: *Associate Chair* and *Head of Applied Mathematics Group*; mathematical modeling of biological phenomena, especially the evolutionary ecology of growth, aging, and longevity; quantitative issues in fishery management; mathematical and computational aspects of disease);
- Assistant Professor **Raquel Prado** (S: Bayesian analysis of nonstationary time series; multivariate time series; biomedical signal processing; wavelets; statistical models for genomic data);
- Acting Associate Professor **Bruno Sansó** (S: Bayesian predictive modeling of rainfall at macro and micro levels of aggregation in space and time; Bayesian spatial modeling; environmental and geostatistical applications); and
- Associate Professor **Hongyun Wang** (AM: theoretical biophysics and molecular modeling; energy transduction mechanism of protein motors; thermodynamics of small systems; partial differential equations; statistical physics; classical analysis and numerical analysis).

The current senior search in AM is in the area of fluid dynamics with physical sciences applications.

- In the academic year 2004–05 the 9 ladder-rank AMS faculty (a) published 54 contributions to the scientific literature (38 articles in leading international journals in applied mathematics and statistics, 5 contributions to conference proceedings, 4 book chapters, 2 book reviews, and 5 invited discussions); (b) submitted an additional 14 articles; (c) began or continued work on an additional 5 books and 17 articles; and (d) received 9 research honors.

- In 2004–05 AMS faculty submitted 29 grant applications (totaling $6,900,033), of which 18 were funded (and a number are still pending); the total award amount on these funded grants was $3,691,970 (including collaborations with non-UCSC partners).
- AMS currently supervises 20 M.S. and Ph.D. students (6 in AM, 14 in S), who were initially admitted to graduate study within the Departments of Computer Science, Environmental Studies, Ocean Sciences or Physics (with transfer to AMS when our graduate program is approved).
- Since 2003, a total of 10 students have completed graduate degrees under the partial or total supervision of AMS faculty, of whom 5 have been UCSC graduate students (2 Ph.D., 3 M.S.).
- We expect a total of approximately 2,810 students from at least 25 Departments in all 5 Divisions on campus to take the 34 AMS courses offered in 2005–06.

Appendix 3: AMS Ideal Growth

In Section 5 we demonstrated that there is a pressing need, articulated forcefully by the UCSC Senate, to quickly grow both the faculty in Applied Mathematics and the faculty in Statistics. How large should each of these faculties become, if we are to follow a resource pattern similar to that in the top research universities? The draft SoE 5–year plan envisions 8 ladder-rank faculty in each of AM and S; is this faculty size typical of that in applied math and statistics at the top universities with approximately 17,215 students?

Table 5 below summarizes student enrollment and ladder faculty size in S at the universities with the top 18 S faculties, according to the most recent National Academy of Sciences survey, and Figure 1 below illustrates the relationship between enrollment and S FTE at these universities. The solid line in the figure is a robust scatterplot smooth (trend curve) which highlights the relationship, which is nonlinear above about 25,000 students (this range is not relevant for UCSC). The vertical line is at 17,215 students, the planned size for UCSC in 2010–11, and it intersects the trend curve at the upper horizontal line, implying that if UCSC wishes to follow a resource pattern similar to that in the top research universities in S it should be prepared at 17,215 students to invest in **28** ladder-rank faculty in statistics (by comparison, the lower horizontal line is at 8, the currently proposed faculty size for S in 2010–11). Even if the trend curve is ignored, the median number of ladder-rank statistics faculty at the top-18-in-statistics universities smaller than UCSC will be in 2010–11 is **17**. An analysis (not presented here) that takes account of the public-private university distinction would, if anything, argue for an even bigger S Group at UCSC.

Data of this kind are harder to come by in AM, but it would be difficult to defend the position that the value of the discipline of applied mathematics should be lower at UCSC than the value of the discipline of statistics. This means that

Table 5: *Student enrollment and ladder faculty size in Statistics at the U.S. universities with the top 18 Statistics faculties, according to the most recent National Academy of Sciences survey.*

1995 NAS Ranking	University	Student Enrollment	Number of Ladder Faculty in Statistics
1	Stanford	14,846	19
2	UC Berkeley	32,814	39
3	Cornell	19,660	54
4	Chicago	12,400	20
5	Washington	35,000	28
6	Harvard	18,541	53
7	Wisconsin	40,045	16
8	Purdue	37,762	25
9	North Carolina	24,180	40
10	UCLA	35,796	15
11	Minnesota	37,150	37
12	Iowa State	26,110	27
13	Texas A&M	44,000	34
14	Carnegie-Mellon	8,514	17
15	Rutgers	48,000	18
16	Penn State	40,571	18
17	Yale	11,359	8
18	Duke	10,630	13

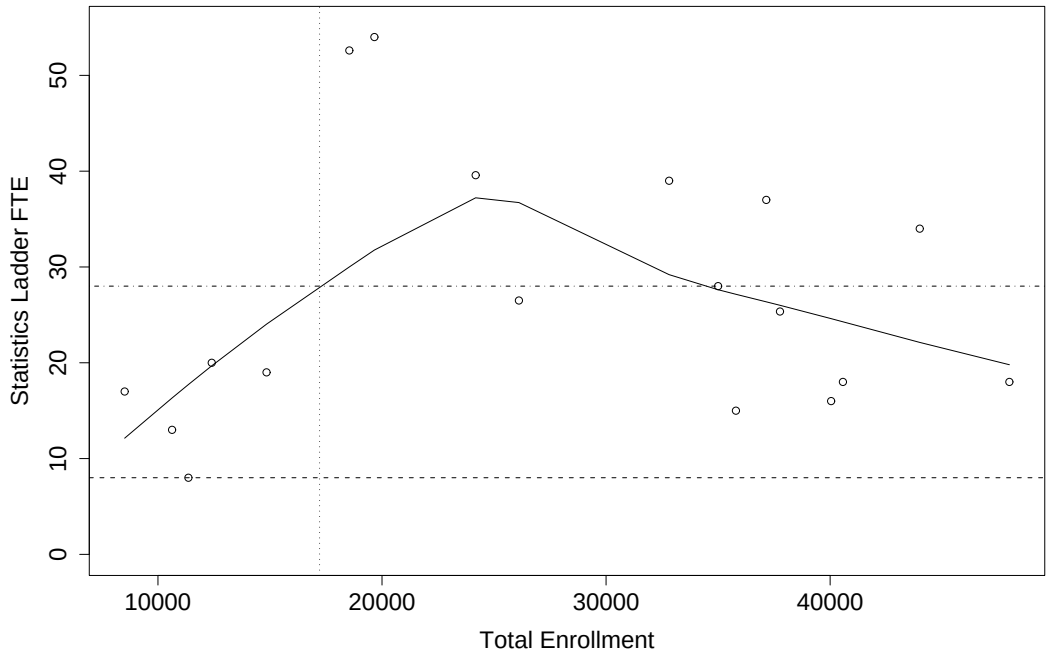
Sources. Ranking: National Academy of Sciences (NAS) 1995 National Survey of Graduate Faculty. Faculty size: `www.amstat.org/education/schools/schoolstext.html` (data as of March 1998; statistics faculty includes all ladder-rank statisticians on campus). University size: Proposal for a Department of Statistics at the University of California, Irvine (May 15, 2001).

> **On grounds of resource usage in applied mathematics and statistics at the top universities in those two fields which UCSC is trying to equal or surpass, UCSC should attempt to devote substantially more than 8 ladder-rank faculty to each of these disciplines at a student body size of 17,215 in 2010–11.**

We draw two conclusions from this analysis:

(1) AMS has so far emulated the small-but-distinguished model of universities like Yale in growing to its present size of 4 faculty in AM and 5 in S, and with notable success to date: for example, the Statistics Group is already being favorably compared with the Statistics Departments at Duke and Carnegie-Mellon, arguably the top two

Figure 1: *Relationship between total Statistics ladder FTE and total student enrollment at the U.S. universities with the top 18 Statistics faculties. Solid and dotted lines are explained in the text.*



Bayesian statistics groups in the U.S. We will need to continue to emulate the small-but-distinguished model in our future growth, and we are confident that we will continue to have success in implementing this model; but it is also clear that

(2) **Every attempt the campus can make to enable AMS to grow beyond the current target of 8 faculty in each of AM and S will have significant positive impact on external reputation surveys such as (1) the NAS ranking summarized (for 1995, in the discipline of statistics) in Table 5 and Figure 1, and (2) the US News engineering school rankings (available for 2006 at**

`www.usnews.com/usnews/edu/grad/rankings/eng/brief/engrank_brief.php`):

with a faculty size beyond 16, AMS will be able to greatly contribute to reaching the goal of the SoE ranking among the top 50 engineering schools in the U.S. by the end of the decade.