Final Assessment Report

Applied Mathematics (MMath, PhD)

November 2024

Executive Summary

External reviewers found that the Applied Mathematics (MMath, PhD) programs delivered by the Department of Applied Mathematics were in good standing.

"The reviewers find that the MMath and PhD programs are well designed and well managed. The faculty we spoke with are very engaged in the program and are striving to sustain high quality and make improvements. The students served by the programs are satisfied with the program."

A total of six recommendations were provided by the reviewers, regarding interdisciplinarity, engagement in data science and AI activities, participation in co-op, graduate student experience, EDI initiatives, and a climate assessment[1]. In response, the program created a plan outlining the specific actions proposed to address each recommendation as well as a timeline for implementation. The next cyclical review for this program is scheduled for 2029-2030.

Enrollment over the past three years

	MMath	MMath (Co-op)	MMath – Aero.	MMath – Quantum	MMath – Water	PhD	PhD – Aero.	PhD – Quan.	PhD – Water
2024-2025 (CURRENT YR)	20	7	0	6	0	39	0	13	1
2023-2024 (LAST YR)	30	7	0	5	0	39	0	10	0
2022-2023 (THREE YRS)	31	7	0	3	0	44	0	9	0

*Based on Active Student extract from Quest on November 22, 2024.

Background

[1] The notion of a "climate assessment" of the department, as requested by the reviewers, has to be understood as an EDI climate survey; the reviewer report states: "On EDI - We strongly recommend a climate survey conducted at the department level through an independent university entity or outside entity. The immediate goal for the department should have women and URM at the level consistent with the averages across North America."

In accordance with the University of Waterloo's Institutional Quality Assurance Process (IQAP), this final assessment report provides a synthesis of the external evaluation and the internal response of the Applied Mathematics (MMath, PhD) programs delivered by the Department of Applied Mathematics. A self-study (Volume I, II, III) was submitted to the Associate Vice-President, Graduate Studies and Postdoctoral Affairs on January 17, 2023. The self-study (Volume I) presented the program descriptions and learning outcomes, an analytical assessment of the programs, including the data collected from a student survey, along with the standard data package prepared by the Office of Institutional Analysis & Planning (IAP). The CVs for each faculty member with a key role in the delivery of the program(s) were included in Volume II of the self-study.

From Volume III, two arm's-length external reviewers were selected by the Associate Vice-President, Graduate Studies and Postdoctoral Affairs: Professor Fadil Santosa, Department of Applied Mathematics and Statistics, John Hopkins Whiting School of Engineering; and Professor Jianhong Wu, Laboratory for Industrial and Applied Mathematics, York University.

Reviewers appraised the self-study documentation and conducted a site visit to the University on May 1-4, 2023. An internal reviewer from the University of Waterloo, Professor Mikal Skuterud, Department of Economics, was selected to accompany the external reviewers. The visit included interviews with the Vice-President, Academic & Provost; Associate Vice-President, Graduate Studies and Postdoctoral Affairs; Dean of the Faculty of Mathematics; Faculty Associate Dean of Graduate Studies; Chair of the Department, as well as faculty members, staff and current graduate students. The Review Team also had an opportunity to meet with representatives from the library, and Co-operative Education.

Following the site visit, the external reviewers submitted a report on their findings, with recommendations. Subsequently, the program responded to each recommendation and outlined a plan for implementation of the recommendations. Finally, the Dean responded to the external reviewers' recommendations, and endorsed the plans outlined by the program.

This final assessment report is based on information extracted, in many cases verbatim, from the self-study, the external reviewers' report, the program response and the Dean's response.

Program Characteristics

There are two graduate programs, a masters' program leading to the degree MMath, and a doctoral program leading to the Ph.D. degree. Both have been in existence since the inception of the Department in 1967, but have expanded in terms of the number of specializations offered under the programs. The following graduate programs are currently offered:

1. Master of Mathematics (MMath) thesis.
2. Master of Mathematics (MMath) thesis (co-op)

3. MMath (thesis)-Water
4. MMath (thesis)-Quantum Information
5. MMath (thesis)-Aeronautics
6. Master of Mathematics (MMath) (Research paper)

The MMath programs have both coursework and research requirements. The thesis programs require completion of four courses, two of which must be selected from the list of departmental breadth courses. Students typically complete this coursework in the first two terms of their program after which they spend 3-4 terms (12-16 months) working on their thesis research. This research, carried out in close collaboration with their supervisor(s), is novel in nature, and often leads to publication in quality journals. Each student defends their thesis prior to graduation.
The Water, Aeronautics and Quantum Information options have additional course requirements that provide domain-specific background related to work at the Water Institute, the Waterloo Institute for Sustainable Aeronautics, and the Institute for Quantum Computing, respectively.

Since 2019, we have offered a co-op option for the MMath thesis program. Students who enrol in this option spend two four-month terms in work placements (in either research for industry) as part of their program. The co-op option is not available to students in the Water or Quantum Information options.

The MMath (research paper) has a heavier course requirement: students must complete six courses, two of which must be selected from the list of departmental breadth courses. Students then spend one term (4 months) completing a research report.

1. Doctor of Philosophy (PhD)
2. Doctor of Philosophy (PhD)-Water
3. Doctor of Philosophy (PhD)-Quantum Information
4. Doctor of Philosophy (PhD)-Aeronautics

Course requirements for the PhD programme vary depending on the student's background. Students admitted from a Master's degree are required to complete four courses, three of which must be selected from the list of departmental breadth courses. Students admitted directly from a bachelor's degree are required to complete eight courses, again with three chosen as departmental breadth courses. Students complete a comprehensive exam in their second year and defend their thesis after, typically, 4 years. As mentioned above, they are also required to teach an undergraduate course or, as an alternative, deliver a series of research presentations.

There are five primary fields for the department's graduate programs:

1. Dynamical Systems & Control
2. Fluid Dynamics
3. Mathematical Medicine & Biology
4. Mathematical Physics
5. Scientific Computing

Summary of Strengths, Challenges and Weaknesses based on Self-Study

Strengths

- Small graduate class sizes.
- High academic quality of students. Strong students, several of whom continue from the Master's to the PhD program or go on to graduate school at other prestigious universities
- Breadth of course offerings - several specialized courses related to research areas of faculty members offered regularly.
- Strong research profiles of faculty supervisors
- Very collegial relations between faculty and students
- Emphasis on interdisciplinarity and application of mathematical ideas to problems in other fields.
- The Department initiated a Masters Co-op program which is healthy and has had a good placement rate.

Challenges/Weaknesses

- Consolidation and strengthening of our Masters Co-op program with a view to potentially introducing it at the PhD level. The difficulties here lie in connecting with problems of interest to industry and other sectors addressing societal needs, and then shaping a PhD-Co-op program that still meets the rigorous demands of our traditional PhD programs.
- The maintenance of a broad spectrum of specialized courses at the graduate level, and this is closely linked with the recruitment of top faculty members in diverse areas of applied mathematics.
- The gender ratio amongst faculty and graduate students remains skewed towards males and a more targeted effort in concert with university efforts and commitments on EDI, has to be made to improve gender balance and improve minority representation in the department. We will focus on improving the diversity of our new hires, and on supporting students from traditionally underrepresented groups, and in

this manner enhance the departmental atmosphere and environment for students, faculty and staff.

Summary of Key Findings from the External Reviewers

"We feel that the MMath and PhD programs quality is high. The programs are able to attract high quality students in spite of stipend levels which seem uncompetitive. From what we can uncover, student experience is good. We encourage the department to grow its interdisciplinary research and educational programs and engage in the university's activities in Data Science and AI."

Program Response to External Reviewers' Recommendations

1. **Promote interdisciplinarity:** We strongly feel that Applied Mathematics should be more central to the research and educational activities in the Faculty of Mathematics and the university. We suggest that Applied Math participate in established and recently launched interdisciplinary programs such as the Master's of Data Science and AI, MMath in Data Science. Faculty members should be encouraged to develop and lead large cross-disciplinary and industry-academic collaborative projects in research and training.

   Program Response
   We are in complete agreement with the reviewers' recommendation 1 and in fact have already been in discussions with the Dean, regarding the department's strong and growing interest and our wish/need to be more actively involved in the Math Faculty initiatives in Data Science and AI (particularly the Master's and undergraduate programs in Data Science). Hopefully, the reviewers' recommendations will expedite this process.
   - In particular, with support of the Dean, the department aims to become an equal partner in the MMath in Data Science, the Master's of Data Science and AI, and the undergraduate BMath in Data Science. The department has formally been admitted to the Steering Committee of the Faculty of Mathematics' graduate programs in Data Science in 2025, including the Master's of Data Science and AI, and discussions will start in Fall 2025 about which courses Applied Mathematics will contribute to the programs.
   - To this end, the department is introducing several new courses, including AMATH 445/645 "Scientific Machine Learning" (approved in 2024) and AMATH 446/646 "Introduction to Mathematics of Deep Learning" (going through the approval process in 2025, with, as a first step, departmental approval obtained in June 2025). Applied Mathematics will also co-teach the course CS479/679 "Neural networks" with Computer Science, and the cross-listing AMATH449/649 has been approved in 2025. Further courses will be considered in data-driven mathematical modelling and at the advanced graduate level. These courses will better position the department to become equal participants in the undergraduate and graduate Data Science programs. Courses that address the ethics

of AI are accessible to Applied Math graduate students through course offerings by the CS department, such as the recent offerings CS489/798 (AI: Law, Ethics and Policy) and CS798 (Machine Learning and Society Impact).

- With the help of the Dean and other departments, the department will explore moving the Data Science programs from specific academic units to the Faculty level, which would substantially simplify the governance of the programs and would naturally promote broader and equal participation of all the interested academic units in the programs. This has been completed for the Master's of Data Science and AI, which has been approved in 2025 to follow the Faculty of Mathematics' interdisciplinary program governance model. Going forward Applied Mathematics will be a participant in the governance of the program.
- The department will also hire new faculty members in these areas to strengthen its teaching and research profile in these fields. In Fall 2023, the department advertised a tenure-track position in the area of Scientific Machine Learning, and a second position was pursued jointly with the Perimeter Institute in the area of Machine Learning and Theoretical Physics. The first search was successful and a new faculty member was hired in the area of Scientific Machine Learning. This remains a priority area for further faculty hiring in the coming years.
- The new courses in Machine Learning and Data Science will also be used to update/modernize the department's undergraduate majors and make them more attractive to students, including the BMath in Applied Mathematics, the BMath in Mathematical Physics, the renamed BMath in Applied Mathematics with Scientific Computing and Scientific Machine Learning, as well as the department's Master's and PhD programs.
- Faculty members in the department are also actively involved in efforts to establish interdisciplinary research collaborations with other UWaterloo Faculties in line with the "5 Global Futures" which the University of Waterloo has identified in its "Waterloo at 100" Strategic Vision to address the most pressing challenges for humanity and our planet, including the new provost-funded Interdisciplinary Master's Fellowship in Computation and Data (i-Comp-Data), which promotes cross-Faculty co-supervision of master's students. In addition, two faculty members in the department have obtained substantial external funding for research in Data Science and AI in 2025: David Del Rey Fernandez has been appointed the Pratt & Whitney Canada Chair in Industrial Artificial Intelligence, and Achim Kempf has been appointed the Dieter Schwarz Chair in the Physics of Information and AI.

Dean's Response

The Applied Mathematics department continues to do great work on interdisciplinarity and were indeed able to hire a faculty member in scientific machine learning.

Discussions are already underway to better integrate the department into our Data Science programs, both research and professional (course-work) oriented.

2. **Increase engagement in Data Science and AI activities at Waterloo:** We strongly recommend that the department explore ways to raise its involvement in data science and AI activities - both educational and research - at Waterloo. We are convinced that there are important roles for the department to play in this growing and important space. It has the desirable effect of connecting the department to other units and creating opportunities for collaboration.

   Program Response
   Again, we are in complete agreement with the reviewers' recommendation: as explained extensively in the response to Recommendation 1, the department is actively exploring ways to raise its involvement in data science and AI activities - educationally with new courses in Data Science and Machine Learning, and on the research side with a variety of efforts. Already, roughly half of applied math faculty members actively develop and use data science and AI methods in their research.

   Dean's Response
   As mentioned in the previous response, discussions are underway to determine how to better integrate Applied Mathematics to our Data Science programs. This is a timely discussion since the Faculty is looking to increase enrollment in these programs, both at the graduate and undergraduate level, and especially at the professional (course work) masters level.

3. **Encourage student participation in Co-op:** We were impressed by the department's participation in the Waterloo Co-op program. We believe the enriching and broadening experience provided by the program to students has the potential to make Applied Math a leader in graduate education in the Math Sciences. There is the added benefit of leveraging this program into sustainable industrial collaboration. The program should be more widely advertised to Applied Math graduate students.

   Program Response
   The Co-op MMath program is still in its infancy and the department is exploring ways of growing the program and establishing closer connections with Industry with a view to increasing industrial collaborations (and associated industrial funding for research projects). In particular, as a major example, the new Pratt & Whitney Canada Chair in Industrial Artificial Intelligence will directly involve a substantial number of Master's and PhD students doing research projects and internships with Pratt & Whitney Canada, thus substantially strengthening work-integrated learning opportunities. This will be a model for exploring similar industrial partnerships over the next years. A second example is the

2024 NSERC Collaborative Research and Training Experience (CREATE) grant titled "Training for Novel Directions in Quantitative Climate Science" which was awarded to Marek Stastna ($1.65 Million over 6 years). This grant is a collaboration between University of Waterloo, University of Toronto, Dalhousie University and McGill University with government partners Northwest Atlantic Fisheries Centre & Institute of Ocean Sciences of the Department of Fisheries and Oceans; and Canadian Meteorological Centre of Environment and Climate Change Canada. This project will facilitate graduate student training in direct collaboration with those government partners. Third, another example is graduate student collaboration and internship opportunities resulting from Applied Mathematics' leading role in the new Future Cities Institute at the University of Waterloo. David Del Rey Fernandez is the institute's Cluster Lead on modelling, which provides graduate student opportunities with partners including the City of Kitchener. These new work-integrated learning opportunities will be combined with increased advertising of the co-op Master's program.

Dean's Response

Through our Associate Dean Co-op and our Mathematics Innovation Office, we can support the department in its efforts to reach the stated goals for the co-op graduate program. As well, we work closely with our central Co-operative and Experiential Education (CEE) office to facilitate and expand co-op opportunities.

4. **Enrich and enhance graduate student experience:**

a) Social Life in the Department - Reboot pre-pandemic social activities and initiate new ones. Create a sense of FOMO (fear of missing out).

b) Strengthen Alumni Connections

c) Offer Career Pathway Informational Events - develop informational events wherein career pathways for AMath graduates are discussed. These events could include Career Services, recent employers, and alumni.

d) Space – While we were unable to see the spaces currently available to the department, we were given the impression that space is an issue, from the standpoints of quantity and quality.

e) Develop AMath Program-specific EDI initiatives.

f) Include graduate students in the recommended climate assessment of the department.

Program Response

The department has already started rebooting pre-pandemic social activities and the current Chair is looking into and rolling out new initiatives that will enrich the grad student experience, including a beefed-up colloquium offering with substantially increased frequency, and regular weekly departmental social time. The department will look into strengthening alumni connections and data gathering in collaboration with staff Alumni Specialists at the level of the Math Faculty and the University. The department is looking at

ways of organizing periodic events by inviting successful alumni in industry and academia to provide information on career pathways and opportunities for current AM graduate students. While space is an issue, we expect the construction of M4 to eliminate many of these problems, since the Dean has committed to increasing office space relative to our pre-M4 footprint from space that will be freed up in MC after completion of M4. The department is developing AMATH Program specific EDI initiatives by striking an AMATH-specific EDI committee which will address and explore many of these issues. For example, the EDI committee has developed guidance documents "Applied Mathematics: Equity and Inclusion Principles", "Expectations in Supervision: Discussion guide", and "AMATH Research Group Manual". The graduate chair has rolled out several new initiatives in 2024 and 2025, including an annual 1-day graduate research conference and an annual week-long interdisciplinary graduate research workshop. These initiatives are being developed in close consultation with the graduate student body, which is also involved directly in climate assessment and improvement initiatives led by the departmental EDI committee and the Chair.

Dean's Response

As noted in the response, once we have our new Mathematics 4 building, this will create space in the Mathematics & Computer building where Applied Mathematics is located, which in turn will help the department with its space needs. Furthermore, increasing the sense of community has been identified as a "lens" within our newly launched Strategic Framework, and is thus fully integrated into our decision-making to enable strategic initiatives over the next five years.

5. **Develop AMath Program-specific EDI initiatives:** We are encouraged by the recent development in the University and the Faculty of Mathematics for an enhanced capacity to support EDI initiatives, we recommend that the department take full advantage of these resources to develop AMath Program-specific EDI strategies and initiatives.
   a) Use data of declinations by female candidates to develop an improved hiring process.
   b) Explore the possibility of multiple "homes" for candidates.
   c) Make competitive offers given that strong interdisciplinary candidates are typically recruited by other disciplines.
   d) For the on-going open rank recruitment in broad areas of research, we encourage the AMath Program to develop a strategy that is guided by the program-specific measures of success, and coherent with the program's plan to sustain and grow its central roles in interdisciplinary research and training.

Program Response

In response to the reviewers' recommendation, the department has created an Applied Math specific EDI committee to explore and address the points raised above. In consultation with the graduate officer, the EDI committee will help formulate data-driven strategies for the

department to improve the representation of female graduate students. The graduate officer and chair will explore with the Associate Dean, Graduate Studies (who is also a co-chair of the departmental EDI committee) what may be suitable ways a climate survey can be conducted at the department level, potentially through an independent university entity or outside entity. The goal for the department will be to have women and URM at the level consistent with the averages across North America. In terms of financial support, the department has consistently been increasing the support level in graduate offers over the past 5 years. The support we offer is now the highest in the Faculty of Mathematics, and we will continue to increase the support levels. Sustained financial contributions from the Faculty of Mathematics have been instrumental towards this end, and we also rely on increased contributions by faculty members from their grants, and on increased external funding success obtained by our professors (Pratt and Whitney Canada, Schwarz Foundation, NRC, NSERC Alliance, etc.). Our 3-year faculty hiring plan indeed prioritizes strategic areas that include AI, Health and Medicine, Climate and Sustainability, and Quantum Computing. The EDI committee in consultation with the Chair will produce a broad-ranging EDI report following the EDI climate survey with proposed action items, including hiring benchmarks.

Dean's Response
The Faculty can provide guidance to the department with respect to EDI activities through our Faculty Equity Officer.

6. **Climate Assessment:** Conduct a climate assessment of the department and include graduate students in this assessment.

Program Response
As discussed above, the graduate officer and chair will explore with the Associate Dean, Graduate Studies (who is also a co-chair of the departmental EDI committee) what may be suitable ways a climate survey can be conducted at the department level, potentially through an independent university entity or outside entity. The goal for the department will be to have women and URM at the level consistent with the averages across North America. The department is committed to making a concerted, deliberate, and persistent effort to this end involving the graduate students and the entire department. The EDI committee in consultation with the Chair will produce a broad-ranging EDI report following the EDI climate survey with proposed action items, including hiring benchmarks.

Dean's Response
The Dean agrees with the program response.

Recommendations Not Selected for Implementation

N/A

Implementation Plan

	Recommendations	Proposed Actions	Responsibility for Leading and Resourcing (if applicable) the Actions	Timeline for addressing Recommendations
1.	Promote interdisciplinarity.	The department has already been strongly and actively promoting interdisciplinarity, which is characteristic of our brand of Applied Math. We propose to continue on this path and with the Dean's support aim to be more actively involved in the Masters of Data Science and AI, the MMath in Data Science, and the BMath in Data Science as an equal partner. Explore moving the Data Science programs from specific academic units to the Faculty level for easier governance and broader participation.	Department Chair	Fall 2026 Current progress: The department has formally been admitted to the Steering Committee of the Faculty of Mathematics' graduate programs in Data Science in 2025, including the Master's of Data Science and AI, and discussions have started in Fall 2025 about which courses Applied Mathematics will contribute to the programs. The programs are now governed at the Faculty level.
2.	Increase engagement in Data Science and AI activities at Waterloo.	Discussions with Dean and the Dean's Advisory Council. Creation of new AMATH Data Science and AI courses and full participation in the Faculty's undergraduate and graduate Data Science programs as an equal partner. Faculty hiring in Machine Learning/Data Science.	Department Chair and Associate Chairs (Grad & Undergrad)	Fall 2026 Current progress: see Recommendation 1 above. One faculty member was hired in scientific machine learning in 2024, and a faculty search in AI+Theoretical Physics is being conducted in Fall 2025, fully funded by a large external donation.
3.	Encourage student participation in Co-op.	More active promotion of Co-op MMath program. More active engagement and connections with industry, using Pratt & Whitney Canada chair, Schwarz chair, NSERC CREATE, Future Cities Institute, and further similar initiatives to be developed.	Associate Chair (Grad) and Chair.	Fall 2026

4.	Enrich and enhance graduate student experience.	Math Faculty and Department has already kick-started many of these, including a beefed-up in-person colloquium offering with substantially increased frequency, and regular weekly departmental social time. The department will look into strengthening alumni connections and data gathering in collaboration with staff Alumni Specialists at the level of the Math Faculty and the University. While space is an issue, we expect the construction of M4 to eliminate many of these problems, since the Dean has committed to increasing office space relative to our pre-M4 footprint from space that will be freed up in MC after completion of M4. The department is developing AMATH Program specific EDI initiatives by striking an AMATH-specific EDI committee which will address and explore many of these issues. The graduate chair has rolled out several new initiatives in 2024 and 2025, including an annual 1-day graduate research conference and an annual week-long interdisciplinary graduate research workshop, and further initiatives are being developed, including regular student-led research seminars etc.	Chair and Associate Chairs	Fall 2026
5.	Develop Applied Math Program-specific EDI initiatives.	The department has created an AMATH-specific EDI committee to address these. The Chair and Associate Chairs will also be involved in these intiatives. This includes concerted efforts to improve representation of female graduate students, improved financial support levels, and an EDI climate assessment.	AM-EDI Committee/Chair/Associate Chairs	2026

6.	Conduct a climate assessment of the department.	The department will conduct an EDI climate survey at the department level. The EDI committee in consultation with the Chair will produce a broad-ranging EDI report following the EDI climate survey with proposed action items, including hiring benchmarks.	AM-EDI Committee / Chair / Associate Chairs	2026

The Department Chair/Director, in consultation with the Dean of the Faculty shall be responsible for the Implementation Plan.

Date of next program review 2029-2030
Date

Signatures of Approval

June 25, 2025

Chair/Director Date

AFIW Administrative Dean/Head (*For AFIW programs only*) Date

June 27, 2025

Faculty Dean Date

Note: AFIW programs fall under the Faculty of ARTS; however, the Dean does not have fiscal control nor authority over staffing and administration of the program.

Dec.16, 2024

Associate Vice-President, Graduate Studies and Postdoctoral Affairs Date
(For graduate and augmented programs)