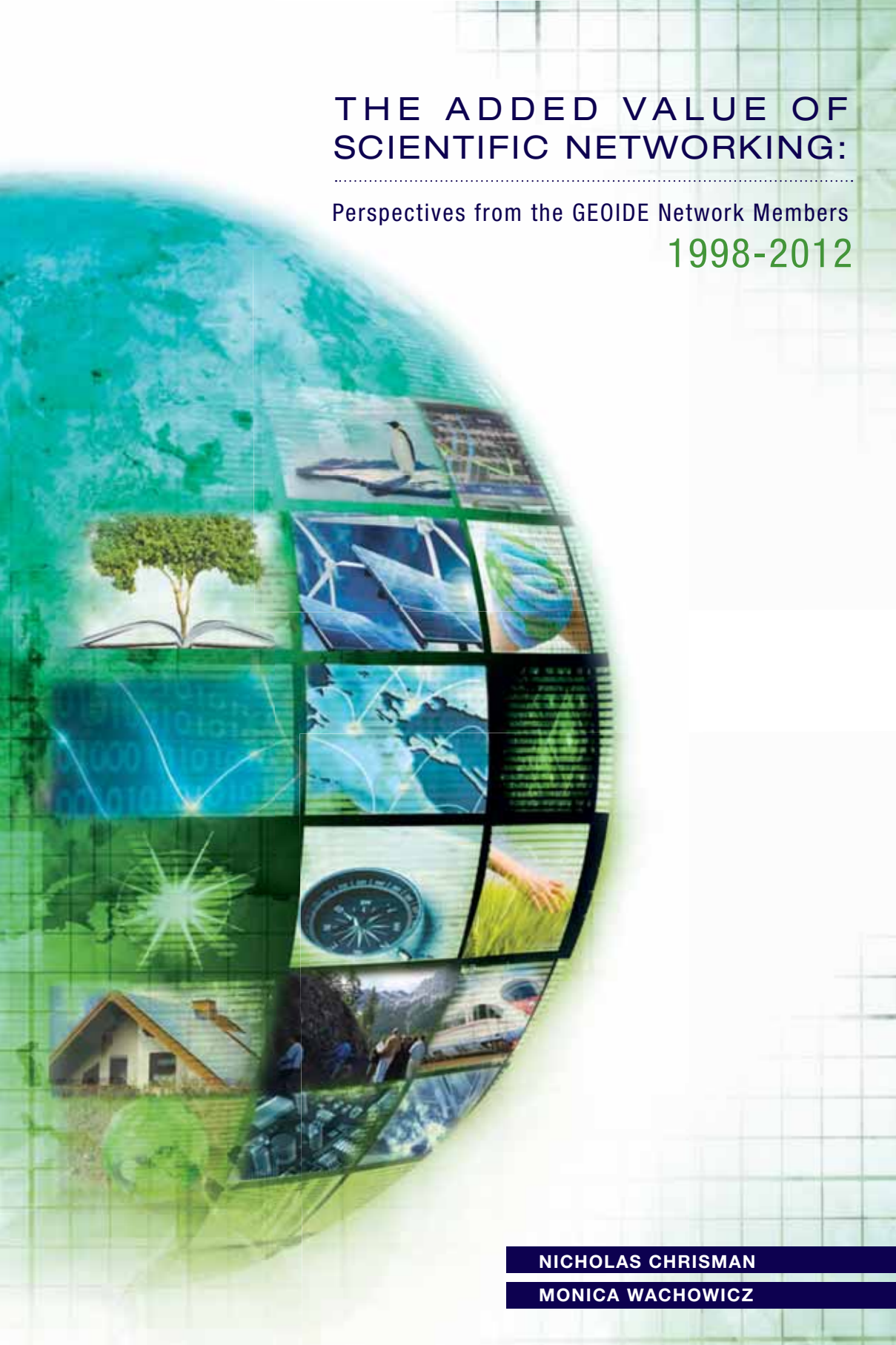


THE ADDED VALUE OF SCIENTIFIC NETWORKING:

Perspectives from the GEOIDE Network Members
1998-2012

NICHOLAS CHRISMAN
MONICA WACHOWICZ

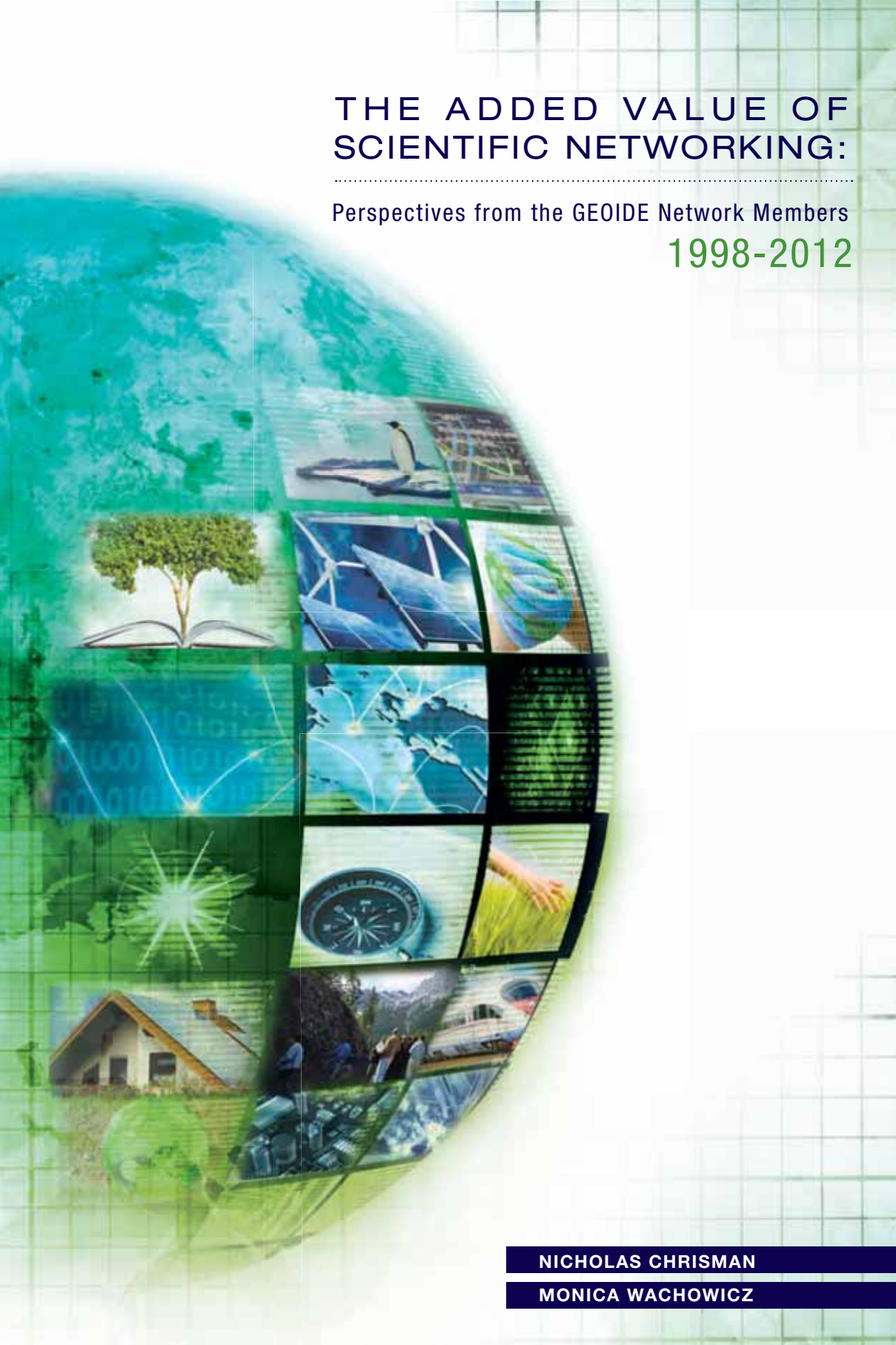


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Edited by Nicholas Chrisman and Monica Wachowicz



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Preface

What is GEOIDE? Certainly it has been a Network of Centres of Excellence, a source of funding. But to many it has been more: a vision, a multidisciplinary community, a variety of new generation tools, innovative approaches, successful spin-offs as well as a part of Canadian academic, education and research life for the past fourteen years.

This book explores the trajectory of GEOIDE, Canada's geomatics network which has served the education, industry, government and research community, from its inception in 1998 to its state in 2012. The call for chapters aimed to address two important questions. *Does it make any difference to organize multi-disciplinary, multi-institutional projects? What is the value-added by the network form of collaboration?* These questions remain unanswered as long as there are limited anecdotal results. A big part of the problem is the lack of long-term follow-up as researchers all move on from one project to the next. This book provides a moment of reflection in this rush to the next new things. It assembles contributions from a number of distinct perspectives, each responding to the basic questions.

The first five chapters in this book describe some of the lessons learned over GEOIDE's history. Chapter 1 provides an outline of the history of the Network, written by two of the Scientific Directors who managed the operation. It provides a framework in which the subsequent chapters can be located. It also set out a list of many of the people that made GEOIDE possible.

Chapter 2 continues the narrative of GEOIDE's history, specifically with respect to the students' organizations of the Network. Rodolphe Devillers, Trisalyn Nelson and Steve Liang joined the network as PhD students while GEOIDE was getting organized. In their chapter; they provide their perspective on the GEOIDE Students' Network (GSN) and its synergy with the

GEOIDE Summer School (GSS). They describe the main stages in the development of those initiatives in addition to the different actors, discussing the successes but also the challenges and the failures. In drawing lessons from those facts, they come with a number of recommendations that can be used by other organizations that would like to create and benefit from GEOIDE's experience.

Continuing this theme of lessons learned, Teresa Scassa, Jennifer Chandler, Yvan Bédard and Marc Gervais draw attention to how the GEOIDE Phase IV broke with the tradition of funding science-led collaborative research projects by supporting an innovative project where the legal and ethical issues were at the forefront of the research agenda (Chapter 3). Their perspective on this project demonstrates the value from bringing together key researchers linking legal, ethical and technological solutions to emerging normative challenges raised by digital geospatial data.

The importance of an interdisciplinary learning environment is voiced by Charmaine Dean, W. John Braun, David Martell, and Douglas Woolford. In their chapter (4), they give us their perspective on the essential ingredients which they believe have contributed to the interdisciplinary collaboration and training successes that took place on their GEOIDE teams. They show the way on how joint training can be extremely useful provided the students' interests remain paramount throughout the collaboration.

Finally, the chapter (5) written by Kevin Schwartzman, Paul Brassard, Jason Gilliland, François Dufaux, Kevin Henry, David Buckeridge and Sherry Olson examines a twelve-year collaboration by giving their perspective on how they got started, where did collaboration took them, and where will it might take them next. Along the particular frontiers between epidemiologists, architects, historians, and geographers, they make some generalizations about the benefits of networking and their personal and institutional assets have proven to be useful.

The second part of this book includes five more chapters that focus on the transformative nature of the research conducted within the network. The first perspective (Chapter 6) is on the transformative nature of the research described by Pamela Tudge, Renee Sieber, Yolanda Wiersma, Jon Corbett, Steven Chung, Patrick Allen, and Pamela Robinson on The Participatory GeoWeb for Engaging the Public on Global Environmental Change. Their team has sparked unlikely alliances and predictable hurdles, but it has also shown that everyone had the opportunity to be a scientist as they have collaborated towards innovation. They were guided by three research questions: What defines effective public participation on the GeoWeb? How do we contextualize

web-based environmental change models and data on the GeoWeb? And finally, how do we build a cyber-infrastructure and enabling policies that serve this two-way engagement? Geolive is now being deployed by the university associates in partnership with four community organizations based in British Columbia and Ontario, each working at different spatial extents (from the local, to provincial to national level) and on different issues. These organizations include: The i2i Intergenerational Society of Canada, the Kawartha Heritage Conservancy, the Ottawa River Institute and The Sustaining What We Value Project (a collective of several non-government organizations and government agencies).

The second perspective (Chapter 7) is on the transformative nature of the research described by Bernard Moulin on multi-agent and population-based geo-simulations for decision support. This chapter tells the ‘inner story’ of these 12 years of research which, in retrospect appear as a complete and articulated research program on MAGS for decision support. It presents the main milestones of this program and emphasizes how the GEOIDE Network provided opportunities to team up with industrial and governmental partners and different Canadian and international research teams in a series of projects, PADI-Simul, MAGS, MUSCAMAGS and CODIGEOSIM, and a constellation of companion projects.

The third perspective is about the transformative research in the development of Mobile Educational Games as described by Rob Harrap, Sylvie Daniel, Michael Power, Joshua Pearce and Nicholas Hedley. In their chapter (8), they pave the way for others interested in pursuing vision of fusing geomatics and game design to produce a serious game to teach children about gaming, technology, and sustainability. The Energy Wars Mobile game allows discovery and exploration of environment and space through location-based and augmented reality tools. They also provide a fruitful insight in how the game and side-projects reflected their vision, and what the GeoEduc3d group has to say about network based science.

The fourth perspective (Chapter 9) is from Julian Dodson, Normand Bergeron, Patricia Johnston, Richard Hedger, Patrice Carbonneau and Michel Lapointe on the use of cutting edge geomatics tools for the measurement of fish habitat variables over long river segments. Their research applied these advances to the problem of understanding Atlantic salmon spatial behaviour and survival in relation to habitat characteristics. The major challenge GEOSALAR faced was the integration of spatial referencing techniques with data acquisition from heterogeneous sources, including landscape complexity, fish movements across the landscape and the impact of human activity on landscape complexity at different spatial and temporal scales. The chapter

demonstrates how a collaborative, interdisciplinary effort can change the framework for enquiry in a given domain.

Finally, the last perspective is based on a Local Climate Change Visioning process that has adapted geospatial tools to a range of contexts and thematic areas. In Chapter 10, Ellen Pond, Olaf Schroth, Stephen Sheppard, Rob Feick, Danielle Marceau, John Danahy, Sarah Burch, Laura Cornish, Stewart Cohen, Majeed Pooyandeh, Nishad Wijesekara, David Flanders, Kristi Tatebe and Sara Barron describe how GEOIDE has enabled a decade of collaborative development of geospatial decision-support tools on sustainability issues, working with several regional and local governments, and multiple academic teams. It is interesting to see how the evaluation goals have shifted over the life of the projects, from initial testing of awareness and learning about climate change, to testing particular geovisualization tools and a simpler scenario development process, to evaluating the effectiveness for capacity-building and decision-support using a longitudinal evaluation and case study comparison.

These ten chapters only provide a partial story of the remarkable results of the GEOIDE Network from 1999-2012. The authors of each chapter responded to the call for chapters and responded in their manner to the questions; they deserve thanks for breaking with the typical format of scientific publication to reflect on these issues. The editors also wish to thank the reviewers of these chapters, members of the GEOIDE Research Management Committee, and others from around the world. Also, the support team at GEOIDE, particularly Atiyeh Ghanbari, and the design team at MS Communications contributed to the production of this book. This book is in every way supported by the funding obtained from the Networks of Centres of Excellence (NCE); without this support there would be no network to report upon. The NCE Secretariat is not responsible for any views expressed.

There is much more to be said about networking and the value of collaboration. Each case relates to specific circumstances and personal perspectives. Perhaps this volume may spark further reflections.

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March 2012

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Chapter 1

A Short History of the GEOIDE Network

Keith Thomson and Nicholas Chrisman

Scientific Directors

GEOIDE Network

Abstract. Over fourteen years, the GEOIDE Network has set a standard for excellence in delivering results of research to user communities across disciplinary boundaries. This chapter provides a skeleton history of the organization, and acknowledges the many contributions that made this possible.

1 GEOIDE Network: Collaboration Designed for Public Benefit

Quick Summary of the Network. Fourteen years ago, a team of geomatics researchers, at Université Laval, University of Calgary and the University of New Brunswick, built a national collaboration of government, industry and the research sector to win a highly competitive competition. The result was the GEOIDE Network (GEOmatics for Informed DEcisions), funded by the Networks of Centres of Excellence (a permanent programme of the Government of Canada) for these past fourteen years. It has engaged teams of researchers from 34 institutions across Canada with over 500 partners in every sector. The inputs and outputs are easy to catalogue, but it is the benefits for society that matter.

Over its fourteen year existence, GEOIDE assembled researchers across Canada, in a range of fields including termed "geomatics" in Canada (including surveying, geodesy, photogrammetry, remote sensing, image processing, geography, planning, and geographic information science). It also mobilizes domain specialists from various environmental sciences, engineering, public health and the social sciences. Over the full period, GEOIDE has funded a total of 121 projects, with a total investment of 79.3million\$CAD. In these projects, 395 research scholars from Canada have participated, and a total of 1437 students. In addition, 174 industrial affiliates have been engaged, alongside 95 governmental entities at all levels. Researchers from around the world have been linked formally and informally from 146 institutions (research laboratories, universities and the like). In terms of traditional output measures, GEOIDE projects report 2675 peer reviewed papers and another 2070 in non-peer

reviewed outlets. So, in the traditional measures, GEOIDE has been a big research enterprise, but it also shows results beyond the traditional outputs of research.

Interdisciplinary Mix- What is in a Name? The mix of disciplines involved in Geographic Information Science or geomatics has fallen out differently from place to place, country to country. The role of institutions has varied, with strong state support in some places, and more industry role in others. Overall, this multi-disciplinary convergence presents an interesting case study in the history and sociology of science and technology. The naming of the field itself demonstrates this diversity of approaches, as well as signaling the complexity in building true international coherence. The long-established disciplines of cartography, surveying, geography, and geodesy have merged in various combinations in different countries. For example, cartography as an academic subject is mostly practiced inside geography departments in North America, but this is not the case in most of Europe. Surveying as an academic subject has declined in North America despite the dramatic technological advances in the field. Michel Paradis saw this coming in 1981 and used his opportunity as keynote speaker to present the new term "geomatics" (Paradis 1981). This neologism is easier to understand in French, since the term for computer science is 'informatique'. In most countries there have been mergers, but which have merged with the others is not uniform between countries. The more recent fields of photogrammetry, remote sensing, geographic information systems have been merged in some places with some of the older disciplines under the title of geocomputation or geographic information science. In Canada, the term "geomatics" (*géomatique en français*) took root twenty-five years ago as a covering term for the whole collection of undertakings to collect, analyze and distribute geographic information (Gagnon and Coleman, 1990). The GEOIDE Network added a form of common identity for researchers at the geomatics engineering departments in New Brunswick, Ontario, Alberta, and Québec. In Australia, the term 'spatial sciences' has become the rallying term for the same coalition.

Whatever the name, the interdisciplinary nature of GEOIDE has been crucial to its results. GEOIDE includes many disciplines for belong those involved in the technically-oriented geomatics coalition, but the chapters in this book provide a glimpse into its scientific results as well as the challenges of building these collaborations. Table 1 provides a snapshot of the disciplines involved at the end of Phase III (2008). Other points in the GEOIDE timeline would show different details, but more or less the same mixture.

Mission. The core of the GEOIDE's mission is to promote the development of geomatics research in a way that delivers benefits to Canadians. (see www.geoide.ulaval.ca) Unlike "curiosity-driven" research councils, NCE favors an interaction between "receptors" and the research community (see note below on the NCE programme). Through this two-way flow, the traditional linear model of a linear pipeline of "technology transfer" is restructured to provide for full feedback and interaction. Projects have been selected for their robust interdisciplinary communication and for their collaborations with a user sector in industry, government, or the non-

profit sector. Substantial additional funding is expected from these user sectors, and GEOIDE has been more and more successful in obtaining cash contributions, in some cases matching the research council funding 1:1. Overall, the recent average is closer to 1 (from users):2(from the councils).

Tab. 1. The disciplines involved at Phase III (2008)

Departmental affiliation of Network Investigators (Phase III)	Number of researchers	% of total
Geomatics	23	17.3
Geography	19	14.3
Earth Science (Geology, Geophysics, Atmospheric Sciences)	19	14.3
Civil and other Engineering	18	12.8
Computer Science	12	9.0
Statistics (Mathematics)	9	6.8
Environmental Studies (Biology, Landscape Ecology, Ocean)	8	6.0
Forestry	6	4.5
Medicine (with Public Health, Kinesiology)	6	4.5
Physics	5	3.8
Planning (with Landscape Architecture)	4	3.0
Archaeology	3	2.3
Business	2	1.5

Innovation- Commercialization of Research Results. One of the central goals of the NCE programme and the Canadian government is to create new enterprises, or to spur innovation in existing companies. GEOIDE projects have led to at least 20 patents, and many more licensed technologies (Figure 1). A few spin-off companies have resulted, most of them still in business. For example, SimActive, Miovision, NSim, Trusted Position and Intelli³ were created by GEOIDE-trained students, with support from GEOIDE Market Development Funds and from other partners. Perhaps the most successful spin-off had the shortest existence, as GeoTango was acquired by Microsoft within weeks of its creation. The technical directions of GEOIDE research point the way for Canadian contributions to web mapping, positioning technologies, image processing algorithms, business intelligence and many more. At this stage it is premature to make a definitive list, since many innovations incubate for a long time before leading to commercialized outcomes.



Fig. 1. GEOIDE Logo – there is a whole story behind it, but it became just a logo.

Training of Highly Qualified Personnel. Over many years, the Network has funded over two hundred students each year. Over the life of the Network, 545 students have completed graduate degrees (Masters and PhD). Results of the cumulative investment have been particularly clear as a generation of graduates from the network have taken up positions across the geomatics community. These students were trained in a different manner, placing greater emphasis on interdisciplinary teamwork. Chapter 2 of this book provides the history of the founding and operation of the GEOIDE Student Network, a key innovation.

Perhaps a third of the students moved directly into industry jobs, but the new generation is most visible in the academic sector. Over the past four years, 18 former GEOIDE trainees have taken tenure-track positions in academic departments across Canada. In some geomatics departments, half of the new junior hires have been GEOIDE students from earlier Phases. Twelve of the 95 researchers in the main projects of Phase IV are former GEOIDE trainees, including two project leaders and three deputy leaders. As a result, research leadership in the Network is turning to new faces with real experience in networking.

The students are the key result of the network. Taken as a group, this new generation of geomatics professionals working in all sectors of the geomatics community has been making an impact on the economy, in the form of new businesses and innovation within existing companies. On the academic side, the research community is being renewed and the spirit of networking firmly established. These students are an enduring legacy of GEOIDE and an indicator of future accomplishments. Chapter 2 of this book will continue with much more detail on the ways the GEOIDE supported student initiatives.

International Connections. Over the years, GEOIDE developed stronger relationships with an increasing number of international partners. In 2006, GEOIDE hosted a workshop that assembled the scientific directors (or equivalent) from organizations representing France, Ireland, Australia, Netherlands, USA, European Union, and Latin America. Subsequently, connections have been made to Mexico, Sweden and South Korea. Each organization has its own origins and distinct objectives. Some are research networks much like GEOIDE, with funding for research initiatives. GEOIDE has actively engaged with these groups, sending representatives to their national meetings, attending their workshops, and bringing their teams to GEOIDE events. These efforts have led to enlarged teams (affiliated foreign researchers increased from 17 to 39 in Phase III), bringing Canadian expertise to a new worldwide leadership position. GEOIDE has joined with Australia, Mexico, Sweden, and South Korea to create an organization termed the Global Spatial Network. This unincorporated entity seeks to promote common operations and enhanced exchange (Table 2).

Tab 2. List of members and affiliate members of Global Spatial Network

<i>Full Members</i>	
CRCSI (Cooperative Research Centre for Spatial Information)	Australia (and NZ)
CentroGeo	Mexico
KLSG (Korean Land Spatialization Group)	South Korea
Future Position X	Sweden
GEOIDE	Canada
<i>Affiliate members</i>	
AGILE (Association of Geographic Information Laboratories in Europe)	EU
UCGIS (University Consortium for Geographic Information Science)	USA

2 Before GEOIDE

In writing a short history of the network, one has to return to the point of origin. In the last years of the twentieth century, the fields of geomatics were growing at rates that appeared astounding at the time. Canada had launched RADARSAT-1 in 1995, and the plans were well underway for RADARSAT-II (though it actually took many more years until it was launched). Beyond big flagship projects, GIS technology had popped up in every level of government, and in the private sector. What had been a very small sector of the economy had taken on new force. At Université Laval, the Centre de recherche en géomatique (CRG), founded ten years prior, had an active programme covering everything from cadastral legislation to radar remote sensing. Two other centres of excellence in geomatics had equally strong (and perhaps complementary) strengths at Calgary and Fredericton. The situation fit the requirements of the Networks of Centres of Excellence (NCE) programme of the Canadian federal government.

The NCE programme was at this point a ten-year old institution, newly converted from an experiment to a permanent entity. Keith Thomson, at this point director of CRG, started to assemble a proposal for a geomatics network, assisted by Geoffrey Edwards and Annick Jaton. At the same time, a similar effort had started under the leadership of Crestech, an arm of the Ontario Centres of Excellence (OCE). At the very last minute, these two efforts were merged, and submitted by Université Laval, under the name GEOID (the E was added later on to make the acronym bilingual). The review process required 40 paper copies with CVs for all the researchers, and other piles of documentation. Not trusting in Canada Post or any delivery service, Edwards and Thomson established a GEOIDE tradition by renting a van and driving the proposal themselves to Ottawa.

The GEOID proposal entered into a huge competition. In the first round, there were 77 letters of intent from other organizations. Of these 11 were selected to submit a full

proposal. The proposal process required much effort to develop a common research strategy, and to contact and retain Partners from government and industry. The model of the time relied on a membership model, something that worked for the first two Phases of the Network. The sponsorship scandal and the Government Accountability Act of 2006 changed the landscape in many ways for the later Phases. GEOID went through a rigorous review process, and was selected as one of three new networks, from the original field of 11 (a fourth network, CIPI in photonics, was awarded later in 1999). The work had just begun. The paper proposal had to become a functioning organization. It took unto February 1999 for all the universities to sign the Network Agreement, so the 1998-1999 fiscal year only had a few weeks of research operations.

3 Getting Organized

The proposal included 28 collaborative projects with researchers from multiple universities. In order to mount the proposal, a Steering Committee had been chosen to reflect the range of partners (see Appendix for a list of members and sectors represented). The Steering Committee used a matrix that crossed application areas with technologies. The idea was to show full coverage of all cells in this matrix. Perhaps this methodical approach was a part of the reason why the proposal was selected. As is usual, the final funding package was somewhat less than the proposal, and cuts had to be made. In this process, a few projects were withdrawn, and not all tempers were cool. (For the actual Phase I projects, see Appendix).

Once the funding was approved, the whole organization took shape. Some members of the Steering Committee took seats on the Board of Directors, and Dr. Phillip Lapp became the Chair of the Board. Lapp had a long career in aviation, navigation and robotics with deHaviland and Spar Technologies (developer of the Canadarm on the Space Shuttle). His PhD work had been in analogue (gyroscopic) navigation for missiles at MIT, he had moved into the computer era and geomatics. Phil Lapp served ten years as GEOIDE's Board Chair, a record perhaps across the NCEs. The other members of the initial Board came from the Partners of GEOIDE (including a number of federal Ministries and the Québec government), industry and the academic sector, following the charter of the Network.

Alongside the Board, a Research Management Committee was established to provide review of project proposals and project reporting. Again, the membership was drawn from three sectors, government, industry and academics, with some care taken to balance. Near as soon as constituted, the RMC had to get working on the selection of Phase II projects. Phase II was subject to a midterm review, conducted in 2001. In the Phase I period, as well, the graduate students engaged in the network projects took on the network concept and organized their own organization (see Chapter 2, Devillers and others). Enthusiasm was high, and a number of initiatives were taken to develop the network in different sectors. Efforts to reach out from engineering and measurement disciplines to social science and health were undertaken. A book for children

was commissioned and published, though it did not displace Sesame Street in the educational market.

There was some turnover in the management of the network as well. Keith Thomson had taken charge as Scientific Director at the founding of the organization. A Network Manager was appointed, but left after a short time. Thomson retired from his position at Laval, and Geoffrey Edwards took on the role of Scientific Director in 2002. He resigned a year later, and Keith Thomson resumed the position to take charge of the renewal process.

4 Renewal

The NCE formula of the era prescribed a seven year term for each network, with a maximum of two seven-year ‘cycles’. Confusingly, each cycle had two ‘phases’, and a mid-term review between them. Thus Phase I and II constitute the first cycle, and the new cycle launched Phase III. The renewal application was even heavier than the original application, because it required documentation of results from the network, along with the proposal for the next cycle. Table 3 lists the 19 projects at the core of the proposal for Phase III, selected according to the established model of a matrix of applications and stages of the technology cycle. These projects were all included in the renewal application, therefore selected in 2004, and on hold until the approval of the second cycle of funding. This laborious process has some negative consequences that GEOIDE tried to remedy in the transition between Phase III and Phase IV with the ‘pilot project’ procedure.

Phase III also saw the arrival of a new Scientific Director. Nicholas Chrisman replaced Keith Thomson starting in January 2005. Keith Thomson remained on the Board of Directors through to 2012, and has been active in business development. Phase III saw a dramatic shift in the role of Partners in the network. In the original proposal certain federal agencies, specifically Natural Resources Canada, Fisheries and Ocean Canada and the Canadian Space Agency, committed to substantial annual funding for GEOIDE-led research. Québec, Ontario and British Columbia joined in this model as well. Each organization committed to invest their funds to support projects that fulfilled their mission. During the first cycle this remained in place, but the political climate was changing. There emerged scandalous stories of subsidies and grants given out without due process and transparency. It was called the ‘sponsorship scandal’. The dominant Liberal government of Jean Chrétien had channeled funds to federalist forces in Québec, and eventually a revived Conservative party came to power in Ottawa. Funding of lump sums for not-entirely defined projects was no longer possible. All of this took some time to change, but the partnership model had to be changed. The concept of filling in every cell in a matrix was no longer the model in a world much more targeted on specific results.

Tab. 3. GEOIDE Phase III Full 4-year Projects 2005-2009

No/Title
1. Hyperspectral Reflectance Spectroscopy for Rapid Characterization of Oil Sands
5. SIST-Chronic Diseases and Primary Care
6. GIST II- Intelligent Sensor Data / Knowledge Fusion for Geotechnical and Policy Decision Support
8. Multi-Scale Multi-Agent Geo-Simulation to Support Decision Making in Multi-Actor Dynamic Spatial Simulations MUSCAMAGS
11. Integrated Expertise Towards the Development of an Ice Jam Related Flood Warning System (FRAZIL)
12. Integrated Geomatics for the Coastal Zone: Fusion of Terrestrial, Airborne and Marine Data (FUDOTERAM)
13. Géomatisation for Archaeological Digs: From Data Collection to Analysis in Context
14. Integrated Modelling of Juvenile Atlantic Salmon Movement and Physical Habitat in Fluvial and Estuarine Environments
15. Development of a 3D Predictive Modeling Platform for Exploration, Assessment and Efficient Management of Mineral, Petroleum and Groundwater Resources
17. Promoting Sustainable Communities Through Participatory Spatial Decision Support
20. Collaborative for Interactive Research with Communities Using Information Technologies for Sustainability
27. Mapping the Ocean Surface with Geodetic and Oceanographic Tools
31. Next-generation Algorithms for Navigation, Geodesy and Earth Sciences under Modernized Global Navigation Satellite Systems (GNSS)
32. A National System for Water Vapour Estimation Using GPS and its Applications
34. Geomatics Enhancement With Dual Use of GPS II/III and Galileo
35. Monitoring Changes to Urban Environmental using Wireless Sensing Networks
36. Space Gravimetry Contributions to Earth Monitoring
37. The Development of M2G- A Mobile Multi-sensor Geomatics system for Inventory and Analysis of Highway and Road Network Features
38. Coastal Security and Risk Management using GIS and Spatial Analysis

5 Phase IV

A major focus during 2006 was to develop a new strategy. The Network worked with specific user communities, groups of government, industry, and associations to determine the most pressing needs by region across the country. This process culminated in a workshop held in conjunction with a Board meeting. The new approach will

decide the broad directions of research, including the potential partners interested in working with the research community right from the start. The intent is to combine a more top-down selection of network directions with the ability for researchers to develop innovative solutions that pass through the refinement of peer-review from the bottom-up. The new strategic plan also includes innovative ways to ensure self-sustainability at the end of the NCE funding in 2012. In preparation for Phase IV (2009-2012), specific themes have emerged through a process of strategic planning. The three themes were purposely broad but also designed to avoid too much duplication (see list of projects in Appendix).

Mobility. Centers on tracking and predicting the motion of people and objects. User representatives include transportation sector, logistics enterprises, and security services. Researchers working on tracking technology, space-time models and simulations, and dispatching analysis at various scales form the teams working on this theme.

Environmental Change. Centers on modeling changes in the earth system, fast or slow. User representatives include natural hazard response agencies, geomatics industry representatives, and environmental policy makers. Researchers working on instruments, remote sensing applications, and sustainability policy dimensions join this grouping.

Distributed Sensors. Centers on advanced technology to measure the environment and deliver innovative information products to users. User representatives include instrument manufacturers, geomatics service providers, and infrastructure managers from government and private sector. Researchers working on sensors, distributed network interactions, and integrative software form teams on this theme.

As Figure 2 demonstrates, over the history of GEOIDE, the rate of selection has become more and more rigorous. The acceptance rate started at 56%, and fell to 21% in Phase IV. Phase III saw more proposals, but for somewhat smaller projects with an acceptance rate of 25%. The network did not turn into a clique of insiders who divided up the spoils; there was substantial turnover, along with certain teams that were able to continue funding in a more and more selective peer-review process.

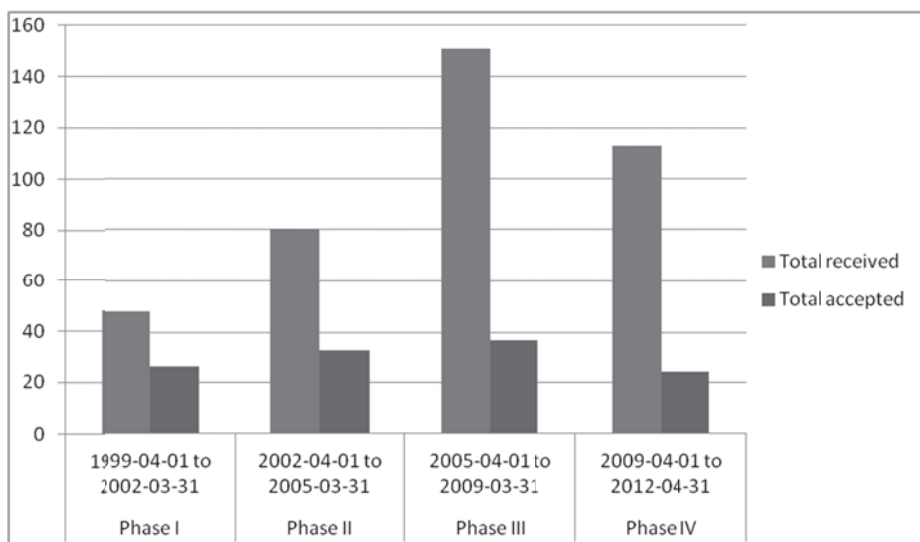


Fig. 2. Proposals submitted and funded by Phase, 1998-2011.

In the following round of short-term SII projects, many of them clustered around a theme of the Canadian North, covering a range of issues from the use of Radarsat-II imagery for geology and ice-mapping to habitat simulations for caribou. In the process of developing a business plan for the future, GEOIDE obtained support from the Neptis Foundation for two projects focused on sustainable urban development. These projects will continue past the end of NCE research funding. GEOIDE will seek other similar opportunities to continue to operate as a research programme manager.

The NCE funded period of the GEOIDE Network comes to an end in 2012, with some extension for the Business Centre through the Management Fund of NCE. The NCE formula provides for a limited term, and a hard end-date. Many find a flaw in this approach, since networks are perhaps most successful after some years of learning the ropes. The counter-argument is that successful networks should become self-sustaining eventually, and a firm end date is required to free up NCE funds for other initiatives.

GEOIDE does not at this moment know exactly how it will manage the transition, but a number of proposals are in process, and announcements are imminent. Even if there is no more money, the interactions created by the network's fourteen year history will remain to shape the future of geomatics in Canada and around the World.

6 Acknowledgments and Thanks

The GEOIDE Network was by its very nature a collaborative enterprise. There are many, many parties engaged, and each deserves to be acknowledged and thanked for

support over the years. In Appendix to the chapter there is a list of all members of the GEOIDE Board of Directors and the Research Management Committee, these volunteer bodies met regularly and contributed to the success of the organization. In addition, the Partners and Corporate Members have provided long-term financial support. Beyond the decision making bodies, a research enterprise depends on continued dedication, along with sporadic inspiration, of the researchers and most critically their students. The list of these crucial members is too long for this chapter, but the thanks are none the less. Finally, GEOIDE must recognize the NCE Programme of the Government of Canada. The opportunity to organize this network was catalyzed by this innovative collaboration of the Canadian granting councils.

7 Conclusions

GEOIDE, founded in 1998 under the full title "Geomatics for Informed Decisions; géomatique pour les interventions et décisions éclairées" provides an example of a fourteen year experiment in conducting research linking various sectors, and eventually how this became a model for other similar entities around the world. GEOIDE has been interdisciplinary, international and designed around delivery to user communities (industry, government, and non-profits generally). This NCE-funded period has delivered on its promises, and with this heritage, the organization will embark on new challenges.

It will take a more detailed review of GEOIDE to extract all of the lessons learned by all the parties. Perhaps the most apparent lesson is how long it takes to see results. One does not change culture and expectations immediately, not matter how much money and other resources are mobilized. The GEOIDE Network adjusted to the circumstances, and adjusted those circumstances as well. Major external events had an impact, specifically in nullifying the original business model. In light of this, the main result of 14 years of funding may well be in the students of the network. A whole generation has been trained in collaborative interdisciplinary projects. Some moved from students to project leaders, launching careers much faster and maintaining their network connections across long distances. The subsequent chapters in this book provide the more concrete documentation of these results.

A Note Concerning NCE. There are many factors in developing a knowledge management infrastructure, but perhaps the most fragile involves mobilizing people from diverse backgrounds to work together. Canada has a long record of innovation in science management, in part due to its multiple heritages (France, England) and proximity to USA. Canada went through periods of centralized science typical of the early twentieth century with the National Research Council, actually more of a centre of government-funded researchers similar in concept to CNRS in France. Canada also established science funding councils in the 1950s that took precedence for university-based research, along the lines adopted in the United States. By the 1990s, various tendencies led to the creation of an institution to engage researchers more closely with

"recipient communities" (such as industry and government). This entity was called the Networks of Centres of Excellence (NCE). (See Atkinson-Grosjean 2005 for more detailed history.) The NCE built new kinds of institutions, "networks" in place of "centres". Much of this could seem like bureaucratic smokescreens for the same old arrangements, but these networks do operate differently.

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Appendices

Membership: GEOIDE Board of Directors 1999-2012; RMC 1999-2012
Partners and Corporate Members
Projects from all four Phases

Board of Directors – Membership 1999-2012

Name	Organization	Start Date	End Date
Daood Aidroos	GEOIDE inc.	1999	2000
Louise Filion	Université Laval	1999	2000
Brian Gilliam	MacDonald Dettwiler	1999	2000
Virendra Jha	Agence spatiale canadienne / Canadian Space Agency	1999	2000
Brian L. Bullock	Intermap Technologies Limited	1999	2001
John Douglas McLaughlin	University of New Brunswick	1999	2001
Denis Parrot	VIASAT Géo-Technologies Inc.	1999	2001
Klaus-Peter Schwarz	University of Calgary	1999	2001
Les Whitney	Ressources naturelles Canada / Natural Resources Canada	1999	2001
Paul Bellemare	Pêches et océans Canada / Fisheries and Oceans Canada	1999	2002
Geoffrey Edwards	GEOIDE inc.	1999	2002
Robert Moses	PCI Geomatics	1999	2002
Ian Rowe	CRESTech	1999	2002
David V.J. Bell	York University	1999	2003
John W. Dawson	Ministère de la défense nationale / Department of National Defence	1999	2003
Marc Denys Everell	Environnement Canada / Environment Canada	1999	2003
Ed A. Kennedy	L'association Canadienne des entreprises en géomatique / Geomatics Industry Association of Canada (GIAC)	1999	2003
Sylvie Boucher	NCE / RCE	1999	2005
Louise Ouellet	Ministère des ressources naturelles et de la faune du Québec	1999	2007
Philip A. Lapp	Philip A. Lapp Limited	1999	2008
Trisalyn Nelson	Coordonateur RÉG / GSN Coordinator	2000	2001
Harold Zwick	MacDonald, Dettwiler and Associates	2000	2001
Jean-Marc Chouinard	Agence spatiale canadienne / Canadian Space Agency	2000	2005
Irwin Itzkowitch	Ressources naturelles Canada / Natural Resources Canada	2000	2006
Denis Brière	Université Laval	2000	2007
Keith Archer	University of Calgary	2001	2002

Name	Organization	Start Date	End Date
Marie-Josée Fortin	University of Toronto	2001	2002
Kevin Lim	Coordonateur RÉG / GSN Coordonator	2001	2002
Janet Ronsky	University of Calgary	2001	2003
Judith Sandys	Ryerson University	2001	2005
Henry Kucera	Swiftsure Spatial Systems Inc.	2001	2006
Steve H.-L. Liang	Coordonateur RÉG / GSN Coordonator	2002	2003
Jim Huff	Telus Geomatics	2002	2004
Pierre Labossière	Université de Sherbrooke	2002	2004
Stephan Moran	CRESTech	2002	2004
David Stanley	PCI Geomatics	2002	2006
Wendy Watson Wright	Pêches et Océans Canada / Fisheries and Oceans Canada	2002	2006
Evert Kenk	Integrated Land Management Bureau BC	2002	2008
Rifaat Abdalla	Coordonateur RÉG / GSN Coordinator	2003	2004
Richard Nasmith	Association canadienne des entreprises de géomatique / Geomatics Industry Association Canada	2003	2004
Naser El-Sheimy	University of Calgary	2003	2005
Sylvain Poirier	GEOIDE inc.	2003	2005
Ricardo DePani	Groupe CGI inc.	2003	2006
Dianne Richardson	Ressources naturelles Canada / Natural Resources Canada	2003	2006
Alexandre Aubiès-Trouilh	Coordonateur RÉG / GSN Coordinator	2004	2005
Rainer Knopff	University of Calgary	2004	2006
Pierre-François Le Fol	Networks of Centres of Excellence / Réseaux de centres d'excellence	2004	2008
Richard Worsfold	Ontario Centres of Excellence (OCE)	2004	2011
Sylvia He	Coordonateur RÉG / GSN Coordinator	2005	2006
Claire Samson	Carleton University	2005	2006
Pierre Labossière	Université de Sherbrooke	2005	2008
Savi Naranayan	Pêches et Océans Canada / Fisheries and Oceans Canada	2005	2009
Réal Choquette	Secretary, GEOIDE inc.	2005	2010
Keith Thomson	Consultant	2005	
Ken Jones	Ryerson University	2006	2007

Name	Organization	Start Date	End Date
Michael Sideris	University of Calgary	2006	2008
Jacques Charron	Kheops Technologie	2007	2009
Edwin Bourget	Université Laval	2007	2010
David Coleman	University of New Brunswick	2007	2010
Stuart Salter	Ressources naturelles Canada / Natural Resources Canada	2007	2010
Chantal Aboud Debs	Networks of Centres of Excellence / Réseaux de centres d'excellence	2008	2008
Yvan Bédard	Université Laval	2008	2010
Peter C Keller	University of Victoria	2008	2010
Mark Zacharias	GeoBC	2008	2010
Sara Esam	Networks of Centres of Excellence / Réseaux de centres d'excellence	2008	2011
Greg McQuat	Coordonateur RÉG / GSN Coordinator	2009	2010
Paul Mrstik	Terrapoint Canada	2009	2011
Gilles Cotteret	GEOIDE inc.	2010	2010
Steve Liang	University of Calgary	2010	2011
Christiane Constantineau	GEOIDE inc.	2010	2011
Blake Walker	Coordonateur RÉG / GSN Coordinator	2010	2011
Guy Béliveau	LaserMap - ImagePlus Inc.	1999	
Richard Delagrave	Défense nationale du Canada / National Defense of Canada	2003	
Nicholas Chrisman	Directeur scientifique / Scientific Director	2005	
Kevin O'Neill	MDA Corporation	2006	
Doug Bancroft	Ressources naturelles Canada / Natural Resources Canada	2010	
Réal St-Laurent	Ministère des ressources naturelles et de la faune du Québec	2007	
Claude Levesque	GEOIDE inc.	2010	
Olaf Niemann	University of Victoria	2010	
Keith Thomson	Observer until 2005, then Director	1999	
Paul Fortier	Université Laval	2010	
Chantal Arguin	Groupe Trifide	2011	
Sylvie Daniel	Université Laval	2011	

Name	Organization	Start Date	End Date
Susan Skone	University of Calgary	2011	
Kimberly Douglas	Networks of Centres of Excellence / Réseaux de centres d'excellence	2011	2012
Alborz Zamyadi	Coordonateur RÉG / GSN Coordinator	2011	2012

Research Management Committee 1999-2012

Name	Organization	Start Date	End Date
Andrew Rencz	Ressources naturelles Canada / Natural Resources Canada	1999	2001
Benoît Rivard	University of Alberta	1999	2003
Rejan Landry	Université Laval (Non-voting member)	1999	2000
Daood Aidroos	GEOIDE inc. (Observer)	1999	2000
David J. Coleman	University of New Brunswick (Non-voting members)	1999	2002
Geoffrey Edwards	GEOIDE inc. (Scientific Director 2001-2003)	1999	2003
Henry Kucera	Swiftsure Spatial Systems Inc.	1999	2001
John MacDonald	MacDonald Detweiller	1999	2000
Jörg-Rüdiger Sack	Carleton University (Non-voting member)	1999	2002
Ken Jones	Ryerson University	1999	2003
Marie-Josée Fortin	University of Toronto	1999	2003
Michael Sideris	University of Calgary (Non-voting member)	1999	2003
Michel Mellinger	Centre de développement de la géomatique	1999	2000
Patrick Hally	Pêches et Océans Canada / Fisheries and Oceans Canada	1999	2000
Phil Teillet	Ressources naturelles Canada / Natural Resources Canada	1999	2001
Stewart Fotheringham	University of Newcastle	1999	2001
Marc Journault	Pêches et océans Canada/ Fisheries and Oceans Canada	2001	2003
Serge Kéna-Cohen	Intélec Geomatique	2000	2004
Daniel Lebel	Ressources naturelles Canada / Natural Resources Canada	2001	2004

Name	Organization	Start Date	End Date
Werner Kuhn	Muenster University	2001	2004
Sylvie Boucher	NCE / RCE (Observer)	1999	2005
Richard Worsfold	CRESTech (Non-voting member)	1999	2004
Keith P.B. Thomson	GEOIDE inc. (Scientific Director)	1999	2005
Alain Vanasse	Université de Sherbrooke	2002	2005
Ronald Pelot	Dalhousie University	2002	2005
Lucia Lo	York University	2003	2005
Spiros Pagiatakis	York University	2003	2005
André Godin	Université du Québec à Rimouski	2003	2005
Sylvain Poirier	GEOIDE inc.	2003	2005
Dianne Richardson	Ressources naturelles Canada / Natural Resources Canada	2001	2006
Kevin O'Neill	RADARSAT International	2001	2006
Jim Little	University of British Columbia	2002	2006
Iain Christie	Neptec Design Group Ltd	2005	2006
Washington O'chieng	Imperial College London	2005	2006
Paul Mrstik	Terrapoint Canada Inc.	2000	2006
Randolph Franklin	Rensselaer Polytechnic Institute	2006	2007
Stefania Bertazon	University of Calgary	2003	2007
Nadine Schuurman	Simon Fraser University	2005	2008
Monica Wachowicz	Wageningen University and Research	2007	2008
Monique Bernier	INRS - Eau, terre et environnement	2003	2008
Yves van Chestein	Défense nationale du Canada / National Defense of Canada	2003	2008
Pierre-François Le Fol	Networks of Centres of Excellence / Réseaux de centres d'excellence	2005	2008
Yves Michaud	Ressources naturelles Canada / Natural Resources Canada	2005	2008
Naser El-Sheimy	University of Calgary	2005	2009
Thierry Schmitt	CIDCO-UQAR	2006	2009

Name	Organization	Start Date	End Date
Daniel Alvarez	VIASAT Inc.	2006	2009
May Yuan	University of Oklahoma	2008	2009
Réal Choquette	GEOIDE (Observers)	2003	2009
Robin Harrap	Queen's University	2005	2009
Carmen Reyes	CentreGeo	2008	2009
Frank Ferrie	McGill University	2006	2010
Phillipe Teillet	University of Lethbridge	2006	2010
Sara Esam	Networks of Centres of Excellence / Réseaux de centres d'excellence	2009	2011
Gilles Cotteret	GEOIDE Observer	2008	2011
Christiane Constantineau	GEOIDE Observer	2011	2011
Nicholas Chrisman	Directeur scientifique / Scientific Director	2005	
Sandy Kennedy	Novatel inc	2007	
Gordon Plunkett	ESRI Canada	2007	
Claire Samson	Carleton University	2007	
Phil Graniero	University of Windsor	2008	
Christian Nadeau	MDA	2009	
Ayman Habib	University of Calgary	2009	
Denis Gouin	DRRC	2009	
Boyan Brodaric	Natural Resources Canada	2010	
Claude Levesque	GEOIDE Observer, Secretary and Treasurer	2010	
Scott Bell	University of Saskatchewan	2010	
Trisalyn Nelson	University of Victoria	2010	
Christophe Claramunt	Naval Academy Research Institute (IRENav), France	2011	
Kimberly Douglas	Networks of Centres of Excellence / Réseaux de centres d'excellence	2011	

GEOIDE Partner Members and Corporate Members

Français	English	Start Year	Left Year	Return Year	End Year
Agence spatiale canadienne	Canadian Space Agency	1998	2005	2008	2009
British Columbia - GeoBC - Integrated Land Management Bureau	British Columbia - GeoBC - Integrated Land Management Bureau	2002			2010
Ontario Centres of Excellence (Crestech)	Ontario Centres of Excellence (Crestech)	1998			2012
Pêches et Océans Canada	Fisheries and Oceans Canada	1999	2005	2006	2009
Défense Nationale	National Defence	1998			2005
Recherche et développement pour la défense Canada	Defence Research and Development Canada	2006			2012
ESRI	ESRI	2006			2012
K2 Geospatial (Kheops)	K2 Geospatial (Kheops)	2007			2009
Université Laval	Université Laval	2000			2005
MDA Corporation	MDA Corporation	1998	2001	2006	2012
Ministère des Ressources naturelles et de la Faune	Ministère des Ressources naturelles et de la Faune	1998			2012
Ressources Naturelles Canada	Natural Resources Canada	1998			2005
Ressources Naturelles Canada	Natural Resources Canada	1998	2007	2008	2009
PCI Geomatics	PCI Geomatics	2001	2006	2007	2010

Phase I (1 April 1999 - 31 March 2002)

Project #	Project Leader	Project Title
ACQ#10	Michael Sideris	Precise Geoid Determination for Geo-referencing and Oceanography
DEC#02	Yvan Bédard	Designing the Technological Foundations of Geospatial Decision-Making with the World Wide Web
DEC#09	K. Olaf Niemann	Development of Automated Techniques to Extract, Generalize, and Access geospatial Information from Hyperspatial Remotely Sensed Data
DEC#30	Geoffrey Edwards	Simulations of Memory, Mental Imagery and Mental Models - Applications to Spatial Planning and Electronic Map Use
ENV#04	Marie-Josée Fortin	Quantitative Spatial Descriptors for Improved Natural Resources Decision-Making
ENV#13	Irene G. Rubinstein	The synergistic use of Multi-Sensor Remote Sensing for Monitoring of the Earth's Surface and Atmospheric Parameters
ENV#14	Rock Santerre	Improvement of Precise and Reliable Kinematic GPS Positioning in Real-Time over Long Distances for the Support of Bathymetric Surveys
ENV#17	J. B. Merriam	Natural Hazards and Disaster Monitoring
ENV#19	James Elder	Extraction of Features from Remote-Sensed Imagery for a Search and Rescue Synthetic Vision Database
ENV#60	Ronald Pelot	Marine Activity Geomatics and Risk Analysis in the Coastal Zone
HSS#55	Susan Nichols	Good Governance of Canada's Oceans: Determining the Use, Value and Potential of Marine Boundary Information
HSS#56	Sherry Olson	Sharing Geodatabases in Historical Dynamics / MAP: Montréal, l'Avenir du Passé
HSS#57	Douglas J. Willms	Spatial Variation in Health and Human Development
MNG#26	Jörg-Rüdiger Sack	Parallel and Distributed Geomatics
RES#06	John R. Miller	Imaging Spectroscopy for the Management of the Canadian Landscape, with Emphasis on the Boreal Forest and the Tundra
RES#25	Daniel Lebel	Three-Dimensional Digital Integration of Geological, Photogrammetric, Remote Sensing and Geophysical Data: Application to Resource Assessment in Foreland Thrust and Fold Belts

Project #	Project Leader	Project Title
RES#31	Benoit St-Onge	Integrated Decision Support System for Watershed Management
RES#47	Peter Klaus Schwarz	Airborne Gravity for Exploration and Mapping (AGEM)
RES#50	Paul Treitz	Three-Dimensional Analysis of Forest Structure and Terrain using LIDAR Technology
RES#52	John Robinson	The Georgia Basin Digital Library: Infrastructure for a Sustainable Future
RES#54	Alain A. Viau	Analysis of Reflectance and Fluorescent Remote Sensing Techniques for Detection of Plant Stresses in Precision Agriculture
SOC#1	Yvan Bédard	A Cartographic Interface for the Multidimensional Exploration of Environmental Health Indicators on the World Wide Web (W3)
SOC#08	Martine Lee-Gosselin	Human Behavior and GIS-based Environmentally Sustainable Land Use and Transportation Modelling
SOC#12	Ken Jones	Geomatics for Strategic Planning in the Business/Commercial Sector
SOC#23	Janet L. Ronsky	Biometrology
TCO#51	Amer Shalaby	Real-Time Bus Location, Passenger Information and Scheduling for Public Transportation
TCO#53	Yang Gao	Development of a Real-time Mobile Information Management Technology in Support of Energy and Resources Operations

Phase II (1 April 2002 - 31 March 2005)

Project #	Project Leader	Project Title
ACQ#GAO	Yang Gao	Development of Single-Point Real-Time Kinematic Positioning Technology
ACQ#SHE	Naser El-Sheimy	Next Generation MEMS-Based Navigation System for Vehicles and Personal Location and Navigation
ACQ#SID	Michael Sideris	Development of a Dynamic Seamless Vertical Reference System for Environmental, Climatic, Geodynamical, Oceanographic, Hydrographic and GIS Applications.
ACQ#VNK	Petr Vaníček	Precise Geoid Determination for Geo-referencing and Oceanography

Project #	Project Leader	Project Title
DEC#BER	Stefania Bertazzon	Multivariate Spatial Regression in the Social Sciences: Alternative Computational Approaches for Estimating Spatial Dependence
DEC#CSI	Ferenc Csillag	What is the Difference Between Two Maps? Global Statistics for Spatial Data
DEC#JON	Kenneth G. Jones	Perception-based Modeling and Business Geomatics
DEC#NIY	Théophile Niyonsenga	Geomatics and Spatial Statistics: Inseparable and Essential Tools Used to Better Understand Health Issues
DEC#ROB	John Robinson	GeoCognito: Connecting People with Ideas and Ideas with Place
DEC#SCO	Darren M. Scott	Transportation Implications of Canada's Aging Population
ENV#DOD	Julian Dodson	Modelling of Atlantic Salmon Smolt Production Using Remote Sensing and GIS-Based Methods
ENV#PEL	Ronald Pelot	Marine Activity Geomatics and Risk Analysis in the Coastal Zone
HSS#LLO	Lucia Lo	A Geomatics Approach to Immigrant Settlement Services: The Integration of Supply and Demand over Space and Time
HSS#RON	Janet L. Ronsky	Biometrology for Informed Decisions in Medical Diagnoses, Procedures and Treatment Evaluations
HSS#VAN	Alain Vanasse	Spatio-Temporal Information System for Coronary Thrombosis
MNG#BED	Yvan Bédard	Generalization and Multiple Representations for on-Demand Map Production and Delivery (project GEMURE)
MNG#BER	Monique Bernier	Web-based Sensing Networks for Environment Applications
MNG#ELD	James Elder	Intelligent Data Fusion for Aircraft Navigation and Disaster Management
MNG#HAR	Rob Harrap	Development of the Geotechnical In-Situ Technology Network (GIST) for the Management of Geohazards
MNG#NIE	K.O. Niemann	Fusion of Multiple Spatial and Temporal Data Sources to Assess the Spatial Dynamics of Coastal Environments
MNG#TAO	Vincent Tao	Automating Photogrammetric Processing and Data Fusion of Very High Resolution Satellite Imagery with LIDAR, iFSAR and Maps for Fast, Low-Cost and Precise 3D Urban Mapping
RES#LON	Bernard Long	Tailored Geomatics Applications for Geohazards and Geo-resource Exploration
RES#MIL	John R. Miller	Imagery spectroscopy: Developments for renewable and mineral resources

Project #	Project Leader	Project Title
RES#RIV	Benoît Rivard	Automated Core Logging of Lithology by Hyperspectral Remote Sensing
TCO#LEE	Martin Lee-Gosselin	An Integrated GPS-GIS System for Collecting Spatio-Temporal Microdata on Personal Travel in Urban Areas

Phase II – SII (1 January 2004 - 31 December 2005)

Project #	Project Leader	Project Title
SIACQ#01 / ACQ#NOU	Aboelmagd Noureldin	Development of an INS/GPS Integration Software Using Artificial Neural Networks and Wavelet Multi-Resolution Analysis
SIACQ#05 / ACQ#HAB	Ayman Habib	Co-registration of Photogrammetric and LIDAR Surfaces for Evaluation and Validation of the Systems' Calibration
SIACQ#07	Claire Samson	Tracking the Transmitting-Receiving Offset in Fixed-Wing Transient Electromagnetic (EM) Systems: Methodology and Application
SIENV#08	Monique Bernier	River Ice Monitoring with Synthetic Aperture Radar (SAR)
SIENV#13	Marie-Josée Fortin	Spatio-Temporal Landscape Connectivity Tools for Sustainable Forest and Wildlife Management
SIHSS#06	Alain Vanasse	Measurement of Health Care Centres Accessibility
SIRES#11	Kim Lowell	An Improved Prototype of a Socially Responsible Spatial Wood Harvesting Planning Tool
SITCO#09	Yang Gao	Development of a Platform for Rapid Deployment of Mobile Asset Management Systems (MAMS)

Phase III (1 April 2005 - 31 March 2009)

Project #	Project Leader	Project Title
SLMASR-01	Benoît Rivard	Hyperspectral Reflectance Spectroscopy for Rapid Characterization of Oil Sands
HSSDFM-05	Alain Vanasse	SIST-Chronic Diseases and Primary Care
TDMDSD-06	Jean Hutchinson	GIST II- Intelligent Sensor Data / Knowledge Fusion for Geotechnical and Policy Decision Support
TDMDSD-08	Bernard Moulin	Multi-Scale Multi-Agent Geo-Simulation to Support Decision Making in Multi-Actor Dynamic Spatial Simulations MUSCAMAGS
TDMDFM-11	Monique Bernier	Integrated Expertise Towards the Development of an Ice Jam Related Flood Warning System (FRAZIL)

Project #	Project Leader	Project Title
SLMDFM-12	Bernard Long	A software Tool Integrating Terrestrial, Marine and Airborne Data for Coastal Zone Management
HSSDFM-13	Michel Fortin	Géomatisation du Processus de Fouille Archéologique: De l'acquisition des Données à leur Analyse Contextuelle
SLMDFM-14	Julian Dodson	Integrated Modelling of Juvenile Atlantic Salmon Movement and Physical Habitat in Fluvial and Estuarine Environments
SLMDFM-15	Jacynthe Pouliot	Development of a 3D Predictive Modeling Platform for Exploration, Assessment and Efficient Management of Mineral, Petroleum and Groundwater Resources
HSSDSD-17	Robert Feick	Promoting sustainable Communities through Participatory Spatial Decision Support
HSSDSD-20	John Robinson	Collaborative for Interactive Research with Communities Using Information Technologies for Sustainability
SLMASR-27	Spiros Pagiatakis	Mapping the Ocean Surface with Geodetic and Oceanographic Tools
TDMASR-31	Marcelo Santos	Next-Generation Algorithms for Navigation, Geodesy and Earth Sciences under Modernized Global Navigation Satellite Systems (GNSS)
SLMASR-32	Susan Skone	A National System for Water Vapour Estimation Using GPS and its Applications
TDMASR-34	Gérard Lachapelle	Geomatics Enhancement With Dual Use of GPS II/III and Galileo
TDMDFM-35	James Elder	Monitoring Changes to Urban Environmental using Wireless Sensing Networks
SLMASR-36	Michael Sideris	Space Gravimetry Contributions to Earth Monitoring
TDMASR-37	Naser El-Sheimy	The Development of M2G- A Mobile Multi-sensor Geomatics system for Inventory and Analysis of Highway and Road Network Features
SLMDSD-38	Ronald Pelot	Coastal Security and Risk Management using GIS and Spatial Analysis

Phase III – SII (1 January 2006 - 31 December 2007)

Project #	Project Leader	Project Title
SII-41	Pierre Gosselin	Development of an Interactive Web Tool to Better Understand the Impacts of Climate Change on Public Health
SII-42	Yang Gao	Fast Convergence of Precise Point Positioning Solution for Real-Time Applications

Project #	Project Leader	Project Title
SII-43	Ayman Habib	Development of LIDAR-Aided Photogrammetric Mono-Plotting and True Ortho-photo Generation System
SII-44	Rodolphe Devillers	Geomatics for the Sustainable Management of Fish Stocks
SII-51	Charmaine Dean	Forests, Fires and Stochastic Modeling
SII-57	David Clausi	Classification of Operational Sar Sea Ice Imagery
SII-59	Barbara Lence	Tsunami Loss Estimation and Emergency Planning
SII-60	Stephen Sheppard	Future Visioning of Local Climate Change Scenarios With Integrated Geomatics/Visualization Systems.

Phase III – SII (1 January 2007 - 31 December 2008)

Project #	Project Leader	Project Title
SII-62	Claire Samson	Sensor Complementarity for Platform Mobility : Integration of Laser Information into Positioning Stream.
SII-71	Naser El-Sheimy	The Development of a Two-Component Multi-mode Personnel Navigation System for Improved Usability.
SII-73	Phil A. Graniero	An Integrated Sensor Web Deployment Infrastructure for Watershed Monitoring.
SII-74	Susan Skone	The Development of a Meteorological Probe and MEMS-Based Inertial Reference for Aircraft Use.
SII-79	Alla Sheffer	Extraction of Terrain and Vegetation Layers from LiDAR Data.
SII-84	Xiaoyi Bao	Development of a Distributed Acoustic and Vibration Sensors for Water Sound and Currents Monitoring.
SII-86	Stéphane Roche	A Tool to Assess the Socio-Economic Impacts of Geographical Information
SII-99	Ali Asgary	Real-time Multi-criteria Spatial Decision Support Systems (MCSDSS): Improving Fire Response in Canadian Communities.
SII-120	Brian R. MacIntosh	Multi-Sensor System for Improved Quality of Life for Movement Disorders.

Phase III – PP (1 April 2008 - 31 March 2009)

Project #	Project Leader	Project Title
PP-03	Aboelmagd Noureldin	Multi-Sensors Systems for Tracking an Mobility Applications

Project #	Project Leader	Project Title
PP-05	Jianghong Wu	CODIGEOSIM - Geosimulation Tools for Simulating Spatial - Temporal Spread Patterns and Evaluating Health Outcomes of Communicable Diseases
PP-17	James Elder	Three-Dimensionalizing Surveillance Networks
PP-18	Georgia Fotopoulos	Advancing Coastal Hazard Assessment with Satellite Geodesy (gCOAST)
PP-23	Marc Gervais	Public Protection and Ethical Dissemination of Geospatial Data - Social and Legal Aspects
PP-24	Sylvie Daniel	GÉOÉDUC 3D - Geomatics for Gaming and Learning
PP-32	Stephen Sheppard	Local Climate Change Visioning - Tools and Process For Community Decision-Making
PP-41	Renée Sieber	Participatory Geoweb for Engaging the Public on Global Environmental Change
PP-43	Charmaine Dean	Stochastic Modelling of Forest Dynamics

Phase IV (1 April 2009 - 31 March 2012)

Project #	Project Leader	Project Title
PIV-03	Aboelmagd Noureldin	Multi-Sensors Systems for Tracking and Mobility Applications
PIV-05	Jianghong Wu	CODIGEOSIM - Geosimulation Tools for Simulating Spatial - Temporal Spread Patterns and Evaluating Health Outcomes of Communicable Diseases
PIV-17	James Elder	Three-Dimensionalizing Surveillance Networks
PIV-23	Marc Gervais	Public Protection and Ethical Dissemination of Geospatial Data - Social and Legal Aspects
PIV-24	Sylvie Daniel	GéoÉduc3D - Geomatics for Gaming and Learning
PIV-32	Stephen Sheppard	Local Climate Change Visioning - Tools and Process for Community Decision-Making
PIV-41	Renée Sieber	Participatory Geoweb for Engaging the Public on Global Environmental Change
PIV-43	Charmaine Dean	Stochastic Modelling of Forest Dynamic

Phase IV – SII (1 January 2010 - 31 December 2011)

Project #	Project Leader	Project Title
SII-PIV-50	Michael Sideris	A Geoid-Based Vertical Reference Frame for Height Modernization in North America

Project #	Project Leader	Project Title
SII-PIV-52	Rob Harrap	Bedrock to Blue Sky - High Resolution Mapping for Sustainable Energy Studies
SII-PIV-54	Nadine Schuurman	Spatial and Environmental Injury Surveillance
SII-PIV-70	Christian Gagné	Integrating Developmental Genetic Programming and Terrain Analysis Techniques in GIS-Based Sensor Placement Systems
SII-PIV-72	Ayman Habib	Development of Innovative Tools for Quality Assurance, Quality Control, and Object Recognition for LiDAR Mapping
SII-PIV-80	Paul Treitz	Precision Planning Inventory Tools for Forest Value Enhancement
SII-PIV-87	Aaron Berg	Monitoring Agricultural Land Management Activities from Space
SII-PIV-89	Steve Liang	TrafficPulse: A Participatory Mobile Urban Sensor Web for Intelligent Green Transportation

Phase IV – SSII (1 April 2011 - 31 March 2012)

Project #	Project Leader	Project Title
SSII-101	Trysalin Nelson	Geomatics Solutions for Conservation of Canada's Boreal Forests
SSII-102	Danielle Marceau	A Scenario-Planning Model to Forecast Land-Use Intensification and Mitigation Measures on Albertan Woodland Caribou
SSII-107	Scott Bell	Positioning, Geocoding, and Navigation Indoors
SSII-108	Brigitte Leblon	RADARSAT-2 Polarimetric SAR and Optical Images in Support of Surficial Geology Mapping in the Canadian North
SSII-109	Spiros Pagiatakis	Improved Global Web Map Visualization
SSII-111	David Clausi	Ice Classification Using SAR Imagery to Support Canadian Ice Service Operations

Phase IV – TSII (1 April 2011 - 31 March 2013)

Project #	Project Leader	Project Title
TSII-201	Eric J. Miller	Geomatics Decision Support for Canadian Urban Regions
TSII-202	Andrew Hunter	PlanYourPlace: A Geospatial Cyber-Infrastructure for Sustainable Community Planning

Part I
Lessons Learned and Best Practices

Chapter 2

The GEOIDE Students' Network and the GEOIDE Summer School: History and Lessons Learned from Thirteen Years of Students' Networking in Canada

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Abstract. Over its existence, the GEOIDE Network has contributed to the training of about 1400 students that now compose a significant part of the new generation of geomatics professionals and scientists working in Canada and abroad. From its start, GEOIDE recognized the need to create a network within the network that could improve students' training and professional skills through collaborations across Canada. This chapter presents, through the history of the GEOIDE Students Network (GSN), the challenges of developing such broad interdisciplinary and bilingual network in a large country like Canada. We discuss the impact that leadership, communication tools and face-to-face meetings can have on the success of such network, and look at the synergy that existed between the GSN and its sister initiative, the annual GEOIDE Summer School (GSS). From this experience, we draw a number of recommendations that can be used by other organizations that would like to create and benefit from such network.

Keywords: GEOIDE Student Network, GEOIDE Summer School, research, networking, students.

1 Introduction

The GEOIDE Network has been a primary source of funding for collaborative and interdisciplinary geomatics research in Canada from 1999 to 2012. Beyond GEOIDE's mandate to advance science and support policy, a key network objective was the training of highly qualified personnel (HQP) that were to become the new generation of geomatics professionals in the Canadian industry, government and academia. Since its start in 1999, GEOIDE has contributed to the training of over 1400 students. Graduate students have collectively, through their theses work and research assistantships, conducted the majority of GEOIDE's research. Most of the projects funded by the network have involved researchers from multiple Canadian universities and provinces. Students involved in these projects composed a very heterogeneous group, coming from a number of different countries, speaking different languages, studying at different levels (undergraduate to post-docs) and in very different disciplines (e.g., computer science, biology, business, sociology, medicine). From its start, GEOIDE recognized this challenge and the need to encourage student networking in order to allow students, and Canada, to benefit from such large network.

This chapter presents two of the most successful GEOIDE initiatives. The first one is the GEOIDE Students' Network (GSN), which has existed since the start of the GEOIDE network in 1999. The second one is the GEOIDE Summer School (GSS), which has been created in 2002 and organized each year since. The chapter is structured chronologically, describing those two student-driven initiatives from their conception to now. We describe the main stages in the development of those initiatives in addition to the different actors, discussing the successes but also the challenges and the failures. And drawing lessons from those facts, we come with a number of recommendations that can be used by other organizations that would like to create and benefit from such network.

2 GEOIDE Students' Network - The Concept (1998-2000)

The idea of creating an entity that would encourage student networking finds its roots at the origins of the GEOIDE Network itself, being present in the initial proposal for funding submitted to the Networks of Centres of Excellence of Canada (NCE). Inspired by other similar initiatives, such as the doctoral symposia of the Conference on Spatial information Theory (COSIT) and the student's involvement in the US National Center for Geographic Information and Analysis (NCGIA), Prof. Keith Thomson, Prof. Geoffrey Edwards and other founders of GEOIDE included this element in the proposal and defended the idea in front of the NCE review panel. The idea of having a student network turned to be a strong element that has contributed to the funding of the proposal. Once the network was funded, the newly created GEOIDE office turned this plan into action when Daoud Aidroos, the first GEOIDE executive director, approached Alex Bruton, PhD student at the U. of Calgary at the time, to organize a student meeting at the first annual GEOIDE conference in Quebec City. At the time,

GEOIDE projects were only starting and most students coming from all across Canada had not had opportunities to meet yet. Bruton emailed invitations to the relatively small student body of the time and led the first students' meeting on September 10, 1999, sharing the vision of a pan-Canadian student network in geomatics and gathering ideas from students present in the room. The number of students working in the GEOIDE projects at this time was estimated to 75, but was already representing 25 Universities and a large diversity of disciplines. At this initial meeting attended by probably about 25 students, Alex Bruton and another student, Chris Storie (Wilfred Laurier U.), were mandated by the group of students present to take the lead for this first year of activities.

During this first year, the two GSN directors worked on defining the basic role and structure of the GSN. Two months after the meeting, they submitted to the GEOIDE board of directors a plan of action that stated the GSN mission as being "to facilitate communication and create opportunities for students, both of which reflect their roles and activities within the GEOIDE Network". This document also laid down some of the key activities that the network was to emphasize on in its early years and after, such as communicating information to its members and supporting a scholarship program that would encourage students networking and excellence. The need to have the GSN involved within GEOIDE governance was also recognized from the beginning, which led the GSN director to automatically sit as an observer on the GEOIDE board of directors. In addition, in order to ensure a synergy between GEOIDE and the GSN, the GEOIDE administrative office assigned a staff as the primary contact for GSN business. This last task was handled in the first years by Tom De Groeve, which played a significant role in getting the GSN off the ground by sharing ideas, enthusiasm, and be a catalyst of GEOIDE's support. The two GSN directors worked in this first year with GEOIDE to secure an initial operating budget that would support the scholarship program and other networking activities.

Most of the work done in this first year was conducted by the two directors but did not really engage, or got the engagement from, other GSN students. The need for students' participation encouraged initiatives that could bring the growing students membership together to increase knowledge exchange. One of such key early initiatives was the concept of a Digital City, later named "GeoVillage", promoted by Pierre Marchand (Laval U.). GeoVillage was to be a digital geographic environment that could become a place where students and maybe other GEOIDE members could access and share information. The GeoVillage proposal won the GEOIDE contest "Design geomatics in 50 years time" but remained at the stage of a visual prototype. Marchand also proposed, with Rodolphe Devillers also from Laval U., an approach for knowledge management and dissemination within the GSN. This approach was awarded the first GSN network improvement award. It suggested allocating virtual credits to students that would achieve different networking tasks, from face-to-face meetings with students, to co-organizing workshops, co-publishing or proposing new research initiatives. These efforts would allow students to go through different phases of knowledge process known as socialization, externalization, combination and inter-

nalization. While most of these early ideas have never been turned into practice, they proved to be key to get the networking started, as they encouraged students to understand the value of networking, think about specific networking strategies, and start putting it into practice with other students through joint initiatives.

3 Setting the Foundations (2000-2002)

At the end of its first year of existence, the GSN student body met in Calgary during the 2nd GEOIDE annual conference. Alex Bruton, who was graduating, stepped down as director. Chris Storie became the director for the second year and the new GSN structure opened a position of assistant director that was given to Trisalyn Nelson (U. of Victoria). The weeks following the meeting witnessed some disagreement in the student body that resulted in Trisalyn Nelson becoming interim director of the GSN. These discussions triggered an unprecedented involvement of students that led to finalize the foundations of the GSN. A group of students developed a formal network agreement for the GSN, which has been voted by the students in October 2000 and used since. The agreement described the mission, objectives and rules governing the GSN, in addition to describing the positions on the GSN board of directors. The formal GSN membership reached 170 students in the summer 2000; however this is an underestimate of student involvement as many additional students were assisting with GEOIDE projects. Nelson and others worked on a number of initiatives that could help better reach the GSN membership, such as conducting phone and email surveys amongst GEOIDE students, analyzing and updating the students' database.

Two specific approaches illustrate the type of issues faced by the GSN at the time, and in some extent for most of its existence. First, students having their research funded by the GEOIDE network were automatically member of the GSN. Many of those students were initially not listed as their supervisors and project's leaders omitted to register them. Project's leaders have then been contacted to make sure they registered every new student working in their project and a more systematic way of collecting this information has been developed over the years as part of the annual projects' reporting. In many cases, students registered in GEOIDE were not made aware of this and did not see the benefit of being part of GEOIDE or the GSN. As early GSN communication was perceived as a nuisance from a number of students, the GSN had to be more explicit about what it was and had to offer to its members. It was explained that GSN memberships became an automatic benefit of any student funded by GEOIDE and that no registration fees were required. This led to the creation of a student package that has been distributed to all the students joining GEOIDE, indicating for instance that only GSN students could apply for GSN scholarships, in addition to mention other benefits, such as receiving relevant news or being invited to GSN sessions and workshops during the annual conference.

The second challenge was that GEOIDE membership was scattered across more than 20 universities in a large country. Trying to engage students in this context was chal-

lenging as, while some universities had a lot of GSN students and could generate some local synergy (e.g., U. of Calgary and U. Laval), others just had one or two students that were typically not studying in a geomatics or geography department and hence felt no sense of belonging to a geomatics group. This led to the creation of a group of GSN ambassadors that could act as an intermediate layer between the GSN director and the students. Ambassadors were identified and asked to meet with the other GEOIDE students in their university or region to explain what the GSN was, and make sure they received the appropriate information. The success of this initiative has been variable as it directly resulted from the leadership of each ambassador. These approaches proved to be very important in the start of the network and allowed to increase significantly the number of GSN student registered, in addition to get a larger number of students actively involved in the network.

The interim GSN director and some of the students that volunteered in projects organized elections in late October 2000 in order to elect the five GSN board of directors representatives that were defined in the new network agreement. The first GSN board was composed of Trisalyn Nelson (coordinator), Brad Corner (human resources councillor), Rodolphe Devillers (funding councillor), Zhe Liu (communication councillor), and Kris Morin (financial advisor). These positions reflected most of the challenges faced by the new board, which were related to the communication strategy, the ability to improve students networking and learning experience, but also the need for the GSN to secure the external funding necessary to match the funds provided by the GEOIDE network. The first GSN board met in February 2001 in Calgary, Alberta, and discussed a lot of initiatives, including a revision and expansion of the GSN award program, different funding strategies, and the need for a mentoring program. In the early stages of the network there were relatively few female project leaders. A partial response was to create opportunities for mentorship of female students. Two programs were launched. The first one was an award honouring mentors of women. Nominations for this program were typically put forward by female students to acknowledge a female faculty that had demonstrated mentoring excellence. The second award was to support female students interested in working with a female mentor from another university, although the program changed later to apply to both male and female students.

A new GSN Web site, independent from the GEOIDE one, was developed in the summer 2001, presenting the network agreement, the awards program and the other on-going initiatives. The Web site has been key to give the GSN an identity among students and improve the communication between the board and the GSN members.

This second year ended with the 3rd GEOIDE Annual conference in Fredericton, New Brunswick, with a series of initiatives organized by the GSN, including a talk between students and the industry regarding job hunting and a panel discussion for women working in geomatics. The GSN board presented their achievements to the students during the student session and conducted elections to create a new board for the next

year. At this point, most of the GSN operational structure was defined, allowing students to benefit from being part of a large national network.

4 The Rise of the Network (2001-2012)

Based on the foundations developed from 1999 to 2001, the GSN has been operating for another 11 years with yearly changes to its board of directors, allowing about 50 students to get involved in its governance over the years, and having more than 1400 students in total benefit from its activities. Some of the statistics about these students are presented on the Figure 1. It is worth noting that a number of international graduate students decided to become Canadian citizens after their graduation, supporting the goal of attracting and retaining geomatics HQP in Canada.

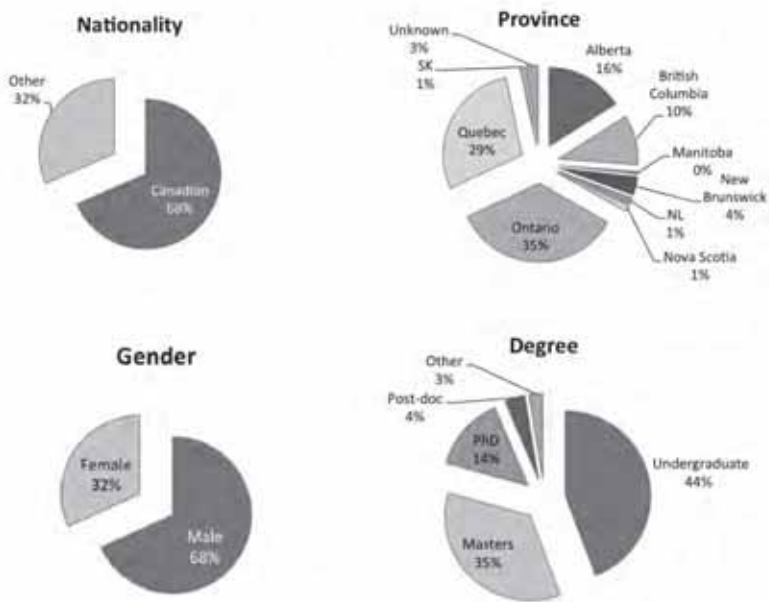


Fig. 1. Distribution of GSN students based, from left to right, on their nationality, gender, province and degree of study at the time of their involvement in the network (n=1396).

While a number of GSN activities remained similar over the years, most GSN boards started new initiatives that allowed providing new educational opportunities and services to the GSN members. For example, a number of regional workshops have been regularly organized over the years on different themes. For instance, in 2005, a workshop organized at Dalhousie University (Nova Scotia) involved 5 speakers from the region that have presented their work in geomatics to an audience of about 40 local students and professionals. The same year, a workshop discussing challenges with

graduate studies was organized at York U. (Ontario) for about 30 graduate students from four different universities, and a third workshop was held at Laval University (Quebec) discussing research communication and open-source software. Those regional workshops helped bringing together GEOIDE students from the same region outside of the annual conference and the GSS, in addition to sometime involve local participants that were not part of GEOIDE. The advances of the Internet also allowed offering online seminars (webinars) that could benefit students distributed all across Canada. A first webinar presenting the LiDAR technology was offered to about 35 people in March 2009 by Greg McQuat, who became GSN coordinator two months later. A number of webinars were offered in the subsequent years. In 2003, the GSN also started to be more international, getting an increasing visibility in geomatics communities around the world and also linking with a number of other students groups (e.g., the European Geography Association for Students and Young Geographers – EGEA) or geomatics summer schools (e.g., Vespucci and MAGIS). In 2010, the GSN held its first “Student Showcase” as part of the general GEOIDE Annual Scientific Conference program, under the umbrella of the 1st Canadian Geomatics Conference. This showcase aimed at celebrating students’ research by having them present their work in a specific session for which papers had been peer-reviewed. The GSN has also regularly updated its Web site design as well as developed other communication strategies for promoting its activities. A constant struggle over the years has been to let new students know that they were part of the GSN and inform them of what the GSN was and the potential benefits of being members. While strategies to address this issue have changed over the years, trying to have ambassadors, to distribute information packages to new students, or simply contact them by phone or emails, no single solution was found and a constant effort to engage students has been necessary. The rise of Web 2.0 social networking tools, such as the GSN Facebook group, seems to have however significantly helped develop a stronger feeling of belonging amongst students.

During these 11 years, new students joined the GSN, some left after their graduation, others continued within GEOIDE for further degrees and a few former GSN students became involved with GEOIDE as industry or government partners or as university principal investigators. Figure 2 presents information about the field and country of employment from a smaller sample of alumni. The smaller sample size illustrates the difficulty to collect information on the alumni, a challenge shared by many similar networks. Note that the 34% appearing to be part of academia includes students that are still studying, but not within a GEOIDE-funded project. The sample shows however a significant number of students working for the Canadian geomatics industry. A number of GSN alumni worked for the GEOIDE office, helping to link with the GSN and GSS (e.g., Kim Tran, Amit Joshi, Gilles Cotteret). Others started their private business (e.g., MioVision, NSim, SimActive) and sometime became partners on new GEOIDE projects. And a number of former GSN students became university professors all across Canada, some of them leading or getting involved in new GEOIDE projects (e.g., Alex Bruton at Mount Royal U., Chris Storie at U. of Winnipeg, Rodolphe Devillers at Memorial U. of Newfoundland, Andrew Hunter and Steve

Liang at U. of Calgary, Mir Mostafavi and Marc Gervais at U. Laval, Trisalyn Nelson at UVic and Tarmo Rimmel at York U.). Some of these new professors supervised graduate students that became in turn involved in the GSN and GSS, such as Krista Jones and Andrew Cuff (Memorial U.) and Leah Li (U. of Calgary), closing the loop.

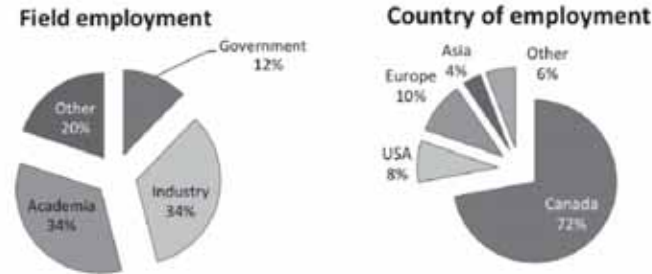


Fig. 2. Distribution of GSN students after their graduation based on the field of employment (left) and the country of employment (right). N.B. Statistics are based on a smaller number of students for which the information was available (n=235).

5 The GEOIDE Summer School (GSS)

GEOIDE’s students have been organizing an annual international geomatics summer school from 2002 to 2012. The idea of holding a summer school was first suggested by Prof. Stewart Fotheringham (UK), an international GEOIDE board member, in the first two years of the GEOIDE network. Planning for the first school took place in the Spring 2001, while the first GSN board was ending its mandate. Rodolphe Devillers (U. Laval) that was ending his term on the GSN board took the lead of the organization of a first summer school that took place in Toronto’s region, together with the help of Tarmo Rimmel (U. of Toronto), Yue Wu (Dalhousie U.) and Prof. Marie-Josée Fortin (U. of Toronto). Since 2002, the GSS has been managed independently from the GSN, with a specific board and a separate budget provided by GEOIDE. While most of the school program was framed around short-term courses, tutorials and keynote addresses, one of the main goals of the school has always been to reinforce students’ networking by bringing a limited number of Canadian and international students (typically 30 to 50) on a same site to network (Figure 3). The GSS committees often felt that the scientific program was more of a “bait” that could attract students. While courses were providing important skills for their research, the value of the school on the long-term often laid more in personal relationship developed with other students during social activities.



Fig. 3. Participants of the 8th GEOIDE Summer School (2009) in Vancouver, British Columbia.

During this first year, some decisions were made that have been used for all of the other GSS. First, it was decided that the GSS would be organized either shortly before or after the GEOIDE annual conference, in order to reduce travel costs, accommodate people that could only attend such an event if they were to also attend a scientific conference, and increase student's sense of belonging to the GEOIDE Network. Second, while the school was mainly targeting GEOIDE students, it was also made open to other Canadian students, professionals, professors, and to international students. The rationale was to foster collaborations between students and the Canadian geomatics professional community, in addition to increase GEOIDE's international exposure and help students develop an international network. The international focus has been financially supported over the years through either the support of international student's travel fees, or by waving their registration fees. Some of this support has been made possible in more recent years through formal agreements with international organizations (e.g., AGILE and MAGIS). This helped attracting a number of international students to the GSS over the years. Some of these students have decided to continue their graduate studies or career in Canada or developed work relationships with Canada from their home countries. Third, the GSS program was designed to provide students with expertise that extended beyond what they strictly required for their research. The core of the GSS program was typically framed around two 1.5 days short courses on topics thought to reflect recent developments in geomatics or being relevant to the Canadian community (e.g., distributed sensors, spatial statistics, climate change visualization, LiDAR). Instructors were typically high-profile Canadian or international professors with expertise in those fields. Students had to

choose among three courses for each of the two 1.5 days short course. Similarly, a number of shorter talks focused on soft-skills (e.g., project management, interpersonal relationships, intellectual property) typically not taught at University, in addition to key “vision talks” from industry, government or academic leaders discussing emerging trends in geomatics.

While the academic component of the GSS was the one that was the most advertised, the social program was key to develop stronger relationships between the GSS participants. This included icebreaker/team building activities (see Figure 4), half-day or evening tours of the region, barbecues, geocaching, special dinners, etc.



Fig. 4. Team building activities during the first GEOIDE summer school (2002) in Toronto, ON (left), and during the 2005 summer school in Quebec City, QC (right).

In the later years, the GSS developed linkages with other international geomatics schools. For instance, GEOIDE started in 2003 a scholarship program, which allowed 2-3 GEOIDE students or young scholars to attend the Vespucci Initiative Summer Institute on Geographic Information Science, organized yearly since 2003. While the GSS’s mainly targets Master’s and PhD students, the Vespucci Summer Institute is more designed around discussions and teamwork related to specific new research trends, having for target advanced PhD students, post-doctoral fellows and early-career researchers. The Vespucci Summer Institute is held in Firenze, Italy, during two weeks of the summer, each week having a different theme, group of students and guest instructors. All the instructors and students are together during the week and the program includes talks, discussions and teamwork related to the topic of the week. GEOIDE also developed in 2011 an agreement with the French geomatics network, the GDR MAGIS, which organizes since 2009 an annual summer school. The MAGIS summer school mainly targets French geography and computer science PhD students

and post-doctoral fellows and is organized during a full week during which all the students can follow half-day courses led by different instructors on different themes. GEOIDE and MAGIS have a program that allows some of their student members to attend the summer school of the other network.

While being independent from the GSN, the GSS and the GSN had a lot of connections as the GSS served as an important recruitment tool to involve new students in the GSN board or activities, and on the next year's GSS committee.

6 Lessons Learned – Keys to Successful Networking

Each year the GSN and GSS reached out to hundreds of students from various disciplines and locations in Canada. While some networking tools can be effective for any student network, others successful strategies are context specific.

One challenge faced by GEOIDE was to connect students that could be up to 5000 km apart, making face-to-face meetings rare and expensive. While a student network operating in a large city could possibly organize weekly or monthly meetings that could bring all of their members at the same time, networking across a large region involves less frequent face-to-face meetings and often a smaller proportion of the membership. As a consequence, a number of alternative tools were used to communicate with and between members.

The experience from the GSN and GSS allowed identifying a number of key factors that led to a successful student network.

6.1 Involving Student Leaders

Key to the success of such a network is to engage student leaders willing to volunteer time and energy beyond their graduate requirements. Many students used the GSN and GSS to develop leadership skills. Ideally, the network coordinator should be one of those leaders, but should be also supported by likeminded students. Without student leaders, the student network becomes a train without a locomotive, which will either not move, or will not get in the right direction. The GSN and GSS experienced variability in the strength and commitment in student leaders and, as a result, student engagement varied through time. To cope with this challenge, it was helpful to have members from the GEOIDE network, such as past students, professors, or GEOIDE board members, actively recruit potential student leaders and motivate them to get engaged with student initiatives. For example, the annual GSS served as a great venue for the past GSN/GSS leaders to observe the students and to engage potential new GSN leaders.

6.2 Obtaining Strong Organizational Support and Funding

The second most important factor is to have a strong support from the larger organization (i.e., GEOIDE). The GEOIDE network was always highly supportive of student initiatives and provided significant time and funding. In addition to providing support, GEOIDE gave students a large amount of freedom and were encouraging of new activity ideas. The degree of freedom did vary depending on the students involved in the GSN governance and their ability to use funds to develop or support networking activities. While the GEOIDE upper-level administration provided support in the early years, eventually specific staff was hired to link with the GSN and GSS.

6.3 Ensuring Continuity

An important factor that was a constant struggle with the GSN and GSS was the need to ensure continuity from one year to the next. Students' terms on the GSN and GSS boards were for one year, and the new student board elected was rarely provided with clear directions of what was done the year before, or with experience of successes and failures. The resulting loss in organizational memory varied annually. While some rare students decided to stay on the executive for a second mandate, the continuity has often been ensured by the GEOIDE staff person in charge of the GSN and GSS.

6.4 Encouraging Students to be Involved in the Network's Events

Another strategy is to encourage students to be involved in the network's events, an example being the GEOIDE Annual Scientific Conference (ASC). All GEOIDE funded projects in a given year are required to share their results at the conference. Instead of asking project leaders (i.e., professors) to present the project progress, GEOIDE often required graduate students to present. GEOIDE also gave students opportunities to chair ASC sessions. In some years, GEOIDE even allocated specific presentation slots for GSN in plenary sessions, including the best hours of the day that are normally allocated to keynote speakers. The above strategies provided the following benefits. First, it raised the GSN profile within the GEOIDE network. Anyone looking at the conference programme could see that students are important in the GEOIDE network. Second, it reminded project leaders of the importance of students training in GEOIDE-funded projects. Third, it offered great training opportunities for students and helped students gain communication skills. Finally, such strategies also deliver a strong message to the students attending the ASC, letting them know they are a key component of the GEOIDE network and showing them some of the benefits to be involved in GSN activities.

6.5 Implementing an Appropriate Communication Strategy

From its start, the structure of the GSN required a careful communication strategy that would foster networking among students that were distant both spatially and in academic disciplines. One of the first steps was to collect and maintain, in association

with GEOIDE, an accurate database of the membership. This has been achieved through the registration of new students through the GEOIDE online database but also through an active reporting from GSN ambassadors of unlisted GSN students, and through various telephone, email and Internet surveys done over the years. In our case, the communication strategy involved a large number of tools, ranging from technological tools (e.g., Web site, emails and later Skype and social networking tools such as Facebook) to the involvement of students ambassadors, the development of a new student's package, and the organization of students' sessions during the annual conference. While the relationship between students and the GSN was more on an individual basis, the GSS created a group dynamic that favoured social networking tools, encouraging networking to continue after the school.

6.6 Encouraging Face-to-Face Meetings

A popular adage says "a picture is worth a thousand words". We argue that "drinking a beer with another student is worth a thousand emails". Nothing can replace face-to-face meetings. While we know other Canadian research networks that do not organize annual meetings, we believe that a successful network will only develop with in-person meetings, as face-to-face meetings develop the level of trust and familiarity necessary for developing a long-term work relationship. In our context, this involved significant funding from GEOIDE to bring together students from all across Canada to the annual scientific conference, the summer school, and regional workshops. To encourage project leaders to send their students to the annual scientific conference, GEOIDE created early on a matching fund that helped cover students' travel costs. While some networking activities can be done remotely, the strongest work and personal relationships that have been developed over the years have clearly resulted from face-to-face meetings. Once those relationships are built, they can be maintained using less direct communication tools.

6.7 Encouraging Transparency and Providing Benefits to the Members

As it is the case for any organization, members have to understand how they benefit from network involvement. The student network needs to have clearly outlined goals and programs and has to be transparent and allow its members to be aware of its activities and functioning. This can be achieved by email communication, Internet, newsletter or during annual general meetings. The student network needs to be able to provide membership with regular activity updates and more formal annual reports. The network also needs to provide students with services that can include learning opportunities (e.g., summer school, workshops, webinars, mentoring program) and financial support (e.g., award and prizes).

7 Conclusions

Since its beginning, the GEOIDE Network has encouraged and supported two major student's initiatives: the GSN and GSS. The GSN and GSS allowed GEOIDE students to see beyond their specific research projects and gain a more complete academic experience and professional training through collaborations with large interdisciplinary body of students. It has helped students' transition from an academic environment valuing relationships with their supervisor and other students, to a professional environment valuing relationship with their peers that can benefit their entire professional life. While a number of GEOIDE students decided not to take this opportunity, those that did have realized that in such network, "the whole is greater than the sum of its parts".

Measuring the success of initiatives like the GSN is not trivial as most of the benefits to students are indirect and can only be assessed on the long-term. In addition, it is hard to find a baseline that can be used for comparison to assess what specific benefits the network has provided. Examples of benefits include the professional network students have created, the added scientific knowledge gained through networking and the GSS, the soft-skills gained through GSN leadership experience, the GSS and workshops, the improved communication skills developed through networking, and the ability to work with people from other disciplines or cultures.

Perhaps one of the greatest successes for GEOIDE and the GSN/GSS was to enable a culture of collaboration amongst a new generation of geomatics professionals and scientists that came from very different backgrounds and cultures. Many of the students who engaged in the GSN now have careers that emphasize collaboration and multi-disciplinary work; collaboration comes naturally as they plan their projects. Additionally, the Canadian geomatics community is now much more connected than it was before GEOIDE, as most the 1400 HQP trained under GEOIDE now have geomatics-related jobs. Students trained at different universities, such as the authors of this paper, were connected through GEOIDE and are now geomatics colleagues initiating new pan-Canadian collaborations. Having a network of colleagues has supported GEOIDE graduates in early career stages by providing opportunities to seek advice, share students, and conduct research collaboratively.

The success of the GSN and GSS is to our knowledge unique amongst Canadian NCE networks. It has inspired other networks and has played an important role in the review GEOIDE received over the years. While the concept of a student network was a strong point in the initial proposal, its success has been positively received by the expert panels assessing the different GEOIDE funding renewals. This in turn translated into a constant support from GEOIDE for student's initiatives, which turned to be a win-win situation for both.

The experience gained from the GSN and GSS allows us to make recommendations for other organizations that would like to create large students' network. While we

believe that a number of factors, such as the number of members, their geographic distribution or cultural differences may require different strategies, we think the following criteria can apply to most student networks. The most important criterion for the success of such network, as it is for most organizations in general, is likely to find natural leaders that can engage with the students and move such network forward. A second criterion is to have a strong support, both moral and financial, from the organization students belong to (i.e., GEOIDE in our case). Financial support is critical for implementing a number of programs (e.g., scholarships) and bringing students together, particularly in a large country like Canada. A third point is the importance of face-to-face meetings that are critical in ensuring a real and long-term networking. While Internet and social media can be effective in maintaining a network, we believe that a face-time is required to initiate networking relationships. Finally, the structure needs to support continuity from one year to the next, which allows learning from past mistakes and reinforcing successful initiatives.

The GSN and GSS are now facing their biggest challenge, which is to keep the network alive after the end of GEOIDE's funding. The 11th and last GSN board of directors is currently working on strategies that could ensure the survival of the network and move from a student network to a larger network of Canadian geomatics students and professionals.

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Chapter 3

Working at the Intersection of Law and Science: Reflections on a Fruitful Geospatial Data Collaboration

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Abstract. It is relatively rare for largely scientific collaborations to involve researchers from law, and when this is done; their contributions are often peripheral to the goals of the main project which are to advance scientific or technological knowledge and to develop applied outcomes. GEOIDE Phase IV broke with this tradition by funding a science-led collaborative research project that put legal and ethical issues squarely at the forefront of the research agenda. In our project, the researchers sought to examine what legal considerations were relevant to the evolution of GIS-related practices, how technological innovations and standards should adapt to normative frameworks, and where law reform might be needed to advance the goals of GIS in a rapidly changing information environment. In this chapter, the authors reflect on the merits and challenges of such an approach, drawing from their own experience as legal researchers and as scientists within a predominantly science and technology-oriented research network.

Keywords: law, geomatics, interdisciplinary.

1 Introduction

This paper reflects on the challenges and benefits of cross-disciplinary research collaboration in the context of a project that brought together researchers from geomatics and from law. In writing this paper, we do not seek to situate it within the literature on interdisciplinarity, but instead have sought to share our experiences and observations with others who are interested in similar collaboration. We do not claim that our practice always met the standards we describe in this paper; our reflections and recommendations are based upon what was a learning process for all involved.

The GEOIDE-funded Project IV-23 on legal and ethical aspects of the use of geospatial information was initiated by two of the co-authors of this chapter, Marc Gervais and Yvan Bédard. Both are professors of geomatics from Laval University with a background in land surveying, including the legal training necessary to be public officers. Both have carried out research on geospatial data quality and methods to reduce the risks of data misuse. The other two co-authors, Teresa Scassa and Jennifer Chandler, are law professors at the University of Ottawa and are members of the University of Ottawa's Centre for Law, Technology and Society. They both brought to the project considerable experience in research at the intersection of law and technology.

The principal goal of the project was to develop innovative solutions to evaluate the quality of geospatial information and to contribute to its responsible commercialization with a view to public protection. To this end, the researchers considered the impact of geospatial data use on privacy, issues of ownership and licensing of geospatial data, and the circumstances that might give rise to civil liability for faulty geospatial data products and services. Researchers also considered new mechanisms for the certification of geospatial data quality, and tools and techniques to assist users of geospatial data to assess the quality and suitability of data sets. Particular attention was given to geospatial data mashups and volunteered geographic information. Our project built on a solid foundation of existing work in data quality, consumer protection and legal issues related to GIS. For example, four members of our team were involved in the late 1990s in the European project REVIGIS on data quality and which considered issues of consumer protection, and user-readable information about data uncertainty (Devillers et al, 2002; Gervais 2003; Bedard et al, 2004). The legal obligations of data producers were explained in detail by Gervais et al (2007) while research on the prevention of data misuse led to topics such as spatial data quality audits (Gervais, Bédard and Larrivée, 2007), quality certification (Larrivée et al, 2011), and quality warranties.

The GEOIDE Project IV-23 built on some of this past work in its research relating to system design methods and professional responsibility (Bédard et al 2009). For the first time, a scientific questionnaire covering legal, procedural and technical strategies to manage the risks associated with distributing and using geospatial data was sent to hundreds of practitioners across Canada (Gervais et al, 2011). The direction followed by the members of the team was inspired by others (e.g. Antenucci et al 1991; Onsrud et al 1994; Cho 1998; Cho 2005; Devillers et al 2010), but it also differed from the mainstream of the GIScience literature as it involved material related to the legal status and obligations of professionals in Canada (including ethics and deontology) (Bédard, 2011), consumer protection, and privacy (Scassa 2010a).

In this chapter, we reflect on the benefits of the collaboration from both scientific and legal perspectives. Following a brief description of our team, we identify what we perceive to be some of the challenges and the opportunities of this form of collaboration. We then consider some of the barriers to effective collaboration. These include

significant differences in research culture and expertise as well as audiences for the research. We consider how to integrate legal expertise within a scientific study and consider the challenges of integrating industrial partnerships with interdisciplinary projects. Our paper concludes with recommendations to guide future collaborations of this kind.

2 Building the Team

As our society enters its fifth decade of experience with digital geospatial data, geospatial data products have become mass-market commodities. Their amenability to data mashups has also led them to be integrated within the web 2.0 crowdsourcing movement and raises new issues not addressed in the geomatics literature of the early 1990s. The resulting challenges regarding liability, privacy, copyright and public protection are ideally suited to research by a team combining disciplinary expertise from law, geography, geomatics and engineering. Our goal was to bring together key researchers in order to develop both legal and technological solutions to emerging normative challenges raised by digital geospatial data. Our team included four scientists with an interest in legal and normative issues who were already involved in geospatial data quality and crowdsourcing-related projects, three legal researchers who together brought expertise in liability, ethics, copyright and privacy issues related to new technologies, four international collaborators in law and science from the UK, France, the Netherlands and the USA, and twelve partners from industry and government agencies with policy mandates at the national and international levels.

3 Challenges and Opportunities

Cross-disciplinary research collaboration presents excellent and indeed often essential opportunities to resolve problems or answer questions that cut across disciplinary divisions. That being said, such collaborations also present challenges. In this section, we present our views on the benefits and challenges in general, and highlight some that were particular to this project.

Among the benefits of cross-disciplinary collaboration is the opportunity for researchers to access detailed expertise in a relevant but “foreign” discipline, as well as to identify interesting research questions that are not obvious when a matter is examined from a single disciplinary perspective. Yet such cross-disciplinary research collaboration is complicated by the fact that different disciplines often have distinct research cultures. Differences include not just theoretical and methodological approaches (Foster & Osborn 2010), but also variations in disciplinary expectations around research output and dissemination. These differences can be significant and must be properly acknowledged and addressed.

The culture and language of law may also create challenges for research that extends beyond national boundaries. A complex patchwork of national and international rules

may be applicable to emerging technologies with global application. Legal academics tend to be grounded within the legal context of their home state although many develop some expertise with comparative law methodology. Even with Canada, a comparative methodology is often warranted, given its bijural legal context (i.e. the civil law of Québec and the common law of the other provinces). Comparative legal analysis is also often limited by language ability, as primary legal sources tend only to be available in a country's official languages.

Legal context can also play a role in normative debates. Federal states, for example, face particular constraints in dealing with emerging legal issues that unitary states do not. Within a federal state, a given legal issue might fall within multiple legislative jurisdictions, which may lead to challenges in coordination within a single country. Our legal team collectively had capacity in three languages, three national legal systems, federal systems of law, and European Community law. Our team, made up of both francophones and anglophones, also reflected Canada's bilingual context. This is more than a national peculiarity; in a more globalized research context the language of collaboration can be very important to team dynamics. Throughout our project, the differences in disciplinary and linguistic backgrounds of the researchers ultimately helped to enlarge and enrich discussions. At the same time, they presented challenges to the team, especially regarding vocabulary and vision.

In the context of some of these challenges we note that there was great value in holding regular, face to face meetings of the team. Meetings of all team members and partners were held annually, and provided an opportunity to network, exchange ideas, and build collaborations. In addition, the core members of the team found other opportunities to meet collectively or in smaller groups. These meetings were extremely useful in learning to work across very different research cultures.

3.1 Value for Law

In an era of rapid technological change, there is great value for those trained in law to collaborate with those with scientific and technological knowledge, particularly in relation to the regulation of technologies. This is even more the case as change is now so rapid that even a legal academic with a science background will struggle to keep abreast of new and emerging technologies.

It is often said that the law is reactive rather than proactive in its dealings with science and technology. This is only partly true, as a review of the laws and regulations designed to encourage scientific and technological advancement (such as intellectual property law and taxation law) demonstrate. However, the law often responds only after a scientific or technological change has generated a problem that requires a legal solution or that has rendered the law obsolete. This reactive model can lead to problems, as, for example, where financial investment or social adaptation make it difficult to change a particular technology after a problem has become widespread. Over the years, policymakers have sought various mechanisms for forecasting or perform-

ing technological assessments in order to try to avoid problems, rather than having to address them once they come into being (e.g.: Cavoukian, 2009). Whichever approach is adopted, it is clear that law and technology are closely intertwined and that just as laws may react to technology, technological development may also be shaped by law and policy.

Legal academics who focus on emerging science and technology are often interested in contributing in a proactive rather than a reactive way. They wish to identify, at a sufficiently early stage, the potential advantages and disadvantages of technological change in order to use the law to support efforts to pursue the benefits and to mitigate the harms. Other legal academics may focus instead on the way in which changes in science and technology raise interesting problems that call into question the theoretical underpinnings of the legal system itself. For example, developments in science and technology that enable the gathering of more kinds of information (e.g. genetic information) or that enable the gathering, storing and processing of greater quantities of information may cause legal researchers to re-evaluate the meaning of personal information and the proper scope of privacy protection (e.g. Murray 1997, Solove 2004). This type of inquiry is less oriented toward a particular policy outcome, and more to understanding the law in more philosophical terms. All of these inquiries require knowledge of the current state and the likely path of evolution of the relevant science and technology. They require a good understanding of both the intrinsic capabilities of the technology and the ways in which it is implemented and used. It is also important to grasp how technologies that overlap or have complementary capabilities may also generate information or enable services that would not otherwise have been possible (as is often the case with geospatially-enabled information technologies).

For a legal academic working in areas that intersect with science and technology, the insights provided by the scientific team members into the science or technology under study are invaluable. Clearly those with scientific expertise will be better placed to understand the science or technology in issue, and the ways in which it will likely evolve. Scientific experts, particularly those with an interest in the social consequences of scientific and technological developments, will be better able to identify social issues, questions or problems that require a regulatory or legal response. Scientists will also be in a better position to provide realistic case studies in which legal issues might be explored. At the same time, legal academics may be able to identify issues not obvious to those in the scientific field, including those that arise in different jurisdictions (i.e. a deployment of technology in one country may not conform to the legal norms in another). They are also well placed to explore public policy and law reform issues related to the development of new norms or regulations to govern emerging technologies.

In civil law systems, civil codes are drafted at a certain level of abstraction or generality to ensure their flexible application to new situations. The common law method involves the gradual elaboration of legal principles by judges resolving specific disputes. The work of the lawyer in a common law system is to deduce the higher level

or more general legal principles from the specific cases so that they can be applied in new factual contexts. In both cases, the way in which these fairly general principles apply in new situations can be difficult to predict without a detailed understanding of the factual context of these new problems. In order for a legal academic to go beyond identifying applicable legal principles and offering speculations about how they might apply in novel cases, they must have detailed and specific facts related to the scientific or technological activity in question, as well as knowledge of its likely applications and its predicted evolution. Scientific experts are best placed to provide this critical information to the legal academic. This allows the legal analysis to move from highly general observations to more concrete and specific illustrations. This is particularly evident, for example, in research on liability for faulty data that was carried out as part of this project (Chandler & Levitt, 2011).

Legal analysis can be affected by assumptions about science that may not be accurate. For example, there have been instances where courts have assumed that maps are inherently reliable or that facts are objective and immutable (*Feist v. Rural Telephone*, 1990). The Quebec Court of Appeal has ruled that facts drawn from a map could be considered definitively proven such that a court might take judicial notice of them (*Baie-Comeau c. D'Astous*, 1992). However, experts in geomatics know that a map or geospatial database is only a model of reality and that its quality and character will be highly dependent on the initial goals, data collection techniques, generalization operators or other operations performed on the data. Legal academics can produce better theoretical and policy writings when their assumptions about science and technology are fully tested through interdisciplinary collaboration.

Copyright law provides an illustration of how a blend of scientific and legal perspectives may greatly enhance understanding. A basic principle of copyright law is that there is no copyright in facts – these are considered to be in the public domain in part because they are considered objective, observable, and hence not the property of any one person. Copyright protection for a compilation of facts only extends to what is considered to be the contribution of the author. This is not the facts themselves, but only their selection or arrangement. Yet the creators of compilations of facts tend to assert claims to copyright in their compilations that often extend to the facts themselves (Judge & Scassa 2010). One question that then arises is the extent to which the generation of geospatial information in various contexts reflects acts of “authorship” that go beyond simply recording or observing facts. Answering this question requires an understanding of how such data is generated, tested, verified and recorded. In other words, it requires a blending of both science and law.

It is important to underscore the necessity of a two-way discussion in this process. The scientific expert is unlikely to know what information is legally significant, while the legal academic will not necessarily know enough about the science or technology to be able at the outset to identify the potential legal issues. An ongoing discussion is thus essential in educating both sides to the necessary level of detail so that a full understanding of the science or technology and its legal ramifications can emerge.

The work that is the fruit of such collaborations may support courts and policy-makers to develop, interpret, and apply laws in ways that are more appropriate to a given technology.

3.2 Value for Science

As society becomes more diverse and complex, and its members better informed and connected, there is a growing need for scientists to be aware of changing legal norms and the diversity of such norms across jurisdictions. Rules may govern the process of scientific research (research ethics obligations, safety regulations, and so on), the immediate fruits of scientific research (intellectual property and contract law), as well as eventual technological applications of the scientific research. The dissemination to the public of these new technological solutions may be met with contractual obligations, rules for public protection, environmental protection issues, privacy obligations, and a host of other regulatory concerns. The insights provided by legal researchers into the applicable legal and normative issues can be invaluable. In the geospatial data context, for example, these insights may directly affect system design, specifications for data acquisition and dissemination, technology development and client relationships. These insights allow scientists to move from a position of general awareness that there may be normative questions to a greater understanding of the specific legal issues that must be taken into account when designing and implementing systems and procedures.

In the case of information technologies, a primary concern of many scientists (and their funders) is to develop something innovative that can be brought to market as soon as possible. This is especially evident in the context of geomatics where there has been a flood of innovation. For example, in the past ten years we have witnessed the rise of many major technological developments such as Google Earth, smart phones with embedded GPS and maps, 3D augmented reality, a web of real-time sensors, and very high-resolution satellite imagery. These technological innovations have enabled corresponding location-based services. These products and services raise challenging legal and ethical issues that concern not just how they are deployed, but how they are designed and developed. Issues considered in the context of our project include the extent to which data can be used and re-used, modified and integrated into new products (Judge & Scassa 2010), intellectual property rights in “new” data or data-based products (Scassa 2010b), and liability for the accuracy of data or for the uses to which it is put (Chandler & Levitt 2011).

Scientific and technological discussions around a Global Spatial Data Infrastructure have necessarily had to take into account licensing issues (Janssen 2008, Onsrud 2010). Similarly, new practices embraced by the public and private sectors alike, including the integration of crowd-sourced or volunteered geographic information, geospatial business intelligence, and geospatial data mashups have spawned a need to consider legal and ethical issues (Goodchild 2007, Elwood 2008, Scassa 2012).

This rapid pace of technological development reinforces the tendency for technology-driven projects to lead the way, with legal and public policy concerns being typically addressed only once a new technology has been developed and deployed. Yet many of the legal and public policy concerns raised by such technologies are serious, and both developers and the public might be better served by a greater integration of law and public policy with scientific research. There may also be instances where technological design implementation and practices are affected by inaccurate assumptions about the law and policy context. These might arise from reliance on outdated laws or from misunderstandings of how existing laws are interpreted and applied. The international furor over Google's collecting of WiFi access point and related data by its Street View vehicles is an illustration of the public relations nightmare that can arise when technological capability outstrips society's normative boundaries (Privacy Commissioner 2011).

The involvement of lawyers is beneficial at many stages of scientific research and technological design. Many decisions made during the data production process can also be influenced by legal and normative advice. The same is true for establishing data diffusion policy, for properly warning the users of limitations flowing from data quality, for requiring accreditation when pertinent, and ultimately for adequately managing the risks of data misuse and properly allocating this risk between providers and users. For example, our experience in the geomatics community suggests that geospatial data producers focus their efforts mainly on internal quality management (i.e. meeting the technical specifications) but not enough on external quality management (i.e. validating fitness for use). However, the law sets out a number of legal principles to be respected when a producer provides information such as the duty to provide advice and warning (Chandler & Levitt 2011, Gervais et al 2007). While these principles are more related to the dissemination and use of geospatial data, producers would do better to take such issues into account throughout the production process. In doing so, they could integrate new business processes to facilitate external quality management, to improve user satisfaction, and to reduce the risk of civil liability. This approach to improving geospatial data production is uncommon and is currently a relevant research area that can benefit from the involvement of legal researchers.

Scientists who are also members of professional associations are usually required to respect a code of good practices (derived from a profession's code of ethics). These will generally include requirements to protect people and the environment. For example, article 2.01 of the Code of Ethics of the Ordre des Ingénieurs du Québec clearly states: "In all aspects of his work, the engineer must respect his obligations towards man and take into account the consequences of the performance of his work on the environment and on the life, health and property of every person." (Code of Ethics of Engineers, 2011). Similarly, "[a]n engineer must refrain from expressing or giving contradictory or incomplete opinions or advice, and from presenting or using plans, specifications and other documents which he knows to be ambiguous or which are not sufficiently explicit." (Code of Ethics of Engineers, art. 3.03.02). In the field of geo-

matics, there are many other codes of ethics with similar rules such as those from the American Planning Association (<http://www.planning.org>), the Association of American Geographers (<http://www.aag.org>) and the GIS Certification Institute (<http://www.gisci.org>). Properly understanding how such principles can be applied in the geospatial information context may require collaboration with researchers in law. The same applies where such principles are extended to other specialists involved with system design and implementation who do not have a professional Code of Ethics in their field. The involvement of legal researchers can assist in properly understanding the boundaries of appropriate practices and can protect against potential data misuse and the resultant liability.

So far, only a small number of scientists have focused on developing a social vision for the coming decades of geomatics – a vision that anticipates the social impacts of technology and that pro-actively proposes innovative solutions. For such scientists, the contribution of legal researchers at an early stage in the development of a social vision is of major benefit. When scientists work closely with experts in law, this adds credibility to the societal vision proposed, to the issues identified, and to the proposed solutions.

3.3 Value for Society

There are a number of societal benefits of effective collaboration between law and science. Many of these flow from the fact that the research is responsive to both innovation and public policy objectives. The improved ability to define problems cannot be over-emphasized. Much legal and policy scholarship is carried out at a fairly high-level. This is not inherently a bad thing, but it does mean that there are specific issues, problems, or questions that do not get addressed. Further, a legal academic who is left alone to formulate a research question might be less able to identify quickly and easily points of difficulty or controversy experienced in the scientific discipline. Instead, relying solely on published materials, they may identify questions that were important a year or two previously, but that have been superseded by new issues or emerging technological challenges.

Similarly, the importance of foreseeing the impacts on society of new technologies cannot be over-emphasized. Typically, most writing about new technological developments is narrowly focused and relates solely to the innovation at a scientific or technical level. However, collaboration between scientists and law experts permits us to go beyond this natural tendency and to explore at an early stage the potential for unintended uses of the technology, as well as the technology's potential social, economic or environmental impacts. The earlier these issues are raised, the earlier the solutions can be identified. This will lower the overall costs and potential harm flowing from the innovation. As noted by Bédard (2011): "Society always organizes itself when a mass of citizens is facing increasing risks of misusing given products or services". The closer the collaboration, the higher the likelihood of identifying issues that

are not properly addressed by existing laws, technologies or practices and which require further research or development.

It may well be that the stresses placed on public policy-makers by such rapid technological development has increased the need for this type of collaboration. The expertise developed by the legal researchers involved in this project resulted in them being sought out by scientists and technologists in various contexts external to the project. For example, they were invited by Transport Canada to study the issue of privacy in intelligent transportation systems, and they were also invited to speak to cartographers on privacy and intellectual property issues. We determined that there was a strong demand for legal experts with an understanding of the scientific context of geospatial information. Our team developed an expertise that could be translated to other contexts.

4 Building Effective Collaboration between Law and Science

Based on our experience, we suggest that a proactive approach to establish how law and GIScience may build knowledge together is crucial, in spite of the “emergent” nature of many of the most difficult problems in this area. Although there may be a risk that collaborations will explore speculative issues that do not actually materialize, such research has the potential to anticipate problems and to shape the development of new policy

4.1 Respect for Academic Expertise and Specialization

Successful cross-disciplinary collaboration requires building mutual understanding of the questions participants consider valuable and to which they can make contributions.

Co-authors Scassa and Chandler have experience with interdisciplinary collaborations in science and technology. They note that in some cases legal academics are invited to join science-led projects as an after-thought to meet a perceived need to address “social issues,” and not as part of the original project conception or design. Where this occurs, there is a tendency to view the legal contribution as a set of legal opinions related to the technology under development. An example might be to provide an assessment of whether the proposed technology is consistent with existing legal norms around privacy. For legal academics, this is not particularly interesting legal research. This is more akin to providing a professional opinion in a law practice context. Although the answer to the question may be of importance to the science team, for academic legal researchers this type of specific legal opinion work is unlikely to contribute much to the broader legal research programs they are pursuing.

Similarly, co-authors Bédard and Gervais, from the field of geomatics, also note that in some interdisciplinary collaboration they have been invited to participate as devel-

opers of applications rather than as core researchers who seek to improve geospatial concepts, methods and technologies. Academic researchers who also have professional and practical skills tend not to want to be involved in research projects solely to provide professional or practical services or to do mere development. This type of work is more like “consulting,” which falls outside the scope of universities’ missions, and is a better fit with private industry.

Early participation of all members of the team in formulating the research questions is important in order to avoid later finding that the questions the science members of the team are most interested in having answered are the ones that the legal members of the team are least interested in exploring, and vice-versa.

4.2 Understanding the Limits of Researchers’ Expertise

In order to build successful collaborative and interdisciplinary projects, it is necessary for the team members to have a clear understanding of the limits of their collaborators’ expertise. For example, there is a tendency outside the field of law to view all lawyers or legal academics as “generalists,” or at the very least, as having very broad competency across a wide range of subject areas. The reality is that for all academics, specialization is essential because of the breadth and complexity of most areas of inquiry. In law this means that a specialist in intellectual property law is not likely to have any expertise in issues of civil liability. In science-led projects, there may be a tendency to assume that team members with backgrounds in law can easily respond to all potential legal issues that might arise. To avoid frustration on all sides, it is safer to choose legal team members for their expertise in specific sub-specializations where a particular type of legal knowledge is central to the goals of the research project.

Similarly, outside of geomatics, there is a perception that specialists in geomatics are fully versed in each type of technology used to observe the Earth and its phenomena, to measure objects, to design geospatial databases, to develop systems, to perform all kinds of spatio-temporal analysis and to upgrade existing methods. Although this is the goal of the field of geomatics as a whole, and although successful geomatics education programs aim to develop broad competence, the reality is that specialization is the norm, certainly at the academic level. A specialist in GIS will probably have just enough knowledge about land surveying to properly integrate such field data into the workflow, a specialist in remote sensing usually has limited knowledge about spatial database design or about GPS, and a specialist in photogrammetry usually has limited background in spatio-temporal analysis.

In science, it often makes sense to have broad, international collaborations – what is important is that all team members share the same scientific specialization. Scientific knowledge and technology is usually the same everywhere even though professional and procedural contexts may vary across regions. This approach is more challenging in law because legal expertise is often limited to specific jurisdictions. Thus Canadian team members who are asked to reflect on the legality of a certain technology in

France will likely lack the relevant expertise, even if they are Canadian experts on legal issues in that particular field. Legal and regulatory issues in the EU can be quite opaque to those with no specific expertise. Even within Canada, the answers to legal questions may vary from province to province, and the variance may be greatest between the common law provinces and the civil law of Quebec. Involvement of all participants in framing the research questions can be very useful in identifying where additional expertise will be required, and in ensuring that the appropriate team members have been invited to join the project.

Finally, it is also important to note that normative analysis – discussion of what should or ought to be rather than of what is – takes various forms, some of which legal academics are not necessarily trained to do. Legal academics are familiar with constructing arguments about what is “right” based on policy considerations, political philosophy, or ethics, and can express these arguments within the frameworks of legal rules and principles. This does not mean, however, that they have deep training in the underlying social sciences or philosophy or that they are best placed to come up with those policy or ethical considerations. On the other hand, some legal academics do develop this type of expertise, and are deeply interested in this kind of work. In any event, where a project requires this type of fundamental normative expertise, it is necessary to keep this consideration in mind in composing the research team.

4.3 Understanding the Different Disciplinary Cultures and Expectations

One of the most challenging issues for cross-disciplinary collaborations may lie in the cultural differences between the disciplines. Each discipline will have its own norms for how it recognizes and evaluates scholarly contributions. These differences may have an impact on the expectations of the researchers in terms of the kind of research output that is to be produced. For example, in law, sole-authored papers are still the norm, and papers tend to be long (40 printed pages, for example). As a result, an author’s output may be quite limited over the course of a year simply because these lengthy, intensive, sole-authored pieces take a great deal of time to produce. While it is possible to collaborate on shorter, multiple-authored pieces, there is a tendency for these types of publications to be discounted in law-based peer-assessment processes, such as tenure and promotion. Untenured law professors might be well advised not to commit too much of their energies to work with those in other disciplines that will lead primarily to this form of publication.

Conversely, the high costs and complexity of technological research require collaboration in order to obtain funding for projects and in order to achieve the expected results. A project will usually involve a number of fundamental issues that need to be solved in order to lead to the final result, and will typically lead to the completion of several theses. It is not uncommon to see complete results ready for technology transfer in industry only after a decade of research, experimentation and testing. The involvement of multiple researchers is essential. Consequently, in technology-related

fields, it is normal to have short papers with multiple co-authors that propose solutions to specific problems that are part of a larger research undertaking.

In law, it is less common for professors to publish with students for a number of reasons. First, graduate students in law are very independent in choosing their thesis topics. These may have little relation to the professor's work in progress, and they may also have little to do with the grant-funded research. Even where the graduate student's thesis work is related to the grant-funded research, their project may be quite different from the one on which the supervisor is focusing. Because of this, there may be a reluctance to ask the student to take time away from work on their thesis to find the common research ground necessary in order to co-author a paper. Law professors also tend to be cognizant of the fact that the student, who might eventually be seeking employment as a legal academic, will be judged in part on their publication record. Co-authored publications are less valued in law than sole-authored publications, and where the co-author is a faculty member, the student's contribution may be discounted by assessors. On the other hand, academic scientists are encouraged to have their graduate students publish and be the primary co-author if the publication is related to their student's MSc or PhD research. Typically this research is directly under the funding of the thesis advisor and a part of the advisor's research agenda. Consequently, graduate students and their advisor(s) work very closely and become co-authors of papers. In Canada, research granting organizations in sciences give higher scores to academics who collaborate when publishing research results. Scores are even higher if the graduate students are the primary authors since R&D is seen as a means to educate future researchers rather than solely as an end *per se*. The sequence of the co-authors represents their level of contribution and has an impact on intellectual property issues in technology transfer or in an application for a patent.

In some cases differences between disciplines are so dramatic that some forms of research output are difficult to have recognized at all. For example, during the course of this collaborative project, a legal team member produced a poster along with her graduate student for a poster session at one of the GEOIDE annual conferences. The poster session is a key part of scientific conferences, but is something that is virtually unheard-of in law. Although the poster, which provided a visual overview of civil liability issues related to geospatial data use, was enjoyable to produce and was well-received by attendees, it is a form of research output that is completely unrecognized in the legal academy. Accordingly, students and pre-tenure professors in law may be better advised to devote their time to other forms of output.

The methodology, citation style and format of papers tend to be very different between law and technology disciplines. Because law favours dense footnoting, with a need to justify and provide authority for each proposition in the paper, sparsely foot-noted papers often feel substantively light, and may be judged to be so in peer-review processes in law. On the other hand, footnoting is rarely used in scientific papers.

These “cultural” differences between academic disciplines should not be a barrier to collaboration. Indeed, it is only through repeated collaboration that disciplinary expectations will begin to evolve. Nevertheless, it is important for team members to share with each other these different expectations in order to better understand the kinds of research output that team members will feel obliged to produce. An understanding of the different conventions for acknowledging authorship is also important to avoid misunderstandings and to ensure that all expectations are met.

4.4 Addressing Different Audiences

Another challenge faced in interdisciplinary collaborations relates to the ability of the team to effectively address the expectations of different audiences in publishing the results of their research. In our law/geomatics collaboration, the audiences for our research were quite different. Although we did publish work on law that was aimed at a legal audience, and on geomatics aimed at a scientific audience, the very nature of our project required that we find ways to effectively bring law to scientific audiences and science to legal audiences.

One challenge is to be able to produce work that will have recognizable merit in one’s home discipline. For example, papers that explain legal issues in a science or technology field will generally eschew the kind of policy/legal analysis that a paper written for a legal audience would engage in. Where the detailed legal analysis is left out in the interests of clarity and accessibility for non-lawyers, this will make the resulting paper seem “light” from the point of view of peer-evaluation in law. Conversely, the inclusion of complete scientific detail may overwhelm peer-reviewers in legal publications, most of whom are lawyers rather than technical experts. Peer-reviewed legal publications are read mostly by lawyers, and are of two main types: the general law review and the subject-specific law review. The general law review is often less receptive to legal publications related to science and technology than a legal journal devoted to, for example, “law and technology,” “aviation law” or “health law” or another specific sub-field of legal specialization.

The same situation holds true in scientific journals although to a lesser degree as there is a wider diversity of scientific journals, some of them being more open to less-technical issues. Ultimately, it can be challenging to write one paper that would satisfy the expectations and standards of both legal scholarship and scientific scholarship at the same time. Nonetheless, there is a real benefit to trying to meet this challenge even if the resulting paper will necessarily be a kind of hybrid outside the strict norms of both disciplines. The challenge is therefore to bridge different disciplines and to write something that is meaningful to a wider audience.

Because truly interdisciplinary literature and readership are rare, collaborations between scientists and lawyers will often involve publications in the separate scientific and legal literatures. The risk here is that the collaborators, focusing on the standards and expectations of their separate literatures, may be drawn away from the interdisci-

iplinary aspect of the collaboration toward the framing of research questions, methods and publications to meet disciplinary expectations. As mentioned above, we feel that this need not be the case, and that there is sufficient room and flexibility within at least some peer-reviewed journals in each discipline to accept and welcome “hybrid” publications. At the same time it may be necessary to prepare a variety of papers with different target audiences in mind.

4.5 Developing a Shared Language

Each academic discipline develops its own vocabulary, which may be opaque or closed for those outside the community. This is true in both law and in geomatics. Indeed, in law, some terms have meanings that are counter-intuitive. For example, most people would understand the term “person” to refer to an individual human being. In civil law, corporations and other such entities may also be considered “legal” persons (C.C.Q., s. 298-299) and the common law also has a concept of “juridical personality” which includes corporations.

In some cases, the meaning of a statutory term is, on its surface, fairly comprehensible. However, its meaning in specific contexts may be discernible only with knowledge of the court cases that interpret the term. For example, the term “fair dealing” is used in the Copyright Act to describe an exception to copyright infringement that permits certain uses of a protected work in prescribed circumstances. While it might be easy for the reader to understand the basic meaning of fair dealing, it will be much more difficult to know whether a proposed dealing with the work will be considered fair without knowledge of the jurisprudence that has interpreted this provision. This example also serves to illustrate the confusion that can result from jurisdictional variation in legal vocabulary. There is a great deal of writing and media reporting on the U.S. concept of “fair use” which plays a similar role to Canadian “fair dealing,” but which has a significantly different content. Non-specialists in law may feel that they have a good grasp of the concept based upon their reading of articles, commentary, or popular U.S. discourse about fair use. However, this does not translate at all into the Canadian legal context. Thus uses of works that are considered legitimate in the U.S. because they constitute “fair use” may nonetheless be infringing in Canada (Vaver 2011).

In geomatics, the situation is no easier. Some technical terms are rarely used in ordinary language. Others may be more widely used, but their common and technical meanings may be quite different. For example, the term “tile” in geomatics refers to a regular division of a given territory and not a ceramic square used to cover buildings, although some analogies may be drawn from the two concepts. Moreover, as in law, the geomatics community uses expressions that will be either misleading or meaningless to the uninitiated. For example, the term “logical consistency”, which is one of the evaluation criteria used by ISO for geospatial database internal quality, is clearly a term of art in geomatics that is distanced from its common meaning. The vocabulary in geomatics evolves as rapidly as in computer science, with new terms appearing

every year. These terms are often used by software companies in marketing campaigns; this is a practice that can introduce further variations in meaning. Since software companies have much more visibility than academics, their use of the new vocabulary sometimes becomes a de facto standard within their large community of users and can create confusion within the geomatics community. As a result, it is not uncommon to see specialists in the same field using the same terms differently.

Finally, the proliferation of acronyms, in both law and science can significantly affect the mutual understanding of researchers. There may be a tendency to assume that acronyms in common use in one's own discipline are widely understood; this can lead to opaque presentations and discussions. Members of an interdisciplinary team must be sensitive to the differences in vocabulary and must make particular efforts to ensure that communications are as clear and straightforward as possible. In new collaborations, an incubation period may be helpful during which the researchers can familiarize themselves with the terminology and research cultures of their collaborators. The length of this period may be inversely proportional to the degree of mutual knowledge of experts joined in the project.

4.6 Finding the Proper Role for Legal/Normative Expertise within a Scientific Study

In some areas of science and technology, there is pressure on scientific researchers to incorporate reflection on the ethical, economic, environmental, legal and social aspects of their research. Many researchers are genuinely interested in this aspect of their work, although it still often remains peripheral to the central focus of their project. The result is that other academics whose disciplines involve this type of inquiry are approached fairly late in the conceptualization of a research project. At this point, it can be more difficult to structure a project in a way that permits the adoption of novel and innovative approaches. From the perspective of a legal academic who might be invited to participate in such a project, work that consists largely in providing legal opinions on how to deploy a particular technology within existing regulatory constraints is not usually appealing. Instead, a deeper integration is needed between the legal and scientific work that allows, for example, for legal or ethical insight to contribute to the development of technological applications. In this context, our GEOIDE project was quite unusual in that it placed legal and scientific questions on an equal footing and sought to integrate the scientific inquiry with issues of ethics and law.

However, one aspect of our project was that the team was expected to “service” other GEOIDE-funded projects by playing a rather loosely defined legal/ethical support role. One objective of GEOIDE was to form a network (inter-projects) of networks (each project team). As our project was the only one whose research objectives were chiefly directed towards legal and ethical issues, we did attempt to develop collaborations with other projects. The initial idea was to examine the technological developments made by other research teams and use these as test sites. Some projects were

targeted first because their research topics could more obviously raise privacy, copyright or civil liability issues. In two targeted projects, members of our research team became integrated with other project teams, facilitating collaboration and exchange. In both cases, specific projects were initiated. For example, a workshop on collaborative production of geospatial data was proposed in conjunction with Project IV-41, a code of ethics for geospatial data production was developed with Project IV-24 and a few sub-team informal meetings took place with the other projects.

Apart from these joint initiatives, this aspect of the project was the least successful for a number of the reasons that we have already outlined in this paper. Perhaps most importantly, there was no collaboration with experts in law or ethics in the formulation of the research questions for those projects. It is very difficult to shoe-horn in, *ex post facto*, this type of research focus. Such an approach makes it even more likely that the only room for contribution from legal academics will be to look at certain technologies and provide a legal opinion on whether they comply with existing regulatory norms. As noted earlier, this is not usually interesting from a legal research perspective. It is also not particularly interdisciplinary in terms of method or result.

4.7 Industrial Partnerships in Collaborative Interdisciplinary Research

It is increasingly common for government funding agencies to insist that large-scale collaborative research projects involve industry partners. This is even more the case in the sciences, where it is expected that there will be a flow of knowledge and innovation between academic and industry players. Patentable inventions are frequently an expected research output in grant-funded research in the science field.

The emphasis on industry partnerships can pose challenges for research at the intersection of law (or the humanities more generally) and science. In the first place, the interests of industry partners are much more likely to be focused on specific innovation targets and on bringing products to market. In this context, the partner might want the legal researchers to perform the kind of “legal opinion” type of research that, as we explain above, is neither appropriate nor interesting to legal academics. The kinds of partners who are most likely to be interested in academic legal research output that focuses on law reform and policy will be government departments or agencies. In some cases, these may not be eligible partners for grant applications. In most cases, they will not be able to make cash or in-kind contributions in amounts that come close to meeting the expectations of science-based funding agencies.

Many industry partners may be reluctant to contribute to projects that have a focus on legal or ethical issues. Although these questions may ultimately be crucially important in the field more generally, they do not typically offer solutions that benefit the funding company over all other players in the marketplace (and consequently cannot be tax deductible). Further, some companies may feel that given the rapid pace of technological innovation, they will not have time to truly benefit from the research and to adapt it to their own context.

The collaboration of the legal team in this project was made possible in large part due to the flexibility of GEOIDE as a funding source. Researchers were not asked to operate on a research contract model where industrial partners chiefly fund the research, which focuses on specific deliverables. They were permitted to involve a wide range of partners, and it was accepted that some partners might make small contributions or contributions that were entirely in-kind. The model fell between an industry-academic partnership on one end of the spectrum and pure grant-funded research on the other.

We note that bringing together researchers from two or more disciplines can change the nature of the partners who are involved in the research project. In our case, we had different partners than either group of researchers would have had on their own. This made management of participation and of expectations more complex, but it had advantages as well. From a law perspective, it provided an opportunity to interact directly with industry players and to understand law and policy issues in concrete contexts. From a science perspective, it provided direct contact with regulators and policy-makers and allowed for insights into their preoccupations and priorities.

4.8 Relationship of Normative Questions to Scientific Research

In some cases, scientists are uncomfortable with the methods used in legal scholarship and the humanities. Normative thinking may seem incompatible with a positivist vision of scientific inquiry as the pursuit of objective knowledge about the world through testable hypotheses. In this view, neither knowledge nor particular technological artifacts in themselves can sensibly be described as good or bad, ethical or unethical. Instead, normative evaluation must be directed at the uses to which human beings put the knowledge or artifacts. This is perhaps an extreme version of a particular philosophical orientation, but a lack of interest in or discomfort with normative thinking for some scientists is understandable given educational specialization. After all, most lawyers and philosophers are not much good at doing science or engineering, either. In any event, the supposed non-relevance of normative inquiry (i.e. legal or ethical inquiry) to science and engineering is not generally a problem in collaborations between scientific experts, ethicists and lawyers for the reason that those who are drawn into collaboration tend to be those who are interested in the normative content of science and technology. Nonetheless, for scientific experts whose focus and method excludes much normative thinking, the approach may seem either unhelpful or irrelevant. In the specific case of our research team, the scientists involved were open to and skilled with normative inquiries, particularly since their focus had to do with maximizing the social benefits of innovations in geospatial data technologies. Their own research did not rely solely on traditional research methods and they were not pursuing pure scientific research questions. The geomatics researchers were used to dealing with subjectivity and with context-sensitive issues and to taking this into consideration in their research methods. This facilitated the collaboration within the team but the absence of such an approach may have impeded collaboration with some other teams.

5 Recommendations for Effective Collaboration between Law and Science

The most effective and rewarding collaborations between scientists and lawyers are likely to be those in which the project is conceived as a collaboration from its earliest stages. In this way, the project avoids the pitfalls of “grafting” an ethical or legal component onto a completed scientific research question. Instead, far more interesting to the academic lawyer is a collaboration that aims at truly interdisciplinary questions – questions that are novel and advance understanding in both disciplines. For example, a scientific or technological change may destabilize a settled legal concept or rule in a way that opens interesting avenues to reassess the proper role of the concept or scope of the rule within the legal system. Scientific experts collaborating in such a project may thus contribute to the reimagining of the legal system, rather than merely receiving the legal or ethical assessments of their new technologies from collaborating lawyers or ethicists. Of course, scientific collaborators will not be motivated solely to advance the objective of understanding or improving the concepts and rules that make up the legal system. Their interest is also in engaging in ethical and legal reflection on the scientific or technological development itself and in disseminating their findings within their community to improve awareness and to contribute to building a more mature discipline. For legal experts this will also be an important part of the research process. In order to determine whether there is some need to reimagine an aspect of the legal system, it is necessary first to understand the ethical and legal ramifications of a scientific or technological change.

With this in mind, we have distilled the following recommendations to guide future collaborations between law and science:

- Late engagement of the legal researchers in a science-led grant application (or vice-versa) should be avoided in order to minimize the risk of a mismatch in expectations and a focus on research questions that do not fully engage all team members.
- Respect for the other researchers and their discipline is essential. Differences in research culture and methodology must be appreciated; researchers must have open minds towards trying new approaches or engaging in new modes of research.
- Curiosity and patience are crucial. In some cases, there will be a preliminary phase of mutual education as those from each discipline begin to understand the vocabulary and dynamics of the other disciplines involved in the project.
- Face to face contact can be essential in building an early rapport between researchers and in more quickly coming to terms with differences in research culture. Other forms of communication should also be used regularly in order to avoid the fragmentation of the team into separate mono-disciplinary re-

search projects that do not fully realize the potential of the collaborative interdisciplinary approach.

- Recognizing the differences with regards to the requirements for academic performance measurement is important for the team members and for the funding organizations to ensure renewal of funding.

Our experience in the context of this GEOIDE-funded project was positive and productive. One legacy of the project is that we have created a group of researchers across the disciplines of law and geomatics who like and respect each other, and who have an appreciation of the work the others do in their own disciplines. Another legacy is that a number of students have been involved in such a context and are now better prepared for their future. Through our own research, and through other initiatives such as collaboration in teaching, working with industry partners, and presenting papers at workshops, we have collectively developed not only new knowledge, but also the foundation for future collaboration.

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Chapter 4

Interdisciplinary Training in a Collaborative Research Environment

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Abstract. This paper describes our experience in conducting interdisciplinary collaborative research within our GEOIDE research network. We begin by listing factors that we feel contributed to our ability to carry out research in an interdisciplinary environment, noting impacts on both the students and other researchers involved in the project. Challenges arising from cross-institutional, cross-disciplinary research are described next. We conclude with a list of some of the successful outcomes of this collaborative experiment.

Keywords: cross-disciplinary research, collaborative research environment.

1 Introduction

GEOIDE's mission in geomatics training in Canada has many facets which reflect interdisciplinarity and collaboration: teams have been developed across disciplinary boundaries and many have developed liaisons with industry and government agencies which aim to remove barriers between knowledge development and application in many areas including policy development and evaluation.

Participation in our collaborative research network on Stochastic Modelling of Forest Dynamics afforded graduate students an expanded range of options for growth and development as well as for valuable interactions during the course of their studies. Some of them were intimately connected with companies and government organizations that implement research results. These students gained first-hand experience in

working in truly collaborative research environments. Fundamentally, the design of the GEOIDE project team has been recognizably distinct in this collaborative training aspect and made it possible for us to attract high calibre students seeking the opportunities provided. This short Chapter discusses some of the key aspects of the collaborative training environments that emerged within our GEOIDE network.

2 Creating an Interdisciplinary Learning Environment

We begin with a list of some of the essential ingredients which we believe contributed to the interdisciplinary collaboration and training successes that took place on our GEOIDE teams:

- Substantial expertise, broad knowledge and firm grounding in one or more disciplinary areas involved in the research. Successful interdisciplinary collaboration is predicated upon the presence of strong, vibrant and dynamic disciplinary expertise where there are agreed upon common goals. It is important to both value the research being undertaken within the disciplines involved and to understand its importance to interdisciplinary research, recognizing that collaboration takes place both within as well as across disciplines.
- Basic knowledge of the other disciplines involved (or a strong willingness to acquire such knowledge) including fundamental aspects such as knowledge of traditional methods, the scientific or technical jargon used, experimental procedures, methods for establishing credentials for debate and for evaluating hypotheses in all the areas investigated in the study. It is essential to allocate time for students to learn material outside of their home discipline and to be patient as they climb what may be a steep “learning curve”.
- Intellectual security and confidence – not being afraid to ask “dumb” questions to foster better communication and ensure clarity.
- An openness and interest in the larger questions under study not simply in the specific area being addressed by the student’s area of investigation; a keen interest in research broadly. Students need to expand their knowledge by drawing on the expertise of the team as a whole and such learning can be enhanced by short visits to team members at other locations. It can also be fostered through networking events or through reading group meetings or summer schools, or work experience at affiliate laboratories, companies and government organizations.
- A focus on creating methodology to suit the fundamental scientific questions rather than implementing tools which are conveniently at hand - creating methodology to solve a real problem rather than applying methodology of questionable value in the context.
- Communication skills, including an ability to see another’s viewpoint and to tolerate differences in viewpoints and social skills: being gracious and open

to alternative frameworks for investigation. Since the research results should be disseminated to all the scientific fields involved, knowledge of communication norms for the various disciplines and for interdisciplinary outlets is required.

- Developing a true “team mentality”: involving senior graduate students or postdoctoral fellows in the organization of events and in the training of more junior students; encouraging all students to attend, participating and networking at such events with other team members, including both faculty and other students.
- Regular communication and networking with and between supervisors as well as team members: time must therefore be allocated for focused on-site research visits. Webinars and other internet-based resources are effective technological tools for informal and more formal communications. At every networking opportunity, discussions should critique what is and is not going well and how improvements may be made in the team’s effectiveness to monitor the work of the team as a whole. Celebration of the successes of each team member should also be routine at larger networking events.

Statisticians, mathematicians and operational researchers as well as other quantitative modellers sometimes draw on problems in other disciplines to motivate their development and use of specific tools or methodologies. Some do not always take the time required to develop a sound understanding of the problems to which they are applying their modelling expertise. Their failure to develop an adequate understanding can result in their developing inappropriate solutions to problems that reduce their credibility amongst in those other disciplines. On the other hand, they may end up replicating methodologies which have already been developed in these other disciplines. In either case, this is a tragic waste of intellectual resources as the modellers would of course prefer to solve new and “real” problems and specialists in the other disciplines could, of course, benefit from true collaboration.

3 Some Challenges

Joint training can be extremely useful provided the students’ interests remain paramount throughout the collaboration and the students have the skills and interests as described above. Moreover, joint training supervised by individuals at different institutions can now be accomplished much more easily than was possible in the past. We found that holding regular meetings and maintaining contact using internet-based videoconference resources greatly improved communication between team members.

That empirical science must be based upon sound statistical foundations has been widely accepted since the 19th century and that need has and continues to be addressed in many ways. It is, for example, widely recognized, that most researchers must acquire at least some basic understanding of statistical methods. However, over time,

advances in statistics have made it difficult for researchers to both keep abreast of their discipline and maintain mastery of the advanced statistical methods available to them. One early approach to dealing with this problem, and one which persists to this day, is for statisticians to establish statistical consulting services that made it possible for statisticians to share their expertise with other scientists' pro-bono or on a funded consulting basis. Such initiatives benefit both statisticians and other researchers in many ways including; exposing statistics graduate students to real statistical problems, bringing new challenges to the attention of statistical researchers, providing other researchers with free or relatively inexpensive access to advanced statistical expertise and providing a forum for researchers from other disciplines to interact with statisticians, possibly leading to long term collaboration.

Our group recognized and appreciated such benefits but we wanted a forum to support integrated and collaborative initiatives that would result in statisticians learning more about fire and forest ecosystems and of the need for new advances in the theory and practice of statistics to address the challenges faced by forest researchers and for forest researchers – i.e. to develop truly collaborative rather than “service” type relationships with statisticians. Two of our objectives were to develop a community of statisticians that have a sound understanding of forestry as well as the statistical problems forest researchers struggle with and for forest researchers to develop a deeper understanding of advanced statistical methods they could draw upon to enrich their research.

4 Were We Successful?

Some indication that we were able to achieve our interdisciplinary objective is provided through the evaluation of our training success with the large number of students involved in this project. Many students immersed in mathematical and statistical training as undergraduates became acquainted with the language and tools of forest science, giving them a much broader perspective than that provided by the traditional training routes. Learning to interact with forest scientists across the country provided many of these students' communications and research experiences which gave them increased breadth and depth. These students have either gone on to higher education in statistics or have found high level employment.

Furthermore, the authors of some of the forestry/statistical research papers that the members of our research team have published include statisticians as co-authors (rather than just acknowledging statistical assistance). The lead authors of some of those papers are statisticians [1-2], forest researchers [3] and authors from other disciplines. Equally important, some of the papers were published in the forest science literature [4-7] others in the environmental and applied statistics literature [8-9] and others in the statistical methodology literature [9-10]. The listed papers are only a sampling from the large number produced by the network over the life of the project – one final indication of the success of our interdisciplinary initiative is that the science

is moving forward, more rapidly than it would have without the existence of the network.

Were we uniformly successful? Not always. There were some failures along the way: interdisciplinary science is difficult, for reasons mentioned above. We have noted the challenges but we have also noted the factors which can lead to success. Ultimately, we were successful because members of the team had a strong commitment to learn, both inside the boundaries of their own discipline as well across disciplines. Mutual respect across both sides of the “divide” were crucial to ensure effective communication could flow in both directions in a safe, open environment, as close to ideal as one can imagine for both students and researchers alike.

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Chapter 5

Geomatics as a Tool for Bridging the Cultures of Research

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Abstract. From an opportunistic venture initiated in the first phase of GEOIDE funding (2000–2002) emerged a twelve-year collaboration – ramified and open-ended – generating research approaches and GIS applications in History and in Health. From the experience the authors argue that the professional environment for scientific networking has changed little in 12 years, but suggest some “conversational” strategies for throwing bridges across disciplinary divides.

Keywords: epidemiology, urban history, health, GIS.

1 Introduction

From an opportunistic venture initiated in the first phase of GEOIDE funding (2000–2002) emerged a twelve-year collaboration on tools and strategies for research in History and Health. At the outset, two groups of scholars were seeking to take advantage of a municipal engineering GIS that epidemiologists would use to map cases of active tuberculosis 1996–2002, and historians would use to ensure a rigorous geometry for rectifying century-old maps and geocoding nineteenth-century census

records. Working in parallel, we needed precision in linking Montreal households to addresses.

As conversations proceeded – among graduate students, newly minted technician, librarians, and puzzled colleagues (the students were teaching geomatics to the professors) – common interests emerged and more daring possibilities opened up, with some practical results, funding from other sources, and discoveries no one had anticipated. As collaboration widened to include more colleagues in bioinformatics, social history, and history of architecture, we were building bridges between the “two cultures” of the sciences and the humanities. As C.P. Snow pointed out (1959, 16), “The clashing point of two subjects, two disciplines, two cultures – of two galaxies, so far as that goes – ought to produce creative chances.” For us, the richest vein of discussion has been articulation of processes occurring at various scales, and a GIS feature – the on-screen zoom – was bringing us, day after day, side by side, to explore scale relationships in time and space.

Practical results for the local public health agency included innovations in data entry and contact investigation, and the spin-off of a piece of shareware for intranet mapping. A dozen joint papers spilled across academic compartments on transmission of tuberculosis past and present. Both historians and public health personnel evinced a greater appreciation of “place” and expressed some impatience to rethink research routines in their several disciplines. None of those outcomes was foreseen in the initial GEOIDE grant.

Because Canadian granting agencies are relatively short-sighted (GEOIDE 1 or 2 years, Canadian Institutes for Health Research 3–5 years, the Natural Science and Engineering Council 3 years, and the Social Science and Humanities Research Council 3 years), a twelve-year collaboration goes beyond the anecdotal. Claude Bernard, in the paper that took medical research from anatomy to physiology – from the static to the dynamic – transformed an anecdote in the digestion of a rabbit to the notion of a “found experiment” (Bernard 1865, 271f.) Here we propose to treat the 12-year process that issued from Project HSS#56 as a found experiment in scientific networking.

The chapter outlines our adventure in this order: How did we get started? Where did collaboration take us? Where will it take us next? Along these particular frontiers – between epidemiologists, architects, historians, and geographers – can we make some generalizations about the benefits of networking? Did geomatics serve as a catalyst? What personal and institutional assets proved helpful? Although we do not see a notable reduction in the obstacles to interdisciplinary networks, we can suggest some techniques for throwing more bridges across the “Great Rift” between the sciences and the humanities. Since these are conversational strategies, we allow ourselves some informality in the account, with first names and, in quotation marks, some interjections and queries we do not attribute because we can no longer remember who said what.

2 The Starting Line: An Opportunity in GIS

The spark for collaboration between Kevin's team in respiratory epidemiology and Sherry's team in urban history was the attraction of a tool of municipal engineering – the GIS of the City of Montreal.¹ From an epidemiologist's perspective, the tool would situate a Montreal TB patient or contact (at risk of infection) in a dwelling at a precise address, in relation to all the other addresses in the city.² From the historian's viewpoint, the city GIS would provide a rigorous and consistent ground truth for georeferencing heritage maps and creating layers for a new "HGIS" for mapping data from nineteenth-century sources. There was no prototype at this level of precision for a Victorian city of this size.³

At the outset, each of the two teams had its own objectives, its own methods and habits, and its own students.⁴ A group of four researchers – clinicians, epidemiologists, and laboratory scientists – were building a citywide database of cases of tuberculosis. They had no experience in GIS but had worked together since 1996 under a series of joint grants and in a variety of situations: hospital rounds, university classrooms, public health routines, and recurrent emergencies.⁵ The team in urban history was a looser

¹ The SIURS 2000 (Ville de Montréal, Système d'information urbaine à référence spatiale) was created from airphotos and autocad files to high-precision building footprints (30cm on the ground), but as a relational database it was obsolete; the city's Service de Géomatique has since rebuilt the system for Island-wide reference.

² At the time we added geomatics to our toolkit, epidemiologists in the fields of respiratory and sexually transmitted infections were seeking to advance from mapping of incidence toward an understanding of transmission, its spatial contexts (Lewis et al. 2002, Zenilman et al. 2002), and the social networks in which it occurred (McElroy et al. 2003, Riben et al. 2002, Munch et al. 2003). More precise geographies were required, moving from characterization of populations by states to counties, census districts (Cantwell et al. 1998), US zipcode areas (Acevedo-Garcia 2001), block groups (Barr et al. 2001), smaller Canadian postal codes, or individual buildings, and ultimately characterizing the individual patient in a household setting. For a broader literature review of earlier GIS applications to disease, see Cromley 2003.

³ A model on paper was Charles Booth's map of London 1890; see <http://booth.lse.ac.uk/>

⁴ The joint papers show the institutional affiliations: at McGill University, the Department of Geography (Faculty of Science), the Division of Medical Microbiology and Infectious Diseases, the Department of Epidemiology and Biostatistics, Respiratory Division (Faculty of Medicine), and the McGill Centre for Bioinformatics; research institutes of three affiliated hospitals: the McGill University Health Centre, the Montreal Chest Institute, and Montreal General Hospital; and two provincial public health agencies: the Laboratoire de Santé Publique du Québec (LSPQ) and the Division of Clinical Epidemiology under the Direction de la santé publique, Agence de la santé et des services sociaux de Montréal.

⁵ In addition to grants from Canadian Institutes for Health Research for the molecular laboratory (Behr p.i.) and Association pulmonaire du Québec for the database of cases on Montreal Island (Schwartzman, p.i.), in place prior to our networking, these scholars were supported also by salary career awards: Brassard and Behr as New Investigators from CIHR; Menzies as Chercheur National, and Schwartzman as Chercheur-Boursier Clinicien from the Fonds de la Recherche en Santé du Québec (FRSQ).

coalition, newly embarked on a two-year grant for a GIS project that would involve a dozen graduate students, all focussed on Montreal but variously lodged in departments of history, geography, economics, sociology, demography, and architecture. Each group was already interdisciplinary. We never intended to fuse the two teams, or to divert scholars from their original goals. But the GIS opportunity, shown as the tangent in Figure 1, represents a moment of encounter between the two teams. As the two balls rolled along, other encounters occurred; we drew other tangents and involved other people.

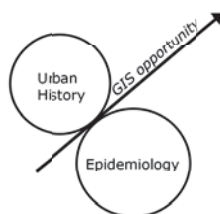


Fig. 1. Starting point: two networks seize an opportunity to exploit a geobase.

We won't say much in the chapter about the GEOIDE grant itself or the layers we created in the informal network of digital humanities known as "MAP, Montréal l'avenir du passé". The two-year grant is a mission accomplished, and we have since expanded the scope.⁶ Jason and his students, with SSHRC funding, have generated an analogous project in London, Ontario, for environmental history (fire, flood, and oil); they cooperated with a team focussed on interactions of race and sex in the frontier economy of Victoria (British Columbia) in the 1880s, and the three groups jointly measured comparative evolution of segregation in the three Canadian cities 1881–1951 (<http://vihistory.ca>; Dunae et al. forthcoming 2011; Hayek et al. 2010). Nor will we attempt to report all of the other activities in the "TB network" such as cost-effectiveness modeling and the search for better diagnostics, with projects in India and in arctic Canada, as well as Montreal. Instead, we focus on the networking *between* our two communities.

The Challenge of Tuberculosis. To see what happened in this network, there are some things you, the reader, may want to know about tuberculosis, a costly and complicated disease. These simple facts were new to many of us.

⁶ The initial geobase was elaborated for 1848 and 1880; volunteer efforts have been extended to provide building footprints for 1912, a taxroll of property owners, automated address-coding for all 1901 census households, and the full census data for one quarter of them (Sweeny and Olson 2003; www.mun/mapm).

Transmission of *Mycobacterium tuberculosis* (Mtb) occurs by airborne infectious droplets: coughing, sneezing, spitting. This usually means intimacy in confined spaces at a scale of the bedroom, sickroom, or vehicle. Most of the people infected promptly develop immunity (which can be tested); they don't get sick and are not contagious. Their infection is said to be "latent", but if the immune system is compromised by age, severe undernourishment, or assaults of other diseases (notably HIV), the infection can progress to "active disease".

Latent or active, TB can be reliably cured, but the course of antibiotics takes 6 to 12 months and sometimes has hard-to-manage side effects. For half a century after the causative bacterium was identified (1882), TB stymied the strategies of Pasteur who envisioned a live attenuated vaccine (cf. Latour 1984). In Canada today, incidence of active tuberculosis is rare (5 cases per 100,000 people, among the lowest in the world). Most persons born in Canada after World War Two have not been exposed and lack immunity. Worldwide, however, it is still one of the biggest killers (1.45 million deaths in 2010), and Canada receives more than half its immigrants from countries where most people *have* been exposed, harbour the bacillus, and therefore show an immune reaction on the tuberculin skin test (TST).

Since persons with active disease transmit infection to others, the public health department tracks every one of the 100-150 cases diagnosed on the Island of Montreal each year. Family members with latent TB infection are treated with a preventive course of antibiotics, and the nurses inquire about other close contacts. Because some strains have developed resistance to one or more antibiotics, samples of the patient's sputum are cultured and examined in a high-security lab with specific questions in mind: Is this strain known to be resistant to a particular drug? Does the genotype of the bacterium recovered from a patient match that from another case already discovered? This would imply a transmission pathway linking the two.

Initially, the two research groups shared an interest in the use of GIS to make links at the household level, but we soon recognized that we shared also a conception of the city as a system of circulation – circulation of people, the air they breathe, and microbes as fellow travellers.

3 Where Collaboration Took Us

Important in setting off new lines of questioning were the graduate students who were selected for a modicum of experience with GIS – greater than that of their supervisors. In this section we point out some of the practical results in local public health surveillance, patterns of transmission, and interpretations of how these patterns emerged.

An initial, successful grant application to CIHR allowed us to develop and pilot test a spatial approach to TB in Montreal, using previously gathered epidemiologic and

bacteriological data for the years 1996-2000. Geomatics would lend itself to the data management process, but compilation of the spatial component would invite re-thinking the entire chain of investigative routine: recording of data, transcription, and coding, in relation to the new tools of inquiry – both the more intensive laboratory analyses and the spatial analyses. How would we assemble the databases? How would we introduce the *Where?* and *When?* into a system designed to reference clinical observations and lab samples? The date stamp on a record was crucial: Which patient developed symptoms first? How much time elapsed? “What markers of time should go onto the computer record?” “What do we need to know about the home?”⁷

Ian, the first of the jointly supervised students, by comparing the residences of 595 TB patients with a control sample (5950 dwellings in buildings with no report of TB) uncovered higher-than-expected incidence of disease in a particular slice of the housing market (Wanyeki et al. 2006). He used variables from the city GIS: age of the building, number of storeys and dwellings, and value per square metre of land. This was the classic approach of the epidemiologist: a case-control analysis. “Why don’t historians adopt case control methods?” “Can we evaluate changes in urban form from samples like this?” Even allowing for interference of confounding factors such as median income and percentage foreign-born in the census tract, Ian’s results were unexpected: Higher rates of disease were not associated with the oldest houses, as studies elsewhere had suggested, but with the high-rise apartments of the early 1970s, built with lower ceilings, smaller windows, tighter insulation, and recirculation of “re-conditioned air”. His analysis pointed to a further problem: the 5- and 6- story walk-ups hastily built after World War II and now in need of renovation, “collectors” of families with few options in the housing market, among them refugees, recent immigrants, and large, low-income families.

A second student, by applying nearest-neighbour and spatial scan statistics to the Island-wide data, pinpointed three unrecognized “hot spots” of local transmission (Haase et al. 2007, 2008). His was also a case-control study, and he took advantage of the first batch of data from the molecular lab (816 geocodable cases) to distinguish a special group: When samples from two patients (or more) show the same bacterial “fingerprint”, it is likely that they acquired the infection in the city and were involved in a chain of transmission events. This could reflect direct transmission between the patients, or indirect transmission, where two persons have been infected by the same third party. Were cases with closely related fingerprints living closer together in the

⁷ This approach was built into a joint application to CIHR in 2001 (Schwartzman, p.i., MOP-53184). Using GIS for surveillance of tuberculosis, Stone et al. (2001) and Moonan et al. (2004) had identified spatial clusters of residences in Texas; and Klov Dahl et al. (2001) was using GIS to infer places of contact other than residential. In addition to a higher precision of location of TB cases, ours was the first application to combine the full kit of tools: characterization of individual patients, computerized mapping of their households and contacts, the spatial scan statistic to evaluate clusters of cases, and molecular typing of the infectious agent to confirm local transmission (Haase et al. 2007, Yeo et al. 2006).

urban space than cases with unrelated strains?⁸ “But these patients do not seem to be acquainted?” “There isn’t a clue in the contact inquiries.”

The pioneer physiologist mentioned earlier once described the life sciences as “... un salon superbe tout resplendissant de lumière, dans lequel on ne peut parvenir qu’en passant par une longue et affreuse cuisine” (Bernard 1865, 28). Constructing the database was painstaking but tidier work than Bernard’s vivisections. From the handwritten files of the public health department nurses, we transcribed the notes they had taken for each case. Day by day or week by week, over 6 to 12 months (depending on the medication prescribed), data came in scraps: “She visited her cousin’s baby in New York, and she’s afraid to tell her cousin she has TB.” Or a phone call to the pharmacist: “Did he come back for his refill?” At the start, all of us shared the task – not for the sake of equity, but to ensure that we would all be making the same interpretation of the protocol. “What if there’s no address?” The extent of missing data for *where and when* led to elaboration of plans for a subsequent “prospective database” that Dick’s team would pursue to 2012, and to design of an electronic data entry form: “Wouldn’t the nurses save time if they typed it into the computer in the first place?”

The precision of Canada’s 6-digit postal codes offered a convenient geocoding mechanism: 46,240 codes on the Island of Montreal, usually specific to the block-face or apartment house. But were they reliable? The postal code is hard to remember and challenges a typist. Initial checks led us to evaluate the extent of address errors in the public health databases for “reportable” diseases such as TB – over 10 per cent. We created a verification algorithm, introduced it into public health practice, and confirmed the serious implications of these errors in terms of geocoding, positional accuracy, and estimated spatial density of a disease (Zinszer et al. 2010).

In the records for contacts, information about places was alarmingly sparse. “Look at this! He works in a bar, but what bar?” Only half the recorded work locations were geocodable; three quarters of the patients were recorded as “not working”, and 30 per cent were living alone. “If not at work or at home, where did the patient meet that microbe?” If we ask for details of location, how should we classify places? “Reporting of contacts was aggressive only for patients recognized as the most contagious” (Carter et al. 2009). Paul was involved in tracking one such outbreak in which 7 secondary cases of active TB arose among university students who sat (unacquainted) in classrooms in the same poorly ventilated building (Muecke et al. 2006). Re-visiting the case files made us aware of other costly investigations: 200 volunteers and personnel were tested for possible encounters with a homeless person at a shelter, and

⁸ Genetically “related” strains amounted to 11 or 33 per cent of cases, depending on choice of a threshold of similarity. To overcome a bias of nearest-neighbour estimates in such situations – where the number of controls is much larger than the number of cases – Kevin and a fellow student in biogeography conceived a resampling and bootstrapping method (Henry et al. 2003).

several hundred were tested after attending the same rave as a young woman with highly infectious laryngeal TB.

While we were still checking the first batch of data and tinkering with formats, Andy, the two Ians, and the two Kevins were already making maps: world maps by national rates (Figure 2), maps of “hot spots” on the Island of Montreal (Figure 3), maps of contacts reported by patients, and maps of cases that shared the same bacterial strain, such as the 20 homeless itinerants who frequented shelters and city parks (Figure 4). TB is still spread by person-to-person contact (as in Figure 5) and still treated on an individual basis (Figure 6), but intensified movement of populations worldwide means that latent infections are concentrated in neighbourhoods of recent immigrants from countries where TB is common. The “hot spots” in Montreal arise from global patterns of transmission and are revealed by the bacterial analyses (Figure 7). In other words, to uncover recent local transmission, assess local risk, and apply local remedy requires thinking at scales ranging from global to molecular.⁹

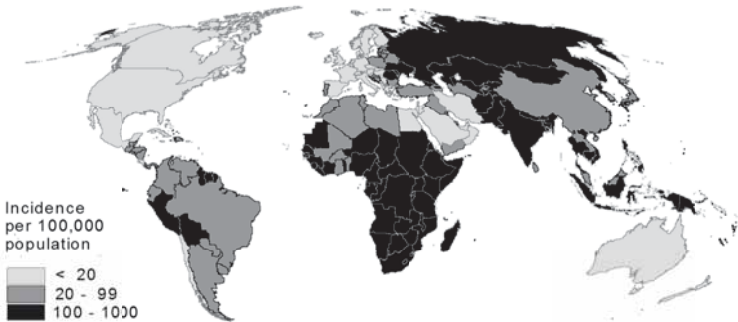


Fig. 2. Worldwide incidence of active tuberculosis. Rates are classed as light gray less than 20, gray equals 20-99, and black greater than 100 per hundred thousand people (maximum 1287). Source: World Health Organization, estimated incidence by countries, 2010, displayed in Mollweide projection.
<http://who.int/tb/country/data/download/en/index>

⁹ For a wider perspective on spatio-temporal scales and the application of molecular tools, see Muellner et al. 2011.



Fig. 3. Distribution of tuberculosis cases reported from Montreal Island 1996-2000. “Hot spots” – areas with the greatest number of cases - are not always those with highest incidence per hundred thousand population. Distribution reflects the concentrations of recent immigrants from countries of high incidence. Source: Haase et al. 2007, p. 636.

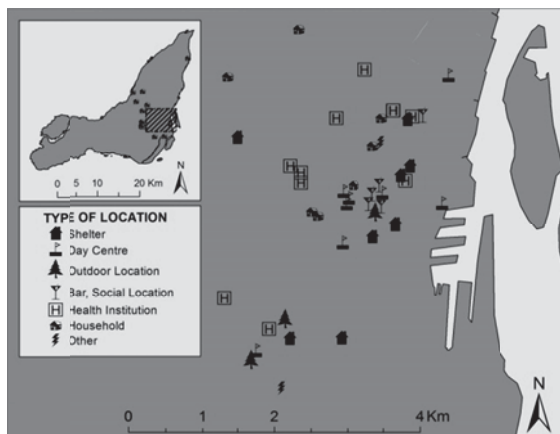


Fig. 4. Locations associated with homeless persons with TB. Of 20 homeless cases on the Island 1996-2007, 11 belonged to genotype-defined clusters (2 to 7 persons) harbouring the same bacterial agent. The high proportion indicates local transmission. The 20 individuals reported 10 shared locations. Source: Tan et al. 2011, p. 6.

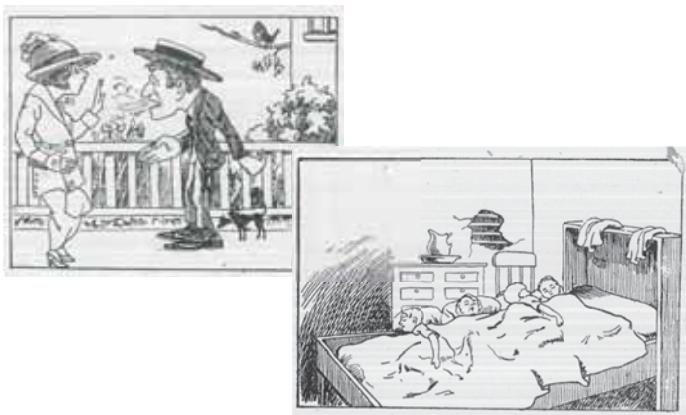


Fig. 5. The spread of infection by close contact. Public health propaganda of 1920 centred attention on personal habits and risks in the home. A particular target in Montreal was the windowless room, and the postcard urges, “This is a sure means for developing tuberculosis. Don’t rent a dwelling like this.” The lower postcard is titled “The dangerous cougher”. Source: Bruchesi Institute, Annual Report, 1919-1920.



Fig. 6. Pneumothorax machine designed by Norman Bethune. Although the machine looks like a bicycle pump, the object was to reduce pressure, deflate the lung, and leave it at rest. Portable, it could be used in a hospital, a dispensary, or on a home visit. Bethune, after training at the Royal Victoria Hospital, introduced numerous surgical innovations at Sacré Coeur hospital, an institution managed by the Sisters of Providence for patients with advanced tuberculosis. Source: Reproduced by courtesy of the Osler Library of the History of Medicine, McGill University.

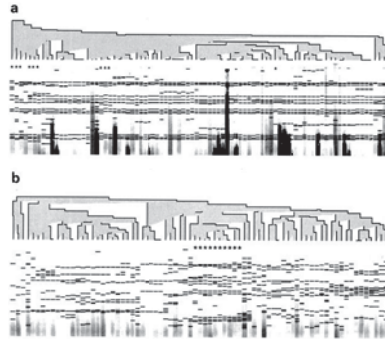


Fig. 7. Similarities in the DNA “fingerprints” of *Mycobacterium tuberculosis* organisms resistant to pyrazinamide. The dendrogram shows IS6110 RFLP patterns for the 77 resistant isolates and 10 others that were closely related. Source: Nguyen et al. 2003, p. 2880.

Since the maps were revealing, how could we make them available to the public health nurses who are the front-line investigators? How could they access the data and create their own case-and-contacts maps? When David arrived (2005), with greater experience in GIS and a focus on emergency responses in public health, he obtained a grant from Geoconnections, a federal agency intent on developing Canadian standards in geomatics. He and Christian, a newly graduated programmer, assembled a “shell” for map query by internet. The user can select records from the database and generate a map. “Are there other cases in the last month with the same bacterial fingerprint?” “What is the geographic distance between reported contacts of my patient?” Or, without a thought for the diversity of software underneath, obtain a spatial scan statistic from the proprietary SaTScan program: “Do the cases of the last 6 months add up to a cluster with higher-than-usual incidence?” Software components – PostgreSQL, PostGIS, MapServer, PHP, and JavaScript – were glued together with Python commands. The web application required secure access and insulation of users from the several agencies of public health and university research, but because the Dracones framework offered wider application and components of the shell were all open-source, Christian made it available under Open Source Initiative BSD license (<http://surveillance.mcgill.ca/dracones/>), and the historians are now all ears, impatient to move their own geobases to the web.

At each step, we were discovering more of what we had in common. Process makes history, and every small outbreak was a historical event. The medical researcher is used to dealing with case histories – the expected course of a fever, the normal course of a pregnancy, or, in the case of TB, the stage at which side effects of a drug may appear: How soon will the patient cease to be contagious? How soon will “feeling better” bring the temptation to neglect the medication? Because infection with TB may remain dormant for years, a search for the source of an individual’s infection demands consideration of a lifetime of personal encounters, and, as Paul’s investiga-

tion shows, incidence of infection in a population may reflect a history of interpersonal contacts over generations.

Paul had been studying an unusual strain of TB that does not respond to an antibiotic called PZA (pyrazinamide). About 100 cases turned up in the 1990s among elderly people born in Quebec. Assuming they were exposed in childhood, would tracing their ancestors pick up a historic disease event? Perhaps a mutant microbe carried by an immigrant 300 years ago? He had already arranged to track his patients through the genealogical database known as BALSAC – French Canadian marriages since the 1650s. Kevin H, who was coaching all of us in GIS, was intrigued since his own doctoral research in historical geography involved tracing surnames of those pioneer settlers into the various regions of Quebec. “Let’s look at a map!” The distribution differed from that of Canadian-born patients with other strains of TB. “Why the tight little cluster around Shawinigan?” In Shawinigan itself, a small industrial centre founded in 1900, there were no such cases. “Why are most of the patients with the PZA-resistant ‘bug’ living in rural habitats?” Sherry, from earlier work in forest history, was intrigued with the map: These were villages that lived from a combination of farm and forest work.

Meanwhile, in Marcel’s lab, Dao had identified a sequence of three mutations, the second of which conferred the resistance to PZA (Nguyen et al. 2003). For patients harboring each of the three bacterial mutants, and for another array with unrelated strains, Michèle, data analyst at BALSAC (in Chicoutimi) selected control groups and re-created the genealogies: Where did their grandparents live? Their great-grandparents, great-greats... ? She found no trace of a single common ancestor, but regional variations from one generation to the next. Ancestors of each patient revealed a location history much like those of Michèle’s controls – people selected at random from the same small region. But geographic ranges of the several bacterial groups differed, reflecting the sequence of mutations. The BALSAC protocol had been widely applied to tracking of genetic disorders, but this was the first application to an infectious disease, and the findings pointed to a history of mobility. It looked as if the PZA-resistant strain might have spread in the Saint-Maurice valley 1840–1860 as farmers were recruited into winter logging camps on the fringe of settlement. A census of January 1861 reported the county of birth of men and boys in the logging camps, and Kevin’s analysis of the surname frequencies confirmed their diversity of origins (Brassard et al. 2008a; Olson et al. 2010).

This is a small part of a story scholars are pursuing worldwide, to discover how, over thousands of years, the relationship evolved between the human organism and the bacterial organism. From laboratory analyses, a global phylogeny is established for *Mtb* (Mostowy et al. 2002; Gagneux et al. 2006). Which came first, tuberculosis of humans or cattle? How did TB spread in India? Did a strain spread from French Canadian fur traders (*voyageurs*) to communities of Native Peoples and Métis? In Saskatchewan, it provoked major outbreaks only when children, generations later, were gathered in large institutions like boarding schools (Pepperell et al. 2011a and 2011b).

Contemplating the big picture, we realized how little we knew about the history of the disease in Montreal. In 1880 it accounted for 30 per cent of recorded deaths of adults (ages 15–50) with puzzling interactions of gender and origins (Thornton and Olson 2011). The entire TB team was associated with the Montreal Chest Institute, initiated as the Royal Edward Institute by the anti-tuberculosis movement in 1909. This institution pioneered the local introduction of practices of open-window schooling, lung collapse, surgical thoracoplasty, and, in the 1950s, the antibiotics (first streptomycin, and then para-aminosalicylic acid and isoniazid) that changed the prospects of people with active TB.

To track those changes, we sought out additional partners – Annmarie, an architect specialized in the evolution of hospital design; Raphaël, an urban planner specialist in municipal regulations for building and zoning; Mary Anne, an experienced social historian, and their imaginative students in architecture and planning. As originally proposed, the project might sound like a conventional piece of social history, medical history, or history of architecture, but informed by Annmarie’s analytic approach to *material culture*, it moved along several interfaces. From a broom closet at the Chest Institute, and a storeroom that was once the morgue, Kevin and Annmarie salvaged scrapbooks, floor plans, and photographs. In the photos, they paid attention to the equipment in the room, the furnishings, the view through the window, and the dress and pose of the figures.¹⁰ With the introduction of chest radiography in the 1890s and computed tomography (the CT scan) nearly a century later, how did the patient experience the “visualization” of microbial invasion of his lung? These were tools analogous to the satellite photo and the layered GIS.

Meanwhile, Mary Anne was interviewing retired nurses and patients from a sanatorium that was about to be demolished. “How did the architectural design of the two sanatoria in the Laurentians reflect the practice of rest therapy?” By examining municipal spending on chronic disease among “indigents”, she and Sherry uncovered the ironies of the stubborn 50-year attempt to prescribe “fresh air” for citydwellers and impose bed rest on people who could not afford to be idle (Poutanen 2006; Poutanen et al. 2009).

Networking is not new, and we uncovered extraordinary networking, both local and global, that characterizes the long struggle against TB. The Chest Hospital was networked with the two rural “sans”, a school operated by the Protestant school board, and the Herzl Clinic from which sprang the Jewish General Hospital. A lone carton of social work case records Mary Anne discovered in the Canadian Jewish Archive complemented the medical case records extracted from the hospital archive, and a sample of 200 cases showed involvement of 50 local organizations, all bitterly underfunded. In the French-language community, the Bruchesi Institute initiated the city’s

¹⁰ Adams 2005; Adams et al. 2008; Minnett 2006. David Theodore, who “managed” us, is now at Harvard doing a double-barreled doctorate in architecture and history of science. On observation of material culture, see also Swiderski 1995.

first effective and lasting collaboration of lay leaders – doctors, volunteers, and fundraisers – with a religious community, the Sisters of Providence. The nuns, from their experience in home nursing of TB cases, articulated the problem of the stigma disease attaches to places as well as persons – to a neighbourhood, a type of housing, or a workplace.¹¹ Today, as a result of such circumstances, the risk of aggravating a frightening perception of the disease requires close attention to the ethics protocol, care in display of data, and constraints on the scale at which we publish our maps.

Because delay of diagnosis or treatment reduces chances of prompt recovery, health prospects are still affected by inequalities in access to care, housing, food, schooling, or sympathetic communication. In 1922, the Bruchesi Institute had identified the problem more starkly: “The dispensary, created to combat a social evil ... does something to compensate for the harm done to a portion of the people by the way society is organized ... For us, a motive of our duty is justice.”¹²

Our mutual queries of the historical record suggest we must revise our century-old perception of the urban space. In both popular assumptions and public health practice, a “first circle” of infection is presumed to be centred on the home, a “second circle” close by (nearby work or local school), with rapid distance decay of risk. A century ago most people did work close to home; their dwellings were crowded, and they visited relatives and went to school “in the neighbourhood”. Cities were built to high densities; recent immigrants were concentrated near the centre, and marriages were presumed lifelong. But urban lifestyles have changed, and today’s cities are characterized by small households, rapid turnover of partners, more leisure time outside the home, and mass movements for entertainment and tourism. In Montreal, half of TB patients are traveling more than 5 km to their workplace or educational institution, and half the metropolitan population, including recent immigrants, are dispersed in suburbs beyond the jurisdiction of the Island health authority (Carter et al. 2009).

As collaboration took us in new directions, we sought other sources of support.¹³ GIS was seen as a tool to answer scientific and public health questions of interest to the various group members. They came up with the questions, so that the application of

¹¹ Fear of TB, based on historical and foreign contexts, fosters resistance to contact investigation, notorious in workplaces. The stigma is been better recognized in the case of sexually transmitted diseases, and delays of research on HIV (cf. Brassard, Hottes et al. 2009; Macdonald et al. 2010; Shilts 1987).

¹² Institut Bruchesi, Annual Report for 1920-1922, 18, as cited in Poutanen et al. 2009, 106. « Créé pour combattre un mal social, dont la cause réside dans la Société, le Dispensaire anti-tuberculeux est un peu le compensateur des torts causés à une portion du peuple par la mauvaise organisation de notre état social. Pour nous notre devoir a un motif de justice. »

¹³ The additional grants directed to transdisciplinary objectives were these: from CIHR, Schwartzman p.i., 2002–2004 and 2004–2009, for applying GIS as an innovation in detection of TB; from Geoconnections, Buckeridge p.i., 2006–2008; from SSHRC, Adams p.i., 2003–2006. A succession of SSHRC teams (headed by Gilliland, Gauvreau, and MacKinnon) pursued the census databases for 1881 and 1901, incorporated into MAP.

geomatics was enhanced. Overall, the grants were directed to broader objectives – more efficient contact investigation, more comprehensive record-keeping, greater cost-effectiveness, or more reliable molecular markers – and most of the money went to laboratory work: storing samples, growing bacteria, and supporting graduate students in molecular research.¹⁴ As in Pasteur's day, the cellular and molecular seemed to hold the keys to *How?* and *Why?* In the boundary layer where we were active, we addressed the common objectives by increasing attention – in both the history of Montreal and the epidemiology of TB – to cues of *Where?* and *When?*

4 Where do We Go Next?

There's no telling. The objective was not to perpetuate a particular network, but to continue opening up new options, and to diffuse the capacity for networking. The students schooled in this informal way, like the three princes of Serendip, moved into other contexts and new collaborations brought unexpected rewards.¹⁵ The three GEOIDE students who 12 years ago were sparkplugs in conceptualization of HSS#56, have developed independent networks in Health and History. Jason's young team at Western works closely with town planners in London, Ontario, and researchers in the UWO faculty of medicine. ("He's so easy to work with!") These center on observation of children at play, factors that influence the choice of walking to school, and the effects on a child's weight, health prospects, and sense of wellbeing. Kevin Henry spent 8 years enabling GIS analysis at the New Jersey cancer database. "Why are some cancers more common in northern or southern parts of the state?" "How strong is the effect of racial discrimination in delays of diagnosis?" Now in Utah, he is making GIS the catalyst for partnership between university scholars, the libraries that house the maps, and the Utah Population Database.¹⁶ François, as part of a heritage buildings team in Quebec City, collaborates with two religious orders (the Augustinian and Ursuline nuns) to document the evolution of their hospital and convent buildings over three centuries ([http:// arc.ulaval.ca/files/1-MHDQ-03-2008.pdf](http://arc.ulaval.ca/files/1-MHDQ-03-2008.pdf)). With his students in a school of architecture, he combines the tools of geomatics with architects' computer-assisted design, do-it-yourself SketchUp models, and the "space syntax" approach to analysis of circulation in the spaces of buildings and city streets (Hillier and Hanson 1984). In Montreal as well, his analyses of the temporal sequence of historic maps provides insights into undocumented portions of the urban heritage

¹⁴ CIHR support was in place prior to involvement of the historical geographers: for the genealogical research, Brassard p.i. 2001–2004; for the micromolecular laboratory, Behr p.i.; and for development of the TB Keys database, Menzies p.i., 2006–2010.

¹⁵ The notion of "serendipity" is attributed to Horace Walpole who borrowed from a Persian fairy tale; the three princes were reknowned for the happy faculty of finding things they were not looking for. See Remer 1965; Merton and Barber 2004.

¹⁶ On the decades of residential histories, see the Utah Population Database at <http://www.huntsmanccancer.org/research/shared-resources/utah-population-database/overview>. These take full advantage of the resources developed by the Latter Day Saints, more familiar to genealogists and historians.

(Dufaux and Olson 2009) and the urban geometries that offer guidelines for re-design of viable neighbourhoods. Career trajectories of other trainees who worked on our joint projects show the same kind of versatility and openness to new encounters: a highly successful career in laboratory research on other respiratory pathogens; public health work in NGOs in Africa; and, in Canada, health care management and administration; and GIS applications in transportation planning.

5 The Obstacles Remain

Two emerging ventures, sidelined for a decade, will point out some of the obstacles. The “prospective” database, ongoing to 2012, includes a home visit with measurement of rate of “leakage” of air. “With Dick’s expertise in ventilation of hospitals and office buildings, why did it take a decade to follow up Ian’s findings of differential rates of TB in various types of housing?” “How will we obtain measures for a set of control dwellings?” Second, Christina and Kevin anticipate further research on immunity to chickenpox. In their clinical practice with immigrant patients, they are challenged by their susceptibility to many diseases that Canadians think of as having been conquered. Vaccination against chickenpox is not universal, and, in the wet tropics, the rarity of outbreaks among young children leaves them vulnerable in adolescence or adulthood. A first GIS display Andrew generated for Christina (2005) confirmed the potential for analysis of climatic factors from seroprevalence among immigrants to Canada. With the breadth of its immigrant intake, Montreal is a laboratory for global variance.

Taking a broader view, has the professional environment for scientific networking changed over the last 12 years? Despite lip service to the transdisciplinary, structures of incentive and reward in universities, public health, and research funding severely inhibit knowledge transfer. The mission of each institution – a hospital, a museum, or a library– is rigidly defined and operates under a separate chain of command. Knowledge transfer from faculties of science and engineering into corporate production often takes 8 to 10 years (Gögl and Schedler 2010, 176), and transfer into the practical settings of hospital or health department is affected by dual bureaucracies. The local public health agency, for example, in the 1990s cooperated on an early GIS application to swimming pool deaths, 15 years later on a spatial analysis of pedestrian accidents, and our own venture in reportable diseases; but each of the several teams, unaware of the others, had to reinvent the wheel. Epidemics or emergencies such as the H1N1 influenza outbreak have disrupted budgets and diverted skilled personnel rather than mobilizing new resources. “The opposite of teamwork is hierarchy” (Gögl and Schedler 2010, 11), and command structures of silo and status tend to obstruct communication.

The public health agency and the hospitals, for example, found it difficult to agree on a standard data entry format. Turnover of personnel and recurrent understaffing meant resurrecting the issue again and again for 6 years. Similar resistance, on a much larger

scale, delays the “universal” system of electronic medical records on which the provincial ministry has already spent millions. And, of course, findings are not always applied by the institutions that fund the research. Cost effectiveness studies of Kevin and Dick demonstrate that it would be more efficient for the U.S. and Canadian governments to invest in diagnosis and treatment of active tuberculosis in high-incidence countries where treatment would be cheaper and yield higher in terms of improved health, as opposed to expensive and often inefficient screening of the small set of individuals who have emigrated to North America (Schwartzman et al. 2005).¹⁷

The Canadian granting agencies acknowledge three scientific cultures, and they are not equal. The large disparities of operating funds for research make beggars of the social scientists: 43 per cent for natural sciences and engineering, 43 per cent for medicine, 14 percent for the social sciences and humanities.¹⁸ Is this likely to produce “informed decisions”? At the federal level, a path breaking proposal for TriCouncil collaboration and a longer horizon of funding for research on “the environment” shrank back into a joint program of accounting standards and CV formats that reduce careers and personalities to check-boxes. Continued emphasis on the paradigm and preeminence of the independent “principal investigator” running a laboratory tends to penalize other researchers who devote time to collaborative efforts. In such a context, collaboration must ensure rewards for all members such as opportunities to publish as lead author, and shared credit for successful grant applications. Styles of journals also reflect cultures of the disciplines, and many of the new “interdisciplinary” journals are tight in conception (e.g. *Environmental and Molecular Mutagenesis*, *Spatial and Spatio-temporal Epidemiology*, or *Emerging Infectious Diseases*), or targeted to establish new disciplines such as bioinformatics or health informatics.

At the provincial level, the University of Québec institutes (INRS), created 40 years ago to overcome a lag in the engineering sciences, and systematically neglected the social sciences and humanities where Quebec scholars shone. (Only two institutes were ever created in the social sciences, and were then forcibly merged.) The exceptional Quebec funding program known as FCAR was successful in stimulating interdisciplinary and interuniversity collaborations, but the collaborative requirement has been abandoned and provincial practice remodeled to mimic the unified federal accounting model. Canadian public agencies continue to “recover full costs” for digital maps and to turn over to private enterprise the management of data created at public expense.

The significant breakthrough in the past 12 years has been reorganization of health research in Canada, with inclusion of an Institute for Population Health and several others focussed on population components: Aboriginal people, Gender, Aging, Children and Youth. The new model favours orientation to health rather than disease,

¹⁷ On resistance to epidemiological findings in workplaces, see Milham 2010; *Microwave News* 14–6 (1994), 1.

¹⁸ Reported from NSERC, CIHR, and SSHRC in the 3 years 2007/08, 2008/09 and 2009/2010.

greater investment in prevention, psychology of patient self-management, and lifestyle factors conducive to health. But as soon as CIHR began providing more generously for “population health”, SSHRC, under severe budget constraints, elaborated rules to restrict support for health-related research.

In universities, top managers are necessarily fund-raisers, and speak the language of “University Inc” (cf. Washburn 2005). Within the several faculties (a medieval legacy), departmental subcultures add inertia to allocation of budgets and staff positions. Snow’s argument in 1959 targeted the inadequacy of British higher education to prepare the nation’s intellectual leaders to manage and harness scientific knowledge. In Quebec, half a century later, the problem persists in a different form. The Ministry of Education, in order to give greater pupil-time to science, has imposed specialization from about the age of 14. Entry to university-level science programs is virtually closed to graduates of high school and college streams in *sciences humaines*; and math prerequisites at lower levels make university instruction in statistics and probability inaccessible as well as unappetizing, largely ignoring the empirical, intuitive, and graphic approaches of experimental data analysis (cf. Tukey 1977).

In addition to the hazards of academic networking between departments, each discipline presents challenges to the uptake of geomatics. To “extend techniques of GIS more widely into Canadian historical scholarship” – the first objective of the original MAP project – word-of-mouth diffusion and distribution of “demos” were not enough. Robert (at Memorial) participates in networks of “digital humanities”, and David has introduced a spatial statistics course in epidemiology, but penetration of “the spatial” into university teaching of history, statistics, or epidemiology has been very slow. GIS courses are now accessible to graduate students in the major schools of public health in North America, but are nowhere required. Teaching in history departments has not kept pace with interactive applications (Web 2.0), availability of nominal census data, record-matching experience of demographers and family history circles, and the opportunities GIS offers for more efficient sampling.¹⁹ University-level teaching shows a 10-year lag, waiting for the arrival of students schooled in on-line banking, purchasing, gambling, and entertainment to kick-start informatics as a tool for learning, adventure and experiment.

Was GEOIDE helpful? Without the initial funding, it’s unlikely that any of these encounters would have occurred, and the GEOIDE Student Network was immensely stimulating. But the training they conceived for “HQP” (highly qualified personnel) was perceived as highly specialized and focussed on the toolkit. We had to insist that

¹⁹ Canadian Families Project <http://web.uvic.ca/hrd/cfp/>; Canadian Century Research Infrastructure <http://canada.uottawa.ca/ccri/>; Population et histoire sociale de la Ville de Québec <http://phsvq.cieq.ulaval.ca/>; Great Britain Historical GIS <http://port.ac.uk/research/gbhgis/>; Census of Canada 1881, <http://www.prhd.umontreal.ca/census/en/main.aspx>; Census of Canada 1901, <http://automatedgenealogy.com>; <http://www.collectionscanada.gc.ca/databases/census-1901/index-e.html>.

our project technician, fresh from a postgraduate certificate, be included as a student. The promotion of a new discipline seemed to take precedence over the polyvalence we needed for collaborative work. Over the last 12 years, most universities in Canada have experienced serious loss of skills in cartography, visual communication, and documentation because cartographers – as teachers, technicians, and librarians – were being replaced by specialists in remote sensing techniques or programming. Rosa is now ideally trained: a diploma in geomatics, two years with our project, and several years experience in a unique “Geographic Information Centre,” jointly conceived and funded by McGill Libraries and the Faculty of Science. Having completed a Master's in Library Science, she now heads a map library as GIS Librarian at York University. Locally, however, standardization in library organization threatens our own GIC, and across the continent the scarcity of specialist personnel in libraries and archives has not been relieved. To promote those “creative chances”, we need personnel prepared for intellectual edge-matching.

6 The Conversational Approach

It is no accident that the science society in Montreal in the 1850s organized its meetings as *Conversazione*. The model was favoured throughout the Victorian era by the London professors of medicine, and in Montreal by fund-raisers at the YMCA, Methodist missionary ladies, and theologians of the Presbyterian College.²⁰ But effective dialogue is low-key and must be forged against background noise, interruptions, and divergent work schedules. “Did it make a difference to have one of us beyond retirement, no longer tuned to promotion, and with a more flexible schedule?”

Conversational skills favour bridging the several cultures: the listening skills of an experienced physician, the relatively small size of the Chest Institute; the specific demands of the two languages in the universities of Montreal. “Experienced executives know how to listen” (Stefan Arn in Gögl and Schedler 2009, 318). Paul spends some of his time doctoring in communities of the Arctic, where TB rates are 20 times those in Montreal (Brassard 2003c, Clark et al. 2002). Kevin and Christina work in teaching hospitals that function in many languages and treat people of many cultural backgrounds. These experiences prepared us for the ambiguities and difficulties of terminology and jargon between disciplines. Social skills go beyond the verbal to include Annmarie’s Christmas treats for her research team and Dick’s end-of-winter maple syrup at the seminar. According to one industrialist effective at the interface between academe and enterprise, “I’ve never done a deal ... which did not first involve a significant amount of time over a beer” (Timothy Barnes in Gögl and Schedler 2009, 123).

In our 12 years of collaboration, we had no manager, no secretary, no office, no rug on the floor, no titles, no formal calendar of meetings, and no routine transfers of

²⁰ For a philosophy of conversation, see Serres 2003, 266–275.

funds. “Such formalities would get in the way!” Conversations took place in our offices (scattered over 10 or 12 city blocks) and in the lab that our students were sharing with several PhD students in remote sensing of ground ice and marsh ecology. (They taught us a number of tricks.) Much of our conversation centred on what we were seeing in front of us on the screen, in the photographs and yellowed clippings, or on the colour-coded ground plans. For sharing an exploratory visual analysis, GIS is indeed a catalyst. Health care professionals are used to working with their eyes as well as their ears — nurses and doctors look carefully at patients and radiographic images, and epidemiologists at figures and graphs. “Are historians visually challenged?” In all these fields, there is a need for learning tools.²¹

If we look back at Figure 1, the geomatic tangent was just one more tool each team was adding to its kit, but this tangent opened up a host of new questions about space and place, distance and scale, horizons and projections, with additional sources of uncertainty and error, and with new possibilities that nourished a running conversation. With hindsight, our interactions demand a sketch more elaborate than those two simple circles. It might resemble the complicated site geometry of protein pockets, folded and crumpled, with potential for a “fit” that favours the reactivity of an enzyme, enhancer, promoter, inhibitor, or regulator.²²

Fitting into those pockets of conversation were the graduate students. Students expect interrogation: “What is the research question?” And they expect/are expected to *ask* questions. “Why not?” “What if?” Because the techniques of geomatics were new to all of us, we were all positioned as learners, with the curiosity of the 3-year-old (Gopnik et al. 1999). The most important outcome of networking is the appearance of new questions. Kevin titled his new proposal to CIHR “*Where is TB?*”

7 The Time Was a Ripe

In looking back 12 years, we can see some advantages of timing of our initiative. In the 1990s, rapid expansion of “GIS for health” was oriented along two productive tracks. GIS methods for location of health facilities were driven by needs of heavy investment in hospitals and, on the supply side, by advances in operations research and the models of “shopping centre geography”.²³ Advancing alongside, wildlife bi-

²¹ For learning tools for exploratory spatial data analysis, see Robinson et al. 2011; <http://geovista.psu.edu/GEX/>; Fischer and Getis 2010.

²² For displays of such network structures, see Feldman and Labute 2010; Liang et al. 1998; and with application to the search for drugs targeting tuberculosis, Kinnings et al. 2010, 8; Downing et al. 1995.

²³ Problems of access to health services remain important for control of TB, apparent in GIS applications in the Canadian Arctic (Clark et al. 2002), in a metropolitan area (Lewis et al. 2002), and in rural Africa where multiplication of supervision points for DOTS programs (directly observed treatment) favours completion of the full course of antibiotics, necessary to minimize emergence of bacterial resistance (Tanser and Wilkinson 1999).

ologists and veterinarians were using GIS for ecological models of animal vectors of diseases such as West Nile virus, river blindness, and malaria. (We've taken advantage of ESRI add-ons they created.) In the 12 years, new priorities have emerged. Public opinion is now tuned to the spatial gradients of environmental hazards like radiation, superfund sites, herbicides, and land mines (Beck 2008); and in medicine, top priority has moved to interactions of genetics and environment, with recognition of the micro-molecular.

Observing a project over 12 years does not tell us what to expect in the next 12. We do know that conversation across disciplines will be necessary, and it will be challenging. Ours was just one of thousands of “found experiments” in scientific networking. Such experiences provide clues to what will make those conversations productive of the “creative chances”. What if this applies to the whole of “the university”? to the whole of “the hospital” – nurses, patients, doctors, as well as research personnel and the institutions of “public health”? to the whole world of research, where the curiosity-driven, in their conversations in the corridors, are straining against the bonds of bureaucracy? The reward is in the conversations themselves, which sometimes take us to unexpected places. Conversation satisfies a thirst.

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Part II

The Transformative Nature of the Conducted Research

Chapter 6

Collaborating Towards Innovation: Lessons from the Participatory GeoWeb GEOIDE Network

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Abstract. The GEOIDE Network has brought together a Geomatics research program with a strong focus on multi-disciplinary research. In this chapter, we present the experiences from our GEOIDE research team, ‘The Participatory GeoWeb for Engaging the Public on Global Environmental Change’ and our case study laboratories. We reflect on the influence of multiple research locations, institutions, and disciplines on the development of new relationships and new knowledge. We discuss the unlikely collaborations that play with traditional roles of the university and mix with the uniform disciplines of academia. Our collective experiences demonstrate how locations, technology and relationships play significant but different roles in collaboration. In the end, our network has sparked unlikely alliances and predictable hurdles, but it has also meant that everyone had the opportunity to be a student as we have collaborated towards innovation.

Keywords: GeoWeb, interdisciplinary, collaboration, research networks.

1 Introduction

Interdisciplinary research networks, such as GEOIDE, have fostered collaboration among academics working across disciplines, locations, institutions, and including individual citizens, to distribute and generate new knowledge. GEOIDE is not alone in what constitutes a growing trend that is fast becoming the new norm in research (Kahn and Prager 1994; Rhoten and Parker 2004). Collaborative research is founded on the idea that bringing in different approaches, different ways of viewing problems and a range of expertise will provide a stronger path towards innovation (Katz & Martin 1997).

In our GEOIDE project, “The Participatory GeoWeb for Engaging the Public on Global Environmental Change” we understand the GeoWeb, or Geospatial Web, as an “integrative, discoverable collection of geographically related web services and data that spans multiple jurisdictions and geographic regions” (Lake and Farley 2007). In practice, the GeoWeb is the platform underlying Google Earth and Internet based computerized mapping systems, which allow for sharing geospatial data online and the seamless interoperability of various online services. We sought to investigate the participatory potential of the GeoWeb as a framework of geographic information technologies to engage the civil society in an open dialogue with government and others on the issues that affect people's lives. We were guided by three research questions. First, what defines effective public participation on the GeoWeb? Second, how do we contextualize web-based environmental change models and data on the GeoWeb? Third, how do we build a cyber-infrastructure and enabling policies that serve this two-way engagement? Our collaboration supported innovative answers to these questions. Furthermore, unexpected connections produced further inquiries that emerged in between those questions.

The result was a research network within the wider GEOIDE network and a team that spanned multiple locations, institutions, and research locations. In this chapter, researchers from our project reflect on their experiences working in an interdisciplinary group and within the larger scientific network. Tapping into our range of findings from students, research assistants, co-applicants and the principal investigator (PI), we strive to present a snapshot of the research through their eyes.

GEOIDE's mission in geomatics training in Canada has many facets which reflect interdisciplinarity and collaboration: teams have been developed across disciplinary boundaries and many have developed liaisons with industry and government agencies which aim to remove barriers between knowledge development and application in many areas including policy development and evaluation.

Participation in our collaborative research network on Stochastic Modelling of Forest Dynamics afforded graduate students an expanded range of options for growth and development as well as for valuable interactions during the course of their studies. Some of them were intimately connected with companies and government organizations that implement research results. These students gained first-hand experience in working in truly collaborative research environments. Fundamentally, the design of the GEOIDE project team has been recognizably distinct in this collaborative training aspect and made it possible for us to attract high calibre students seeking the opportunities provided. This short Chapter discusses some of the key aspects of the collaborative training environments that emerged within our GEOIDE network.

2 Understanding our Network

Questions asked by researchers and society at large necessitate investigations that cross traditional academic boundaries (Detombe 1999). The largest concerns facing humans, such as our research focus of global environmental change, require innovation (Tress 2004). Innovation is not just the development and application of new technologies, but it is, at its root the development of ‘novel’ ideas that move us forward. The idea of a network is that it possesses greater capacity, more intellectual resources and a venue for making stronger connections than do individual researchers working in isolation. Actually, these interdisciplinary networks are not new to academia. However, we can do better in ensuring that as researchers we understand where we are and where we are going with our focus on network-based research milieu. Indeed, collaboration extends beyond mere co-authorship to more intangible and complex relationships (Subramanyam 1983). Subramanyam (*ibid.*, 35) goes further: “a brilliant suggestion made by a scientist during casual conversation may be more valuable in shaping the course and outcome of a research project than weeks of labour-intensive activity of a collaborating scientist in the laboratory.”

Whereas GEOIDE’s focus is on developing a multidisciplinary network that mixes universities, industry and governments, ours is one that extends these players to include citizen groups and community participants. Our interdisciplinary project team (which includes biologists, social geographers, engineers, urban planners, and political scientists) collectively works to understand what defines effective participation through the GeoWeb, in the context of observations and opinions on environmental change, with a larger goal of supporting response and adaptations to climate change. Our approach is to engage affiliates at different levels of government and from non-governmental organizations (NGOs) across various decision-making scales across Canada. Our case study laboratories allow for experiments to be conducted and theory to be developed in collaboration with societal players. Collectively, these studies provide a means to build creative frameworks for effective participation through the GeoWeb, as well as to contextualize observations and opinions on environmental change. In addition, the research team sought to develop a technical and policy infrastructure to support adaptation and responses to environmental change through a set of best practices in governance and public administration.

Collaboration is an over-used word. In a sense, collaboration could describe any work that researchers do because it is built into the nature of our work. Collaboration is a label that can erroneously be applied to a co-authored paper, or a proposal where the addition of names are inserted to serve a niche rather than a productive environment in which ideas are co-formulated and refined. Meaning needs to be put behind the word. We follow Katz and Martin’s (1997, 12) definition that says meaningful collaboration should include:

- those who work together on the research project throughout its duration or for a large part of it, or who make frequent or substantial contributions;

- those whose names or posts appear in the original research proposal;
- those responsible for one or more of the main elements of the research (e.g. the experimental design, construction of research equipment, execution of the experiment, analysis and interpretation of the data, writing up the results in a paper);
- those responsible for a key step (e.g. the original idea or hypothesis, the theoretical interpretation).

We add an extra focus here, on the practice of our research that fundamentally impacts our research questions. Our practice is aimed at understanding the act of participation on the GeoWeb; participation requires a deep understanding of the way we operate as researchers. Fundamentally, our research approach begins with the notion that a more reciprocal relationship between decision-makers and citizens involves a process of collaboration and learning (Healey, 1996; Innes, 1996; Woltjer, 2000). What is more, centralized approaches to local problem solving are less effective than those that actively seek to include and engage the impacted communities (Chaskin and Garg 1997), particularly when developing planning responses to complex environmental issues such as climate change (Robinson, 2006; Robinson and Gore, 2005).

Our project touched on many interrelated themes - community development, environmental management, e-government, and digital activism. Collectively, we sought to develop appropriate technical and policy infrastructure to support these global environmental phenomena. These themes can more thoroughly demonstrate new ways in which geospatial information and tools maybe used by non-experts to impact decision-making. Our overarching goals provide a foundation for us to incorporate the approaches, views, and findings from our different disciplinary platforms through the case study laboratories.

The research team is divided into several research nodes that represent different disciplines and stages in career. These nodes are based at universities across Canada, including University of British Columbia-Vancouver and Okanagan Campuses, Ryerson University in Toronto, McGill University in Montreal, University of New Brunswick in Fredericton and Memorial University in St. John's. The research is deeply situated in these places. For example, the Memorial University team, headed by a landscape ecologist, developed a social networking site so that citizen scientists could contribute information about Newfoundland and Labrador wildlife. The Quebec team of geographers, one of them a professor and the other a postdoctoral research fellow, researched the challenges facing local government adoption in a rural Quebecois farming community. On the other side of the country, one of the British Columbia teams developed several community GeoWeb applications that document environmental impacts such as forest fires and local food production. In the largest city in Canada, the Toronto team, all working in different disciplines such as planning, geography and political science, explored ideas in sustainable development, environmental mitigation, and transportation. Our research locations are unique but

bring something different to each case study, and to the project as a whole. The insights that are derived from urban to rural or French to English Canada brings forth a picture of our diverse nation, informing us on how the characteristics of these places may influence participation.

We have unique insights to the issue of collaboration because we could ‘test’ our theories of participation and communication within our research network. For example, we had different kinds of participation, of which face-to-face seemed to be quite successful in many places, despite our emphasis on digital interfaces from our first research question. Our second research question concerned the context/education of the tools. It certainly helped that the ecologist provided advice on the demands that expert biologists would have, should ecologists make use of volunteered geographic information in decision-making. At other times we had issues with technological sustainability (third research question). In short, our research was centrally concerned with tools that defeated physical distance. As increasingly, networking occurs online and not in person we wondered ourselves whether participation online held the same quality as face-to-face connections.

3 A Networking and Collaboration in Practice

What follows are individual perspectives on our research collaboration that highlight both the successes and challenges of working together. Regardless of whether the individual was a student, faculty, or the PI, something unique was experienced for us to learn from now and into the future.

Managing Predictable Hurdles. It is not uncommon for researchers to have a sense of unease when planning research collaborations that span different locations, universities, and even disciplines. The possibilities of synergistic results of our research motivate us to work together, but the intensive management strategy necessary to achieve this may be where the unease originates. In this section, we discuss what can be described as predictable hurdles to keeping us together, moving us forward, and achieving effective results. Research collaborations, across disciplines begin with challenges that are often what we may expect at the start, such as our misunderstandings of disciplinary language or methods. Furthermore, the vast distance between researchers on our project inhibits regular in-person communication that researchers have working in the same institution. The PI (Renee Sieber) joked with us on more than one occasion about the difficulty in organizing project meetings, joint papers, workshops and conference calls - sometimes she felt as if she were “herding cats”.

One major issue in collaboration, particularly collaboration that resulted in synergy, was the different definitions and assumptions that researchers brought from their domains. For us, this included concepts core to our research and resulted in different definitions of community, contribution, participation, and volunteer. One example was spatial data accuracy. Having an engineer on the project meant that spatial data

accuracy was one of proximity to coordinates that is positional accuracy. For the ecologist, accuracy meant attribution accuracy, the correct identification of species. For the planner, accuracy meant confidence in the results, particularly a vague interpretation of authenticity of citizens' voices. The challenge was to get people to appreciate that definitions and assumptions differed, which occurs whenever this type of research is conducted and to value the differences, even if it does complicate one's own research.

We also have found large variations in skill levels amongst our research team as well as amongst our partners, for example in server side integration of application programming interfaces. To close this gap we created internal course materials (written by students on the project) to bring our partners and researchers up to speed. We also focused on the need to train our students across disciplines. To further collaboration, the more technical among them needed to understand the ideology behind Web 2.0. But the geographers, trained with geomatics, statistics, mapping and visualization needed to understand the computation server-side. In the absence of computer scientists on our team, it was important that our students network with each other, to pool knowledge about, for example, how to use an API (application programming interface). Networking with the engineering students on our project was also invaluable for achieving technical proficiency across research nodes. These techniques lowered the risk of entry and ensured continued participation in the larger project.

We believe that successful collaboration also emerges when one creates a space to take risks and encourages participants to work outside their domain and thus spend the extra time needed to work together. After several student projects ended up stemming from community organizations in locations outside the urban centers, we identified the digital divide between urban and rural locations as one of our research themes. The digital divide in Canada is commonly associated with the difference between rural and urban locations where the latter have better access to digital technologies such as computers and reliable Internet connections. Researchers identified several unique aspects from their work in rural communities, which prompted us to create a special workshop for students and our partners on the rural digital divide in an era of Web 2.0. The workshop helped identify the challenges, opportunities, as well recommendations to elevate the current problems with implementation and lack of access they found. The results of this workshop are to be published in a forthcoming special report.

Putting a Face to a Name. Working across locations, academic roles and studies posed challenges despite all of our collective facilities with advanced communication technologies. Here we illustrate the different ways as a team we were able to come together in person and how this fueled further collaborations. This project overall demonstrates that the human element is foundational.

Some of the most productive ties in the project arrived from informal/face-to-face efforts instead of those mediated by the technologies we study. One example was our

strategic use of conferences such as the American Association of Geographers, which is an annual meeting where we organized special panels - three in total - at which our PI, collaborators and many students shared work. Indeed, it was the insight from an informal remark from Robinson on the institutional challenges of adoption by local government that has led to the more recent collaborative grant application.

Tudge furthers these ideas with her own research experience in working with community members and as a student in Corbett's lab. When she was conducting research in rural BC, her intention was to build GeoWeb tools that presented a way for farmers and local people to showcase their locally grown food. She was primarily working with a small food advocacy organization, but she also traveled out to the community, to farmer's markets and other events to talk to farmers and gather content for the tools. In BC communities, most of the people buying the food live in the denser urban locations, far from the farm and have no idea about who grows their food. The goal was to have information presented through GeoWeb maps of where to find locally grown food, and additional information such as issues facing farmers, or even the individual production methods of different farms. Tudge was new to the communities, so farmers did not trust her agenda in conducting the research. The more she talked to them, the more they got to know her. One farmer, who had a large potato farm, insisted he had no interest when she first met him. A year and several informal conversations later, at places like his farmers' market stall, he looked at the maps and asked "where am I on here, where is my farm?" He only participated in the project when he knew her by name. From another farmer, she visited the farm, purchased some strawberries and took some pictures for the website. That farmer remarked that he/she would have never participated had she not taken the time to visit the actual farm. Ultimately, her online digital tool and its content were built on personal relationships.

The spark for participation did not come from an email, but the author's face at the farmer's market and at remote farms. In the course of her work with rural communities and in working within the GEOIDE Network, the importance of building relationships and meeting one's team in person was emphasized. This contributed to Tudge's ideas of how, despite the communications potential offered by the GeoWeb, it cannot replace the process of people generating ideas together; putting a face to a name. These meetings in shared spaces provide a way to build trust and a path to group participation.

This was also true for Tudge's experience as a student within our team and in the GEOIDE Network. When she began as a student, she knew of the different research laboratories, heard the names of other researchers, got the emails, and even participated in a few conference calls. However, her attention to the wider project did not begin until she attended a team meeting in Vancouver. The connection with people was like a light bulb being turned on. The all day meeting provided a very important step into the world of research collaboration and networks. Her meeting with the other students and faculty allowed her to finally connect and in doing so gave her the fundamental understanding that her research was a piece of something larger. It was this face-to-

face contact that concretized the larger questions –some of which she now felt comfortable lending some insight to and expanded her thinking on her thesis.

Allen, first a student in Corbett's lab and later a research assistant at Ryerson University notes his challenges with maintaining relationships and achieving results across geographic distance. He found that at times it was difficult to get the different individual laboratories to collaborate with the wider team initiatives, as it was to ensure adequate connections with all the project partners, these things he found took time, effort, and regular follow-up.

Building relationships with the community partners was key to Allen's research and his research assistant position. These relationships with partners across Ontario and in British Columbia were based on regular telephone/Skype communication and continued email follow up. As the development phase of Ryerson mapping projects extended beyond anticipated time frames his continued position fueled the ongoing participation of partner's and provided a base for establishing personal relationships. He felt that a shorter term master's student would not have been in the position long enough to see through these relationships that several years later are beginning to achieve the original goals of the partner's as well as providing research results.

Allen also expressed that face-to-face project team meetings were important because it allowed us to share and inspire each other with findings and ideas. However, whether face-to-face or online, follow up to these ideas was difficult. Taking our ideas from our meetings, and implementing them once we returned to our respective laboratories, was often not completed. He found this challenge highlighted a need to establish a defined process or structure for collaborative research and shared analysis.

Unexpected Interdisciplinary Networking. The term networking often conjures up images of interactions between professionals of a similar stripe (e.g., business leaders, politicians) either formally in meetings and conferences or informally via networks of contacts, past and current associations, and acquaintances and friends. Even in academia, students are told that networking is important and is often the best route to landing a job after graduation. Our research networks help our honours students to find suitable Masters positions, our PhDs to secure post doctoral fellowships and for our graduates to find jobs outside academia with our partners, collaborators, colleagues and associates in the private sector or government and non-government agencies. In most cases, the networks are within our disciplinary areas of specialization. Networks are also seen as being broad in reach and geographic extent. We network across universities, across the country and around the world via contacts made in graduate school, current and past collaborators, and individuals we have met at conferences. We do not usually consider networking as something that happens within the confines of our own campus.

Network of Centres of Excellence Network of Centres of Excellence (NCE) funded projects such as GEOIDE emphasize the value of networking across disciplinary and

sector boundaries. The mission of the NCE (as stated on their home page) is to “foster multi-disciplinary, multi-sectoral partnerships between academia, industry, government and not-for-profit organizations.” In addition, GEOIDE grants emphasize the need for co-investigators to represent more than one university, thereby explicitly encouraging networking beyond campus boundaries, and implicitly encouraging networking across this vast country. Here, Wiersma, who leads one of our research nodes from Memorial University in Newfoundland and Labrador reflects on a significant outcome and a strong successful connection she has made from her role on our team.

Developing Tools that Foster Collaboration. Our challenges of geographic distance were surmounted by new Web 2.0 communications technologies. Most, often these involved conference calls, email exchanges, Skype webcasting, list-serve messages and even Facebook messaging. These extended to sub-groups within and across nodes that emerged. For example Sieber and Wiersma are co-authoring a paper using the Google Docs for writing, Dropbox for file sharing and Skype for conversing about paper ideas. These tools, aid us in collaborating but one key reflective stance is how much these tools have provided a space to generate innovative ideas, in comparison to our face-to-face interactions during conferences, team meetings, and student exchanges.

One example illustrating the depth of our collaboration is the partnership that has grown between researchers at University of British Columbia Okanagan (UBCO) and Ryerson University. Corbett leads a research laboratory at UBCO with several students on the team. One major part of his laboratory has been tool development, which has resulted in relationships with other laboratories in the team. Corbett and Gore, working together but embedded in their respective research locations, come together on research to present what were often profound results. The outcome of their work is a tool named Geolive and its development has formed the basis for their relationship. Here, Corbett describes these relationships, the tools and how these two parts have emerged within our team.

Geolive is a platform that enables users to build their own problem-specific application and share their own spatial information using a dynamic map-based interface. The purpose of Geolive is to create an application where many users can view and author spatial data content simultaneously. The software is open-sourced, and thus can be reused and widely distributed. Geolive is now being deployed by the university associates in partnership with four community organizations based in British Columbia and Ontario, each working at different spatial extents (from the local, to provincial to national level) and on different issues. These organizations include: The i2i Inter-generational Society of Canada, the Kawartha Heritage Conservancy, the Ottawa River Institute and The Sustaining What We Value Project (a collective of several non-government organizations and government agencies).

The research component of the project has involved both community partners and university researchers examining the issues experienced in the development, imple-

mentation and management of Geolive, particularly focusing on the usability and sustainability of both the application and the partnerships. Our initial research focus and thus findings were design-centric. In other words how, from a usability perspective, can an online mapping tool be designed and developed to best support the active participation of users in the contribution of location-based, content? In doing so, can such a tool help to promote community involvement in geographically bounded issues? However, the research results soon began to demonstrate that the principle challenges that the project partners faced were not related to issues of usability, data standards, and interoperability, but rather they were intrinsically embedded in local contexts, internal politics, and the management of participant expectations.

While we have had research success in tool collaboration and used various Web 2.0 technologies for communicating among the team, these tools have posed challenges. These challenges are twofold, first with our use of Web 2.0 tools for communicating for collaboration and the second with the tool development for collaborating with partners. The former issue provides a cautionary experience where students and research assistants found that working online limited participation from colleagues to finish tasks that were initiated in person. Students noticed that using Google documents requesting other students and professors input would receive no or limited feedback. For instance, we developed survey questions for GeoWeb users, and managers, but other team researchers did not draw on the surveys as anticipated. Documents like this would have been useful for establishing some consistency between our research objectives and monitoring results, but we could not seem to get onto the same page with our team process. These tools we often drawn for the follow-up of ideas, as mentioned earlier, but without in-person connectivity, we found it hard for these tools to instigate completion of ideas amongst the group.

The second challenge of the tools related to our applications development process. Several labs, including Corbett's, were developing specific applications to collaborate with partners. These tools such as Geolive aimed at providing a way for partners to map their desired subject matter, often onto their own websites, with the aim to participate in the mapping process in new innovative ways. The central problem for the partners was with the process of research, because in many cases it took a long period of time, with often several updates and changes to the tools. Partners would get frustrated with mapping applications that were still in the testing phase, or the tools would get updated and they would need retraining on how to use it. This was partly mitigated through building relationships as Allen expressed earlier in this chapter, however our lesson here is to build a process that streamlines or utilizes applications further in development, and this would have resulted in research results that were derived more from the action of the tools, than the development process with the partners.

Student Collaboration. A focus that has run through many of our team's reflections is the role of students. Students at every level have participated in our team and the broader GEOIDE network. One of our students, Chung, is currently a researcher in the Ryerson research node and during the course of our project has moved from a

Masters student to begin his PhD. He has also been involved substantially in the wider GEOIDE Network. Below he offers his reflections, over the last few years of being a student within the network.

Collaborating with a group of researchers with similar focused research goals allowed for reciprocal feedback on research questions and methodology. Attending conferences generally can provide this, however, the focus brought by longer-term communication and intimate collaboration increases the likelihood of new questions and approaches, and honing of existing ones. Furthermore, having such a large range of student and professional experience in the group helped greatly in acclimatizing to graduate-level academic research.

Diverse, multi-disciplinary backgrounds, ranging from public administration and geography to engineering, have helped to place his research in context of broader ideas. Explorations within the research group have also led to the finding of common threads, very important in comprehending the complexity of communicating global climate change on the GeoWeb. Having access to such human resources is again an invaluable learning experience for students. Likewise, sharing current research with others allows for the coordination of case-study efforts and more efficient use of resources by reducing overlap.

Inter-group interactions through conferences or student organization events were great opportunities for cross-pollination of ideas with other GEOIDE projects. For example, the weeklong GEOIDE Summer School provides an intense learning and networking opportunity with fellow GEOIDE students. The event encourages sharing of research while learning together cutting-edge topics in Geomatics from leading researchers globally. The GEOIDE annual scientific conference also provides a student-centered stage, creating a less intimidating atmosphere for student contribution compared to more generalized conferences. Interesting discussions with other network groups have resulted from participating in these events, and have led to potential further collaborations both within and outside the Network. The overall sense of belonging to an organization is a great strength the formal network has. Regular collaboration with members along with unique learning and networking events for students creates an environment of innovative thinking, and motivation for research.

These ties include students that were in one lab, and once completed found opportunities in other labs. In part, these opportunities came about through our annual student exchange program. The exchange, allowed for students to experience the other teams research labs, institutions and places of research, like the Okanagan or Newfoundland. Students could work with other students and faculty to understand their methods for tool development, community engagement, or to start to get to know the other team members. Often these meetings led to further exchange of ideas, and at times opportunities for further work for the students, post graduation.

Faculty researchers frequently worked across the team to support other team members' graduate student programs. For example, a researcher from one institution served on another researcher's graduate student committee, and co-supervised a paid internship; this experience also resulted in the same student relocating from UBC Okanagan to Ryerson University to become a key engine in the research of that node. These relationships were strategic, as the student brought significant experience that contributed greatly to the work across the team. Another example was Tudge, moved from a student position in Corbett's lab to McGill to work with Sieber in coordinating the team project. These students were able to provide not only research results, but also sustained relationship building across the team that supports new students and research directions alike.

Students at times describe a rich experience full of opportunities. Several faculty level team members reflect that students have emerged as key players in our project; students often were the ones to propel the team forward, in drawing us together at meetings, instigating new connections, and forming the backbone of relationships between case-study laboratories. These relationships strengthened as students moved from masters to PhD candidates or to research coordinator roles and moved between our partner institutions. They organized and led key initiatives like the student exchanges and the rural digital divide research sub-network. In another case, an undergraduate student was the driver behind one of the conference calls. Throughout the project, students functioned as the 'glue' that occasionally concretized the relationships

4 Lessons for Collaborative Innovation

Opportunities to innovate were achieved by our team from many angles, but not without learning some hard lessons along the way. In this last section we summarize the opportunities, challenges, and lessons from each of the following points, which stem from our experience working together in this network. First, the stimulation of ideas through different disciplinary view-points and different places was a challenge, and a chance to spark insights into our research questions. Second, empowering students to lead and network provided a rich training experience and supported representation across laboratories, institutions and the country. Third, the smaller collaborations, between two researchers or two institutions quickly add up to several interesting new paths that fuelled important project contributions. Fourth, our application development process, highlights how tools are exciting points of collaborative innovation for researchers, but can be a challenge for partners in the community who are eager to participate and use the tools. Fifth and finally, we found that our most important 'innovation' was the development of personal relationships through project mediated connections.

Research networks, such as GEOIDE and our project team, expect to collaborate across distance and between academic institutions. Our project team specifically engaged in many valuable research points that were founded in our respective differ-

ences, whether that was a difference in a location or discipline. For example, there were similarities and variations in the experiences of researchers working with communities in cities versus rural small towns or more remote farms. These different research locations resulted in important results for the team that we are currently evaluating as this goes to press. In other cases, bringing interpretations from ecologists, urban planners and geographers into the same research space provided rich discussions, and new paths for our team that may have not occurred. The challenge is ensuring we are able to connect in a shared space that allows for these connections to occur whether that is acknowledging different interpretations of phenomena or generating new paths for research. Our lessons for ensuring fruitful intersections across disciplines and distance are to identify possible shared themes (such as the rural GeoWeb) and initiate interest in the theme through bringing people together via student exchanges, workshops or other in-person ways to connect. Ultimately, this was an important management strategy that was shared across various scholarly levels of our team.

Students are described in this chapter as the ‘glue’ that concretized the relationships across and between different research locations. We described earlier the different roles students played, that involved various leadership and networking activities. Often graduate students were managing the specific projects and in that role participated in the wider networks. It was common for students to participate in forums such as conference presentations or larger GEOIDE network activities. At other times within our group, students worked in partnerships with co-supervisors. Students present their experience as positive for a number of reasons; the main opportunity noted was the vast opportunities for collaboration. The challenge that other students alluded to was that because students have taken on leadership roles, the length of time participating within our network became important. Longer-term students such as PhD students, or students that stayed within the network in changing positions, have become important in sustaining relationships with partners, and between the labs; they continue to be the glue that holds the project network together. Therefore, the lesson with student collaboration, within large network projects such as this one for which operated for several years, was that the longer-term students make good leaders, but in labs without these types of students a faculty member needs to be the thread that connects the partners and researchers overtime.

The identification of themes was often a team-wide initiative; however, we also found opportunity in smaller collaborations. Examples in this chapter include the collaboration between Ryerson and UBCO with Geolive, or Wiersma and Sieber in co-authoring of papers. Collaborations, at this scale are an excellent way for researchers to connect on specific initiatives. In our project, these quickly added up, and have resulted in important contributions in the form of co-presentations, tool testing, student exchange and training opportunities, peer-reviewed articles, and lasting research relationships with new grant proposals in the works. Our lesson from these kinds of initiatives was they required considerably less central management, as motivation between two groups derives from these two groups. Support from coordinators or the

PI was important in fueling their initial meeting perhaps, but not in maintaining the relationship.

Our research into the Participatory GeoWeb involved developing various applications; these applications were developed with partners, in some cases in a co-design process. As discussed earlier, the opportunity to develop and share applications across the team led to some of our smaller collaborations, and made important research contributions to our overall GEOIDE project. Innovation in application design was fuelled by involvement of partners in the development. However, a key challenge identified was the length of time associated with application development. This continual evolution of new tools is the nature of Web 2.0 applications, however partners, often novice to GeoWeb technologies, required significant training in the tools and often required re-training for updates. The lesson from our experience was to avoid an early introduction of applications, to limit the changing nature of applications with community groups or other partners, and to recognize the time investment for both parties.

Finally, the crux of our experience relates to how online collaborative tools, Web 2.0 applications such as Skype, Google docs and the like, provided space to complete, but not to initiate our ideas. The opportunities of Web 2.0 are most often the dominant discussion around these tools, which potentially shorten the distance between researchers. Our use of these tools was met with varying results for communicating and completing research outputs. Hence, the very tools we research have limitations within our own network. Indeed, attempts to stimulate new initiatives online did not get the intended involvement from the group. Also, commitment made in-person was needed to ensure continued engagement online to follow-up and explore ideas presented. The lesson here is to ensure in research networks that there are plenty of opportunities for teams to meet in person, in various ways, in order for researchers to make the personal connections. Establishing these connections was vital for both team members and for research partners. The most important ‘tool’ of our research, the energy behind participation, and the driver for innovation, was the development of these relationships, and our ability to put a face to a name.

5 Conclusions

The reflections of our research team from over the last several years have demonstrated that locations, tools, and relationships matter. However, the experiences on our team varied depending on their roles, for example, from the perspective of our PI some predictable hurdles stemmed from the diverse locations, whereas other co-investigators thrived on bringing together the results from these places. Unlikely relationships emerged from our interdisciplinary nature, and opportunities for students to meet peers and leaders in their fields were greatly enhanced. The ongoing challenges stemmed from the intensive management style required at several levels to ensure the project moved forward, whether that was finishing tasks with the aid of Web 2.0 tech-

nologies or getting everyone organized for various group activities. The time involved to manage networks cannot be underestimated. In addition, our application development process was a highlight for collaboration among the team but some researchers felt it was difficult for partner participation. Finally, an ironic finding from our research encounters was that innovative ideas are found mainly through our face-to-face meetings, and not through using the Web 2.0 tools that we used to connect. At this point in our research, our relationships, the informal and chance discussions and our ability to connect our ideas to faces and tools to process, fuels the steps necessary for researchers to continue to innovate into the future.

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Chapter 7

Twelve Years of GEOIDE-Sponsored Research and Development on Multi-Agent and Population-Based Geo-Simulations for Decision Support

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Abstract. This chapter provides an historical view of twelve years of research on multi-agent geo-simulations (MAGS) for decision support which was applied to a variety of domains such as the design of parks, crowd simulation, the simulation of customer visits in shopping malls, the control of wild fire spread, the simulation of the interactions of insect and animal populations for the spread of West Nile Virus and of Lyme disease. This chapter tells the ‘inner story’ of these 12 years of research which, in retrospect appear as a complete and articulated research program on MAGS for decision support. It presents the main milestones of this program and emphasizes how the GEOIDE Network gave us opportunities to team up with industrial and governmental partners and different Canadian and international research teams in a series of projects, PADI-Simul, MAGS, MUSCAMAGS and CODIGEOSIM, and a constellation of companion projects.

Keywords: agent-based, population-based, geo-simulation, decision support

1 Introduction

In our fast-changing and increasingly interconnected world, decision makers from various sectors (governmental, military, industrial, medical, social) need to monitor the evolution of what I call multi-actor dynamic spatial situations (MADSS). Such situations involve a large number of actors of different types (human, animal, hardware, software) acting in geographic spaces of various extents. Monitoring MADSSs is a fundamental requirement to make informed decisions in several fields such as human security and equipment preservation (i.e. flood, earthquake, and wild fire), respect of public order (i.e. population evacuation, crowd monitoring and control, and peace-keeping activities) and the adequate use of infrastructures (i.e. transportation, communication, and commercial). Certain MADSSs occur on a regular basis (i.e.

daily traffic patterns in an urban area) whereas, often in crisis situations, other MADSSs can evolve rapidly as a consequence of the occurrence of particular events (i.e. natural or man-provoked hazards) and/or changes in individual behaviors (i.e. panic, accidents).

The complexity of MADSSs results from the interactions of various dimensions (spatial, temporal, and behavioral) which cannot be adequately analyzed using equation-based models, classical data analysis approaches or pure statistical techniques. In many areas, software for data collection and data fusion use Geographic Information Systems (GIS) to provide a wealth of data to experts from different organizations who collaborate to devise and coordinate action plans. Usually such systems have complex interfaces and provide limited support for analytical reasoning, decision-making and coordinated team work [50]. Moreover, decision makers need appropriate means to get an overall understanding of MADSSs [49], to monitor their evolution and to devise strategies/tactics to intervene adequately. However, apart from systems used by the military, most available civilian MADSSs management systems lack simulation tools that can be used by emergency teams and managers for rehearsal purposes and training [51]. Decision makers are keen on using so-called What-if analyses [98], but they still lack adequate tools to simulate the situation(s) and anticipate the effects of different scenarios, especially in the case of interrelated MADSSs. For the past twelve years, our research projects aimed to develop such decision support systems using multi-agent geo-simulation (MAGS) or population-based geo-simulation approaches.

This chapter presents an historical review of the different projects that our team developed in this area during the past twelve years with the support of GEOIDE, the Canadian Network of Centers of Excellence of Canada, and a variety of partners, both from industry and government. Throughout the chapter I use a story telling style to present our main contributions to this research field which evolved a lot during all these years. This is an occasion to emphasize outstanding moments and events when the GEOIDE Network offered us the chance to disseminate our research results, to be in contact with industrial and governmental partners, to become aware of practical problems that MAGS could tackle, and to find innovative solutions. Hence, GEOIDE provided us with unique opportunities to launch new research initiatives and to push further our experience with MAGS and its numerous applications.

2 Decision Support for MADSS and Multi-Agent Geo-Simulation

Modeling and simulating MADSS is a critical issue. Classical modeling approaches of complex spatial systems [5] essentially rely on cellular automata approaches [99] and use geo-referenced data from GIS [32]. However, when it comes to MADSS modeling, cellular automata present some limits: they do not have mechanisms to model individual and autonomous agents and their interactions with each other as well as with their environment. To our knowledge, the only approach that is able to model

such complex spatial systems and all their possible interactions is what we call a multi-agent geo-simulation (MAGS) which is a relatively novel approach [64] mainly characterized by the use of agent-based models [61], particularly multi-agent systems (MAS) and GIS in order to model, simulate and study complex phenomena taking place in geographical environments [7].

By combining advanced characteristics of artificial agents and explicit and faithful representations of the geographic space, MAGS has been recognized as an effective approach for: 1) simulating complex systems composed of interacting agents in a simulated geographic environment; 2) for verifying and evaluating hypotheses about how real spatial complex systems operate [2]. Najlis and North [68] discuss the interest of integrating GIS and agent-based modeling systems. See also [73] [96] [13]. Examples of recent applications include pedestrian dynamics, urban growth models and land use models. For agent-based modellers, this integration provides the ability to manipulate agents that are related to actual geographic locations. For GIS users, it provides the ability to model the emergence of phenomena through individual interactions of features over time and space [68].

Since 1998 we have been developing MAGS systems for MADSS decision support in a variety of application domains. We learned that modeling MADSSs needs to take into account at least the following dimensions:

- The involved *actors* and their main characteristics;
- The *world of interest* in which actors move (places and their characteristics, spatial relations between places along which actors may move);
- Situations' temporal characteristics (i.e. durations) and time constraints;
- The rules (or behaviors) that define how actors behave in the world of interest and interact with it, as well as with each other;
- The '*happenings*' and specific *events* that may occur in the world of interest, create perturbations in it and may affect actors' behaviors;
- The *interactions* between all the above mentioned dimensions.

These MADSSs' dimensions need also to be considered with respect to decision makers' requirements, constraints and interests, particularly:

- His/her objectives in relation to his/her mission as well as constraints (i.e. time, budget, responsibilities);
- Relevant *intervention scenarios*, i.e. the kinds of actions that may be carried out in the world of interest;
- *Explanations* that the user needs to understand the effects of interventions;
- The *level of detail* or *scale* (macro, meso, micro or a combination of them) that is needed to explore/analyze the studied phenomena (MADSSs).

As we will see in the next section our 12 years of research on MAGS allowed us to explore all these aspects.

A *Multi-Agent Geo-Simulation* approach (MAGS) goes beyond the use of agent-based models (ABM) that became popular in many areas (especially social sciences) during the past ten years. The interested reader can look at JASSS' outstanding special issue on the use of agents and ABM in social simulations, agent-based and equation-based modeling and methodologies for complex social simulations [43]. Beyond using agent-based models, a MAGS approach [64] puts the emphasis on exploiting GIS data to create 'virtual worlds' in which decision makers can explore the effects of different intervention scenarios in the context of MADSSs of interest. Such a virtual world should comply with the above-mentioned MADSS dimensions and there is a need for a formalism to represent: 1) a *virtual geographic Environment* (VGE), a displayable data structure which contains information about the landscape such as elevations, landscape features and buildings, use areas, transportation networks; 2) *activity places* (specific locations in the VGE where agents can carry out activities); 3) *agents* (static and dynamic characteristics, behaviors, decision making, and possibly perception and memorization); 4) *groups of agents* (as simple as household information that provides constraints to agents, or as complex as large social groups in which agents may play various roles); 5) *assignment of activity places to agents* (agent's knowledge about these places and what can be done there); 6) *objects* (characterized by static and geometric properties and rules for state changes, and possibly enhanced with processes – affordances - that specify activities that agents can perform with them); 7) *happenings* or *events* that may change the VGE content (adding or removing objects, changing their states and location, creating 'fuzzy' objects such as tear gas clouds using particle systems); 8) *interactions* that may take place between all the above mentioned elements.

Moreover, there is a need for models of groups or 'collectives' of agents and their spatial-temporal interactions with other groups, with individuals and possibly with objects. Agents may also belong to various social groups (i.e. household, company, sport team) and have behaviors related to the roles that they play in these groups [66].

When several MADSSs are embedded in each other, decision makers often need to examine various situations simultaneously at different level of details. This is an important issue since the modeled phenomena and observed patterns may be different from one level of detail to another. This is a complex problem because interferences may arise between phenomena evolving in different interrelated MADSSs, which increase the complexity of the models of the MADSSs dimensions that appear at different levels of detail.

Finally, let us emphasize that there is a need for software modules that: 1) allow decision makers easily specify intervention scenarios and 2) can display simulation results that are useful to the decision process, using quantitative and qualitative techniques.

All these aspects have been addressed throughout the projects that we present in the next section.

3 A Retrospective Overview of 12 Years of GEOIDE-Sponsored Research in MAGS

Thanks to GEOIDE and our project partners, we worked on several MAGS projects that helped us explore different research avenues in MAGS, to develop several geo-simulation platforms and deliver applications in different domains. In retrospect, we can divide these 12 years of research into five main stages - each one having its own vision, objectives and achievements: the exploration stage (The PADI Project), the micro-simulation stage (the MAGS Project and its companion projects), the MAGS enhancements stage (MUSCAMAGS Project and its companion projects), the populations dynamics stage (the VNOMAGS and ZoonosisMAGS Projects), the multi-scale stage (which overlaps the MUSCAMAGS and ZoonosisMAGS Projects). Fig. 1 illustrates these stages and provides a timeline of the main projects that were carried out during this period. In the following sub-sections we ‘tell the inner story’ of these different projects.

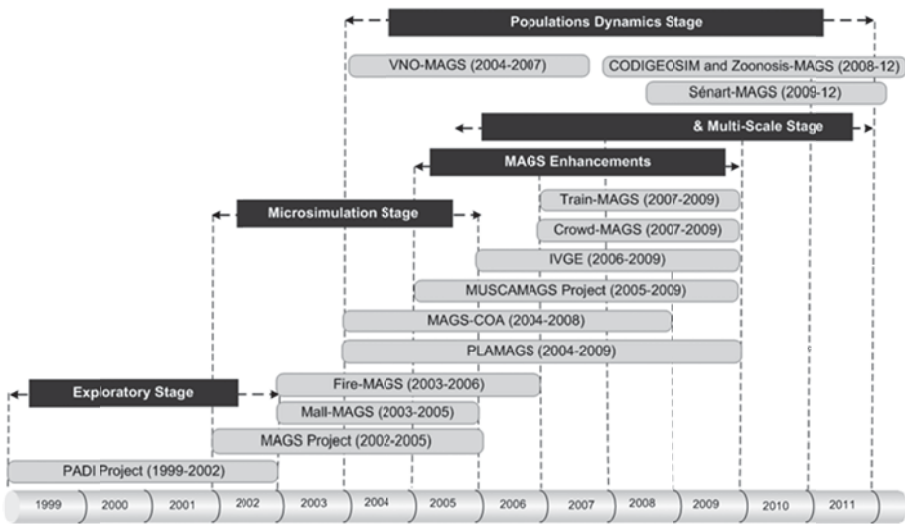


Fig. 1. Overview of our Projects.

3.1 The Exploratory Stage

Triggering Event. Through Project DEC 30 (G. Edwards Project leader, 1999-2002) GEOIDE funded our team to carry out fairly fundamental research on ‘designing and apprehending space’. This was the unique project of GEOIDE’s first wave of projects

which had no industrial or governmental partner. But, we had a group of actively involved international collaborators.

Achievements. With our international advisors S. Epstein, G. Ligozat and J. Glasgow, our GEOIDE team explored innovative ways of modeling and apprehending spaces. As a case study, we chose to study the creation of recreational spaces (parks), taking into account their usage [23]. In the PADI sub-project (1999-2002) my team created our first MAGS platform (PADI-Simul) as an add-on to a CAD tool (PADI-Design) that we developed to support landscape designers who design a natural park using geo-referenced data about the site, expected facilities and use areas. PADI-Simul [65] allowed a user to create a population of agents simulating the displacement behaviors of park visitors. Agents were able to perceive objects and landscape features in a 2D VGE (Fig. 2A).

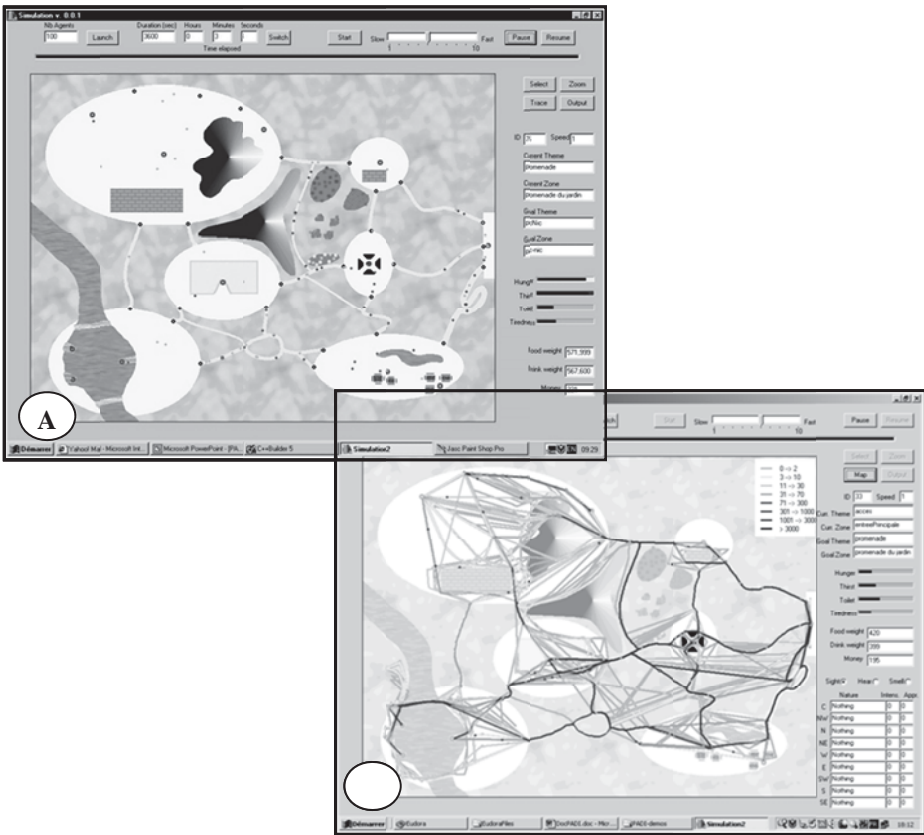


Fig. 2. PADI-Simul System- A: Display of the simulation, small dots represent visitor-agents of different categories. B: Trajectories on the lanes of the park with density colors (number of agents who walked on the corresponding lanes).

Using the simulation results, a landscape designer could identify the most frequently used paths (or trajectories) and use areas (Fig. 2B). Retrospectively, the PADI project allowed us to show the feasibility and interest of using a MAGS approach to simulate space usage and to develop the fundamental components of a MAGS platform coupled with a CAD tool and certain analysis tools to support landscape designers' work.

Main Contributions. Although several researchers proposed in the late nineties to use agents to support architectural design [78], we did not know of any computer aided design system [58] or computer-assisted architectural system which integrated a geo-simulation tool as the PADI System did in 2003. We showed how geo-simulation functionalities can be integrated in a CAAD tool in order to support a designer at different stages of the design process [60], to assess the quality of the on-going design and suggest certain design solutions based on the simulation of space usage [65]. Interestingly, recent research indicates that 'little is known about actual park use patterns' and confirms that geographic visualization of data can help domain experts like landscape designers and park managers to assess park use [71]. Hence, the PADI Project's results are still relevant to the community, even 10 years later after the completion of the project!

Opportunities Created by this Stage. A demonstration of our PADI System at GEOIDE's 2001 General Annual Conference in Fredericton attracted the attention of several participants, especially representatives of Defense Research & Development Canada (DRDC at Valcartier) who got a recent interest in the design and use of 'virtual cities' to support peace-keepers' training (before intervening abroad in urban settings). They proposed us to explore how to simulate a crowd (hundreds of agents) in a virtual city and accepted to finance the MAGS Project (see next section). Incidentally, few months before GEOIDE's conference, the Third Summit of the Americas had taken place in Quebec City, emphasizing the interest of better understanding crowd behaviors. Our PADI System demo also interested researchers from CRAD (Centre de Recherche en Aménagement et Développement, Laval University) who suggested that a MAGS approach might be used in the context of urban planning and the study of people's mobility in urban environments.

3.2 The Micro-Simulation Stage

Triggering Events. The opportunities created by our research during the exploratory stage led us to develop a new research area and to successfully involve partners in a series of subsequent MAGS-based projects, held during what I call the 'micro-simulation stage' of our research program (Fig. 1).

Main Achievements. My team was involved in a GEOIDE funded project on Business Intelligence (Project DEC 7, 2002-05, K. Jones, Project leader) which aimed at applying sophisticated geomatics-based models to a variety of business problems, and especially the development of more advanced spatial models of consumer behavior and perceptions in shopping malls. Being part of this project was a great opportunity

to explore how a MAGS approach simulating customers' behaviors in a shopping mall might provide useful results to mall managers when assessing the mall's spatial layout (considering that the rent of a store depends on its location in the mall). However, in order to carry out such investigations, we needed a robust MAGS platform. Hence, the MAGS Project was launched in 2002 with the support and funds provided by the Defense research center (DRDC Valcartier) which was particularly interested in using MAGS to simulate behaviors of people participating in crowd events.

The *MAGS Project* (2002-2005, B. Moulin Project Leader) led to the development of the *MAGS Platform*, a generic software platform used to simulate, in real-time, thousands of knowledge-based agents navigating in a 2D or 2.5D virtual geographic environment (VGE) created from GIS data [64]. The spatial data characterizing the VGE and its content was coded in a series of bitmaps used by the agents to perceive the VGE and its content, and to navigate in it. We were careful to provide MAGS agents with several knowledge-based capabilities such as perception, navigation, memorization and objective-based behavior, which allowed them to make decisions and navigate autonomously in the VGE, taking into account the VGE's spatial characteristics and the interactions with other agents. A user could specify different scenarios (assigning goals 'or missions' to certain agents, specifying particular events occurring in the VGE such as explosions of tear gas canisters. During the simulation a user could also change the VGE's content by adding objects (i.e. fences in streets), and agents immediately perceived them and adapted their behaviors (Fig. 3B). We coupled MAGS with an external library, AIMSUN, that allowed for the simulation of car displacements and we developed the agents' capability to perception these cars (Fig. 3C). We also developed a generic particle system to simulate the propagation of dense gas and smoke (Fig. 3A) so that agents could perceive them and react accordingly [64]. These characteristics were particularly useful to develop our initial crowd simulations in a portion of 'virtual Quebec city' provided by DRDC Valcartier, and to illustrate the influence of using tear gas on crowd behavior (Fig. 3A), which was of particular interest to our Defense partners.

To complement the MAGS platform we developed an analysis and design method [63] to create agent-based geo-simulations as well as a variety of tools to assess the results of such simulations [62].

In parallel with the MAGS Project, I got with colleagues from CRAD (M. Thériault) and from the Center for Research in Geomatics (Y. Bédard, G. Edwards) a three year funding from Quebec Research Council FQRNT (Project AMUSAL 2002-05, Project Leader B. Moulin). The goal was to explore the use of a MAGS approach and tools to simulate mobility behaviors of individuals in urban environments, taking into account the characteristics and capacity of a transportation network. This research was particularly interesting to us since it was an opportunity to work with a complex VGE (created from a transportation network as well as complementary urban data) and to create very large agent populations using 'real population data' from *Origin Destination surveys* carried out by the Quebec Ministry of Transportation. Fortunately, CRAD

researchers had more than 10 years experience of analysing such data, which enabled us to develop procedures to create agents' profiles and typical behaviors taking into account households' and individuals' characteristics. We could not directly use the MAGS platform to simulate a complex transportation network which is based on vector data. Hence, we developed AMUSAL, a prototype software for the simulation of transportation geo-simulations and to study mobility behaviors of people in urban environments.

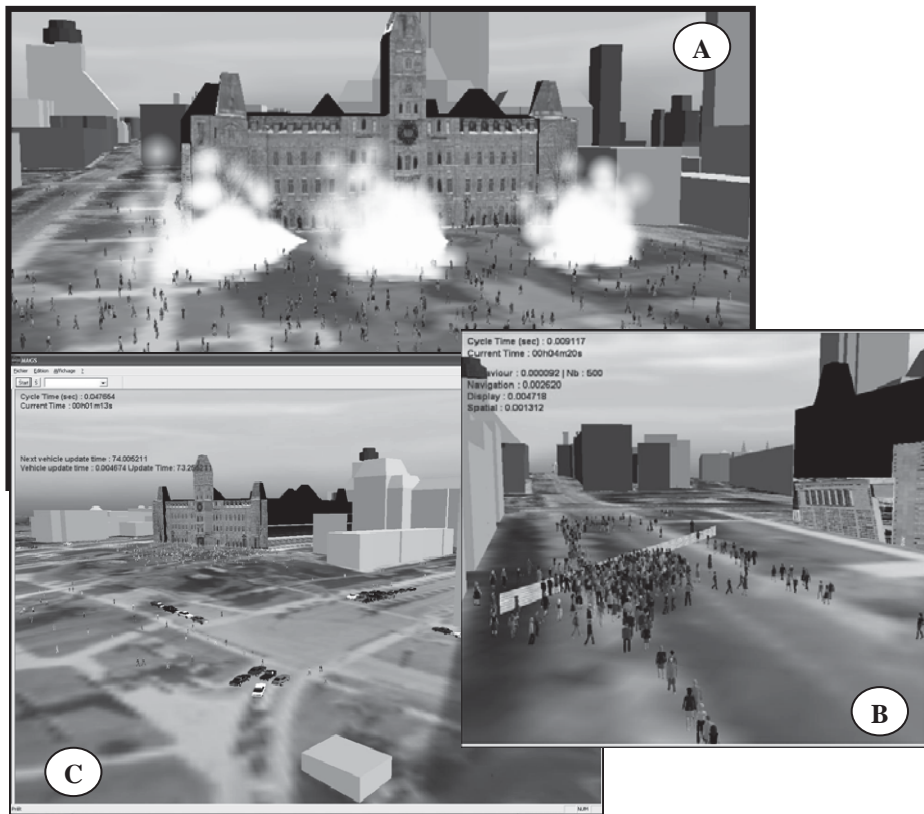


Fig. 3. MAGS System - A: Simulation of a crowd event in front of the Parliament in Virtual Quebec-city. B: The user added a fence which blocks the pedestrians' movements. C: Cars' movements are computed in AIMSUN Library coupled to MAGS.

Main Contributions. MAGS and its companion projects provided a wealth of contributions published in a large number of publications (8 journals, 10 book chapters, 11 international conferences, 1 book) which led to 4 doctoral and 7 Master theses. Indeed, the main contribution was the MAGS System which allowed for the creation of Multi-Agent Geo-Simulations (MAGS) involving several thousands of agents interacting in virtual geographic environments and endowed with spatial cognitive capabilities. In the early twenties different simulation software were available to study trans-

portation systems such as the TRANSIMS System [88]. Based on the SWARM System [93] TRANSIMS uses a cellular automata approach [99] to simulate in real-time the activities of up to 200 000 individual travelers represented by actors whose plans have been predetermined on the basis of their socio-economic characteristics. TRANSIMS is used to conduct regional transportation system analyses [36]. In the late nineties several other systems had been designed to study pedestrian flows and movement such as the PEDFLOW System [45] and the STREETS System [37] which applied an approach similar to the TRANSIMS model to simulate pedestrians' movements in urban districts. Although traffic models used a multi-actor approach, they typically did not contain models of cognitive aspects of human spatial behavior [24] [95]. Indeed, that was a major contribution of the MAGS System to allow for the creation of multi-agent geo-simulations (MAGS) involving several thousands of agents interacting in virtual geographic environments and endowed with spatial cognitive capabilities. These agent's cognitive capabilities (perception, memorization, reasoning, planning) were crucial to model and simulate agent behaviors that took into account the characteristics of the spatial environment, hence providing more realism in crowd simulation for example. In addition, the MAGS System innovated by embedding a particle system to simulate smoke and gas that agents were capable to perceive. Another innovation were the tools that we integrated in the MAGS System to allow a user modify and interact with the virtual geographic environment (VGE) in real time so that agents could immediately react to the new VGE content.

Opportunities Created During this Stage. Thanks to GEOIDE's excellent organizational and networking structure (series of conferences and workshops), our work on MAGS got a national exposure which created new collaboration opportunities, both during the MAGS Project and after its completion in 2005. Hence, we present a number of MAGS 'companion projects'.

MAGS Companion Projects. We present the Mall-MAGS, Fire-MAGS, VNO-MAGS and Train-MAGS Projects, which all used the MAGS platform in different application domains and explored different theoretical and practical aspects of multi-agent geo-simulation.

The *MallMAGS Project* (2003-2005, B. Moulin Project Leader) aimed to simulate customers' behavior in shopping malls [62]. This research was carried out in collaboration with K. Jones' team (Centre for the Study of Commercial Activity at Ryerson Univ.) and two shopping malls, one in Toronto (Square One) and the other in Quebec City (Place de la Cité). Using data that our student teams collected in both shopping malls by interviewing customers, we developed MAGS agents which simulated the spatial displacements of customers in the malls, taking into account the layout of shops in the mall, as well as people's socio-economical profiles, preferences, shopping goals and constraints (Fig. 4A). Tools were developed to display the customer-agents' trajectories in the mall and to inspect the characteristics of agents adopting these trajectories (Fig. 4B, C). The MallMAGS System was a prototype software aiming at helping mall managers assess the spatial configuration of their malls using a

geo-simulation of the customers’ displacements and to compare different spatial configurations while changing the locations of certain shops or stores.

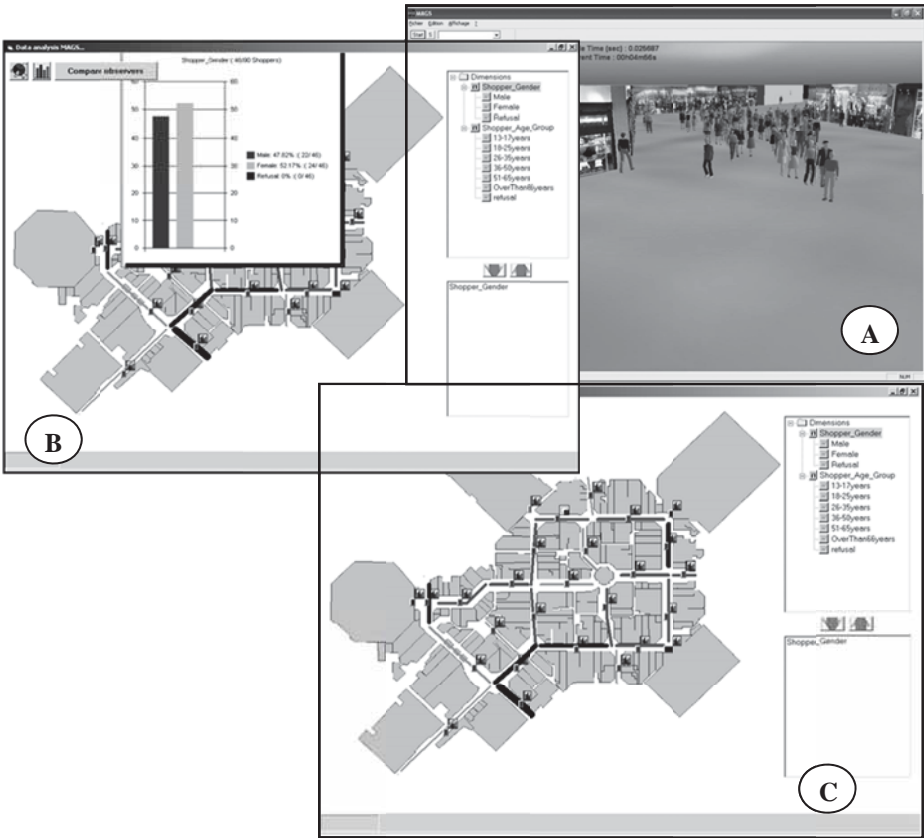


Fig.4. MallMAGS System – A: shows a 3D view of customers in the mall. B: shows the ‘cumulated’ trajectories of mall visitors. C: shows an analysis of pedestrian characteristics on a given trajectory.

With the *FireMAGS Project* (2003-2006, B. Moulin Project Leader) we got the support of Canadian fire fighting agencies (SOPFEU in Quebec and ASRD in Alberta) and showed the interest of using MAGS micro-simulations to support planning activities in dynamic spatial situations, particularly the attack of forest fires [83] [84]. The FireMAGS System was developed and coupled with the Prometheus Library, which enabled our system to simulate changes (the fire spread) in the VGE (a large forest area) (Fig. 5A). In this dynamically changing VGE, MAGS agents (simulating firemen’s dozers) perceived the territory’s geographic characteristics as well as the boundaries of the spreading fire (Fig. 5C). They were equipped with behaviors that allowed them to concurrently find and assess dozers’ potential trajectories (Fig. 5B). These trajectories were proposed to the Fire Fighters’ manager. FireMAGS could be

used to assess and compare different scenarios to create firebreaks, starting from a sketch drawn by a fire manager on a digital map in the virtual environment (Fig. 5B).

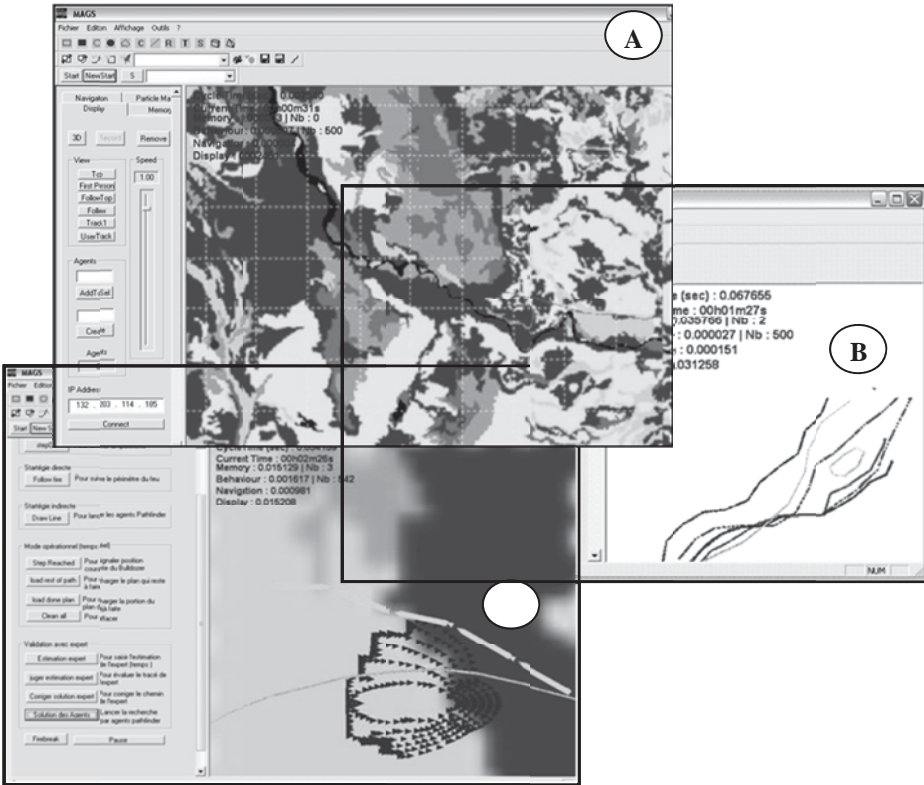


Fig. 5. FireMAGS System - A: the forest map of the simulated area. B: Trajectories of dozer-agents trying to find the best path for dozers. C: In white the trajectory chosen by the commander, in red: the trace of the fire progress.

In addition to the development of the MAGS platform, we created during this stage a comprehensive method to design and implement multi-agent geo-simulations and developed new spatial data analysis tools to analyze MAGS results [62]. The method was initially elaborated during the *Mall-MAGS* project and has been tested and enhanced with the subsequent projects. The method was complemented with tools [3] based on *On Line Analysis Processing* (OLAP) for the non-spatial data analysis and on *Spatial On Line Analysis Processing* (SOLAP) for the spatial data analysis [6]. These innovative tools allowed users and analysts to easily explore data across multiple variables (dimensions) at the same time.

Climate change created another opportunity for our research! The West Nile Virus (WNV) appeared in the province of Quebec in July 2002, the virus being mainly propagated by mosquitoes biting birds (especially crows). The expansion of this epi-

zooty led the Government of Quebec to adopt an intervention plan which included the implementation of a multi-faceted surveillance system in 2003 [33]. This system brought together field data on human, avian and entomological infection and deaths. While these monitoring activities were undertaken to better understand the epidemiology of WNV and the level of risk it can represent for the human population, they do not allow for forecasts of the probable geographic propagation of the virus. Learning about our geo-simulation work, INSPQ (Institut National de Santé Publique du Québec) proposed us to explore how our MAGS approach and tool could help public health managers anticipate the progression of the WNV and to assess various intervention scenarios (climatic and larvicide spread in selected areas). Satisfied by the results of our feasibility study (summer and fall 2003), INSPQ funded the VNO-MAGS Project (2004-07, B. Moulin Project Leader). We enhanced the MAGS Platform with a capability to use mathematical compartment models capturing, in the form of differential equations, the joint evolution of mosquito and bird populations involved in the virus spread. Using the enhanced MAGS Platform and its particle system, we developed the VNO-MAGS System to simulate the propagation of the WNV as a result of the spatio-temporal interactions of two species (*Culex* mosquitoes and crows) in a large territory (Southern part of Quebec province). Moreover, the VNO-MAGS System [9] provides public health officers with an interface to monitor the WNV spread in the VGE and to explore the possible impacts of different intervention scenarios (larvicide application) in the context of various atmospheric conditions (temperature change and rain fall) (Fig. 6A-B).

In the GEOIDE-funded GIST2 Project (R. Harrap, Project Leader 2005-2007) my team got another opportunity to explore how a MAGS approach may help analyzing complex systems which are highly constrained by the geographical environment, such as large railway systems. We were particularly interested in rock fall hazard zoning, the identification of risky zones which are prone to various types of rock falls along railway tracks. In the *Train-MAGS sub-project* my team extended the MAGS System's functionalities to simulate train behaviors and to identify risky areas in large scale geographic environments [56]. This system enabled a user to create a VGE for a large portion of territory crossed by the tracks and to specify the train's characteristics (category, speed, conductor's perception radius, etc.). It also offered the possibility to compare the outputs of several simulation scenarios and to build a table of recommended speeds in the surroundings of risky areas.

Main Contributions of MAGS Companion Projects. MAGS and its companion projects led to 4 doctoral and 7 Master theses and provided a wealth of contributions published in a large number of publications (8 journals, 10 book chapters, 11 international conferences, one PhD dissertation published as a book). Apart from MAGS' main contribution, all its companion projects, Mall-MAGS, Fire-MAGS, VNO-MAGS and Train-MAGS projects introduced innovative solutions based on multi-agent geo-simulation in their different fields of application.

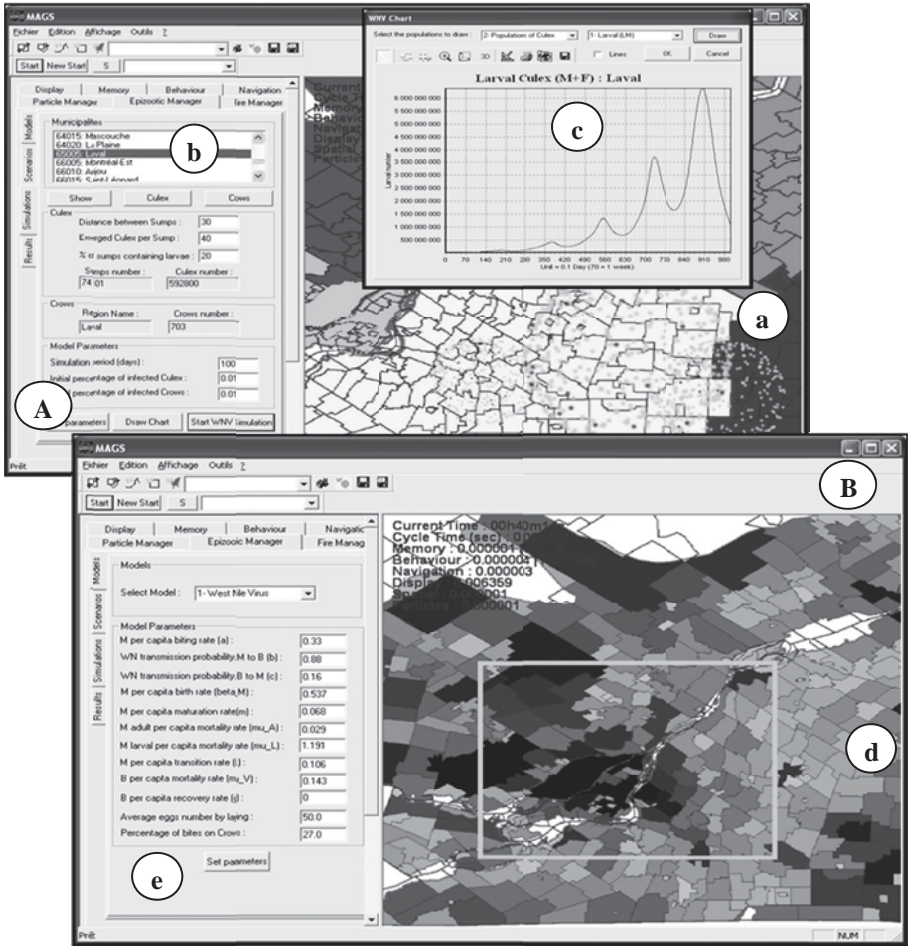


Fig.6. VNO-MAGS System- A displays crows' movements around roosts simulated by particles (a); the user chooses a municipality (b) and the system displays the evolution of the number of larvae over the simulation period for this municipality(c). B shows the map of the municipalities with different densities of infected culex (d) at a given moment of the simulation; and (e) shows the interface in which the user can change the parameters of the compartment model.

In addition, several fundamental advances in multi-agent geo-simulation were made. In the MallMAGS Project, taking advantage of MAGS capabilities, we developed an innovative simulation of shopping behavior in a mall [62]. The only system that attempted such a simulation was the Amanda System [20] that used a cellular automata approach that significantly limited the simulation of shoppers' behavior which were based on simple rules and had none of the MAGS agents' cognitive capabilities. In addition, in MallMAGS we innovated by introducing *Observer Agents* which collected shopper agents' data generated during the simulation and for the analysis of this

output data using OLAP/SOLAP tools [3]. We also proposed a complete and innovative analysis and design method for the creation of multi-agent geo-simulations. Our method goes beyond the mere refinement of models as usually done in social simulation methods [17] [81] and provides a complete software analysis and design method (from the requirement analysis to the software specification) with the use of: 1) MAGS sophisticated agents' models, 2) VGE spatial models, 3) the MAGS Platform to create all these models in an integrated software development framework, 4) integrated OLAP/SOLAP display and analysis tools [63].

In the FireMAGS Project, we developed a general MAGS-based framework which draws a parallel between real and simulated worlds and assists decision makers when solving complex planning problems in real and dynamic large-scale spaces [83]. We developed new agent's spatial capabilities (pathfinding and obstacle avoidance) and created the ACP approach (Anticipated Continual Planning) which overcomes some of shortcomings of the classical continuous planning approach [19] in which plans are built step by step without any guarantee of a final success. Indeed, the ACP approach provides innovative mechanisms to interleave agents' planning and execution [84]. Several works proposed to use agent-based simulation as a mean of planning actions and forecasting events [46] but they do not make the link with the real world as we did in the FireMAGS and later in the TrainMAGS systems, and are thus hardly appropriate to real-world applications in real-time. In the TrainMAGS system we developed a system to assist decision makers identify risky areas (rock fall areas) and optimize the train traffic in the vicinity of such areas. We thus aimed at showing how a MAGS model can solve complex problems in large railway systems [42]. The contributions of the VNO-MAGS project will be discussed in Section 3.4.

Technology Transfer. In 2006 the know-how created during the MAGS Project was transferred to *NSim Technology*, a start-up company founded by two of our team members who were the main developers of the MAGS Platform: J. Perron and J. Hogan. NSim Technology developed *Geo-SDK*, a commercial and enhanced version of MAGS that facilitates users' collaborative work. *Geo-SDK* was based on a new architecture in which a geo-simulation server may be accessed by several client applications from which users specify scenarios, explore the VGE and assess the simulation outputs. GeoSDK has been used in various application areas such as crowd monitoring, civil security and defense operations [47]. For example, in the COLMAS Project we proposed an innovative hybrid approach for the automatic generation of near optimal solutions for the patrolling/surveillance problem, combining distributed reinforcement learning and multi-agent geo-simulation to handle task allocation (high-level planning) and navigation/routing (low-level planning) respectively [77].

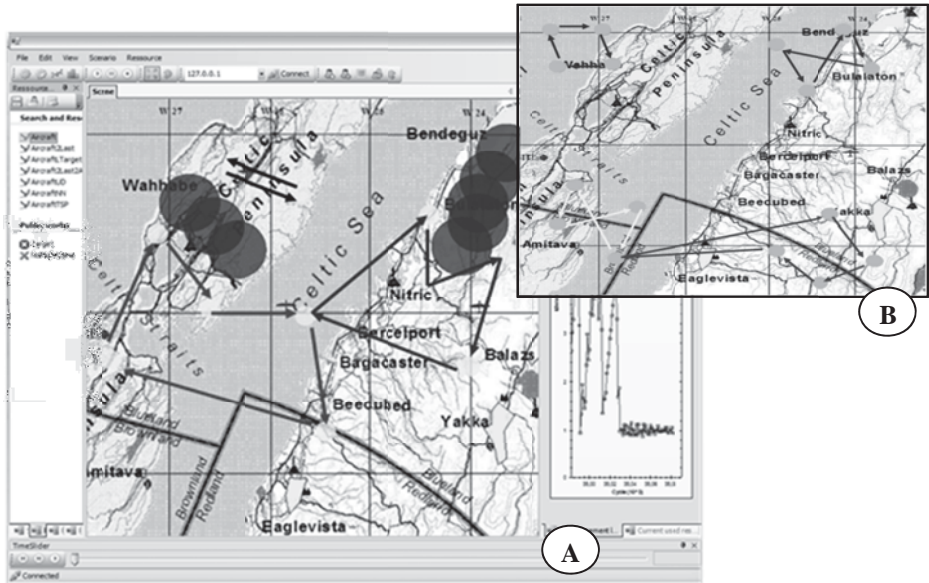


Fig. 7. The COLMAS System using NSim Technologies GeoSDK Platform- A: shows the system's main interface and the patrolling pattern generated by the learning algorithm for 3 UAV agents and 10 targets and obstacles (red areas) B: shows the pattern for 4 AUV and 16 targets without obstacle.

Using GeoSDK, NSim's team developed the COLMAS System which implements the proposed approach and enables a team of Unmanned Aerial Vehicles (UAV) to autonomously navigate and coordinate their actions in a realistic VGE characterized by emerging obstacles and moving targets (Fig. 7). The system demonstrates how a set of UAV agents can automatically find patrolling patterns, taking into account the geographic characteristics of the VGE and dynamic constraints (targets may move without notice) [77].

3.3 The MAGS Enhancements and the Multi-Scale Stages

During the micro-simulation stage we learned some important lessons. In the different domains that we investigated, while we usually needed to model MADSSs at a micro-level to insure a good fit between the simulations and real phenomena, it was clear that decision makers needed to observe/assess the situations at more global levels (mainly at a meso-level where simulation outputs were sufficiently aggregated to provide useful indicators or to show typical patterns of behaviors or interactions). We also found out that decision makers naturally use qualitative and coarse descriptions of situations and of action plans. Hence, there was a need for more flexible simulation/analysis tools that allowed users to explore situations from different perspectives (at different levels of detail) and to compare the outcomes of different scenarios. Our new research (MAGS Enhancements and the Multi-Scale stages)

aimed to study multi-level MADSSs as well as on enhancing several aspects of the micro-level MAGS.

Triggering Events. During the micro-simulation stage, GEOIDE gave us the opportunity to disseminate our research results in a variety of venues (Annual conferences, workshops, seminars), and this led us to launch the MUSCAMAGS Project (2005-2009, B. Moulin Project leader) funded by GEOIDE with the support of a large number of partners: Ministère des ressources naturelles et de la faune du Québec, Alberta Sustainable Resource Development, Center for Spatial Analysis at McMaster University, DRDC Valcartier, Institut National de Santé Publique du Québec, Joint Program in Transportation (University of Toronto), Ministère des transports du Québec, NSim Technology, PROCESSUS Research Network, SOPFEU, Sûreté du Québec, Time Use Research Program at St Mary's University (Halifax), Service de police de la Ville de Québec.

Main Achievements and Contributions. In this chapter we cannot describe all the complementary sub-projects developed in the MUSCAMAGS context and carried out by other team members at Laval University (in Quebec) and at McMaster, Wilfrid Laurier and Queens universities (in Ontario). We only mention here the research components that aimed to develop a methodology and a generic software platform to create multi-scale multi-agent geo-simulations to support operational decision support systems for MADSSs, capitalizing on our MAGS and AMUSAL previous works. Our geo-simulation work in the MUSCAMAGS Project built upon five companion projects: 1) the TransNetSim Project for multi-scale geo-simulations in the transportation domain; 2) the IVGE Project for the creation and use of 3D VGE enhanced with semantic information that agents can exploit; 3) the CrowdMAGS Project for the geo-simulation of the interactions of crowds and control forces; 4) the PLAMAGS Project that aimed to develop a high-level language and a complete development environment to create multi-agent geo-simulations and 5) the MAGS-COA Project for the use of qualitative reasoning techniques to analyze MAGS results. Let us mention that these projects provided a wealth of contributions published in a large number of publications (6 journals, 10 book chapters, 21 international conferences, 1 book) which led to 4 doctoral and 1 Master theses.

Capitalizing on the experience gained in the AMUSAL Project, the *TransNetSim Project* (2005-2009, B. Moulin Project Leader) aimed at developing tools to create large populations of agents and plausibly simulate their displacements in urban areas (such as Quebec-city) in MADSSs that can be examined at different scales (spatial, temporal, behavioral). We created an innovative, generic and scale-independent method to model and create an urban VGE in a way that combines data about the population, the transportation network and particular locations [15]. We used this new form of VGE in simulations carried out at different scales without major changes in its data structures, which was an innovation with respect to tools that were currently used at that time [11] [4].

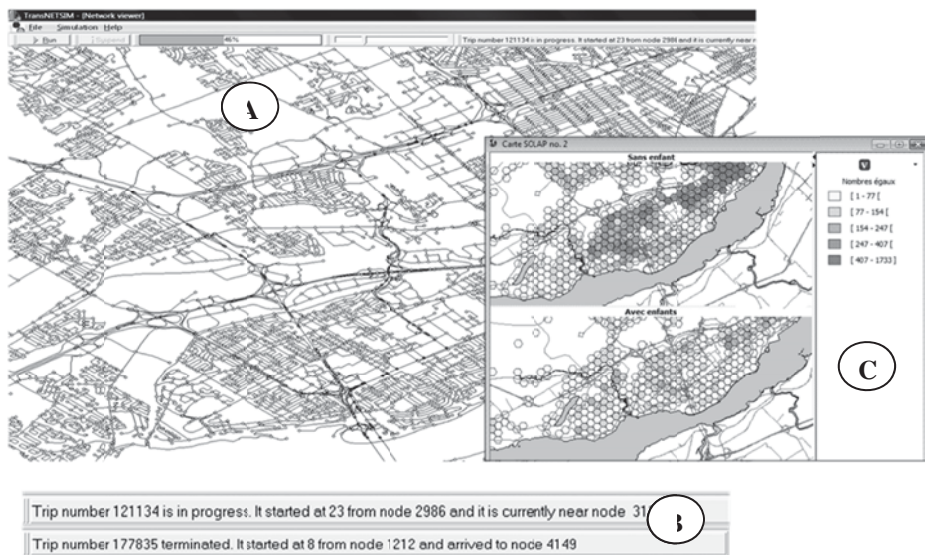


Fig.8. TransNetSim System - A shows the main window in which the movements of thousands of cars are displayed as dots on the road network. B: shows the trace of the current state of the trajectory of an agent (called ‘trip’) in relation to its position relative to the nodes of the road network. C: shows the hexagonal tessellation of the area which is used to locate places and to analyze spatial data.

In the *TransNetSim Project* we applied this method and developed a meso-scale traffic simulator, TransNetSIM (Fig. 8), which plausibly simulates the daily displacements of a large population (600 000 individuals with single purpose trips) at a meso-scale (a transportation network of 81000 links and 32000 nodes). Our experiments showed that TransNetSIM was 757 times faster than TransCAD, the popular GIS used in transportation applications, using similar data [14]. This innovative research showed the interest of efficiently associating population and behavioral knowledge related to the IVGE (in this case pre-computed routes) with much less computing power than required in systems such as TRANSIMS. See [14] for a comparison between TransNetSIM and TRANSIMS.

In recent years, there has been a growing interest in the development of hybrid or multi-scale approaches, not only in traffic simulations but also in the larger context of urban simulations [5]. Let us mention for example the approaches that couple macro and micro traffic behaviors [11] and commercial software that perform multi-scale traffic simulations (also called hybrid simulations) such as TransModeler [97] and AimsunNG [4]. Traditional approaches usually separate the supply and the demand forecasting by separately modeling the travel demand and the transportation network. Such a separation introduces calibration difficulties because, at runtime, one simulator needs to provide travel demand to other lower level simulators in a consistent way which depends on how the network is decomposed in each simulator, and on the level

of detail of these decompositions. The TransNetSIM approach innovated by integrating as much as possible the transportation network and the travel demand in multiscale models, which significantly simplifies the calibration tasks [14]. We also explored the use of SOLAP tools to analyze the results of TransNetSIM simulations [16].

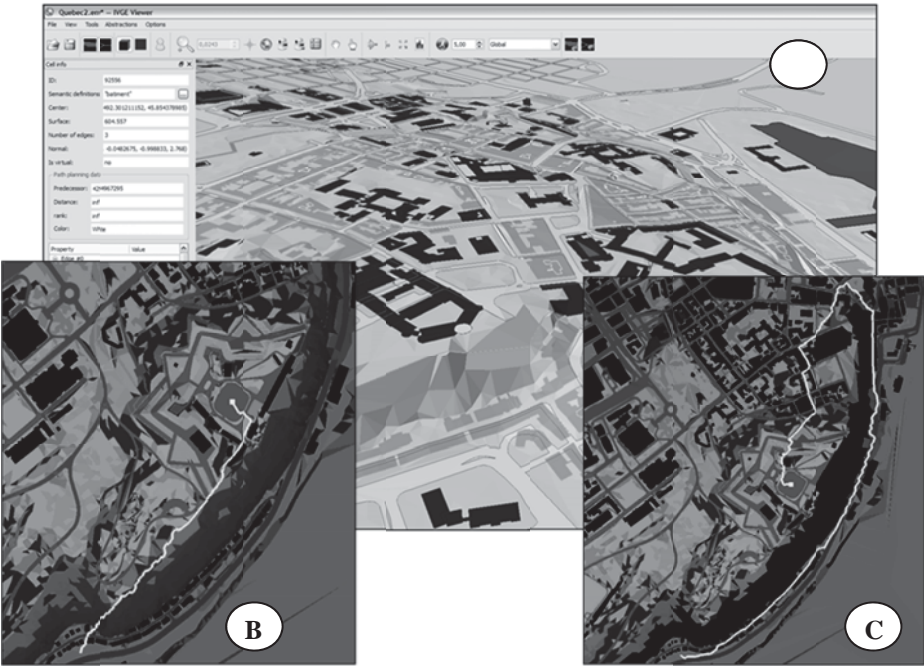


Fig.9. IVGE System – A shows the main window and a 3D view of the Quebec-city VGE in which cells are associated with different spatial and semantic information. B: presents in 2D the trajectory (shortest path) of a ‘climber agent’ who does not mind crossing steep slopes to go to the ‘old city’s citadel’. C: shows the trajectory of an agent who follows roads to go around the steep slopes toward the citadel.

In parallel, the *IVGE Project* (2006-2009, B. Moulin Project Leader) was co-financed by GEOIDE and RDDC Valcartier and aimed at efficiently simulating agents’ path finding capabilities in an accurate 3D VGE. Instead of providing agents with large quantities of spatial knowledge and sophisticated reasoning capabilities, which is not efficient if we want to simulate the simultaneous displacements of thousands of knowledge-based agents, we proposed to put as much knowledge as possible in the VGE and to enable agents to access it when needed. Hence, we created a semantically-enhanced and geometrically accurate virtual geographic environment called an *Informed VGE* (IVGE). We proposed a novel approach and developed a tool [57] to automatically build an accurate IVGE using an exact decomposition of realistic spatial data provided by a GIS (Fig. 9A). The IVGE model relies on a hierarchical topo-

logic graph structure built using geometric, topologic and semantic abstraction processes, and enhanced by spatial and semantic information represented using Conceptual Graphs [89]. Taking advantage of the IVGE's space partitioning and qualification (terrain elevations are qualified for spatial reasoning purposes), agents can efficiently perform path planning activities and determine paths in the VGE that agree with a qualitative characterization of spatial constraints (i.e. qualitative characterization of slopes) and the agent's profile (i.e. displacements' capabilities) (Fig. 9B-C).

We developed the IVGE System and IVGE-Viewer an associated tool [57] to visualize multi-level (hierarchical) multiple views of complex and large-scale 3D VGE, as well as agents' displacements in it. The system has been used in different domains (path planning in urban and natural environments, deployment of sensors). Informed environments [25] have been used in the computer animation and behavioral animation research fields for different purposes, including the simulation of inhabited cities and the simulation of virtual humans [30]. In the IVGE Project we went beyond these works by fully exploiting the power of GIS enhanced with artificial intelligence techniques. Indeed, our approach and tool are able to use GIS data to generate a geometrically-accurate and semantically-enriched VGE that provides agents with the capability to reason about a contextualized description of their virtual environment during the simulation. Taking advantage of this agent's reasoning ability we developed an innovative hierarchical path planning algorithm (using Dijkstra and A*) to determine paths which take into account the agents' and environment's characteristics in large scale and complex geographic environments [55].

The *PLAMAGS Project* (2004-2009, B. Moulin Project Leader) overlapped the MAGS and MUSCAMAGS project. It aimed to develop PLAMAGS (Programming LAnguage for Multi-Agent Geo-Simulations), a high-level language and a complete development framework allowing a designer to quickly model, implement and execute multi-agent geo-simulations [31] in a 3D VGE created from GIS data. Extending the MAGS conceptual framework, PLAMAGS offers a complete programming language dedicated to the specification, the execution and testing of multi-agent geo-simulations and a software development framework which provides: 1) a program editor (with real-time error checking); 2) a project management tree; 3) a contextual tree (describing the components of the file); 4) a language validation engine (similar to a compiler); 5) a runtime engine (an interpreter); 6) a 3D engine to visualize the simulations. Considering the creation of agent-based simulations for animation purposes, different software such as HPTS [21], AI.Implant [1] and PathEngine [74] provide good navigation mechanisms for animated characters. To specify the agents' behaviors other tools such as SimBionic [26] and SPIR.OPS [90] offer sophisticated mechanisms and models inspired by finite state machines. But, the use of finite state machines leads to complex graphs, even for representing relatively simple reactive behaviors. Behaviors developed using these tools lead to reactive agents or "navigation driven" agents [18]. In contrast, extending the MAGS Approach [64] the PLAMAGS environment allows for the specification of 'proactive agents' with space-related knowledge-based capabilities: perception, reasoning and decision-making

functions taking into account the VGE spatial and semantic content. In addition, the PLAMAGS Language and framework naturally lead a designer to use a modeling and design method, the PLAMAGS method which supports every step of the development cycle of a multi-agent geo-simulation (MAGS), from the requirements analysis to the modeling, implementation and validation steps. This is possible thanks to the language and framework that support all these steps while offering all the necessary mechanisms for the specification and integration of geographic data, agents' behaviors, and the spatial interactions between agents as well as with the VGE content (objects, geographic features). In this way, PLAMAGS eliminates the translation steps between the models and their implementations that designers need to carry out when using other MAGS specification approaches. Hence, PLAMAGS greatly reduces the implementation effort and increases the fidelity of the simulations relatively to the designers' conceptual models [31]. PLAMAGS has been used in various projects and provided the core of the Crowd-MAGS System.

The *MAGS-COA Project* (2004-2009, B. Moulin Project Leader) was also financed by RDDC Valcartier in the context of a Defense TIF project (M. Bélanger, Project Leader). We developed a general framework to qualitatively assess courses of action (COA) which need to be executed in a realistic and changing geographic space. Particularly, the framework aimed to support commanders' mental anticipation of the effects of different plans of actions by simulating the execution of COAs in a virtual geographic environment, which can change during the simulation. We proposed a MAGS-based approach to support a kind of qualitative spatial-temporal reasoning called "What-if" reasoning which allows a person to explore the consequences of different alternative plans by asking questions of the form "WHAT would the situation be IF ...". Built on top of the MAGS Platform [64], the MAGS-COA System allows a user to explore different COAs (i.e. scenarios) and to analyze their outcomes [39]. It allows a user to introduce events that modify the VGE and to explore their effects. The MAGS-COA System innovated by taking advantage of different approaches such as cognitive archetypes, ontological definitions of geographic space, conceptual graphs and MAGS concepts [38]. The resulting combined temporal and spatial models allow a user to represent spatio-temporal causal constraints and the system to reason about causality, which is an innovation in the domain of MAGS and decision support systems [39]. The system was applied to Search and Rescue (S&R) in the aerial domain, in which an S&R controller tries to reconstruct the 'events' that might have occurred in order to identify an area where a lost plane may have crashed. The MAGS-COA System simulated the plane's course of action and different scenarios were assessed, taking into account different hypothesis (What-if alternatives) such as meteorological changes (poor weather conditions, change of wind speed and direction) and plane constraints (fuel consumption, pilot's abilities). The system's assessment component provided explanations of the causality chain that might explain a pilot-agent's goal failure. In the GIScience literature, event-based approaches [27] [28] [29] [101] [102] allow to fully model spatio-temporal phenomena (also called dynamic geographic phenomena) in geographic environments. But, they can be used neither to model phenomena involving objects other than spatial regions, such as the

resources of a COA, nor to simulate dynamic geographic phenomena. In this context, the MAGS-COA Project innovated in proposing a new conceptual model of spatio-temporal situations [38] and offering a system that supports qualitative spatio-temporal causal reasoning about COAs in changing geographic spaces [39]; all this being applied in the practical context of What-If analyses.

The *Crowd-MAGS Project* (2007-2009, B. Moulin Project Leader) was a companion project of the IVGE Project and financed by RDDC Valcartier in the context of another TIF project (L. Stemate, Project Leader). In the Crowd-MAGS Project we aimed at combining a MAGS approach (micro level) and a system dynamics simulation approach (macro level) to assess the impact of the use of non-lethal weapons by control forces in crowd-related events [92]. The project's goal was to help commanders assess the influence of using different types of non-lethal weapons to control a crowd. We proposed an innovative approach of crowd simulation [66] that explicitly models individuals, groups and their interactions, based on their social characteristics, as well as on the assessment of these characteristics by the individual agents during the simulation. Extending the PLAMAGS Platform, we developed the CrowdMAGS System a generic platform to simulate the behaviors and interactions of a crowd and of control forces in urban environments in order to assess different intervention strategies using non lethal weapons (fences, tear gas, and plastic bullets).

CrowdMAGS's simulations involve agents gathered in crowds as well as agents simulating control forces and their collective behaviors in a 3D VGE representing a portion of a city (Fig. 10A). Playing the role of a commander, a user provides orders to control forces' agents and can observe and compare the effects of different control strategies (involving the use of different non-lethal weapons) on crowds (possibly of different types) in a urban VGE (Fig. 10B). The CrowdMAGS software also offers different visualization and analysis tools (Fig. 10A, C).

The results of the CrowdMAGS' micro-simulations were input in a software based on System Dynamics and developed by the RDDC team, which aimed to assess and compare control strategies involving the use of different lethal weapons. System Dynamics simulations can only model a phenomenon at a global level (macro-level) since they use global indicators and cannot capture the spatial and individual aspects of the phenomenon. The CrowdMAGS simulations complemented the System Dynamics Model by providing the realism of agents' perception, decisions and actions in a 3D VGE representing an urban environment, taking into account individual and group behaviors as well as the manipulation of objects (weapons, tear gas canisters, etc.).

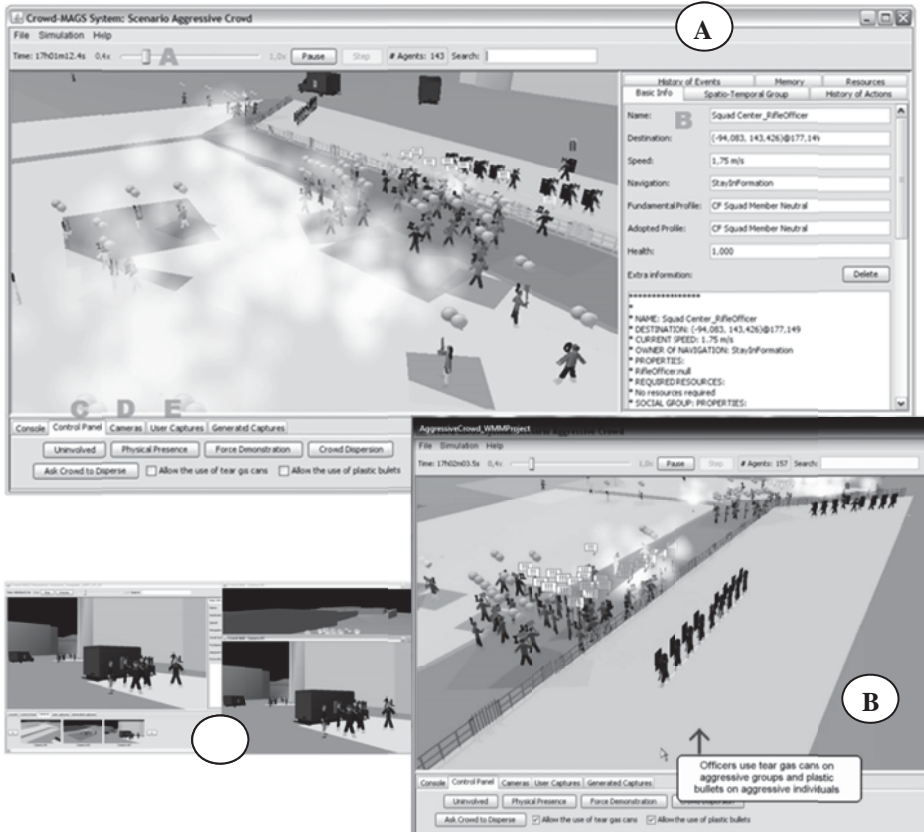


Fig. 10. CrowdMAGS System – A shows the main user interface in which the simulation is displayed: we see the crowd and control forces on each side of fences. The polygons drawn on the ground show the ‘groups’. B shows another view in which there is an angry crowd and an officer has thrown tear gas canisters. C shows the views that the user can have on the scene, using multiple cameras.

The *CrowdMAGS Project* brought up a number of scientific innovations. This is the first approach of crowd simulations that explicitly models individuals, groups and their interactions, based on their social characteristics [87] as well as on the assessment of these characteristics by autonomous agents. Several approaches tried to incorporate psychological factors in crowd simulations [44] [86]. Most approaches offer models to specify the individual’s characteristics (physiological, psychological and emotional) and the individual’s behaviors. However, they do not provide sufficient constructs and mechanisms to specify and simulate the interactions between individuals and groups. When it comes to modeling police forces, we did not find any system that convincingly modeled agents and groups and their interactions with crowds. In the few simulations that introduce agents simulating policemen or soldiers, these agents had limited autonomous behaviors as in the Crowd Federate System [52]. Several systems are able to simulate some aspects of the dynamics of groups in a crowd

[94], but only in a ‘kinematic way’, taking advantage of the geometric properties (such as distance between group members, orientations, personal space) of agents moving in groups and of attraction/repulsion rules/forces that enable the system to maintain the group’s geometrical coherence. Simulating groups in a kinematic way may be sufficient for animation purposes as in the V-Crowd System [67].

However, there is a need for more elaborated models integrating both the individual’s characteristics (psychological, emotional) and social rules/behaviors in order to explain why agents may join or leave a group, why perceiving and interpreting the actions carried out by the members of a group may induce an agent to change behavior or even ‘change of identity’ as some sociologists call it [80]. This is what we achieved with our CrowdMAGS approach and tool which allow for plausibly simulating the interactions of a crowd and control forces that result from both individual and collective actions. The CrowdMAGS model allows for the explicit modeling of groups and their interactions with other groups and agents. CrowdMAGS agents perceive individuals and groups, assess their behaviors and may decide to join a group (to participate in its ‘collective actions’) or to leave it (and again behave individually) according to their preferences (or ‘social values’). Agents also react to simulated non-lethal weapons (NLW) that might be used by control forces. To conclude, we must mention that this project has been fairly effective in opening new grounds for the development of crowd simulations with agent models in which the social dimension is explicitly taken into account not only at the individual level, but also at the group level [66].

Lessons Learned. During this fourth stage of our research we learned important lessons during projects that needed to combine different modeling and simulation paradigms. We particularly explored the link between simulations of a given phenomenon taking place at a micro and a macro level and experimented with the coupling of MAGS and Systems Dynamics models in the CrowdMAGS Project, and in an indirect way in the VNO-MAGS Project. System Dynamics is useful to model policies (translated in terms of global action plans) at a global level and taking into account their interactions. Such policies provide guidelines to decision makers when attempting to control an evolving situation (such as a growing aggressiveness of a crowd in a demonstration or a rapid increase of the number of crows infected by the West Nile Virus in a given area). By comparing the results of System Dynamics simulations, decision makers may assess different sets of interacting and evolving parameters in order to determine the ‘targets’ (general goals) of the proposed intervention plans. But, they cannot anticipate the outcomes of the intervention plans since Systems Dynamics can take into account neither the spatial characteristics of a given situation, nor the actions of individuals (or groups) involved in such a situation. This is where a MAGS approach can be extremely useful since it takes into account the agents’ autonomy and ‘situated behaviors’, as well as the spatial and temporal characteristics of situations (evolving in the VGE) to plausibly simulate the situation dynamics at a micro level (as in the case of crowd demonstrations) or at a meso level (as in the case of the WNV spread). Other authors have suggested the coupling of system dynamics and agent-based approaches [85] [8].

During this stage, we also got an increasing experience with projects that aimed to model agent groups and large populations of agents and we experimented with different approaches and modeling paradigms. In the TransNetSim Project, we created several thousands of agents which plausibly represented the population of an urban area according to data collected by OD surveys on a significant sample (around 8%) of the real population. However, the simulation took place at a meso level (displacements of cars on a transportation network) and the agents did not need sophisticated knowledge-based capabilities (perception is replaced by data about the agent's geographic location, simple decision making, and no planning since routes are pre-computed by the system and agents chose them according to their preferences and profile). Moreover, the number of agents that can be simulated in a micro-simulation is limited since each agent is autonomous and needs sophisticated abilities (perception, memorization, decision making and acting, and even planning in some cases) and knowledge (about the environment, other agents and itself).

We also experimented with increasingly sophisticated agents in micro-simulations during the MAGS, IVGE and CrowdMAGS projects. Although crowd have simulated in a 'mechanistic way' for a long time [41] we found out in the CrowdMAGS Project that it is illusive to expect that group social behaviors might practically emerge in a MAGS from the interactions of individual agents because the amount of knowledge required by agents is huge and the psycho-sociological models of such phenomena are not available yet. Hence, grounding our approach on research works on the sociology of crowds and on 'collective actions' [22] [80] we introduced and implemented a new type of group agents that are capable of 'orchestrating' collective behaviors carried out by individual agents [66]. Individual agents can perceive groups and decide to join them or to leave them. This was an innovation of the CrowdMAGS Project with respect to current crowd simulation approaches. However, such an approach is not applicable when dealing with extremely huge populations as it is the case in phenomena involving insects and very large groups of animals. This led us to the fifth stage of our research presented in the next section.

3.4 The Populations Dynamics Stage

In retrospect, this stage started when we tried to model and simulate the spread of the West Nile Virus and launched the WNO-MAGS Project (see Section 3.2). When trying to model and simulate the spread of communicable diseases, the main challenge is to represent huge populations of individuals that may be at different stages of their evolution cycle as well as the spatial interactions of the individuals of different species (in this case mosquitoes and birds such as crows) that may result in the transmission of viruses or bacteria. For a long time, various mathematical models have been used by epidemiologists and mathematicians, mainly based on compartment models (such as [100] which are composed of a set of differential equations that can be analyzed to identify some global characteristics of the disease spread (such as the speed of the 'traveling wave' of an epidemics). The introduction of other factors relevant to public health decision makers such as the influence of temperature and human inter-

ventions (i.e. spreading larvicides) can significantly increase the models' complexity, and usually the system of differential equations is converted into a System Dynamics model [69] which is enhanced with the relevant factors. However, these mathematical systems have shortcomings: they neither take into account the geographic characteristics of the phenomenon, nor the spatial interactions between the populations of the involved species and their variations in relation to the landscape.

Early Achievements. We first addressed this challenge in the VNO-MAGS Project. Since this approach is somewhat new to most readers, we provide here a lengthier description of how we modeled huge populations of two species (mosquitoes and crows) and their spatial interactions in the context of a geo-simulation taking place in a VGE representing a very large territory (i.e. southern part of Quebec province). Using a compartment model extending Wonham's model [100] with a temperature component, we modelled the transitions between the different stages of each species (eggs, larvae, susceptible adults, infected adults for mosquitoes, and susceptible adults and infected adults for crows), taking into account possible interactions between crows and mosquitoes. Considering the available data and the intervention level of public health authorities, the VGE was composed of a tessellation of irregular cells (municipalities or census tracts) obtained from GIS data. Since mosquitoes' movements are negligible at this scale, we considered that mosquito populations are stationary and that the corresponding data (characterizing each compartment of the population) can be attached to the cell. We found out means to 'roughly' estimate the initial mosquito populations in each cell at the beginning of Spring [9]. But, we also needed to model the displacements of crow groups.

During early Spring bird couples spread over the whole territory and remain for few months around their nesting areas. By the end of June, crows change their social behavior and regroup in roosts at night, while flying to surrounding areas in search of food during the day. Since July to August correspond to the peak period for mosquito populations' growth and risk of WNV spread, we decided to simulate the phenomenon between the end of June and the end of September. Processing historical ornithological data (EPOQ data base) as well as field data, we implemented crows' roosts in the VGE as special stationary agents from which groups of crows (modeled by particles of variable numbers of individuals) would spread to a certain distance (of several kilometers) during the day and go back at night. Moreover, we used MAGS' particle system capabilities to simulate the displacements of crow groups (Fig. 6Aa). At each simulation step (step duration: one day) and for each cell, the VNO-MAGS System determines how many crows will go to a neighboring cell.

Considering the number of individuals for each mosquito compartment and for each crow compartment in a cell, the system uses the equations of the compartment model (an extension of Wonham's model [100]) to determine the new values of the number of individuals of each individual that will be used at the next simulation step. Hence, the system simulates the evolution of the different compartments of mosquitoes' and of crows' sub-populations for each cell and at each simulation step. In this way, the

VNO-MAGS System simulates the WNV spread by displaying in color codes (in what we called ‘an intelligent map’) the variations of the number of individuals of the infected compartments for mosquitoes and crows in each municipality of the province (Fig. 6Ac, 6Bd). The system also enables a user to specify scenarios in order to explore various meteorological situations (influence of temperature changes, of heavy rains) and different intervention strategies (i.e. spreading larvicides in sumps along the roads of certain municipalities). In addition, the VNO-MAGS’ user interface enables the user to modify the parameters of the mathematical model (Fig. 6Be), to visualize the infection progress in and around the crow roosts, to extract data from the simulation and generate graphs showing the evolution of the involved populations (Fig. 6Ac).

Contributions of the VNO-MAGS Project. The interest of using agent-based simulation in epidemiology is increasingly recognized but the languages and tools (Swarm, Ascape, RePast, StarLogo) that have been used in previous years are not sufficient, especially because they were not able to use plausible GIS data [75]. Let us quote Patlolla and his colleagues: “Even though agent-based modeling tools useful to epidemiologists exist today, the unique features of epidemiology require the development of new tools. Data from various sources and in different formats need to be input into these models, highlighting the need for developing tools to convert existing data into uniform formats. Also, data are most commonly available in GIS format, but agent-based tools are not able to directly read data from these sources”. This is exactly what the VNO-MAGS System does; integrating data from different sources (temperature, roosts positions, number of sumps in each municipality, etc.) and GIS data. But, beyond this advantage, the VNO-MAGS System is based on a population-based geo-simulation approach and not on an agent-based approach. We have shown that huge populations of different interacting species cannot be modelled and simulated by agents. In addition, our system integrates compartment models for the evolution and interactions of the species, a module to specify climatic and intervention scenarios, and tools to assess the evolution of the individuals at each stage in each municipality or census track. However, agent models [48] can be advantageously used to model and simulate the spread of communicable diseases among populations of interacting agents (such as humans) as for example in the simulation of measles outbreak in an urban environment [76].

Opportunities. In 2007, the promising results that we obtained with the VNO-MAGS System attracted the attention of researchers in Ontario (at Queens and York universities, particularly the Center for Disease Modeling / York Institute of Health Research) who specialize in the mathematical modeling of disease spread [59] [82]. That was the beginning of a new collaboration and the creation of a team including other researchers from Manitoba, Ontario and Quebec. In 2008 GEOIDE accepted to fund our CODIGEOSIM Project (Project Leader, J. Wu) that aimed at : 1) creating mathematical/statistical, environmental, mobility, and population risk models and dynamic simulation tools to explore the spatio-temporal spread patterns and optimal control measures for a variety of communicable diseases (WNV, Lyme Disease, Avian Influenza, pandemic influenza); 2) developing geo-simulation and decision support sys-

tems that integrate the aforementioned models, data and information, and enable what-if analyses through the specification of various kinds of scenarios such as climate/environmental change, host mobility and intervention plans. During the same period, INSPQ identified Lyme disease as a new zoonose that needed to be monitored in Quebec as a potential threat to public health [34]. INSPQ's specialists suspected that ticks (which transmit the bacteria responsible for the disease to rodents, birds, deer and humans if they can bite them) were likely to spread further north and east from the areas where colonies are already established in southern Ontario and southern Quebec. Hence, they were interested in exploring if a MAGS approach could help simulate the spread of ticks and identify potential risk areas for human populations. They accepted to finance the development of our new simulation tool for zoonoses, the ZoonosisMAGS System. INSPQ also provided us with the opportunity to team up with the Canadian specialists of Lyme disease at the Public Health Agency of Canada (PHAC) in St Hyacinthe (Quebec) [70].

Recent Achievements. In the CODIGEOSIM Project my team was responsible for the development of MAGS tools that can be used to simulate disease spread, and more specifically zoonoses. We mainly worked on two zoonoses: WNV and Lyme diseases. Ticks have a complex life cycle that spreads over two and half years: they go through 3 stages (larvae, nymphae and adults) each of which needs to make a blood meal to go to the next stage or for adult males to fecundate females and enable them to lay eggs. Larvae and nymphae can bite either rodents or birds (reservoir species for the bacteria responsible for Lyme disease) that pass nearby the tick, while adult ticks need to cling to bigger mammals such as deer for feeding and fecundation. Each of these stages is characterized by different compartments (such as hardening or maturing, questing, feeding, engorged, infected), and the transitions (after a temperature and time dependent maturation period) from one compartment to the next depend on the temperature and on the possibility of biting a host. Hence, the compartment models are mathematically complex, and System Dynamics models have been used (Ogden et al. 2005) to model the evolution of ticks and in some cases their interactions with rodents. However, as mentioned before, these models cannot take into account the geographic and spatial characteristics of the phenomenon. Hence, a MAGS approach was recommended. Since the VNO-MAGS System was not generic enough, we decided to work on a new generic geo-simulation approach applicable to any zoonose and launched the ZoonosisMAGS Project (2008-2012, B. Moulin, Project leader).

Thanks to the experience acquired during the MUSCAMAGS and VNO-MAGS projects and aware that different decision makers may need to assess a given situation at different levels (macro, meso, micro), we decided to create a hierarchical VGE composed of different spatial levels at which the simulated phenomenon (such as the tick spread) can be observed and assessed; each level corresponding to a tessellation of irregular cells. Exploiting land-cover data in relation to the habitat suitability to various species is a real challenge [72]. Indeed, an important issue is to identify and automatically generate sets of cells that respect the characteristics of the phenomenon's biology. For example, if we want to identify areas suitable to the survival of ticks, it

does not make sense to use a tessellation based on ‘artificial’ administrative boundaries. Instead, it is appropriate to use GIS data to determine such areas, considering the kinds of land-covers that are suitable to ticks (similar tessellations need to be computed for birds, deer). We are currently developing a system to automatically create such ‘biologically friendly tessellations’. These ‘biologically friendly tessellations’ are exploited by the geosimulator to plausibly simulate the biological phenomenon, but the resulting simulations may be too detailed for the end-user who often needs to make decisions in an administrative context. So, we need to aggregate simulation results in another space tessellation using administrative boundaries such as municipalities, census tracks or health administrative regions. The hierarchical characteristics of our new VGE allows for such aggregations.

Assessing the complexity of Lyme disease modelling (resulting from the interactions of ticks with rodents, birds, deer, humans and their pets), we realized that we could not directly use the VNO-MAGS geosimulator which used an equation solver for the compartment model for mosquitoes and crows [9]. The compartment models associated with the species involved in the tick propagation (and Lyme disease spread) were too complex and too much dependent on the temperature as well as on local geographical conditions (suitable areas). In addition, we had to model and simulate different kinds of displacements: Spring arrival of migrating birds carrying juvenile ticks ‘grabbed’ during stopovers in tick infested areas in the US; Spring and Summer displacements of birds; deer’s displacements which change during the year from Winter quarters to Spring quarters, and then to Summer quarters before going back to Winter quarters. Such a complexity raised new theoretical and technical challenges and led us to propose a new formalism that integrates all these aspects [10].

Using this new formalism, the ZoonosisMAGS Platform is currently under development and brings about an innovative approach integrating: 1) GIS data from diverse sources in a hierarchical VGE composed of irregular cells reflecting the habitat’s suitability to the different species; 2) populations’ data recorded at the cell level and evolving during the simulation as the result of the interactions of the populations of the different species, of their biological evolution (compartment models) and of the habitat’s suitability; 3) species’ compartment models expressed in terms of transition diagrams that allow for the specification of stage transitions for each species and takes into account the spatial interactions of populations. These stage transitions are compiled into functions and processes that are directly integrated in the geosimulator for efficient evaluation at run time. Indeed, the ZoonosisMAGS approach offers much more modeling and simulation possibilities compared to current disease propagation simulation platforms such as STEM [91] and GLEaMwiz [12] that only offer a limited number of predefined compartment models and only allow for the use of networks (such as intercity networks and the air traffic network) to model populations/groups’ spatial behaviors.

Moreover, our new formalism [10] provides several advantages compared to classical compartmental models which have been used to simulate the propagation of zoonoses

up to now such as [69] and [100]. Indeed, compartmental models do not consider the characteristics of the geographical space in which populations operate. In contrast, our model uses an IVGE generated from GIS data and allows for clearly specifying all the interesting aspects of an ecological system, especially the spatio-temporal interactions between the involved populations. We think that our formalism and approach provides generic models that can be used not only to simulate zoonoses, but also that can be adapted to various other phenomena such as pandemic diseases (i.e. SARS). Let us emphasize that simulation based on classical compartment models only provide results that can be exploited at a very aggregated level (so called ‘macro level’) without taking into account details of the geographic space and its influence on the studied phenomena. Such models are useful to support decision makers at a global and strategic level. In contrast, our approach can produce simulations at different levels of granularity (thanks to the hierarchical VGE) that fit with decision makers’ interests. In this way it can help policymakers to establish guidelines for action at a strategic level, and help tactical or operational decision makers to develop plans for intervention at more detailed levels.

Lyme disease is propagated by ticks which are very often found in forests. This disease is an increasing threat for public health, especially in peri-urban areas where forest spaces offer suitable environments for the establishment of tick colonies and are visited by a large number of persons for different recreational activities. The SénartMAGS Project takes place in a collaborative research work between our team in Quebec and a French Team in Paris. In this project we are interested in the assessment of the risk for people to be infected by ticks when visiting the Forêt de Sénart, a forest which is very much used for recreational activities in the periphery of Paris. Considering human risk assessment for Lyme disease we adopt a geographic perspective based on the analysis of spatio-temporal exposure to hazard as a result of human behavior [35] [53] [54]. We combine a geographic-based approach and multi-agent geo-simulation (MAGS) techniques to explicitly model the spatio-temporal characteristics of human-tick contacts. One important activity of the project is to collect data about visitors and their behaviors (and habits) in the forest in order to identify visitors’ typical activities (activity patterns) and the places they attend, as well as the trajectories they follow in the forest. Interviews are carried out on-site by the French team. My team developed a complementary web data collection and mapping tool which allows visitors to describe their routes and activities in the forest [40] and automatically records visitors’ information in a data base used to carry out various kinds of analyses (Fig. 11). Since our software is accessible through the web all year round, it will be able to collect data for several years, allowing for future studies of visit patterns in terms of seasonality at a minimal cost. We also developed a geo-simulation model of visitors’ behaviors using the OBEUS software [7] and integrated it in our platform. Hence, we create agents that mimic the visitors’ movements and activities in the forest. Hence, we will be able to identify the visitors’ behavior patterns that are at risk with respect to areas where infected ticks present a threat. The ultimate goal of our work is the development of an integrated decision-support system for evaluating (and then reducing) the human risk exposure to Lyme disease in the Sénart Forest [54]. We

will be inspired by a recent paper which presents a review of approaches to map risk and vulnerabilities using GIS data [79]. This system will enable public health officers to assess different intervention scenarios (i.e. post information about tick areas in the forest, close certain areas) to improve the visitors’ safety when attending the forest.

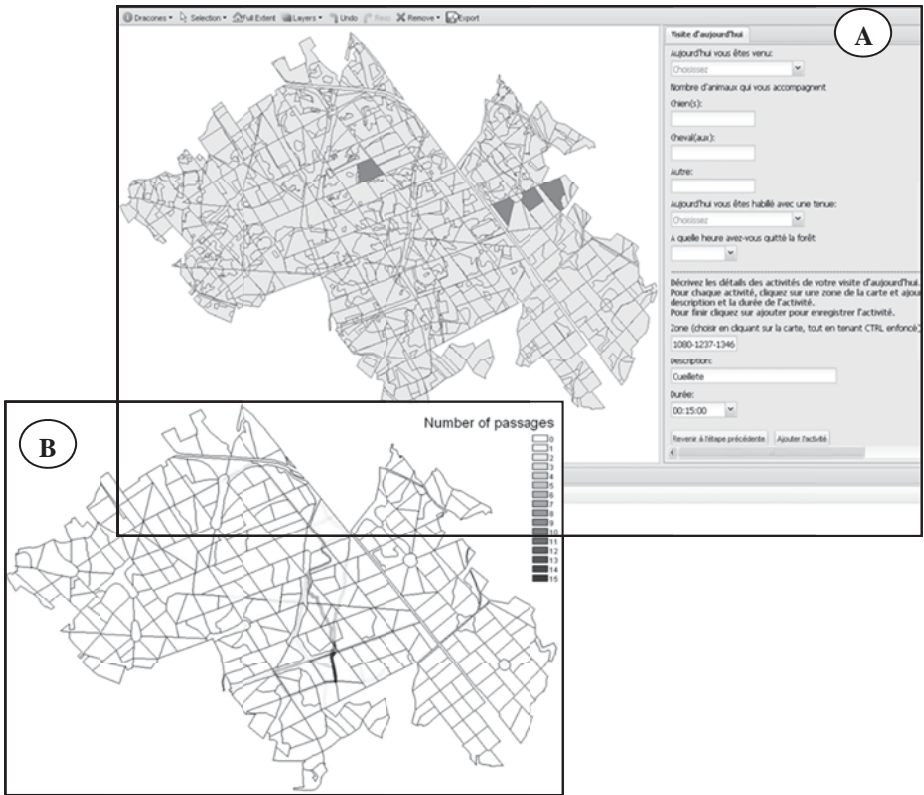


Fig. 11. S nartMAGS System – A shows the main interface of the Web-mapping tool in which the visitor inputs the description of her visit and activities in the forest. B shows the kind of trajectory analyses that we can carry out with the analysis module.

4 Conclusions

Here we are at the end of this story and historical review of twelve years of research on multi-agent and population-based geo-simulations for decision support. In retrospect, we can see that we have achieved a lot with a relatively small team. We were certainly lucky to benefit from the synergies that built up with our collaborations and interactions with researchers and practitioners from different fields (i.e. geomatics, social sciences, health sciences, computer science, artificial intelligence, mathematics) and from various organizations, during this series of projects. In this chapter I have been able to only mention some of our main contributions to the growing field of

multi-agent and population-based geo-simulation. The interested reader will be able to get more details in our 75 publications over the past ten years (15 journal papers, 2 theses published as books, 21 book chapters, 37 papers in international conference proceedings) and in the 6 PhD and 15 MSc theses written by our students, some of which received international recognition as for example M. Mekni who won the William L. Garrison Award (from the American Association of Geographers) for the best 2011 thesis in the field of Computer Science applied to Geography.

I guess that none of this would have happened if GEOIDE had not existed and if GEOIDE had not put together such an excellent national cooperative research organization in geomatics. In some ways this chapter is a BIG THANK YOU to GEOIDE and to all the governmental and industrial partners that accompanied us in these various projects over the past twelve years. This is a big thank you to the NCE, the Canadian Network of Centers of Excellence and to the government of Canada who created this national program to finance and promote research in areas of excellence. This is also a big thank you to all our fellow researchers from different Canadian and foreign universities, graduate students and post-doctoral fellows, who actively collaborated in the various projects presented in this chapter.

I sincerely hope that such a ‘testimony’ from an ‘old GEOIDE researcher’ will be useful to the reader, especially young researchers ... who might be able to read between the lines. This story tells what a great adventure cooperative research carried out in the context of a Network of Centers of Excellence can be. It also tells about the confidence that researchers must have in the occurrence of ‘providential’ opportunities during the course of their research, as a result of their dissemination efforts which are so much facilitated by a network of centers of excellence such as GEOIDE.

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Chapter 8

Design and Implementation of Mobile Educational Games: Networks for Innovation

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Abstract: Research networks foster creativity and break down institutional barriers, but introduce geographic barriers to communication and collaboration. In designing mobile educational games, our distributed team took advantage of diverse talent pools and differing perspectives to drive forward a core vision of our design targets. Our strategies included intense design workshops, use of online meeting rooms, group paper and software prototyping, and dissemination of prototypes to other teams for refinement and repurposing. Our group showed strong activity at the university-centered nodes with periods of highly effective dissemination between these nodes and to outside groups; we used workshop invitations to gather new ideas and perspectives, to refine the core vision, to forge inter-project links, and to stay current on what was happening in other networks. Important aspects of our final deliverables came from loosely-associated network members who engaged via collaborative design exercises in workshops, emphasizing the need to bring the network together and the importance of outside influences as ideas evolve. Our final deliverable, a mobile educational game and a series of parallel technology demonstrations, reflect the mix of influences and the focus on iterated development that our network maintained.

Keywords: mobile educational game, collaborative design, augmented reality, mobile technology, Energy Wars Mobile Game.

1 Introduction

Between 2007 and 2008 a group of researchers came together to work on the design of educational games, under the direction of one of the authors (Daniel). The GeoEduc3d network aimed to use mobile and desktop hardware and software to build games where children - both in classroom and in informal settings - experience urban space and learn about sustainability, climate change, and how geomatics is used in these fields and in game design. The project was brought to the GEOIDE network - 'Geomatics for Informed Decisions' - and subsequently funded with ten core researchers at three institutions. This Chapter focuses on three issues: how the group fused geomatics and game design to produce a game to teach children about gaming, technology, and sustainability, how the game and side-projects reflected that approach, and what the organization and execution of the project has to say about network based science.

1.1 From Vision to Project

GEOIDE is a network funding organization under Canada's National Sciences and Engineering Research Council (NSERC); a specific program at NSERC creates Network Centres of Excellence (NCE's) that focus on areas of common interest to industry, government and academia. The GEOIDE network, headquartered at Laval University, has existed since the late 1990's and completes its mandate in 2012.

The NCE overarching philosophy is that networks of researchers who are geographically distributed between regions of Canada will offer unique perspectives on *what to do* and *how to do it*. The NCE structure requires that projects have industry and/or government partners who will set the context and then take up the results of research, and a strong collaboration with specific partners is encouraged. GEOIDE itself has a Board of Directors and a Scientific Committee which combine to set direction and oversee individual projects, with at least yearly feedback to all project leaders on their direction, productivity, and on possible linkages to other projects. The Scientific Director of GEOIDE (Dr. Nicholas Chrisman since 2005) plays a central role in communicating opportunities arising to project leads and so encouraging a truly networked science community.

Again, the core idea of GeoEduc3d from the onset was that there is a place for gaming in the classroom of the future, and that geomatics has a clear and significant role in such games. Mobile games, where players move around using devices such as cell-phones, are especially relevant in that they balance game play with physical activity. Such games could educate about a theme - such as global warming, or urban development - while simultaneously informing about underlying methods - such as geomatics and computing.

With this as a vision, the project lead (Daniel) worked with an initial team of researchers and partners to establish a domain of common interest and to ensure that the

size of the network and expectations of the members was consistent with the NCE rules and GEOIDE mandate. The project lead then wrote an initial proposal and the deputy-lead (Harrap) made minor changes; at this point the major groups (four institutions, ten researchers) in the research network and their proposed roles existed on paper. The question of which would be active or inactive, and of whether GEOIDE and the partners would be agreeable, remained to be discovered.

At the time of application for funding, GeoEduc3d had strong commitment from industry and government partners, as well as excellent international links to European academic groups with an interest in geomatics education and game design. In terms of the network structure of GEOIDE, it did not exist in a vacuum, as two projects with complementary goals were funded at the same time: one, on climate change visioning, included one of the authors (Harrap) and one, on social media and collaborative geomatics, had a similar interest in networked tool design. As a network of networks, GEOIDE encourages collaboration and cross-fertilization of ideas between groups; one of the things the project would be tasked with is ensuring that other GEOIDE projects were aware of our efforts; another would be to take key outcomes from other projects and put them to good use within the GeoEduc3d initiative.

GEOIDE funded the GeoEduc3d project with an initial pilot year as the network itself was undergoing a re-funding phase with the NCE. When GEOIDE was approved for an additional phase ('Phase IV') GeoEduc3d would go on to full funding and activity.

1.2 Network Science and GeoEdu3D

The advantage of team-based science is, of course, that multiple disciplinary perspectives and multiple minds can be brought to a problem. The range of perspectives increases as teams become larger, but teams of any size face issues that only get worse with larger teams: communication barriers around collaboration, context, and shared vision.

Communications between team members sets the stage for what a project is about, whether the vision starts out top-down from a project leader or is developed within a group. As work towards a vision or visions proceeds, collaborative work requires communications of the common context of work, lessons learned, and emerging opportunities. These issues are significant when a group can meet in person, for example, when members are within a university department or a university as a whole. The issues become much more significant when a larger community is involved.

A second, complementary, set of issues arise from the evolving group mindset, often referred to as 'groupthink.' There is a danger over time that a group will see a drop in innovation because of a lack of outside criticism, new ideas, and new understanding of context. For a project like GeoEduc3d inside a network like GEOIDE, outside groups like the GEOIDE leadership, like other GEOIDE projects, and outsiders from

other national or international groups of relevance could all provide insights to keep an evolving project evolving in a useful direction.

The GeoEduc3d group used a number of networking mechanisms to address context, collaboration, and inspiration issues, and is perhaps unique in GEOIDE in that network science studies were discussed among the project members as part of planning and project execution. The specific mechanisms used are discussed below in historical context followed by a discussion of lessons learned from this larger meta-project. First, however, we provide technical background on the scope and foundations behind the project itself, and review the relevant concepts from network science that inform that history and discussion.

2 Project Scope and Foundations

2.1 History, Focus, Appeal

Games have long been a motivator in the development of new technologies and techniques, particularly in the areas of computer graphics and artificial intelligence. One recent area of investigation has been pervasive games, which offer different styles of interaction than traditional board games or desktop-based computer games [1]. The term “pervasive games” embraces the employment or application of Pervasive and Mobile Computing technologies either to augment traditional games or to create new games that are impossible to realize with traditional media [2]. Pervasive games take the player away from the computer and bring him in the real world, which is richer, more diversified and challenging than any made-up game world. This new generation of games uses information and communication technology to overcome the setting and interactional boundaries of conventional games, creating new, enhanced environments, and making the real environment an intrinsic component of the game [1]. Such games are attractive for education since they combine the appeal of games with environments that can engage and support situated learning, and additionally can be designed to encourage team-based problem resolution strategies.

Spatial context has become an important factor in people's everyday life. GPS is no longer the domain of specialized equipment: car navigation systems and smartphones both use location to provide service to average consumers. While there has been a dramatic spread of such uses of spatial technology, for example driven by Google and its API to online mapping technology, the geospatial and geomatics domains are still relatively unknown by people: they use the technology without being aware that anyone would study it or work at it!

One of the goals in the GeoEduc3d project is to address geomatics awareness via situated mobile games, specifically educational games which use state-of-the-art geospatial technology and which address themes relevant to teenagers such as climate change and sustainable development [3]. Through immersive, reactive and interactive

serious gaming, GeoEduc3d's purpose is grounded in mobility and in the use of mobile platforms in real geographies.

The project rationale relies on the following observation: if geographic information use is to continue to grow, future university students must have a more sophisticated understanding of the field. The current supply of geomatics professionals comes from traditional land surveyors or geo-information specializations, yet these fields have poor visibility among young students. Effort needs to be invested in finding people to work in geomatics, to develop and to use these new technologies, and on finding new perspectives and ideas on what geographic technology should be in the future. By designing and implementing gaming and learning-oriented tools based on geospatial technology, tools developed within the GeoEduc3d project immerse teenagers in games that use geographic information and technology, and highlight how these tools are designed, implemented, and delivered to open the eyes of the next generation to opportunities in geomatics.

Our goal has been to engage students with rich user experiences set in real geographies. The project adapts proven visualization and interaction solutions to enhance game based learning, with a focus on methods from augmented reality (AR). Augmented reality is a newly emerging technology by which a user's view of the real world is augmented with additional information from a computer model [4]. An augmented reality application is said to be mobile if the user is his own avatar and his position in the synthetic world follows his displacements in the real environment [5]. Mobile augmented reality games are a special type of pervasive games. Several mobile augmented reality applications based on smartphones have been released (ex. Layar, <http://layar.com>), but mobile AR solutions offering realistic visualization and interactions with the real world still remain research prototypes [6]. The GeoEduc3d project is concerned specifically with the geomatics challenges inherent to mobile AR solutions (ex. 3d modeling of the environment); the limitations of technology and AR are discussed below.

2.2 Mobile Technology

The newer models of mobile phones used in location based or mobile augmented reality applications (i.e. iPhone4, Nexus One) have built-in cameras, Global Positioning System (GPS), accelerometers capable of rough orientation (tilt) estimation as well as bearing orientation (which way the user is facing). The iPhone4, for example, tracks 6 degrees of motion (3 for orientation, 3 for shift) for the phone using micro-sensors. Even with such advanced devices, there are still challenges remaining when using mobile technology for mapping or serious gaming purposes. These range from hardware issues, to development platform and geospatial infrastructure complexities: the main challenges include battery life, GPS positioning accuracy and availability, and complex and incompatible development requirements for different devices. Mobile games require long-lived devices with precise orientation and positioning and with seamless access to multi-scale content, and the team would prefer to develop

applications for multiple hardware and software platforms to allow wider uptake of our tools.

2.3 Augmented Reality in a Geomatics Setting

Augmented reality applications require accurate tracking in order to superimpose computer-generated information upon the user's view of the real world in a precise and realistic manner. Most of the efficient tracking techniques rely on prepared environments to ensure accurate results. These are environments where the designer has complete control over what exists in the environment and can modify it as needed [7]. Such methods cannot be applied outdoors, where the context is more fluid and where control over setting is less likely. Tracking in unprepared environments is challenging, especially when using a mobile platform. The positioning devices available in mobile platforms are still not accurate and reliable enough for AR. Computer vision approaches, where a sensor in the mobile device observes the scene and calculates orientation and alignment factors are generally necessary to complement GPS and internal positioning sensors. However, computer vision algorithms are sensitive to outdoor conditions (ex. moving objects and people; lighting conditions) and robust solutions have not yet been achieved [8].

The limited computational power of the mobile device is an additional and important hurdle to overcome if mobile augmented reality applications are to be used in an outdoor environment, especially when computer vision methods are involved. Algorithms need to be highly optimized and efficient solutions generally exploit the characteristics of the device processor. Innovation at the hardware level is required to be able to offer an immersive and rich mobile AR experience to the users.

2.4 World Construction

The purpose of mobile location-based or AR applications is not only to situate the user in the world but ultimately to allow them to interact with this world. World augmentation and interaction in current mobile solutions is limited, and there is abundant interest in improving these areas. Both interaction and augmentation require accurate knowledge and representation about the environment, and this world model, or set of models, must exist at a variety of scales – corresponding to the scales at which the user navigates a region (blocks) down to the scales of fine-grained interactions (centimeters). Model features must also have rich annotations that support a variety of interaction styles, search, discovery, and community annotation [9]. Accurate geometric and semantic models of the real world are required. Support for situated activity [10] as well as high resolution urban mapping demands models where features down to 'doorknob scale' are represented. The overwhelming problem to tackle is that of data acquisition at this level of detail. This exceeds the difficulty in fields such as game world building and computer animation where models must be precise (detailed and photorealistic) but not accurate (they don't match any real world setting precisely). Research is needed both in how to construct such a world model, and in where

simplifications are possible - for example, re-use of models - that will not break the fidelity of the model or adversely affect the user experience.

This, then, is the scope of research and perspective of the GeoEduc3d project, to use existing technology to build mobile games incorporating ideas from augmented reality in order to engage and educate young students about technology, geomatics, and sustainability, while also engaging in research about supporting technology and methodologies for such games. We now turn to the issue of networks of researchers before examining how the network aspects of the project evolved and what that evolution informs how future network science might be carried out.

3 Perspectives on Networks

GeoEduc3d is about networks on several levels: first, it is funded by a research network, and comprises a mini-network that spans institutions and disciplines. Second, the project deliberately uses sub-networks to foster innovation. Third, in recent years network science in itself has become central to game design, especially social game design, and ultimately this change has dramatic implications for what motivates students to engage, a key component in our goal of delivering educational experiences via games.

The idea that humans form social networks for collaboration, idea-sharing, and inspiration is intuitively obvious: it underlies such long-standing structures as professional societies, research conferences, and even peer-reviewed publication. The idea remained largely intuitive until the 1960's, when pioneering work on the structure of social networks was done by mathematicians and computer scientists [11] and subsequently and famously demonstrated by an experiment with hand-delivery of mail (often erroneously referred to as the 'six degrees of separation' experiment) [12,13].

Another significant perspective on networks is Metcalfe's Law, originally stated by Metcalfe and documented by Gilder (reported in [14]) and attributed to the architect of the Ethernet networking standard: the value of a communications network is proportional to the square of the number of connected users in the system. Unlike the small world approach, which emphasizes who knows who in a chain, Metcalfe's Law emphasizes that the 'macro' value of a connected network as connections is strongly related to network size.

With the rise of socially-rooted Websites such as MySpace, Wikipedia, and especially Facebook, the idea of a social network of creators and sharers received significantly more attention, and this more or less coincided with the publication of a popularized account of small world networks by Watts [15] a highly active researcher in the field. Some attempts were also made to directly link innovation in science to the nature of a scientist's social network (e.g.[16]). No group has done more to make the idea of the

social network and its representation as a graph more visible than Facebook, who directly refer to their company as one focused on innovation around social graphs.

As researchers, we might care about these results for a number of reasons:

- our ability to connect with each other as directly involved researchers is a function of the connectedness of our network, and the overall size of the network
- we might draw resources from those in our social network
- we might draw inspiration from those in our extended social network, in other words, use social networks to enhance our research
- we might directly make use of social networks in things we design, either by exposing them explicitly (as does Facebook) or implicitly (as does a community such as bloggers or Wikipedia authors).

One key result from academia that informs the last two points, and was central to how the projects described in this Chapter were designed and run, is the relationship between social network membership, connectivity, and innovation. Uzzi and Spiro [17] describe an in-depth study of creativity and success on Broadway as a function of the strength of members of a small network (producing a Musical). After continued success, the productivity and success of a semi-stable group will begin to falter, and innovation returns after substituting a 'new player' from the larger network, especially when that new member was only weakly associated with the original team. In other words, as a group works together, they may be highly successful to a point, but eventually new ideas, preferably quite different new ideas, are needed to renew the creativity of the group. This result is an example of the highly active, emerging field of *science of team science studies* [18] which explicitly examine the effectiveness of multi, inter, and trans-disciplinary teamwork via statistical and network-theory based examination of research publications, patents, and the like. These approaches are driven by recent studies that show the impact of team science [19] and how these are mitigated by organizational structure and geography [20].

The group that comprises the central research team of the GeoEduc3d project includes education researchers and geomatics researchers spread between three universities and spanning Canada. Faced with a diverse and geographically distributed group, the project leaders used a number of measures to manage the project and especially to ensure innovation within the group, and this approach was integral to the formation of the project.

Finally, subsequent to the initiation of the project, a dramatic shift took place in the area of game design and publishing: the most profitable and visible games of 2009-2011 were not graphics-intensive, innovative and immersive experiences, but were instead very simple and highly addictive games that operate within Facebook and directly rely on the social graph and principles of social psychology [21]. This has somewhat influenced what our industry partners are interested in pursuing.

Given the objectives of our project - to design innovative mobile games that educate children about environmental issues and geomatics - and the nature of our distributed and multidisciplinary team, we took advantage of a number of methods, grounded in network science, to keep shared context, collaboration, and innovation alive. These are discussed in detail in the next section.

4 The Design Process: Applying Network Science to Games

A number of tools exist to support team-based work; in fact, there is an entire area in information science and computer science centered on the design and implementation of such tools - 'computer supported cooperative work. These tools range from what is now mundane - telephones, email, and documents sent or shared online - through to newer and less established techniques - web meetings, design workshops, and wiki-based collaborative writing. A number of related methods to extend cooperative work also exist, such as design by variation, bringing outspoken outsiders into design sessions, and 'extreme development' methods.

Our shared design practice was rooted in human-centered design principles such as the use of personas, scenarios, and early testing of prototypes with clients; while these methods were important, they don't relate directly to the network structure that is the focus of this discussion.

A number of specific techniques *were* applied. These individual techniques all contribute to design, shared context, shared visioning, and rapid innovation. They include:

- Design workshops
- Web-based meetings
- Inter-project networking
- Inter- and Intra-project shared prototypes
- Critical review and guidance from partners
- Critical review and guidance from outside critics

Each of these methods also addressed the institutional, disciplinary, and geographic barriers to collaborative science to a degree.

We focus here on the larger-scope and more effective elements, namely design workshops, shared prototypes, and the use of outside critics and 'inspirers'. These are discussed in chronological order below to give a sense of the evolving priorities and state of the overall game design project. Note that the group held regular web meetings before and after these individual activities, and that the discussion below only includes about half of the actual meetings, emphasizing the early, key, workshops and innovations.

4.1 Project Initiation – Building a Network

As discussed in Section 1.0, GeoEduc3d was proposed as a network project to GEOIDE and funded based on strong central goals, relationships to partners, and relationships to other networks. The initial funding was for a pilot project year.

During the initial pilot phase, a number of key activities took place: communication with other groups inside GEOIDE, refinement of relationships with partners, and a preliminary design workshop. In particular, one initial research (and hence one institution) chose not to participate in the evolving project, and several new researchers at the other institutions became engaged in the process.

4.2 Workshop 1 - Game Design by Analogy

The first network-centric activity undertaken was a workshop to refine the overall direction and scope of the project, in other words, to decide on the *specifics* of the project given the general objectives under which the initiative was funded. The workshop was organized at Queen's University (Kingston, Ontario, Canada) in June 2009 and included researchers from inside the project as well as interested researchers and students from the related field of energy sustainability. The group was broken up into design teams and tasked with challenges to address. All our teams involved high school students, undergraduates, graduate students, and faculty researchers with different backgrounds, including geomatics, sustainable design, climate change science, and education. The range of participants broadens the sources for ideas and inspiration; the inclusion of young students provides a strong tie to the culture and interests of our target audience.

The leaders realized at this point that game design is an established discipline although not a traditional academic one; the real evidence of excellence in game design is in the form of existing, classic games. As a result, the design strategy we applied was to take existing board games, have the teams play them, and then to try to infer why the specific elements of the games work.

Figure 1 shows researchers and students participate in scenario-development exercises designed to foster the emergence of original gaming ideas based on a frame game approach [22]. Frame games are, in essence, game shells which have had their original content removed and for which only the structure - the game pieces and game mechanics - remains. Game authors use the shell to build a new game by adding their own content and making minor changes to the game mechanics. During the workshop, participants looked at a variety of board games and analysed them through a variety of lenses [23] such as game content, game mechanics and game dynamics in order to better understand what makes a game work, whether the game mechanics have to be altered to accommodate new content, and the degree to which game dynamics are affected by such changes [24].



Fig. 1. Scenario development using a frame game design approach

Following the framing exercises, the group met in break-out groups to design three independent games, all set in an urban space - the area around a typical school or campus - but still board-based. Variants that were proposed included a mystery game with the participants as investigators, and two variations on a game of capturing buildings to control the overall 'field.' The resulting ideas were discussed, and the exercise was re-run, this time assuming game play would be mobile and would use devices such as smart phones, and perhaps could integrate augmented reality elements.

One key outcome of this process was that some of the younger participants who had a background in game programming and especially game 'modding' (where an existing game is modified to serve a new purpose) began implementation of the design ideas as simple prototypes. The idea of rapid development through experimentation, termed 'extreme development,' allowed the group to see which ideas would be easily realized and which might be a challenge. This also concretized some of the emerging ideas, and gave the group a way forward: instead of starting with a low level game implementation task, we could instead start by developing a 'mod' and use that as a basis for testing and refinement. The downside of this approach was that our first experiment would be desktop, not mobile, computing-based.

The impetus for this direction was from students outside of the actual research group: inspiration and collaboration from the larger network had a significant role, enabled via participation in an intense and enjoyable workshop-based game design process.

4.3 Prototype 1 - Making Design Ideas Tangible

The workshop resulted in the design of two games scenarios, since two of the breakout teams designed very similar games. Out of the two scenarios, one was selected as the foundation of the first GeoEduc3d modding-based prototype. The proposed prototype, *"Energy wars – Rise of the Chimera"* (see Figure 2), is an educational game situated in a real environment: the first version takes place on the Queen's University campus. The goal in the game is to explore the area and then capture and upgrade buildings to make them more energy efficient. The goal of the game is to teach students about energy flows, about cost-effectiveness of upgrades, and about timeliness of acting on evolving situations with energy and sustainability.

Gamers have access to two roles: an engineer and a security officer. In the role of an energy engineer, players can survey and modify campus buildings. Meanwhile, enemy agents are interfering with building occupants and damaging building systems; the security officer can block these attempts. Buildings consume or produce energy resources which are the currency of the ongoing game. Since one player must control both characters as well as manage resources, the result is a game with no single winning strategy and opportunity for repeat play to explore alternatives.

The Energy Wars game is built on top of Blizzard's Warcraft III engine using custom development tools from the game modding community. The buildings in the virtual campus are 3d models of the relevant campus buildings; constrained by mobile terrestrial LiDAR (Light Detection And Ranging) data acquired using Terrapoint (<http://www.ambercore.com>) TITAN technology and checked against photographs. A workflow was designed to input 3d models into the Warcraft III environment, including the use of CAD and 3d Modeling tools.

Since stealth learning (i.e. learning while playing) is one of GeoEduc3d objectives, the energy angle in the game relies on realistic simulation. Information related to the building state of repair, technologies to propose to upgrade the building and the "green energy" the building can generate was provided by an expert in solar photovoltaic systems (Pearce) from outside of the GeoEduc3d network. The results for that research group are discussed in Section 6.4. The renewable energy and energy conservation content in Energy Wars was founded on treating sustainability improvements and upgrades as supported in the technical literature [25].

The actual development of Energy Wars was carried out by a high-school intern and an undergraduate student working for one summer, with input from members of the GeoEduc3d team at key points.

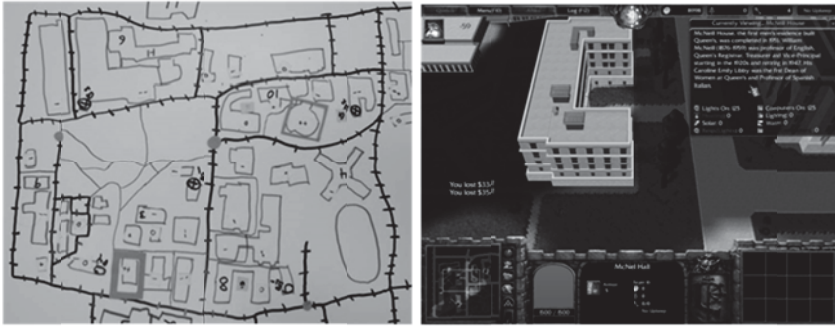


Fig. 2. Game prototype "Energy wars – Rise of the Chimera"; a) Drawing of the game scenario during Queen's Game Design workshop; b) Screen capture of the game prototype built on top of Blizzard's Warcraft III engine.

There were two key results from the prototyping process: first, the team now had something concrete to experiment with, modify, and learn from, and second, the game was a deliverable in its own right, albeit a desktop game.

The Energy Wars prototype was submitted and ultimately selected as a finalist in the 2009 Serious Games Showcase & Challenge (<http://www.sgschallenge.com/>), rated there as the best game by an undergraduate developer group.

4.4 Workshop 2 - Refining Perspectives and Directions

The Energy Wars process demonstrated we could work as a successful research network, engage with other partners and other networks, and deliver an interesting and testable product. However, Energy Wars was a realization of only a small part of the overall project vision, lacking a distinct mobility component, use of augmented reality methods, and with a single-player focus. Context had been established, collaboration had taken place, but inspiration to move the project forward was necessary.

The next approach taken was to host an open workshop with partners from industry and government to show off the project to date, and to use this opportunity to bring in outside views. We reached out across the individual personal 'social networks' of the members invite outsiders to attend and present viewpoints on the state of educational gaming, the future of gaming technology, and to take part in our next phase of development.

The workshop included break-out sessions similar to those held at the first workshop, again exploring existing ideas and brainstorming on how to extend these, perhaps incorporate them into further developments of Energy Wars, and discussing side projects that were being developed to test other ideas in parallel.

The specific focus of the meeting was to examine how to blend the ‘fun’ aspects of a next-generation game with educational aspects. Different approaches were investigated, including game play through a series of staged, low-content activities, and another being social activism to create a long-lived experience that might persist beyond the student-in-classroom setting. Participants in the workshop played an outdoor mobile game with existing technology to get a better sense of the benefits and difficulties of mobile gaming; this framed our next generation design in realistic terms.

The outside visitors, or ‘inspiration agents,’ were active researchers in educational gaming with experience in developing games for high school students. Again, they both pointed out new directions and framed realistic expectations of what could and could not be achieved in a research group of our size. This demonstrates that network interactions can simultaneously affect what you do and how you manage a project. The workshop also included participation of five representatives of partner groups including two talks framing new technology (e.g. 3d scanning) and game design methods (e.g. computer graphics in urban settings) from within the partner organizations.

4.5 Prototype 2 - Innovation and Refinement

Given the strong interest drawn by “Energy Wars – rise of the Chimera”, and given the overall objective of mobile, team-based games with augmented reality components, the results to date were used to launch what became the main focus of the GeoEduc3d project: “Energy Wars Mobile.”

Energy Wars Mobile features a revised game scenario, with player persona and game mechanics adjusted to take advantage of the mobile environment. The game was re-framed to have multiple mobile roles to be played by different students including roles for students who have mobility issues. The revised prototype is situated on Laval University campus (Quebec City, Canada) but can be repurposed to any site with reasonable geographic data access and networking infrastructure. It was developed by the subnetwork at Laval (Daniel, Hubert, Badard [Geomatics team]; Barma, Power [Education team]) over the course of two years (2010-2012).

The student players are members of the *Quebec City Emergency Measures Crisis Team*. They have been requested to take action after a nuclear accident has occurred in Quebec and, as a result, a state of national emergency has been declared. Since local hospitals are already full and can no longer receive patients, a new treatment centre is needed as soon as possible. Public Safety Canada, working with Laval University, needs to determine the best area on campus to base a new emergency treatment center.

This is the main objective of the team of players: they need to find the best located building on campus to open a radioactive-contamination treatment centre and a refugee service area. They have three primary objectives to fulfill in order to meet this

main goal namely, 1) to conduct in-depth field exploration to find contaminated areas around campus and to decontaminate them, 2) to identify the best building on campus to serve as refugee service area, and 3) to retrofit the chosen building to make it more energy efficient, given that there is an energy shortage due to the generation plant failure.

The latest version of the game scenario involves three levels to be completed successively: once the area is decontaminated, the best building on campus to serve as refugee service area is highlighted; once the building is “captured” by the team, they can start to retrofit it. Money accumulated during the decontamination phase – assigned as a reward for carrying out tasks efficiently - is used to buy technologies to retrofit the building such as solar panels and wind turbine.

Figure 3 shows a view of radiation hot-spots spread over the game space, the main control panel of the expert app, the budget tool informing players of their current money status, and the list of technologies available for retrofitting the chosen building.

The multi-level approach adopted for Energy Wars Mobile prototype complies with the recommendations expressed during the second workshop, wherein a series of low level activities were suggested as an approach to better engage the players. The nuclear event context has been chosen to foster the player engagement in the game since a rapid response is required. In addition, the regional risk included in the scenario has been considered a key element to trigger their interest and awareness around environmental issues.

The game involves a team of six players with individual roles, forming a network:

- the commander, guiding the team;
- the scout, wandering around the campus to detect radiations;
- the radio operator, relaying information between the players on the field and the commander;
- the energy expert;
- the material expert;
- the environment expert.

The commander can guide its team either from a remote desktop or directly on the field using a mobile tablet (i.e. an iPad2). This role might best be assumed by a teacher since tools are provided to monitor how the players manage to face the problems presented to them and how they collaborate as a team to overcome them. A smartphone is provided to each player on the field in order to track his position and to allow him to complete his dedicated tasks; the technical challenge in implementing Energy Wars Mobile was to have the individual capabilities work on the relatively limited devices used, and to coordinate the overall game-flow between them.

Specific elements of the game play address the various research focii of the GeoEduc3d group: mobility, augmented reality, and sustainability and environmental issues. Energy Wars Mobile allows discovery and exploration of environment and space through location-based and augmented reality tools. Decontamination of the campus is carried out by roaming the game space and detecting radiation hotspots: these are georeferenced (i.e. geotag) nodes spread strategically over the gaming area. Since the location of each player is tracked, various interactions occur according to position and vicinity to radiation hotspots: some hotspots incur immediate money loss, whereas others provide immediate gain. Some zones trigger quizzes to be solved by the player to be able to proceed with the game. Such an approach takes fully advantage of the mobility side of the game, the network of players, and the notion that repeated simple tests can promote learning and retention [26].

The interaction can contribute to improve the visual and spatial thinking skills of the player. To further develop such competency, radiation zones are displayed using augmented reality visualization methods (see Figure 4). The player can switch from a bird's view of the campus where hotspots are displayed in 2d to an augmented reality view where they are displayed as 3d graphics. This representation change trains the mental associations of the player between the 2d and 3d spaces, allows different types of spatial reasoning, and promotes immersion in the local environment.



Fig. 3. Energy Wars Mobile displays and information: a) game map with geotag database (display in yellow); b) main screen control of the expert app; c) information about the player budget and building sustainability gauges; d) list of available technologies to upgrade for buildings.



Fig. 4. Energy Wars Mobile prototype: visualisation of the virtual radiation markers using augmented reality markup.

Developing the underlying architecture of Energy Wars Mobile exploited researchers – nodes in the immediate network – that until this point had had relatively little input, given that their expertise was not in design but in mobile solutions development and deployment. Energy Wars Mobile relies on a client-server architecture (Figure 5) built using the PhoneGap open source framework (<http://www.phonegap.com>), which allows rapid cross-platform development and provides support for both mobile and desktop platforms. This allows, for example, the Commander persona to deploy either on a desktop or on a tablet computer depending on the teacher's specific needs. The underlying content is stored in a PostgreSQL database and conveyed through an Apache Tomcat server. The Expert and Radio personas are deployed on iPhones currently, and the Scout (which ultimately is to employ Augmented Reality ideas) is implemented on Sony Ericsson Xperia with Android.

The notion that a research network – GEOIDE – funded a group of researchers – GeoEduc3d – to do research that ultimately resulted in a game that uses a network of players – scouts, experts, ... – shows the degree to which network thinking permeates the entire approach taken, from administration to application.

GeoEduc3d involved a number of other meetings and refinement stages similar to those described above, incorporating outside feedback, design sessions, and chances for students especially to show their work to a wider audience. For the sake of brevity we mention only that in each case we brought in the external commentators that we felt would most seriously critique our ongoing efforts.



Fig. 5. Architecture of Energy Wars Mobile prototype.

4.6 Workshop 4 – Testing and Refining Deliverables

Given a new prototype, the network met to carry out preliminary testing; unlike the earlier workshops, which had involved and in fact centered on external input, the testing workshop involved only core researchers and one industry representative; since most issues of the design were not ‘on the table’ and since testing opportunities are limited, keeping the group to a subset of the entire network was desired.

Preliminary testing of the prototype highlighted several shortcomings. The main one was the impact of a general lack of precision of the GPS in the mobile devices. The players had to deal with the uncertainty related to their position and the radiation hotspot location. Players spent a fair amount of time trying to locate hotspot focus areas while the augmented reality tool indicated they were on the right spot. The trigger distance to radiation hotspots had to be tuned accordingly. Testing also showed that the players required more feedback to better understand what was going on in the game. The Expert app interface was subsequently redesigned to include a control panel with information about the current status of the game. All mobile roles were modified so that the phone vibrates each time the player is in contact with a radiation zone, which in subsequent testing received very positive feedback.

Some early experiments were also conducted with educators from high schools. The prototype raised a lot of interest and positive comments from them. The use of mobile devices and the augmented reality tool were key contributors to the positive feedback – the issues that the core researchers in the network thought were interesting and ef-

fective did not completely correspond to what educators, distal nodes in our network, placed value on!

The development of Energy Wars Mobile is ongoing; it is our intention to both continue the development ourselves and to share the work done to date with interested parties so that the project has larger impact and permanence; we are also seeking new members for the research network and actively taking our results to other networks so that they may benefit from the project.

4.7 Reaching out to Other Research Networks

The GeoEduc3d team engaged in internal networking and, as discussed, constantly brought in outside critics to workshops to challenge assumptions and refine the research and development direction. The group also took part in significant outreach both within the GEOIDE network and in the larger domains of education, game development, and geomatics.

Within GEOIDE, the GeoEduc3d team sat in on workshops by other research networks with related interests, such as the Climate Change Visioning project. We also prepared and presented a GEOIDE Summer School Course on game development and geomatics (presented 2010 and to be presented 2012).

Outside of GEOIDE proper, team members interfaced with the public and research sectors through participation in game and education events, with other research networks internationally through shared use of tools and presentations at conferences, and with the larger academic community via conferences and publications. We hope that the open access we provide to our tools will result in uptake that further continues outside linkages and shared exploration of ideas.

5 Secondary Experimentation in the Research Network

With a geographically distributed and thematically diverse network there is the danger – if not the strong likelihood – that a research network like GEOIDE will end up funding teams that implement different solutions in a vacuum, and that *within the GEOIDE projects the same will happen*. GeoEduc3d used workshops and constant online communications (net-meetings, email, and shared files) to instead focus on the shared development of a few research prototypes as discussed above. While this meant all researchers had input on a few strong deliverables, it also meant that many ideas that didn't fit into the central design theme might have been left unexplored.

The danger of a lack of centrality is of course that nothing coherent comes from a project – the network produces essentially a series of projects that are no different than what would have resulted if the researchers were funded individually. The danger of overly strong centrality is that higher risk ideas and issues that might, but might not, be relevant are left unexplored. As a result, in GeoEduc3d the management team

deliberately encouraged experimentation in the early project and created an internal vetting project for higher-risk ‘mini-projects’ in the later project phase. Many of these side-projects informed the development of Energy Wars Mobile, and many delivered ideas and code that are ready for incorporation in future versions.

While history could be rewritten and these aside, or ‘secondary,’ experiments be presented as if they were obviously and initially central, this would misrepresent the intent and furthermore misrepresent one key issue with innovation in networks, which is that different levels of innovation happen in parallel, some high risk and some low risk, and the advantage of this parallelism is that successful side-experiments can be folded into the main development effort while those that are less successful can provide useful lessons learned without endangering the main effort. This is, in fact, one of the key approaches used in Open Source development efforts.

5.1 Building the Augmentable Environment

The Energy Wars Mobile prototype involves three mobile augmented reality applications.

The first and the second application augment the environment at the campus scale. They aimed at visualizing 3d graphics (such as radiation hotspots) in the field; the locations of these are not known by players at the beginning of the game. The approach implemented in these two applications differs. The first one relies on the geographic coordinates of the items to be displayed to overlay the virtual graphics of the items on the real world at those coordinates. This was ultimately incorporated into the ‘Scout’ role in the Energy Wars Mobile game. The second one addresses building the local environment for augmentation. Augmented Reality requires geometric models of an area so that the computer graphics calculations can be done to determine how augmentations overlie (or underlie) viewed objects. The experiment (Figure 6) involved a fast and easy way to create 3d models of buildings to manage occlusion and offer a realistic rendering of the virtual graphics [27].

The third application augments the environment at the player scale. More specifically, it targets augmentation of user interaction at the scale of hands and hand tools. The purpose is to superimpose graphics showing virtual tools the players (i.e. the experts) will have previously selected according to the task they have to achieve. The AR approach relies only on computer vision algorithms (i.e. OpenCV open Source library) used to detect and track the player hand on the smartphone camera feed; an example is shown in Figure 6.



Fig. 6. Mobile Augmented Reality applications used in Energy Wars Mobile prototype: a) Mobile AR apps using geographic location; b); AR apps to augment gamer hand with virtual tools; c) iModelAR apps involving fast and easy 3d modeling of buildings.

5.2 Situated Augmentation of Urban Environments

Beyond the scale of Energy Wars Mobile, the group recognized that urban gaming in the large might involve relatively simple, but high volume, annotations of urban features with simple text and graphics. Starting with a conceptual plan [28] a mobile-device based application was built that allowed landmarks to be identified and described with stories and photographs. The ‘*Situated*’ application relies on a client-server architecture, is multi-platform, and can be extended with new data collection requirements as needed to address specific study requirements. *Situated* (Figure 7) supports both shared content and named groups with private content, has roles such as

administrators and content creators, and has geographic locales supporting the idea that regions may have different communities of interest who wish to document their environment. Ultimately *Situated* has a strong relationship with the idea of hotspots in *Energy Wars Mobile*: in a future game scenario those hotspots might be anything that a community in *Situated* wished to document, meaning that *Situated* communities could transition to game communities.



Fig. 7. A Landmark in Situated on an iPhone. The new Landmark supports storytelling, photo documentation, and ultimately game creation.

5.3 Augmented Reality Landscapes

Researchers at the Spatial Interface Research Lab (SIRL) at Simon Fraser University, led by one of the authors (Hedley), have designed, built and evaluated a constellation of situated, mobile and augmented reality visualization interfaces for distinct problem spaces aligned with GeoEduc3d objectives. Based on Hedley's [29] concept of 'real-time reification' (RTR), these interfaces combine the capabilities of geospatial virtual environments, augmented reality and geosimulation connect students to spatial data, simulations, and abstract concepts in real spaces, in new ways. Their research has integrated partnerships with local government, regional environmental programs, and provincial agencies.

The first collection of interface prototypes combine 3D physics, geosimulation, geo-visualization, geomatics, tangible spatial interfaces and mobile augmented reality (MAR) to allow students to interactively explore precipitation, watershed topography,

and hydrology in everyday spaces. *A Touch of Rain* is a multi-modal geospatial interface that combines location, orientation and motion sensor data with tangible user interface capabilities, allowing users to interactively position and move virtual clouds over terrain, control virtual rainstorms, and see where water particles flow on virtual topography. *A Situated Virtual Touch of Rain* is a situated portable virtual environment that allows the user to look ‘through’ location aware mobile devices as portals into parallel virtual geosimulation spaces at the same time as standing on the equivalent real location. *An Augmented Touch of Rain* is a MAR interface that allows users to switch seamlessly between situated virtual environment and situated augmented reality. Users can create virtual clouds, position them over topography in virtual space, and see the precipitation simulation fall (or flow over topography) in *real* geographic space.

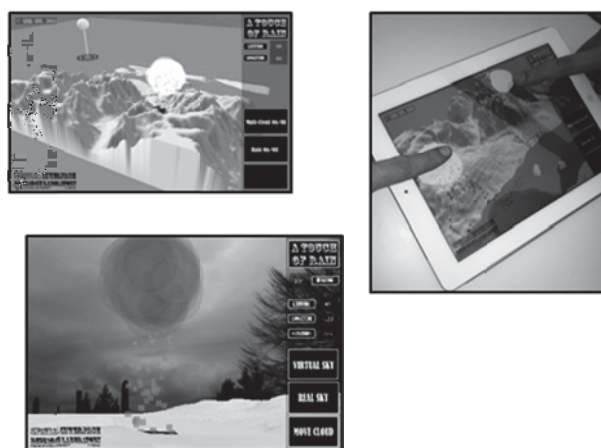


Fig. 8. (L-R) *A Touch of Rain*; *A Multi-Touch of Rain*; *An Augmented Touch of Rain* All images copyright Nick Hedley and Chris Lonergan/SIRL 2010-2012. All rights reserved.

Throughout this initiative SIRL researchers have networked with regional watershed education groups, and are collaborating with GeoEduc3d researchers to create localized versions of *A Touch of Rain* for parallel usability testing in Quebec in 2012.

A second set of interfaces explore the potential of situated citizen sampling, mobile augmented reality (MAR) and geospatial game design for tsunami education – in collaboration with real communities. *EvacMap* allows users to interactively browse user-specific location-aware evacuation maps of Ucluelet. *VAPoR* is an iPhone-based mobile interface tool that can capture and map community perceptions of risk and evacuation – enabling the collection of mental maps of risk perception and evacuation from permanent residents and visitors. *SMARTEE* demonstrates the potential of MAR to augment real communities with GIS-derived risk overlays and evacuation information. This research has raised a number of issues that challenge us to think carefully about the design of geographic augmentations using MAR.



Fig. 9. (L-R) VAPoR field testing; SMARTEE field testing; collaboration in real community All images copyright Nick Hedley and Calvin Chan/SIRL 2010-2012. All rights reserved.

5.4 Spawning New Research Networks

Outside critics and influencers had significant impact on the development of both the core Energy Wars project and on side projects. This was nowhere more true than in the interaction with energy experts during initial (phase 1) game development.

As outside influencers less familiar with both the technical tools used in the project and with gaming in general, Pearce and his mechanical and materials engineering students that participated found the team-based design and prototyping exercises to be, in their own words, both fascinating and enjoyable. The exposure and guidance from GeoEduc3d network members in the use of technical tools and design methods spawned productive new research directions for Pearce's group - e.g. the use of smartphone technology to assist in building energy audits [30] and a spin-off company to commercialize it (Envirolytics: <http://www.envirolytics.ca/>).

The experiments in the scope of energy solutions within GeoEduc3d led us to realize that a sub-network focused on energy modeling of the environment, comprising some of the members of GeoEduc3d and some new members, was worth exploring. The new network, 'Bedrock to Blue Sky' (Harrap, Pearce, Daniel, Badard, Cascante, Hutchinson) was formed in 2009 and approaches similar urban spaces from a quite different perspective. The new network includes three members from GeoEduc3d, one of our external critics, and two new researchers.

6 Discussion - the Social Network, Innovation, and GeoEduc3d

The GeoEduc3d project has had a number of impacts both in the subject areas and as a research network, as discussed above. We now discuss those impacts, strengths and weaknesses of the approach, and ways forward.

6.1 The Intersection of Games and Geomatics

Within the field of geomatics, the work demonstrates the very strong and largely unexplored link between methods in geomatics and in game design. Many issues that are a challenge in game design – construction of large and realistic urban worlds, for example – are within the normal purview of geomatics. Many issues that are a challenge in geomatics – moving from a two-dimensional and static conception of our subject to a dynamic, three-dimensional one – are within the normal purview of game design. Perhaps more importantly, whereas in game design the idea of design is central and crucial, in geomatics application design and experience design (as opposed to cartographic or aesthetic design) are relatively underused, and in particular a focus on user affordances is underappreciated. Finally, our work demonstrates that in the shared space of gaming and urban geomatics, access to reliable positioning even outside is a critical barrier to effective game play.

In the field of gaming proper, the work demonstrates that highly engaging experiences can be shaped out of networked teams with relatively simple roles, and that spontaneous interaction and team building arise when players realize how roles mesh. We have demonstrated that engagement arises from local context, and that there is a relationship between gaming in the local environment and experiencing that environment dynamically (as in augmented reality) or in documenting that environment. Outside of gaming proper, the side-experiments on *Situated* and AR interfaces demonstrate innovative and accessible ways to engage with citizens about spatial problems.

This of course bridges to the educational aspects of the project, where we hope that the game play, the game subject matter, and the context-setting before and after game play together contribute to meaningful learning. We have also demonstrated that informal methods such as game modding, popular with many students, have a role in the classroom and may in fact allow students who would otherwise be unengaged to find a niche for meaningful participation in shared work.

6.2 The Value of the Networks

The GeoEduc3d network was created and informed by a direct consideration of the strengths and weaknesses of stable networks of researchers, of the advantages of connecting across social and scientific networks, and especially of the challenge of creating a network where three different foci – education, gaming, and geomatics – must meaningfully mesh. As noted, we realized that an overly stable network would stifle innovation but an overly fluidly network might prevent any real work at the collective level from being accomplished. We also were very concerned with the possibility that the research network would be a community of interest where individuals share ideas but not necessarily strongly collaborate on specific projects, and our focus on a few central and shared projects as meant to encourage that type of strong collaboration. These reflect the recognized issues with networked science identified by the studies discussed above: geography, disciplinary and institutional barriers. The problem

with network research is that it usually isn't a network for research, but merely one for distribution of funds under an artificial and temporary network structure.

Our approach as discussed above centered on three elements:

- We used a small number of key prototypes and asked all researchers to contribute directly to those at a design, development, testing, and application levels.
- We encouraged side projects to explore key ideas with significant risk in the context of the core projects.
- All of our communications activities, and especially our workshops, involved central roles for outside critics to present their own work, to criticize our work, and to forge new links of collaboration.

The result, overall, was a number of areas where our approach proved strong, and a number of areas of relative weakness.

First, students in the network were educated in a way that was deliberately more collaborative and intertwined with other disciplines and other approaches. For some students, their involvement was part of graduate training, for others it was part of summer internships, but all contributed as equals during design sessions. All students were kept aware of the other disciplines involved in the larger project. And we took this approach out to a GEOIDE Summer School course to broaden the interdisciplinary reach. This links to the idea from network science studies that show that mentoring is perhaps the area where networks of researchers can have the largest impact [18,19].

Second, we managed to incorporate several elements from outside of the traditional research community, partly by incorporating members of outside groups and partly by participating in outside activities and encouraging outsiders to participate in our activities. For example, our early work relied heavily on links to the game modding community, an informal social network of self-educated but highly motivated game designers who collectively know a huge amount about what does and does not work in game design and implementation. Our use of critics is discussed in detail, below.

The original formation of the team was also an indication of a fundamentally networked view of the world: three communities that were relatively unknown to each other took part.

On the other hand, a number of weaknesses emerged, some of which are simply realities of network science in our view and some of which might be handled differently in a future project of this type.

First, the network approach taken was not for everyone. Some researchers, realizing that the project did in fact centre around shared work on a small number of prototypes, drifted out of the network. They clearly saw the purpose of network science as

being to build a community that discusses ideas around private projects, or perhaps projects carried out by a few members of a network, and the idea of working on a larger team didn't engage them.

Second, geography was a significant challenge, as has been recognized in science studies [20]. Although we made every possible use of online meetings, design often involves being in the same space, and more distributed members of the network had a harder time staying engaged and collaborating meaningfully. In particular, we might have done a better job of shifting students between sites to give them more exposure to different perspectives, although our tradition of at least three shared meetings a year did result in some opportunities for sharing results if not early work.

Finally, our use of critics could have been made much stronger if at least some of the critics were re-engaged to provide renewed feedback and a stronger push in interesting directions. The administrative push of the GEOIDE project administration kept us thinking about publications and the like, but those external science and development critics who we so successfully engaged in a one-off manner might better have formed a project-specific oversight committee with continued involvement.

6.3 The Value of Cycles of Criticism

As pointed out, our use of outside critics included those from partner organizations such as game companies, geomatics tool providers, and social groups interested in the dissemination of tools, and these outsiders had a strong interest in influencing what direction our development took. These criticisms took place throughout the development cycle of our project, including criticisms of early prototypes, of speculative parallel projects, and of our final core deliverable.

The normal model in the academic community is that work is done by an individual or group and then this is delivered in verbal or written form to the community who respond with (often anonymous) feedback. There are strong merits to this system, especially during the later parts of a project: it provides assurance of community standards, it provides corrective advice on communications styles and approaches, and it provides insulation between critics and (perhaps irate) authors of work. Guidance of projects is provided up front, when a grant is given, and at the very end, when judgement is rendered, although in some projects interim reporting is done. GEOIDE is a good example of a structure in which up-front, interim, and project completion guidance is provided.

There are two substantial problems with this model. First, who is providing the feedback? Second, at what level of inspection is it happening, and with what resulting impact. In many projects feedback is provided at a managerial and an academic level. In GeoEduc3d we purposefully brought in critics that were *not* from these communities, but were instead from the practitioner community. In GeoEduc3d the inspection by critics happened throughout the life of the project, and at a deep level: the critics

played the prototypes, they showed alternatives, they led visioning exercises to provide insights rather than commentary, and these had a significant impact throughout the development, long before academic papers were being written, and while there was still time for substantive change.

As with other aspects of our project, this again shows the wisdom of some aspects of the open source community, where the idea of fast prototypes and fast feedback are central. Extreme programming, at its core, pushes developers to work with others to gain shared insights, to face repeated criticism on the project rather than on secondary products (such as documentation), and to let a project to some degree evolve rather than be pre-planned. Clearly a middle ground is wise between emergent and highly structured science, but in GeoEduc3d the role of critics, or perhaps 'extreme commenters' was central to the projects success.

7 Conclusions

The GeoEduc3d project designed a networked game to educate students about geomatics, game design, climate change, and computer science. The early prototype of the game - Energy Wars - and the later prototype - Energy Wars Mobile - both relied heavily on student - faculty networking, critiques from professionals from outside of our research network, and intense workshop-based design sessions.

The role of workshops with external critics both informing the core research group about outside developments and challenging our design and development approaches and direction was the largest network innovation taken. Geography is a strong barrier to network science, and involvement in the workshops turned out to be a strong predictor in long-term involvement in the overall research network.

Realizing that a balance was needed between the central development targets and individual interests and strengths, we funded relatively high-risk but also high-impact side projects involving individual researchers and students, continually challenging these side-projects to show relevance at workshops. The mix of central and distributed innovation proved fruitful, and several initiatives arising from this process appear to be the keys to ongoing work by the research network beyond the life of GEOIDE, who funded the GeoEduc3d project.

Finally, the results of science-of-team-science studies, although at first perhaps seen as outside of the interest of specialized researchers in geomatics, augmented reality, and game design, are in fact central to how we conceive of new projects, manage those projects, and in fact manage science in the future. Network-based science is now common, and will likely be the rule for the most important sub-network we engaged with in this project, our students.

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Chapter 9

GEOSALAR:

The Atlantic Salmon (*Salmo salar*) and its Riverscape

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Abstract. The conservation of freshwater and estuarine habitats on which the production of Atlantic salmon repose is of primary concern to natural resource managers. One of the major tools used to predict production potential involves the use of numerical models that couple fluvial habitat characteristics with fish habitat preferences and movements among habitat patches. GEOSALAR was conceived to bring together a multidisciplinary team of researchers to develop and exploit new cutting edge geomatics tools for the measurement of fish habitat variables over long river segments, and to apply these advances to the problem of understanding Atlantic salmon spatial behaviour and survival in relation to habitat characteristics. Here we summarize our achievements during the seven-year tenure of GEOSALAR in 3 general thematic areas: (1) the implementation and application of innovative image analysis methods to determine, from low altitude high-resolution airborne imagery, the spatial distribution of important fluvial habitat descriptors over the entire stream network, (2) the tracking of salmon movements among habitats over their entire life cycle to understand how fish behaviour interacts with structure at intermediate spatial scales and temporal variation of habitat in rivers and estuaries and, (3) the integration of these observations and procedures into new empirical models for the prediction of Atlantic salmon production. The principal achievement of the GEOSALAR project was to apply spatial referencing techniques at different spatial and temporal scales to describe riverscape complexity, fish movements

across the riverscape and, ultimately, to better predict the impact of future human activity on landscape complexity and the life cycle of Atlantic salmon.

Keywords: image analysis, fluvial habitat quality, telemetry, fish movements, spatial scales, empirical modeling.

1 Introduction

Atlantic salmon (*Salmo salar*) is one of the world's most iconic species. It enjoys a global reputation as one of the kings of sport fishes and as a symbol of pristine, flowing waters. In eastern Canada, the species was worth \$255 million and supported 3872 full-time equivalent jobs in 2010. Spending in the recreational salmon fishery in 2010 alone amounted to \$128 million (<http://www.asf.ca>. 10.01.2012). Unfortunately, the species is often locally endangered and in recent years has shown a general decline in abundance across its range (Verspoor et al. 2007). Some salmon populations in Canadian waters have recently been added to the list of endangered species in Canada.

A major difficulty in managing the Atlantic salmon and its habitats is directly related to the complexity of the species' life cycle. Atlantic salmon is anadromous with spawning and early rearing in freshwater followed by a migration to sea for growth and sexual maturation. In this process, the darkly pigmented, bottom-dwelling freshwater juvenile (generally known as parr) is transformed into the pelagic, silvery smolt (or more accurately, post-smolt) adapted to living in a marine environment. Following a variable period of growth at sea (1 to 3 years or more), adult salmon return to their natal streams to spawn. Early in life, salmon exploit a continuum of habitats arrayed across the fluvial landscape (the riverscape (Fausch et al. 2002)) that must coincide with the ecological demands of a succession of developmental stages, from embryos in their gravel nests to smolts migrating across the estuarine salinity gradient. Understanding the relationship between the physical continuity of the riverscape and the early developmental requirements of salmon is thus critical in assuring the well-being of those populations that must cope with the impacts of human activities.

Unfortunately, failure to manage and conserve key fluvial and estuarine habitats occupied during the early life-history of salmon has been identified as a major contributor to the decline, both locally and widespread, of salmon populations. Thus, the conservation and restoration of key fluvial habitats, on which the production of adult Atlantic salmon repose is of primary concern. One of the major tools used to predict freshwater production potential involves the use of numerical models that couple fluvial habitat characteristics with fish habitat preferences. Recent technical developments in the field of geomatics furnish the tools necessary to develop a new generation of habitat models with far greater predictive power. GEOSALAR was conceived to develop and exploit new cutting edge geomatics tools for the measurement of fish habitat variables over long river segments, and to apply these advances to the problem of understanding Atlantic salmon spatial behaviour and survival in relation to habitat characteristics. Here we summarize our achievements during the seven-year tenure of

GEOSALAR in 3 general thematic areas: (1) the implementation and application of innovative image analysis methods to determine, from low altitude high-resolution airborne imagery and shore-based oblique videography, the spatial distribution of important fluvial habitat descriptors over the entire stream network (reviewed by Bergeron and Carboneau 2012). (2) the tracking of salmon movements among habitats over their entire life cycle to understand how fish behaviour interacts with spatial structure and temporal variation of habitat in rivers and estuaries and, (3) the integration of these observations and procedures into new empirical models for the prediction of Atlantic salmon production.

2 Theme 1: Image Analysis of Fluvial Habitat Descriptors

The dynamic landscape model of stream fish population ecology and life history proposed by Schlosser (1991) emphasized the important role of habitat heterogeneity in providing the various types of habitat required by fish at different life stages for spawning, feeding and finding refuge from harsh environmental conditions. The model also stressed the importance of fish movement and habitat connectivity in allowing individuals to access the distinct habitats required to complete their life cycle. Building upon this model, Fausch et al. (2002) proposed a new approach for stream fish ecology based on a continuous view of fish/habitat relationships over the range of spatial scales spanned by critical life history events: *the riverscape approach*. However, they acknowledged that implementing the riverscape approach in real river environments remained a challenge due to the lack of appropriate technology to obtain physical and biological data with sufficient resolution to model fish/habitat relationships at the appropriate scale (10^3 - 10^5 m) encompassing all required habitats. On one hand, traditional field-based methods offer good ground resolution of fluvial habitat variables at the microhabitat scale but they are labour intensive and not well suited to the continuous characterization of long river segments. On the other hand, satellite-based imagery offer a large-scale synoptic description of entire fluvial systems but their ground resolution is currently not sufficient for fine-scale habitat modelling purposes.

One of the main focuses of the GEOSALAR project was therefore to fill the gap between these approaches by developing a new set of remote sensing methods allowing the production of high-resolution spatially continuous maps of fluvial habitat variables over long river segments. The emphasis of the GEOSALAR research effort was placed on the quantification of bed material grain size and water depth, two of the most important habitat variables for juvenile salmon in freshwater (Bardonnet & Baglinière 2000).

The general approach was to develop image analysis procedures that could be used to extract these variables from low-altitude high-resolution airborne optical images of rivers. Therefore, in August 2002, during the period of summer low flow, the XEOSTM imaging system developed by Génivar Inc. was fitted to a helicopter and

used to obtain plan view digital high resolution optical images covering the entire 80 kilometres of the Principal branch of the St. Marguerite River, an Atlantic salmon river of the Saguenay region (Québec, Canada). The images were obtained at a constant altitude of 155 m above ground, which resulted in a dataset comprising of 5550 standard colour images with a spatial resolution of 3cm (Figure 1).

Figure 1 clearly shows that the high-resolution of the image allows identifying sandy patches in the centre of the mid-channel bar and coarser material on either side. GEOSALAR researchers therefore hypothesized that local bed material grain size in the image could be correlated to local image texture. In order to test this hypothesis, Carbonneau et al. (2004) conducted a direct empirical verification of the correspondence between georeferenced local samples of bed material size on exposed gravel bars and several types of image texture metrics.

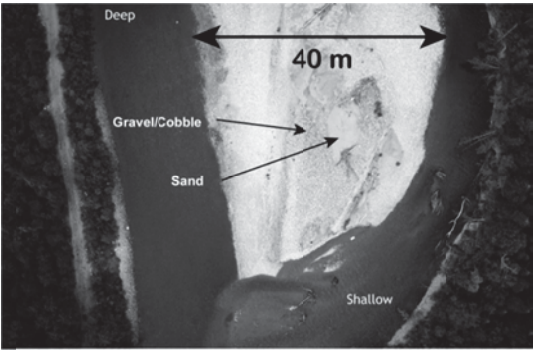


Fig. 1. Example of one the images of the St. Marguerite River (Québec, Canada) obtained for the GEOSALAR project. This 3cm ground resolution image was taken at an altitude of 150m above ground, showing shallow and deep water areas and coarse and fine substrate areas.

Figure 2 shows the calibration and validation curves that were obtained when local two dimensional image semivariance was used as a measure image texture (Carbonneau et al. 2004). Carbonneau et al. (2005a) tested the validity of this approach to map the bed material size of channel wetted areas. They demonstrated that although the water interface inevitably degrades the image quality of submerged areas, enough information is retained to extract particle sizes in clear shallow flow situations (Figure 3).

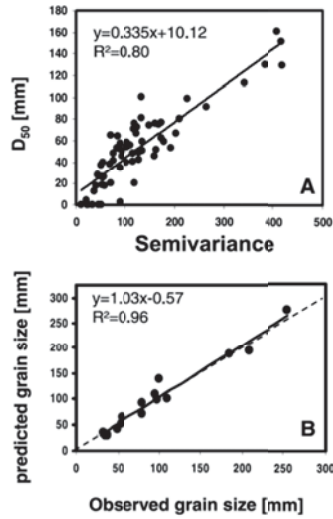


Fig. 2. A) Calibration curve between the local semivariance of pixel brightness and the corresponding field measure of bed material size (D_{50}) on a dry gravel bar. B) Validation curve showing the relationship between the observed and predicted grain size values. The dashed line shows the expected 1:1 relationship. Source: Bergeron and Carbonneau (2012).

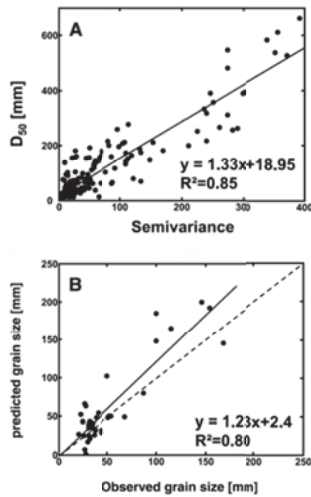


Fig. 3. A) Calibration curve between the local semivariance of pixel brightness and the corresponding field measure of bed material size (D_{50}) for the wetted area of the channel. B) Validation curve showing the relationship between the observed and predicted grain size values. The dashed line shows the expected 1:1 relationship. Source: Bergeron and Carbonneau (2012).

This airborne bed material mapping method was applied on the high resolution images of the Sainte-Marguerite to automatically extract a longitudinal profile of grain size over the 80 km-long surveyed segment of the river (Figure 5B). This long profile helped GEOSALAR researchers to determine that the large scale spatial organization of Atlantic salmon habitat is strongly structured by the presence of sedimentary links in the Sainte-Marguerite River (Davey and Lapointe 2006; Bouchard and Boisclair 2008; Johnston and Bergeron 2010). A sedimentary link is a longitudinal sedimentary unit of intermediate scale (typically 2-20 km long) characterized at the upstream end by a node of coarse sediment supply followed by a gradual downstream fining of substrate and an associated reduction of slope (Rice, 1998; Rice and Church, 1998). Because the downstream changes in substrate and slope are associated with changes in channel morphology and hydraulics, they create a longitudinal sequence of aquatic habitat types moving from steep, fast flowing and turbulent boulder bed channels at the head of links to meandering, slow-flowing, low-gradient sand channels at the downstream end. Biological data revealed that the spatial distribution of various life-stages of the Atlantic salmon population of the SMR was strongly structured by the sedimentary links. Visual surveys of salmon parr along the sedimentary links showed that highest densities were consistently found at the upstream end of links, where the large bed material size and complex flow patterns produced the most favourable habitat for large parr (Figure 4A). A survey of Atlantic salmon spawning sites along the same links showed that the centroid of spawning sites on each link occurred towards the middle to downstream end of the link due to appropriate bed material size (Figure 4B; see section 4 for further explanation).

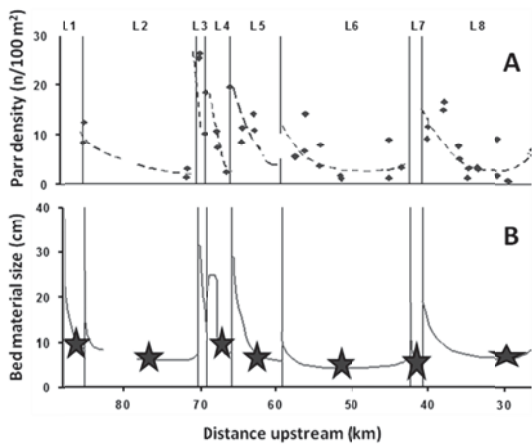


Fig. 4. Illustration of the spatial correspondence between the sedimentary link structure (L1-L8) of the Sainte-Marguerite River and A) the distribution of Atlantic salmon parr densities (Data extracted from Bouchard and Boisclair (2008)), B) the centroid of spawning sites on each sedimentary link. See section 4 for further explanations (Re-drawn from Davey and Lapointe (2007)).

In order to obtain bathymetry maps over the same 80 km-long stretch of the river, GEOSALAR researchers developed a procedure based on the relationship that exists between the local water depth of the river and the brightness values of the corresponding pixels in the image. After correcting for variations of lighting conditions between images during the survey, a fairly good relationship between pixel brightness and water depth was obtained and used to produce a bathymetry map of the entire study segment of the SMR (Figure 5).

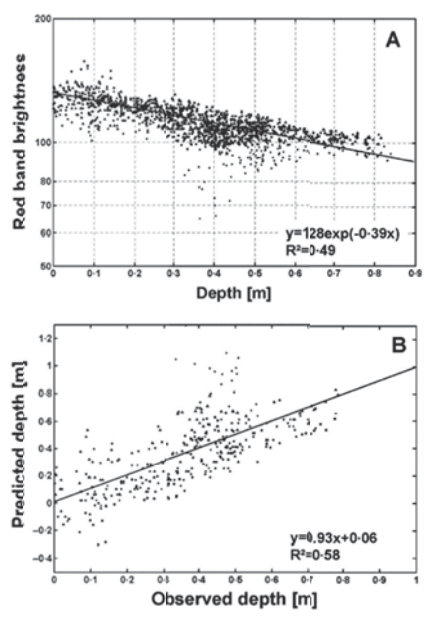


Fig. 5. A) Final calibration curve between red band brightness and water depth after application of the correction procedure. B) Final validation relationship testing the predictions of the calibration equation versus additional, independent, field data. Source: Carbonneau et al. (2006).

3 Theme 2: The Tracking of Salmon Movements Among Habitats

3.1 Small Spatial Scales

During their time in rivers, juvenile salmon move on a daily basis between feeding and refuge habitats, on a seasonal basis between summer and winter habitats and at least once in their lifetime between freshwater and the sea. Nevertheless, the understanding of the link between habitat structure at relatively small spatial scales (50-500 m) and salmon populations has been impeded in the past by a lack of appropriate methods for tracking movements of small individual fish in their natural environment.

In the GEOSALAR project, we aimed to develop new geomatics tools using passive integrated transponder (PIT) technology to resolve some of the usual problems encountered when trying to characterize fish movements in natural settings. Indeed, this technology offers a versatile alternative to traditional telemetry methods (radio or acoustic) because PIT tags are small and inexpensive, last indefinitely and allow the identification of individual fish. They consist of an electronic microchip encapsulated in biocompatible glass and programmed with an alphanumeric code that is emitted when the tag is activated by an external antenna (Figure 6).

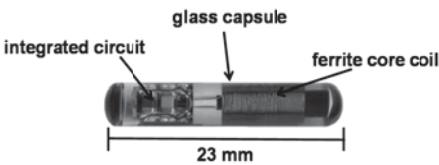


Fig. 6. Structure of a PIT tag

The spatio-temporal resolution achieved when tracking PIT-tagged fish depends mostly on the type of antenna system used. In natural rivers, stationary PIT systems typically allow the monitoring of fish passage at a single location (Figure 11D) (Greenberg & Giller 2000), while a larger spatial extent is covered in some streams with portable PIT antennas (Figure 7A, B) (Roussel et al. 2000; Zydlewski et al. 2001). The main disadvantage of portable systems is that they must be operated manually by a person that wades across the stream, which is time-consuming, restricts the frequency of surveys, and thus limits the temporal resolution of this type of antenna.

Recent developments in PIT systems have combined the advantages of both stationary and portable systems by adapting stationary, single and multiple, antenna systems to natural environments for continuous monitoring of fish with higher spatial and temporal resolution (Greenberg & Giller 2000; Zydlewski et al. 2001; Riley et al. 2003). In the GEOSALAR Project, a flatbed antenna grid designed for continuous remote monitoring of PIT-tagged fish at the reach scales ca. 100 m was developed and used for the monitoring of juvenile salmonid movements (Figure 7C) (Johnston et al. 2009). As far as is known, this flat-bed antenna grid system was the first system that allowed the monitoring of fish positions *in situ* over an extended area, with high resolution and with the ability to collect data consistently over a 4-month period.



Fig. 7. Different types of PIT systems: A) portable system, B) large portable system, C) flat-bed antenna grid (during installation) and D) single-point stationary system. Photo credits: Patricia Johnston (A, B, C) and Jean-Nicolas Bujold (D). Modified from Johnston & Bergeron (2009).

A brief description of the flatbed antenna grid will be given here; we refer the reader to Johnston et al. (2009) and Johnston & Bergeron (2009) for technical details. The flatbed antenna grid is an antenna array buried in the substrate of a stream (Figure 8C). It was composed of 242 antennas that covered a stream section approximately 100 m long by 10 m wide and was adjusted for the detection of half-duplex 23-mm PIT tags (Texas Instruments). Figure 8 shows the site and the location of all the antennas. The detection range of antennas was typically 20 to 40 cm in height and 80 cm horizontally depending on the antenna type (see Johnston et al. (2009) for a description of the antenna types). When a tag was detected by any of the antennas, the date, time, antenna ID, and fish ID (tag number) were recorded. Since all antennas were georeferenced, it was possible to interpolate fish positions by converting antenna ID into spatial coordinates. Antennas were activated sequentially and the interrogation of all antennas required 33 s. Overall, the detection field of the antenna grid covered 27 % of the wetted area of the site at a discharge of $0.07 \text{ m}^3 \text{ s}^{-1}$.

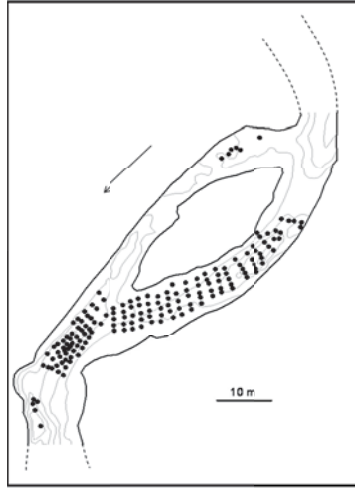


Fig. 8. Disposition of the antennas comprising the flat-bed antenna grid in the ruisseau Xavier. Dotted lines delineate approximate water line. Arrow indicates flow direction. Modified from Johnston & Bergeron (2009)

Portable systems were also developed and optimized during the GEOSALAR project. Typical portable antennas (Figure 7A) were constructed based on previous reports of such systems (Roussel et al. 2000, Zydlewski et al. 2001). They consist of circular antennas (coil inductor loop) mounted on a wand and connected to portable backpack units that include a reader, palmtop, and batteries. The detection range of this antenna type is between 0.7 m and 1 m, depending on the orientation of the transponder. Large portable antennas (Figure 7B) have the same structure except for the size of the inductor loop. They allow the manual tracking of PIT-tagged fish over large surfaces.

Stationary and portable antenna systems complement each other, and combining both is believed to provide a complete representation of fish habitat use. Indeed, fixed PIT systems have been developed to offer continuous monitoring of fish passage at specific locations, while portable systems are more versatile but offer a limited temporal resolution. The comparison of both systems (Johnston & Bergeron 2009) showed that the continuous monitoring of fish positions with the antenna grid provided a higher number of detections compared to the portable antenna surveys and allowed the detection of a higher number of individuals. Nevertheless, over short periods (i.e. 24 hours) a slightly higher number of fish were detected with the portable antenna because individuals not located on the antennas of the grid (i.e. located between antennas or outside the antenna grid area) could be detected. Moreover, we observed that the spatial patterns of fish positions recorded with the two systems were highly dependent on individual spatial behaviour. Both antenna systems tended to underestimate the extent of fish space use, which was apparent when comparing with the total extent of movements measured by combining the data of the two systems for individual fish. The antenna grid system was however slightly better at recording the extent of fish habitat

use due to continuous tracking. For fish that used a restricted space, both antenna systems performed equally, providing similar locations of point positions. The antenna grid system recorded a high number of short movements in the study site that were impossible to monitor with periodic portable antenna surveys alone.

Combining antenna system types (antenna grid, portable antenna and fixed single point antennas) allowed new discoveries regarding juvenile salmon movements and habitat use. One of the most interesting findings is that juvenile salmon move more often and greater distances than we previously thought. Juvenile salmon are generally considered as being sedentary and territorial in summer but the detection of tagged fish by PIT-antennas showed other behaviours. In a small river (second order stream), large inter-individual variations were observed in the movement patterns (Johnston 2011, Bujold 2011). While some individuals moved infrequently and over short distances (i.e. few meters), many others moved often and/or moved over long distances (i.e. between the main river branch and up to 2.5 km in a small tributary). In a larger river, we observed that daily (day/night) movement distances and the total extent of movements gradually increased downstream of sedimentary links, from complex boulder rich habitats upstream to more homogenous habitats downstream (Johnston et al., In preparation). However, day/night differences in habitat values (substrate, velocity, depth) selected by juvenile salmon did not vary. Compared to upstream sites, longer movement distances are thus required at the downstream end of links to reach different microhabitat characteristics associated with feeding and sheltering. PIT technology allowed us to demonstrate for the first time that intermediate spatial scales (i.e. reach scale), and not only the micro-habitat scale, is of significance in determining movements for juvenile salmon (Johnston 2011, Johnston et al. In preparation).

An important question in ecology is how fishes respond to the high temporal and spatial variability of habitat conditions in rivers. The use of PIT systems allows the gathering of empirical data on individual behaviour that is needed to understand population ecology and how individual behaviour translates into population dynamics (Greenberg & Giller, 2000). Multiple antenna PIT systems, such as the one developed during the GEOSALAR Project, have the potential to provide fundamental information in real-time on fish movements when all other methods are impossible to use, such as during high flows, ice-cover formation or break-up and rapidly changing environmental conditions. Future development in PIT technology includes the miniaturization of PIT-tags (smaller 11-mm half-duplex tags recently became available) and the development of larger multiple antenna systems. There is currently a research project at Hydro-Québec which aims to develop an antenna grid system adapted to large rivers with hydroelectric production facilities. This future system would allow the monitoring of fish reaction to hydropeaking (i.e. rapid changes in water levels) and fish use of artificial habitats during all seasons and life stages. Such a system may also be used for monitoring fish movements in a context of habitat modelling, river restoration projects and assessing impacts of anthropogenic modifications and potential effects of climate change.

3.2 Intermediate Spatial Scales

The first migration of salmon smolts from the freshwater habitat, through the surface waters of estuaries and into the pelagic marine environment as post-smolts is purported to involve a mixture of passive and active behavioural processes that must be studied over intermediate spatial scales ($10^3 - 10^5$ m). Smolt and post-smolt migration patterns, and their underlying mechanisms, have come under increasing scrutiny as there is concern that greater rates of marine mortality documented among Atlantic salmon over the past decade may be largely incurred in the near shore coastal zone where post-smolts may be exposed for the first time to a large field of predators (Dieperink et al. 2002). Such studies have been greatly facilitated with the advent of small ultrasonic transmitters which allow accurate monitoring of smolt positions (Voegeli et al. 1998), either through the use of an array of fixed hydrophones (Lacroix et al. 2005) or by the use of mobile tracking (Økland et al. 2006).

In the GEOSALAR project, we used an array of fixed, georeferenced hydrophones (Vemco Ltd., VR2 model) in the inner bay of Gaspé Bay, a coastal embayment in Québec, Canada (Figure 9), to determine migration patterns of Atlantic salmon post-smolts internally tagged with acoustic pingers (Vemco Ltd., V9-6L model) over small and intermediate spatial scales. This extensive resolution provided more accurate estimates of post-smolt swimming speeds because it increased the ability to measure changes in post-smolt position over relatively fine spatial and temporal scales, and detected movements that less dense arrays would have missed.

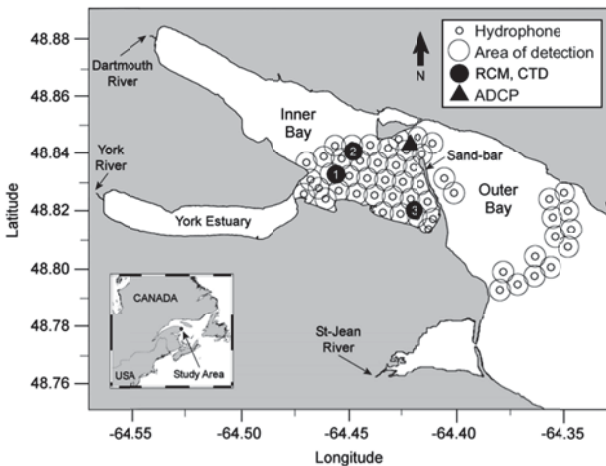


Fig. 9. Study area, showing position of hydrophones, ADCP, RCMs, and CTDs. NB: the detection range around each hydrophone is shown with a radius of 400 m. RCM- current meter, CTD- conductivity, temperature and depth meter, ADCP- acoustic Doppler current profiler. Circles around hydrophones illustrate the estimated 400-m acoustic detection zone. Modified from Hedger et al. 2008b.

Additionally, the fact that hydrophones were in close enough proximity for post-smolts to often be detected at multiple hydrophones over short-time scales meant that it was possible to predict post-smolt centres of activity, rather than rely on the coarse precision of the nearest hydrophone. We firstly developed an optimized method of interpolating post-smolt centres of activity that produced less error than the principal method used in the literature (Hedger et al. 2008a). Then, we developed and employed empirical statistical modelling (Hedger et al. 2008b) to determine the influence of environmental properties on the spatial and temporal migration patterns of wild Atlantic salmon post-smolts with the objective of determining the relative importance of passive and active processes underlying the migration.

We observed complex post-smolt migration patterns with much directional variation (Figure 10). Nevertheless, the pattern of post-smolt migration and environmental variation was consistent with active rather than passive migration, with smolt swimming offshore nocturnally, using increases in salinity on inflowing currents for orientation, and using daytime hours for prey detection and predator avoidance. Swimming speed was significantly related to salinity gradient, with smolt swimming faster against a positive salinity gradient (salinity increasing away from the river's mouth). This suggests that smolt were responding to salinity, actively swimming towards saline areas.

The importance of salinity was also substantiated by the observation that migration was faster in the more saline water of the outer bay than in the fresher waters of the inner bay (Hedger et al. 2008b). Although significant relationships existed between patterns of post-smolt migration/swimming and environmental properties, these properties alone were not responsible for post-smolt orientation. Most importantly, although post-smolt swam strongly against a positive salinity gradient, they did not reverse their behaviour when there was a negative salinity gradient (salinity increasing towards the river's mouth) i.e. salinity was a factor, but it was not the only factor. These observations are consistent with the hypothesis that post-smolt refer to an innate compass to maintain a preferred bearing leading them offshore in an easterly direction (reviewed in Dodson 1988), with swimming velocity modulated by direction of the salinity gradient. These observations also suggest that the high rate of displacement through the coastal zone afforded by active migration and rapid exposure to high salinities, even in the absence of persistent salinity gradients, serves to accelerate the movement of post-smolt towards their offshore feeding grounds and minimize near-shore predation (Hedger et al. 2008b).

The migration of smolts in the freshwater fluvial habitat is mostly nocturnal and has a strong component of passive drift (see Ibbotson et al. 2006) with swimming oriented with the flow (Davidsen et al. 2005). As reviewed above, post-smolt migration in Gaspé Bay demonstrated active seaward orientation (Hedger et al. 2008b). Thus, there must be a behavioural transition in the estuarine environment with mostly passive behaviour in rivers and more active oriented behaviour and greater swimming speeds in more saline environments. We thus studied the influence of environmental properties on the spatial and temporal migration patterns of wild Atlantic salmon smolts

within the York River prior to their migration to Gaspé bay, using a grid of hydrophones moored in the downstream reach of the river. We observed that migration within the York River was predominantly nocturnal and its rate was affected by discharge during the night, consistent with passive nocturnal migration (Martin et al. 2009). In the estuary (salinity greater than 2 parts per thousand), migration was still affected by water velocity as smolts were moving seaward on ebbing tides and landward on flooding tides. Seaward movements, however, were more frequent and ground velocity increased as salinity increased. An increase in salinity during the estuarine migration induced a shift in the behaviour of post-smolts from a generally passive migration to a more active and seaward oriented migration (Martin et al 2009), consistent with the behaviour observed in the bay of Gaspé (Hedger et al. 2008b).

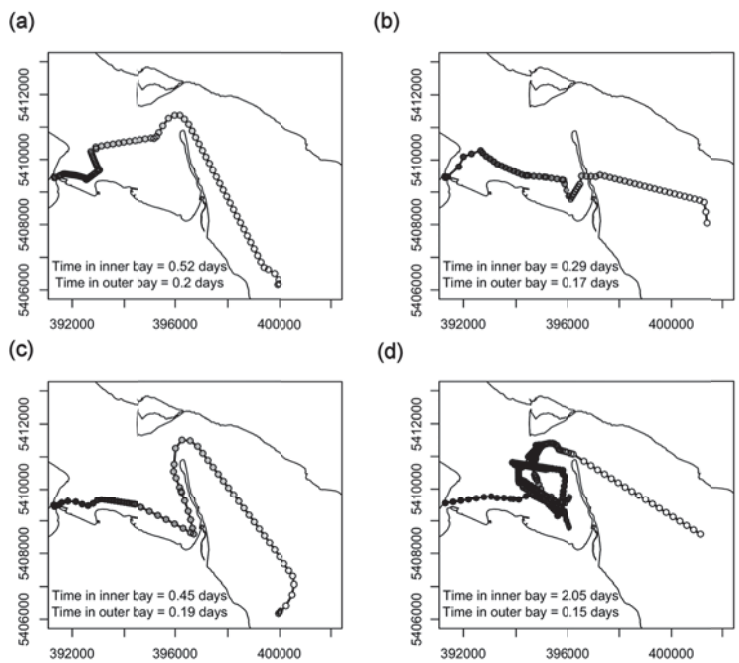


Fig. 10. Examples of post-smolt migration patterns in the Bay of Gaspé, 2006: (a) rapid migration through the channel; (b) rapid migration over a sand bar at high tide; (c) initial migration to the sand bar and deviation towards the channel; (d) meandering migration. Circles represent the time sequence of the tracks: filled circles the beginning, grey circles the middle and open circles, the end of the tracks. Modified from Hedger et al. 2008b.

Postspawning survival rates are quite variable among salmonid fishes, with *Salmo* species exhibiting relatively high survival, depending upon their ability to restore lost somatic energy reserves and to escape exploitation. Atlantic salmon (*Salmo salar*) kelts, defined as salmon that spawned the previous autumn, return to the marine environment, usually during the spring following the fall spawning period (Niemelä et al.

2000). Very little is known about the coastal zone and marine ecology of salmon kelts (Reddin et al. 2004) and the few published accounts available are not consistent. Several studies have shown the importance of diving in adult salmon (reviewed by Reddin et al. 2004). Most have shown, however, that salmon mainly occupy surface or near-surface waters, with periodic descent to deeper waters (e.g. Hubley et al. 2008). We thus exploited the same hydrophone array in Gaspé Bay to determine how temperature, salinity and current direction control the seaward migration and swimming depth of salmon kelts (using acoustic tags equipped with depth sensors) and to compare the migration patterns with those of post-smolts in the same study area to determine if behavioural consistency exists across life-stages (Hedger et al. 2009).

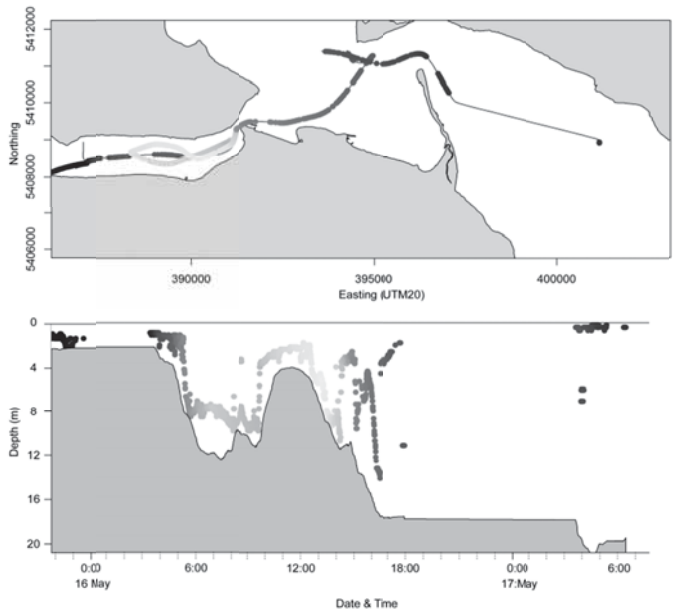


Fig. 11. Longitudinal (upper panel) and vertical (lower panel) tracks of kelt 77 in the York River, York Estuary and Gaspé Bay. The vertical line in lower panel denotes the boundary between the estuary (to the left) and the bay (to the right). Colors denote the time sequence of the track (blue: start) and red (exit from the array)). Kelt 77 was tagged and released on May 4, 2007. After remaining in the river’s delta for 10.2 days, the fish entered the estuary. In just over 30 hours, kelt 77 had left the hydrophone array en route for the Gulf of St. Lawrence (upper panel of Figure). Kelt 77 dived repeatedly to explore the deeper waters at the junction of the estuary and the bay, but left the final hydrophone array swimming at the surface (lower panel of Figure). Forty-nine days and 640 km later, kelt 77 was detected in the Strait of Belle Isle, en route for the Labrador Sea. Kelt 77 maintained an average straight-line ground speed of 13 km per day to traverse the Gulf of St. Lawrence.

We also extended the spatial scale of our study by monitoring acoustic signals on a hydrophone line located in the Strait of Belle-Isle, located 640 km to the northeast of

the York River, between the Quebec north shore and Newfoundland (Hedger et al. 2009).

A large variation in migratory behaviour existed, with some kelts making a direct, strongly oriented traverse across the estuary and bay, and others showing multiple changes in orientation. There was long-term residence (typically several weeks) in the river and rapid migration once kelts reached the estuary and bay, resulting from seaward swimming, with a net seaward movement even on a flood tide. Diving was more frequent during daytime (see Figure 11 for one example of migratory behaviour). The patterns of migration within the coastal zone were similar to those identified for post-smolts implying a universal pattern of coastal zone migratory behaviour in both smolts and kelts. Migration speed within the marine habitat was dependent on date of departure from Gaspé Bay, which in turn was dependent on the length of time kelts remained in the river. The longer they remained in the river, the later they migrated out of Gaspé Bay and the faster they migrated to the Strait of Belle Isle (Hedger et al. 2009).

4 Theme 3: New Empirical Models for Atlantic Salmon Production

The dominant method for determining fish habitat use in rivers is by in situ ground surveys in which habitat characteristics are sampled concurrently with fish density. A variety of approaches are then used to analyze relationships between habitat attributes and fish density (e.g. Hedger et al. 2005). One of the most established approaches is that of empirical preference modelling (Jacobs 1974) which quantifies the change in habitat use as a function of availability. As previously discussed, bed material grain size is a key determinant of habitat selection by juvenile Atlantic salmon. Empirical preference modelling has shown that juvenile salmon prefer moderately coarse substrates of pebbles (0.4-6.4 cm), cobbles (6.4-25.6 cm) and boulders (greater than 25.6 cm) (Bardonnet and Baglinière 2000). However, this approach only considers the habitat where the fish was captured and ignores spatial patterns of habitat use in which fish move across the riverscape to exploit multiple habitats. Thus, fish density will be dependant not solely on the habitat characteristics where captured but on surrounding characteristics. An area of optimal habitat may not support a high fish density if it is surrounded by sub-optimal habitat.

As part of the GEOSALAR project, Hedger et al. (2006) showed how grain size maps (obtained under Theme 1) could be used to improve the prediction of juvenile Atlantic salmon density. Using historical fry and parr density data obtained from 1997 to 2004 at 48 parcels (5m x 20m) distributed along the Sainte-Marguerite River, they derived substrate preference models using substrate size (D50) measurements obtained 1) directly inside the parcel at the time of density estimation using the traditional Wolman count method and 2) inside the larger grain size map of the image including the fishing parcel obtained using the automated airborne grain size mapping methods

described in theme 1. They showed that, although the shape of the relationships between juvenile salmon density and D50 were similar for the two models, the relationship was stronger using mean image D50, suggesting that the habitat surrounding the location of the fishing parcel had a direct effect on fish density. Clearly, this example shows that one benefit of automated methods of grain size measurements is to allow multi-scale analysis of fish habitat relationships that would be prohibitively labour intensive using traditional ground based methods. Such fish-habitat relationships are critical in the estimation of salmon production in fresh waters.

Automated airborne grain size mapping methods based on imagery can be extended to entire channels. The grain size profile information obtained from the automated grain sizing methods developed in theme I allowed the identification of distinct sequences of downstream grain size fining along the Sainte-Marguerite River. Rather than exhibiting a single longitudinal decrease of grain size from headwater to mouth, the river could be segmented into a number of discrete sedimentary links, each characterized by a node of coarse sediment supply followed by a gradual downstream fining of substrate. The sedimentary link concept was originally developed for high mountain rivers where the supply of coarse sediment is mainly related to tributary inputs, valley-side landslides and tributary fan contacts (Rice and Church, 1998). However, using the GEOSALAR grain size data set, Davey and Lapointe (2007) adapted and extended the original concept to account for sedimentary links of lower mountain landscapes of North Eastern Canada where coarse sediment inputs are often related to supply zones (rather than point sources or nodes) originating in bedrock canyon reaches or valley bottom deposits of glacial drift (mainly of fluvioglacial and paraglacial origin).

Because the downstream changes in substrate and associated slope along sedimentary links are accompanied by changes in channel morphology and hydraulics, they create a longitudinal sequence of aquatic habitat types moving from steep, fast flowing and turbulent boulder bed channels at the head of links to meandering, slow-flowing, low-gradient sand channels at the downstream end. Davey and Lapointe (2007) showed how such information on the large-scale variations of substrate size could help understand the spatial organization of Atlantic salmon spawning habitat. These authors assessed the substrate characteristics of spawning sites (D50 of spawning substrate, representing 50% of the cumulative size distribution of the surface layer sediment) and percent sand (<2 mm) in riffle substrate. The mean size of bed surface layer sediments (standard deviation) measured in 19 spawning riffles was 51 mm (11 mm) for pavement D50 and the percent sand content (<2 mm) of the riffle sub-pavement layer was 13% (4%).

Within each of the 10 surveyed links, the centroid or center of gravity of observed spawning activity (its average, along stream location, weighted by reported number of spawners) occurred at a point along each downstream fining zone where median size of the surface pavement was in the suitable D50 range of 40–60 mm. No spawning was reported within any supply zone of a sedimentary link. In the Sainte-Marguerite

River, spawning tends to occur towards the middle to downstream end of the cobble–gravel fining segment in a sedimentary link (median fractional distance=0.7, Fig. 4B). Higher upstream, bed material size was too coarse to allow female salmon of this particular population to dig their redds. Below, the absence of spawning activity was probably related to poor embryo survival associated with the high percentage of sand in riffle substrates.

Following on the theme of spatial complementarity of different essential habitats, Kim & Lapointe (2011) developed a simple but powerful landscape ecology model explaining the large variability in size of salmon runs across Gaspé watersheds in Quebec, Canada based on the relative spatial distribution of three complementary habitat types (spawning habitats, parr habitat and adult holding pools). As noted above, optimal spawning habitat for Atlantic salmon occurs predominantly in reaches with gravel to cobble bed grain sizes (neither too fine for good intergravel flow nor too coarse for the female to dig her redd) and this represents a relatively narrow range of substrate sizes compared to overall watershed availability (Davey & Lapointe 2007). On the other hand, parr require habitat distinct from spawning habitat with coarser, typically boulder-rich substrate and faster water, where they can efficiently feed on drifting prey, hide from predators and take shelter in the large bed interstices (Morantz et al. 1987, Valdimarsson & Metcalfe 1998, Heggenes & Saltveit 1990). For older salmon juveniles in particular, survival to smoltification appears to be optimal in boulder-rich reaches, habitats that are distinct and complementary to spawning reaches where the fish emerged as fry. Finally, large numbers of mature adults are regularly observed to congregate in a limited number of holding pool habitats, where they rest in mid-summer before migrating upstream to spawning reaches in the fall (Crisp 1996).

Although the reason for this behaviour is not known, Hawkins & Smith (1986) suggested that adults compete for the best holding positions below spawning sites, such that they will be the first to attain the spawning grounds when conditions are favourable. Frequent, bedrock canyon segments with particularly deep and slow water pools and groundwater springs off optimal holding pools in the salmon rivers of the Gaspé Peninsula, though the length and distribution of these canyon segments vary from one watershed to another.

Geomorphic analyzes of Gaspé Rivers using aerial photographs and topographic maps revealed three broad partitions of relatively homogenous valley segments based on channel slope, bed sediment size trends and degree of valley confinement. These types were classified as bedrock canyons (BC, that also act as boulder ‘source zones’ triggering ‘sedimentary link’ units, offer deep holding pools and parr habitat but little spawning habitat), laterally confined meanders (LCM, downstream fining, mainly cobble-rich channels displaying regular channel contacts with the valley wall which provide sporadic boulder inputs and locally optimal habitat for large parr) and unconfined meanders (UM, freely meandering channel with downstream fining and a near-absence of boulder habitat) (Kim & Lapointe 2011). Based on the relationships of bed sediment sizes with juvenile habitat and with spawning habitat, these authors quanti-

fied the amount of ‘optimally’ productive habitat’ in a watershed as a function of the observed organization of geomorphologic segments along the river network. Specifically, the total length of ‘optimally productive habitat’ in a watershed was calculated as the sum of the lengths of UMLCM segments with a channel slope of less than 1% (providing a combination of spawning and parr rearing habitat) that are also located within 15 km upstream of any BC segment (the latter providing holding pools). Their model assumes that aggregate smolt production is largely concentrated in these optimal segments. The aggregate length of optimally productive segments, as defined above, was a strong predictor of the average size of the annual salmon runs across these watersheds, explaining over 90% of the variation in abundance across 14 watersheds (Kim and Lapointe 2011; Figure 12).

The model was a significantly better predictor than models based on interbasin differences in total stream length or in estimates of total area of salmon habitat, using standard reach-bases models that failed to take into account the complementarity of the spatial organisation of essential habitats occupied across life stages.

These developments provide potentially powerful tools to better predict the impacts of human activity on fluvial geomorphology and ultimately on salmon habitat. Any human intervention, particularly bridge and road construction, and flow diversions, that reduces optimally productive habitat by modifying the structure of sedimentary links will have a quantifiable impact on salmon abundance. Furthermore, these projections will be relatively cost-effective to obtain given the remote spatial referencing technology developed here. We may also envision in a near future direct intervention in impacted streams and rivers to re-establish critical geomorphological features (e.g. source zones, triggering sedimentary link units). In the medium term, these models and their underlying technology will provide powerful new tools to properly assess the impacts of modifications to the riverscape of Atlantic salmon.

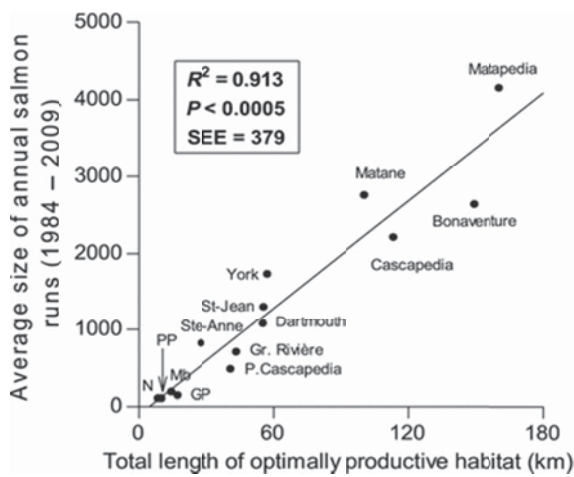


Fig. 12. The average size of the annual salmon runs as a function of the total length of optimally productive habitat for 14 watersheds in the Gaspé Peninsula. N: Nouvelle, PB: Petit Pabos, GP: Grand Pabos, MB: Malbaie.

5 The Added Value of Networking

The GEOSALAR project was central to the attainment of several of GEOIDE's objectives, with spatial referencing technology at the root of the project. The major challenge GEOSALAR faced was the integration of spatial referencing techniques with data acquisition from heterogeneous sources, including landscape complexity, fish movements across the landscape and the impact of human activity on landscape complexity at different spatial and temporal scales. More specifically, the GEOSALAR project was an integrated geomatics project focused on a critical sustainability issue; the conservation of Atlantic salmon populations and their habitats in rivers and adjacent coastal zones. The success of the GEOSALAR project was clearly based on an innovative partnership model that combined highly complementary disciplinary, institutional, and organizational strengths of researchers in a number of institutions or organizations across Canada and from abroad. The results briefly reviewed here could not have been obtained without the collaboration of specialists from disciplines as diverse as remote sensing, GIS, fish biology, fluvial geomorphology, ecosystem modelling and engineering. The team also included strong links to government researchers in organizations (MRNF and Fisheries and Oceans, Canada) primarily responsible for managing salmonid resources in Québec and eastern Canada, respectively. The research program was also based on partnerships with private enterprise (Genivar), who benefit directly from developments in habitat modeling and fish movements, with Canada's largest public utility (Hydro-Québec) who is a major purchaser of this kind of environmental technology via the public sector and with Canada's major non-governmental organizations (Atlantic Salmon Federation, Federation Québécoise pour le saumon Atlantique and Centre Interuniversitaire de Recherche sur le Saumon Atlantique (CIRSA) Inc.) all dedicated to conserving Atlantic salmon as a sustainable resource.

Last but certainly not least, the network environment provided by GEOSALAR, GEOIDE and CIRSA provided a unique training experience for graduate students. The network environment encouraged the development of a research culture that promoted extensive, multidisciplinary collaboration. All students and assistants were exposed to the principals and methodologies of all aspects of the research program. This has been shown in the past to generate tremendous stimulus for co-operation and knowledge exchange between disciplines. In addition, the nature of GEOSALAR's extensive partnerships through its adhesion to the programs of GEOIDE and CIRSA provided direct contact between students, government biologists, managers and members of industry and NGOs, all concerned with issues of sustainable resource development. All of the graduate students who trained within the context of GEOSALAR

are employed here and abroad in both the private and public sector, bringing a unique multidisciplinary vision to the challenges of sustainable resource development.

The specific mechanisms employed to insure collaboration and continued interaction between partners described here were highly varied. First it is important to note that this level of collaboration does not develop overnight, even when participants are fully dedicated to networking. The network described here started in 1995 with the creation of CIRSA and the building of a research station insuring the physical proximity of students and professors during the summer months. The original group was relatively small, with 9 principle investigators. The success of the early stages of CIRSA depended on a common research budget, a unified and focused research program, a common research station and field site, a formal annual meeting of the entire group (now in its 15th year) and strict rules requiring the co-direction of graduate students by at least 2 members of the research time, drawn from different disciplines. This was made possible because of the geographical proximity of the core group of PIs.

Of equal importance in insuring a culture of sharing and collaboration was the development of numerous social events that extended far beyond the formal settings of meetings and conferences. The cohesiveness of this core multidisciplinary group thus facilitated the development of the greater GEOSALAR initiative and its integration into the Geoide network. To foster wider collaboration, an international Advisory and Outreach Board was formed for each phase of the GEOSALAR project that served as a series of nodes for international collaboration and exposure. Finally, the GEOSALAR network profited greatly from two international workshops that we organised in 2005 and 2007. Members of the Advisory and Outreach board were invited to meet with the research team and our government and private partners. These were both highly successful events and served to foster collaboration at the national and international levels.

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Chapter 10

Collaborative Processes and GeoSpatial Tools in Support of Local Climate Change Visioning and Planning

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Abstract. GEOIDE NCE funding has enabled a decade of collaborative development of geospatial decision-support tools on sustainability issues, working with several regional and local governments, and multiple academic teams. Project strengths have been the innovative development and/or application of geospatial tools to climate change within collaborative processes, the on-going development of relationships between researchers and local communities, and longitudinal project evaluation, made possible through on-going, multi-year GEOIDE grants. The linked projects have led to increased local government awareness and capacity-building around climate change, the development of localized and downscaled climate change scenarios tied to local issues, local champion support, and early uptake of spatial planning tools and project outputs within communities. The flexibility of the Local Climate Change Visioning process has allowed the adaptation of geospatial tools to a range of contexts and thematic areas. It is one stream of activities that integrates climate change within the operations of municipal and regional governments.

Keywords: climate change, decision making, geospatial tools, geovisualization, Local Climate Change Visioning.

1 Introduction

Over the past decade, GEOIDE NCE funding has enabled the collaborative development of geospatial climate change decision-support tools with regional and local governments and academic teams within a process termed “Local Climate Change Visioning” or LCCV (Shaw et al., 2009; Burch et al., 2010b; Pond et al., 2010a; Sheppard et al., 2011; Cohen et al., 2012a; Burch et al., submitted 2012). This chapter outlines the research trajectory and collaborative networks that were formed, provides an overview of project processes, and highlights key outputs and preliminary outcomes.

1.1 Background and Research Questions

In the face of urgent challenges to mitigate greenhouse gas emissions (Anderson and Bows, 2011) and adapt to escalating climate change impacts (IPCC, 2007), local governments are emerging as a necessary site of climate action (Adger et al., 2005; Bai, 2007; Province of British Columbia, 2007 & 2008): engaging with local governments and citizens in order to integrate climate change within local planning processes for both adaptation and mitigation has become critical (cf. Snover et al., 2007; Picketts et al., 2012). However, incorporating climate change at the local scale faces challenges, including: climate model downscaling (Shaw et al., 2009), policy response options that are generally formulated at the national scale (Parry et al., 2007), the challenges of science communication (Moser and Dilling, 2007; Shome and Marx, 2009; O’Neill and Nicholson-Cole, 2009), an external expert-driven knowledge generation process that has not benefitted from local input and meaningful engagement (Shaw et al., 2009), and the need for cross-silo local planning as well as the inter-disciplinarity required by sustainability science (Robinson and Tansey, 2006).

The range and relative newness of these challenges calls for better participatory processes and tools to support local stakeholders and municipal decision-making under conditions of considerable uncertainty (Bizikova et al., 2011). Drawing together a range of disciplinary approaches, Sheppard et al. (2008), Shaw et al. (2009), Burch et al., (2010b), and Sheppard et al. (2011) have posited that a process utilizing participatory co-production of knowledge, inter-disciplinary research teams, localized scenarios, and geovisualization tools could help to meet the need for awareness-building, co-production of knowledge, capacity-building, and more effective local decision-making around climate change.

Participatory processes involving stakeholders and scientists provide a way to bridge the global to local scale in terms of knowledge production (Shaw et al., 2009), using co-production of knowledge (Gibbons 1999; Robinson and Tansey, 2006; Bizikova et al., 2011) and shared learning that potentially enables more creative decision-making (Newig et al., 2008). A process that includes local stakeholders is also posited to ensure local ownership towards and accountability for the process (UKCIP 2009 in Shaw et al., 2009), as well as improved outcomes, including enhanced legitimacy

(Lange, 2011; Larsen and Gunnarsson-Östling, 2009) and more meaningful and inclusive results (Dryzek, 2000). Localized, co-produced knowledge is posited to overcome public barriers to engaging on climate change (Lorenzoni et al., 2007; Burch et al., 2010a), avoiding the common information deficit model approach to engagement around climate change (Shove, 2010).

In the planning field, deliberative processes are posited to strengthen outcomes (Healey, 1997; Salter et al., 2010); Arnstein's "ladder of participation" provides a framing tool as to the level of participation at various decision-making stages (cf. Schlossen-berg and Shuford, 2005; Arnstein, 1969). Inter-disciplinary research teams and approaches should be able to handle the complexities of "wicked problems" (Rittel and Webber, 1973), in this case, global to local socio-ecological challenges (Miller et al., 2008; Tansey and Robinson, 2006). Transdisciplinary action research (TDAR) (Schroth et al., 2011b) goes beyond interdisciplinary approaches in bringing academic research to bear on real-world problems (Walter et al., 2007; Miller et al., 2008) through high levels of collaboration and joint decision-making (Walter et al., 2007), while participatory integrated assessments (PIA) are designed to provide meaningful participation into the decision-making process around sustainable futures (Salter et al., 2010).

A critical characteristic of global climate change research has been the development of global scenarios (Nakicenovic et al., 2000; Cohen and Waddell, 2009), developing out of a historically diverse range of approaches to scenarios and their uses (cf. Bradfield et al., 2005; Bishop et al., 2007; Pulver and VanDeveer, 2009). Global change scenarios share key components: they are multi-dimensional, with internal coherence among diverse elements; they are schematic, aiming not for precision and detail but for essential elements and plotlines that show large-scale patterns and a variety of future pathways and conditions; and they have a degree of likelihood, although their probability may not be defined. They incorporate varying degrees of quantitative modeling and qualitative narrative, as well as challenges in integrating the two (Parson et al., 2007; Swart et al., 2004).

Within environmental governance and sustainability science, scenarios can systematically frame complex future pathways, capturing surprise, human choices, and environmental responses, enabling examination of critical issues informing policy decisions, including the feasibility and implications of normative futures (Robinson, 2003; Swart et al., 2004). Scenarios offer a way to handle future uncertainty (Bizikova et al., 2011) and they can illustrate the relationships between key drivers such as economy, environmental values, emissions, and radiative forcing (Shaw et al., 2009). Scenarios thus offer a structured, integrative and knowledge-based method of thinking about the future (Swart et al., 2004; Robinson, 2003). In linking policy to stakeholder communities and decision-makers, they may become "boundary objects", locations of collaboration between science and political processes (Pulver and VanDeveer, 2009). By illustrating the relationships between choices and future consequences, and by enabling participation, they arguably enable more robust decision-making (Bizikova

et al., 2011; Shaw et al., 2009; Swart et al., 2004; Robinson, 2003; Raskin et al., 2002).

The geovisualizations described in this chapter draw on the fields of trans-disciplinary scholarship, participatory integrated assessment, and sustainability scenarios, as well as Public Participation Geographic Information Systems (PPGIS). The latter seeks to form “open and transparent access to spatially enabled data and information handling tools for people interested in place-based problem solving and decision-making in a specific socio-political context” (Jankowski and Nyerges, 2003). PPGIS as a field of inquiry integrates research about place and people, technology and data, and process, as well as outcomes and evaluation. Sieber (2006) highlights that PPGIS is socially constructed and argues that it is therefore necessary to include social science in the analysis of PPGIS. She also refers to Harvey and Chrisman (2004) who point out that the analysis of any GIS implementation requires an analysis of the underlying social relationships and interactions. Diverse web and GIS technologies can be combined to facilitate gathering and processing of local knowledge (Rantanen and Kahila, 2009), while other research has addressed the potential of distributed or different-place collaborative GIS (MacEachren et al., 2006). Further research is required to explore the role of visualization, interactive interfaces, and the emerging discipline of visual analytics (Andrienko et al., 2007).

Geospatial planning tools, developed and communicated using visual media in a structured framework incorporating the best available data, knowledge, and modelling provide one way to engage both experts and stakeholders in planning processes (Bishop and Lange, 2005; Sheppard et al., 2011). GIS-based 3D landscape visualization can fulfill these functions (Bishop and Lange, 2005; Appleton and Lovett, 2003). Sheppard (2005) and Nicholson-Cole (2005) argue that 3D visualizations can also make climate change impacts and mitigation/adaptation solutions more tangible and salient for the public and situate climate change within local places, as called for by Lorenzoni et al. (2007), and demonstrated in a local planning process by Salter et al. (2009). Various previous studies, reviewed in Sheppard (2012), have attempted to integrate climate change and response scenarios, spatial modelling, landscape visualization, and participatory processes in various combinations, but none of these has been systematically evaluated for effectiveness with users/participants.

The Local Climate Change Visioning (LCCV) process, developed by the Collaborative for Advanced Landscape Planning (CALP) at the University of British Columbia with GEOIDE NCE support, has piloted, tested, and adapted such an integrated set of tools, developed within collaborative local partnerships and networks. The LCCV process has been developed through a series of projects, starting with a pilot project in two Metro Vancouver communities, to a second iteration with a small, rural community, to case studies in three provinces and one territory. Evaluation goals have shifted over the life of the projects, from initial testing of awareness and learning about climate change, to testing particular geovisualization tools and a simpler scenario

development process, to evaluating the effectiveness for capacity-building and decision-support using a longitudinal evaluation and case study comparison.

The LCCV projects have thus explored both tool/process development, as well as evaluation of the overall social effects, focusing on answering the following questions: how can geospatial modeling and visualizations be developed and embedded within collaborative learning processes in order to support better informed local decision-making on climate change? Do these tools/processes improve the effectiveness of local climate change planning and decision-making?

In order to answer these questions, the LCCV had to be developed, tested, and evaluated. Methodologically, there are therefore two different evaluation components: the first examines LCCV development, including the processes, tools, and their immediate outputs. The second evaluates impacts and outcomes. Planning literature on evaluation has focused primarily on the former, usually on short-term successes and participants' perception of a process (Shipley, 2002). Shipley calls for evaluation of substantive project goals, including results over time (2002); similarly, Larsen and Gunnarsson-Östling caution against only measuring deliberative processes, rather than impacts and outcomes (2009). As the GEOIDE projects have sought to answer dual methodological questions, an overview of "effectiveness" and related evaluation methodologies is warranted.

Using Moser's framework (2009) as a guide, and drawing on Jankowski and Nyerges (2003), Walter et al. (2007), Larsen and Gunnarsson-Östling (2009), and Salter et al. (2010) we have chosen to assess project *process*, *outputs*, and *outcomes*. In this context, a project is considered effective when the *process* of planning includes climate change and climate science, with process defined as the "establishment of, or improvements in, the process of communication and interaction between scientists and decision-makers [and affected or interested stakeholders]" (Moser, 2009: 14). Additional process results include shared goal definition, legitimacy and fairness, including whether participants felt heard (Walter et al., 2007; Larsen and Gunnarsson-Östling, 2009), and public engagement (Shaw et al., 2009).

Related measures of effectiveness include project *outputs* or products, which are tangible results including project reports (Walter et al., 2007). In the case of LCCV, proposed outputs included downscaled scenarios across climate projections for local areas linked to locally available expert modeling, verified scientific data integrated with local knowledge and issues, and communication of collaborative scenarios or designs using a variety of digital visualization tools including 2D (e.g. mapping, photomontage) and 3D digital landscape visualizations. Taken together, the process and outputs (or, simply, the process with embedded tools) can be measured for immediate *impacts* on both stakeholder and expert/public participants, including immediate changes in awareness, attitude and knowledge (Walter et al., 2007), affective response (Sheppard, 2005), as well as new scientific insights, i.e., impacts on the researchers themselves (Walter et al., 2007).

Project *outcomes* are the “wider and/or longer-term” effects (Jankowski and Nyerges, 2003; Walter et al., 2007; Moser, 2009:14; Salter et al., 2010). The long-term effectiveness of decision-making support is “notoriously difficult to interpret, measure, track, and evaluate” (Moser, 2009: 11; see also Rohmsdahl and Pyke, 2009). Climate change planning and decision-making occur within a complex set of local government institutions and practices (Roberts, 2008; Burch, 2010a and 2010b; Bassett et al., 2010): only rarely is a decision or policy change attributable to a specific project (Walter et al., 2007). Geospatial tools and processes that link academics and scientists to local communities thus operate alongside many other influences: geospatial support, through a process of local climate change visioning, is only one stream of activities among several influencing decision-making. Therefore, evaluation of LCCV outcomes has not sought primarily to find causal relationships between the process and local decisions, but instead has looked for broader institutional changes that enable effective decision-making.

Effectiveness in outcomes is therefore broadly defined as: increased capacity and competence building through issue-driven shared learning, which contribute to increased civic capacity; the distribution of socially-robust knowledge, including adding depth to deliberations about local climate change impacts and response options; the uptake of new and existing spatial planning and visualization tools (eg. GIS, participatory GIS, spatial modeling, and 3D landscape visualizations); decision-making, including an increased capacity to act; building trust; building new networks that increase social resilience; and, transformative or incremental change towards a shared goal (Robinson and Tansey, 2006; Walter et al., 2007; Larsen and Gunnarsson-Östling, 2009; Moser, 2009; Salter et al., 2010). Short projects with minimal post-project evaluation periods often preclude study of outcome effects, which may take several years to come to fruition (Walker et al., 2007; Yarnal et al., 2009). We return to the challenges of measuring effectiveness below.

1.2 Project Overview and Methodology

In an early GEOIDE project, Georgia Basin Quest, a spatially-based socio-economic model was developed for exploring alternative future scenarios based on participants’ world views, policy assumptions, land use trends, etc (Robinson and Tansey, 2006; Robinson et al., 2006). This project was followed by a GEOIDE SII project (2004-2007), which piloted an innovative, collaborative, inter-disciplinary process between UBC, government researchers, and local communities (Sheppard et al., 2008; Shaw et al., 2009; Burch et al., 2010b; Sheppard et al., 2011; Bizikova et al., 2011; Cohen et al., 2012a). Holistic, localized future scenarios were developed to illustrate choices and trade-offs across a range of climate change response options, from “Do Nothing” to “Deep Sustainability” (Shaw et al., 2009). The SII project built on the earlier Quest modeling by bringing climate change and impacts projections into localized scenario development (Shaw et al., 2009).

A bridging project, predominantly funded by others²⁴ during the pilot year of GEOIDE P32 (2008-2012), explored the application of these tools and processes within a more rural, less well-resourced community, the City of Kimberley (Schroth et al., 2009; Cohen et al., 2012b; Burch et al., submitted 2012). Based on the Kimberley project, and drawing from the SII project, CALP produced a Guidance Manual on the LCCV process and tools (Pond et al., 2010a) for interested practitioners and for use during the next GEOIDE project, P32.

Project 32 has permitted two further developments: a) extending the evaluation of the longer-term outcomes from SII and Kimberley and, b) nationalizing the reach of the process with researchers and partners from several universities and local governments, as well as continuing work with the Corporation of Delta, one of CALP's long-standing municipal partners. The four-year comparison of five case studies (Kimberley and four P32 projects), covering Canadian urban, suburban, rural, and Arctic communities, has helped to address the need for more comparative studies of climate change. This has led to further development, as well as divergence, in process, outputs, and outcomes, tailored to local community needs and building on local researchers' strengths.

All projects share a common methodological base to develop the tools for decision-support, characterized by: a) addressing climate-related issues at hamlet to regional scales, b) spatially-based approaches integrating scientific data, modeling and in some cases landscape design, c) participatory processes where academic research teams collaborate with local stakeholders and inter-disciplinary experts, d) exploration of possible future pathways using scenarios or design options and, e) the use of 2D and/or 3D visualization tools. Each project has increased our understanding of the opportunities and challenges in developing Local Climate Change Visioning, through on-going GEOIDE network relationships and partners such as Natural Resources Canada, Environment Canada, and Provincial and local government bodies.

Common methodological development of characteristics a) and b) will be discussed in the project descriptions below (Section 2), while e) is demonstrated through examples of project outputs, and in the numerous project publications. Methodological discussion of participatory processes and scenario development is warranted here.

Participatory processes are here broadly defined to include collaboration between scientific researchers, stakeholders, various "publics", and local knowledge holders (e.g. planning practitioners, decision-makers, elders). Such collaboration may cross scientific disciplines and include decision-makers as well as various government agencies; collaboration may also network across research teams from different institutions, and in widely varying locations (Pike et al., 2005). For some networked pro-

²⁴ The BC Real Estate Foundation, the BC Ministry of Community and Rural Development (now Ministry of Community, Sport, and Cultural Development), and the Swiss National Sciences Foundation.

jects, specialized network infrastructure has been developed and evaluated (cf. Yarnal et al., 2009).

Building on prior projects (cf. Robinson et al., 2006; Salter et al., 2009), the LCCV projects employed a variety of participatory practices locally at the case study level, including stakeholder workshops, and meetings with planning practitioners, citizens' groups, and decision-makers (e.g. Mayor and Council), as well as consultations with various disciplinary experts. Public workshops and public open houses were held in some of the cases. The networked P32 projects, involving research teams at four different universities were treated methodologically as a case study project. Each case study's internal research team brought their own strengths to their case study, ranging from agent-based modeling to landscape architecture, within the general methodological framework outlined above. In addition, early goal setting for each study was done through stakeholder and community participation, a common methodology in transdisciplinary action research (TDAR), so that the projects' foci necessarily diverged to meet local needs.

Various frameworks exist for assessing participatory processes. In PPGIS, for example, Jankowski and Nyerges (2001) have suggested empirical testing of eight categories through experimentation. Although we used similar categories to guide the cross-case comparison, we chose a multiple-case study approach rather than a quantitative experiment. Multiple-case studies are well established valid research methods in various disciplines (Yin, 2003), including landscape related disciplines (Francis, 2001). In contrast to an experiment, case studies do not follow generalization logic but rather replication logic, i.e. the research item, here the LCCV process, is replicated and the comparison looks for similarities, differences, and unexpected results. Retrieved data includes participant feedback as well as insights and observations of the researchers themselves. Although the results cannot be generalized in the same way experimental results can, a multiple case study is more powerful in capturing social-institutional and group participant influences as well as evaluating longitudinal social outcomes. For this project, Kimberley as well as the P32 projects (Calgary, AB; Clyde River, Nunavut; Metro Toronto, ON; Delta, BC) were treated as case studies.

Scenario methods may range from qualitative, participatory, narrative storyline development, to quantitative computer modeling (van Notten et al., 2003; Newig et al., 2008); in addition, various methods including forecasting and backcasting may be employed (Börjeson et al., 2006; Swart et al., 2004). The localized SII scenarios were developed based on the global assessment and future studies literature (Nakicenovic and Swart, 2000; Raskin, 2005; Carpenter et al., 2005; Swart et al., 2004; Raskin et al., 2002). They were constructed using a two-step qualitative downscaling approach: first, global trends were downscaled regionally, and compared to the quantitative, regional, socio-economic Quest scenario model (Shaw et al., 2009). The second step downscaled to specific municipalities, supplementing the qualitative storyline with local quantitative data (ibid; Cohen et al., 2012a). Four main themes were covered: biophysical impacts, response options (including both adaptation and mitigation),

socio-economic change, and governance (Shaw et al., 2009). The four scenarios that were developed became known as the “Four Worlds” (see Figure 1), covering a full range of possible GHG emissions’ pathways.

For Kimberley, the scenario method was simplified to two stakeholder-driven qualitative scenarios (integrated mitigation and adaptation versus adaptation only), backed up with quantitative modeling and spatial analysis of forest fire risks and mountain pine beetle susceptibility under climate change (Pond et al., 2009; Schroth et al., 2009). In P32, qualitative and/or quantitative scenarios with measured indicators were used in most projects, except one case study where landscape design, i.e. an iterative, future solution-oriented method, was employed. While the earlier projects (SII and Kimberley) focused on a broad thematic divergence in the scenarios – positing alternate adaptation and mitigation futures, and widely varying GHG emissions scenarios (cf. Shaw et al., 2009), in some cases the P32 projects instead explored multiple adaptation scenarios, or a variety of adaptive design solutions, without specific assumptions on or modeling of GHG emissions.

Project results have been measured through mixed methods. For LCCV development, the processes and outputs were documented by the research teams. However, project outputs do not themselves measure the immediate impacts of project processes and tools on participants. Therefore, process and output *impacts* were measured for both SII and Kimberley using quantitative and qualitative questionnaires, provided to participants at final workshops and Open Houses (Cohen et al, 2012a; Schroth et al., 2011a; Burch et al., 2010b; Schroth et al, 2009). Changes in awareness, attitude, and understanding were evaluated through the comparison of quantitative pre- and post-questionnaires. The visualization tools themselves were tested in additional quantitative and qualitative questions. Additional evaluation methods included qualitative post-process/Open House interviews, and in Kimberley, video-taping of participants at a GoogleEarth station. These were used to triangulate tool assessment with the questionnaires (Schroth et al., 2009 & 2011a).

A longer-term effectiveness study of the initial projects was conducted to capture potential outcomes from SII and Kimberley. For this research, effectiveness was defined as the ability of the LCCV to foster understanding of, support for, and action on climate change for both the individuals and local governments who participated. Rather than measuring policy outcomes, with difficult causation, the qualitative indicators chosen to evaluate effectiveness were longer-term shifts in awareness and understanding, support for climate policy, and an increased profile of climate change within the local government. Semi-structured interviews were conducted with stakeholder participants in the LCCV processes in Delta, North Vancouver and Kimberley one to three years after the project had been completed. A qualitative method of data collection was chosen to evaluate the long-term effectiveness of these processes because effectiveness is socially complex and not easily quantified: interviews are more able to garner important contextual information (Merton et al., 1990).

For P32, process, outputs and outcomes (including decision support effectiveness), as well as LCCV adaptability under various case study conditions, were measured using mixed methods, through internal reporting templates, a researcher workshop, and cross-project qualitative stakeholder questionnaires. These methods allowed for the collection of data across the range of effects including: outputs (such as the creation of models, scenarios, and geovisualization products), impacts (project legitimacy, knowledge generation), as well as potential outcomes (such as capacity building and changed policy decisions). Early results on process and tools were gathered and shared at a network researcher workshop in May 2011, following case study methods. The stakeholder questionnaires, still being gathered and analyzed, will be used to substantiate researcher insights.

2 Developing Processes and Tools, with Multiple Outcomes

This section briefly describes and summarizes results from the SII and Kimberley projects, and provides descriptions of the current comparative case studies, with preliminary findings

GEOIDE SII – Laying the Groundwork. The 2004-2007 GEOIDE SII project saw a cross-disciplinary research team at UBC pilot the Local Climate Change Visioning process with two Metro Vancouver communities, the Corporation of Delta and the District of North Vancouver. The project brought together local and scientific experts to integrate downscaled climate projection data into land-use development scenarios, and develop ways to communicate project findings using information visualization, 2D mapping, and 3D visualization (Shaw et al., 2009; Cohen et al., 2012a; Sheppard et al., 2011, Burch et al., 2010b). The process was designed “to integrate the best available science..., local GIS mapping, and stakeholder knowledge to visualize potential climate change impacts in a clear and compelling way, and to present possible policy and behavioural choices for communities” (Sheppard et al., 2011: 403).

The core research team included expertise in international climate policy, regional planning, landscape architecture, and digital 3D visualization. An extended, interdisciplinary research team of university, federal and provincial researchers, and local and regional practitioners and non-governmental experts provided additional expertise in sea level rise modeling, impacts and adaptation, GHG mitigation, and local planning issues. Through a series of workshops with local working groups in each community and various members of the extended research team, the future scenarios and visualizations were developed and/or vetted²⁵.

Outputs included a “visioning package” illustrating and exploring the “Four Worlds” scenarios (Shaw et al., 2009). The visuals explicitly link to climate science and local-

²⁵ The process is described in greater detail in Shaw et al., 2009; Burch et al., 2010b; and Cohen et al., 2012a.

ized scenarios (Figure 1). Visualizations range from 3D landscape illustration of scientific data (shown in Cohen et al., 2012a), to experiential and up-close portrayals of adaptation action impacts (Figure 2). They were shown in five public workshops in both communities, as well as in one practitioner workshop for planners from the region. Overall, approximately 150 participants and 12-15 municipal staff saw the final project presentations, yielding approximately 160 completed questionnaires.

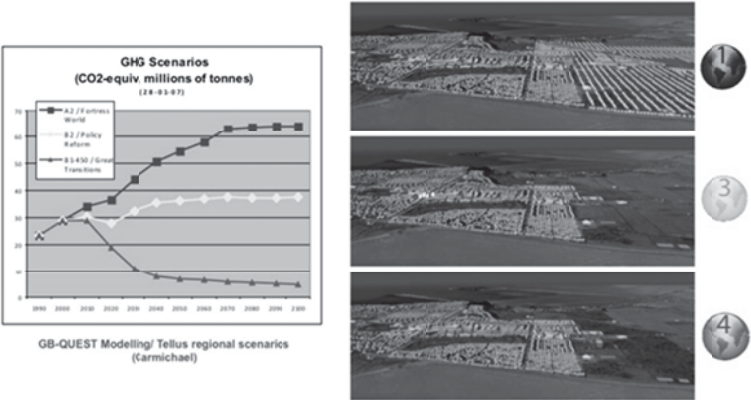


Fig.1. SII Delta project: scenario modeling linked to land use visualizations (modeling: Carmichael/GB-Quest; landscape visualizations: Flanders, CALP).

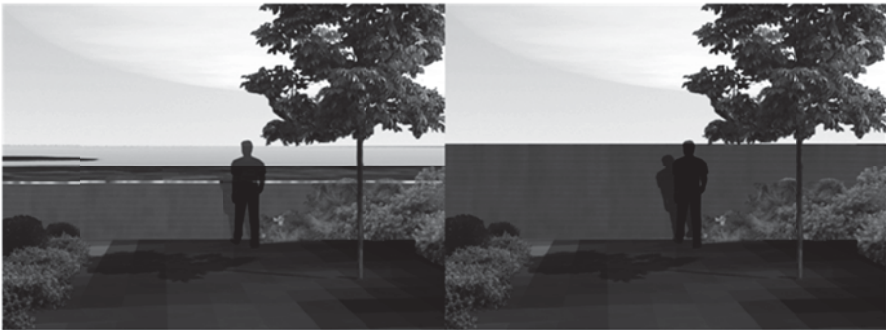


Fig.2. SII Delta project: current seawall and projected future seawall height, Beach Grove, BC, illustrating experiential, quality of life challenges. (image credit: Flanders, CALP; right image previously published in Shaw et al., 2009: 458; both images in Sheppard, 2012: 404).

The effects of the visualizations and other workshop components were measured through pre- and post- quantitative and qualitative questionnaires, administered to participants, including a sample of the public and practitioners, at the time of the final

project presentations. Due to the small sample size (e.g. about 20 in North Vancouver), as well as the potential for self-selection bias (individuals coming to the workshops tended to be already concerned with climate change), questionnaire results should be treated cautiously (Cohen et al., 2012a).

In evaluating the process outputs, the scenario framework was readily adopted by project participants (Burch et al., submitted 2012). A large majority (75%) of post-test respondents agreed or strongly agreed that community policies to reduce GHGs must be in place within 10 years; the presentations were considered credible and positively evaluated by the participants (for detailed results, see Cohen et al., 2012a; Tatebe et al., 2010, and Sheppard et al., 2008). Following the project, iconic images such as the snowpack visualizations (in Cohen et al., 2012a), have been widely presented, with considerable media coverage (Burch et al., submitted 2012).

In terms of the process, the post-project qualitative study has found that participants felt that the LCCV was effective because it was run by a credible, trusted third-party institution, included visually compelling visualizations informed by the latest science, and was integrated and holistic. The study has also found that project outputs (reports, visualizations and visioning package) have not always been readily available post-project for participants and that sustained follow-up is needed to encourage uptake of products and methods. As part of the project team's iterative learning over the larger GEOIDE project's trajectory, this concern is being addressed in the final Delta project (P32, described in section 2.3), with funding secured to make project materials web-available.

In terms of longer term outcomes, the LCCV process seems to broaden and deepen dialogue (Burch et al., 2010b), and can raise previously overlooked important issues (Cohen et al., 2012a). The post-project qualitative study findings also suggest that the LCCV process supported local champions, increased staff support for climate policy, led to at least one new study on hazards, increased environmental concern in general, and increased the profile of climate change within local government. Direct causal outcomes such as behaviour change, environmental activism, and concrete changes in policy have not been found. Rather, the LCCV process has worked as a reinforcing agent for action on climate change within the local governments. Other non-LCCV factors that encouraged and supported climate action, as expressed by study participants, include: local impacts attributed to climate change (e.g. flooding), support from leadership, and most of all, provincial legislation on climate change mitigation (as found in Province of BC, 2007 & 2008).

One of the challenges identified by SII researchers at the time of the project was that of providing a way to "link the research outcomes to municipal and other decision-making" (Shaw et al., 2009: 461). This issue is being addressed in the follow-up P32 Delta project, with a policy recommendations report going to Council.

Kimberley, BC – Adapting the Process. The Kimberley process differed from the SII project in that it was not a stand-alone research exercise, but was instead embedded in a joint process alongside the Kimberley Climate Adaptation Project (KCAP), a community-driven project working to identify local climate change impacts, assess local risks and vulnerabilities, and develop adaptation planning recommendations for the City (Columbia Basin Trust, web; Pond et al., 2010b; Cohen et al., 2012b).

Kimberley is a small town near Cranbrook in the East Kootenays, with approximately 6000 inhabitants. Originally evolved from mining camps, Kimberley's mine closed in 2001, and today tourism, outdoor recreation, and amenity migration provide the main sources of income. Smaller, rural communities such as Kimberley may not necessarily have the resources and tools to engage in spatial climate change planning and 3D visualizations. Thus, CALP was brought onto the Kimberley project to enhance local engagement and project outcomes through scenario development, mapping and visualization of climate change impacts, and linkage of response options to community planning and land use.

The community KCAP process relied on a local Steering Committee and Coordinator, citizen and stakeholder working groups, and community open houses and workshops. CALP's process intersected at various points with the community process, particularly for problem definition, impacts pathways mapping, scenario development, data and visualization review, and a final Open House. With the community located about 800 km from the university, researchers visited the community multiple times, and Kimberley Steering Committee members traveled to Vancouver; the project used Skype and conference calling as well. CALP also worked with researchers from the Geo-Spatial Centre at Selkirk College, located within the larger Kootenay region.

Outputs included a set of technical posters, still in use in the Kimberley planning office, a 3D virtual globe model of the city in GoogleEarth with information overlays for various development scenarios and climate change impacts, and an annotated presentation. In collaboration with the Pacific Climate Impacts Consortium, the project piloted a downscaling method for calculating and spatializing future snowpack conditions. All of these, along with the KCAP adaptation recommendations, were presented at a final community Open House, attended by approximately 50 people (just under 1% of Kimberley's population).

Open House participant evaluation consisted of mixed quantitative and qualitative methods (questionnaires, interviews, and video-taping of virtual globe interactions) focused on assessment of virtual tools and the utility of interactivity (Schroth et al., 2009; Schroth et al., 2011a), as well as participant levels of understanding. As an example of findings (see also Schroth et al., 2009 & 2011b), in the post questionnaire, participants (n=38) were asked "If you were asked for your opinion on mitigation and adaptation strategies for climate change in Kimberley, would the visualizations you have seen help you?" 90% answered "helped a lot" or "helped a little" (Figure 3).

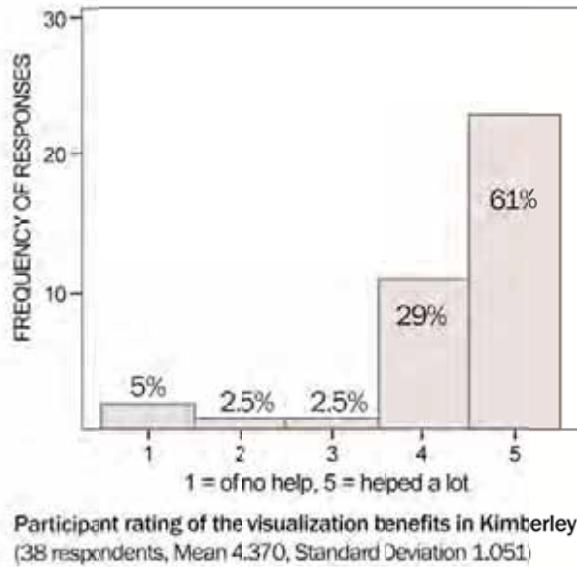


Fig.3. Kimberley project: participant rating of visualization benefits in Kimberley.

Other questions explored the utility of various visualization media, with a focus on interactivity and virtual globes (e.g. Google Earth). Interestingly, the response to Google Earth was bi-modal: while about 2/3 ranked Google Earth as their first choice of visualization medium, about 1/3 rejected it (Schroth et al., 2011a). In this way, the Kimberley project has also contributed to researcher knowledge, another form of social impact (Walter et al., 2007), particularly around the use of virtual globes in planning practice.

The Kimberley project also illustrated that the local effectiveness and impacts of the project process, products, and outcomes must be evaluated within the local context. For example, only CAD rather than GIS had previously been available to the community; GIS data was gathered, integrated, and generated for the project, resulting in an integrated GIS database of current conditions, future land use plans, and biophysical risks and impacts, increasing local planning capacity. Simple spatial analyses such as walking circles (distance to services, a common planning metric) arguably represented a breakthrough in local community understanding. In terms of outcomes, the final KCAP report to Council (Liepa, 2009) contained over 70 action-able adaptation and mitigation recommendations.

In terms of longer-term outcomes, the post-project qualitative study, which interviewed seven project participants, found that a dozen of the recommendations have subsequently informed policy and organizational change within the City. For example, Kimberley has adopted a new sprinkler bylaw, and made operational decisions,

such as purchasing a more fuel efficient fire truck, which fit within KCAP recommendations. Although none of the measures can be linked solely to the KCAP, a wider “ecosystem of change” towards more sustainable operations and policies seems to be developing within Kimberley.

GEOIDE P32 – Adapting to Multiple Contexts. The GEOIDE P32 project sought to test the replicability and effectiveness of local climate change visioning as a way to develop, integrate and deliver available data and local knowledge, spatial modeling, and visualizations to support decision-making around climate-related challenges. Over four years, researchers at the Universities of British Columbia, Toronto, Waterloo, and Calgary have collaborated with local partners to explore how LCCV changes as it is applied to other contexts – from downtown Toronto, to a regional watershed in Alberta, to a Hamlet in Nunavut. Project processes, challenges, and outputs to date can be reported on, with some preliminary outcomes, and insights into potential longer-term outcomes.

2.1 Calgary – Moving to the Watershed Scale

The Elbow River in southern Alberta, Canada, originates from Elbow Lake in the Canadian Rockies and enters the City of Calgary where it merges into the Bow River. The watershed covers some 1240 km², with 65% in the Kananaskis district and the remainder in the rural municipality of Rocky View (20%), the Tsuu T’ina Nation (10%), and the City of Calgary (5%). The watershed supports several uses including supplying part of Calgary’s drinking water, irrigation for crops, and various recreational activities (Elbow River Watershed Partnership, 2012). Since 1960, the population of Calgary has increased by approximately 35% per decade, with a land-cover expansion at the city’s periphery of about 14% per decade. The sprawling city is expected to reach 1.5 million inhabitants in 2020 and 2.3 million over the next 50-70 years (Plan it Calgary, 2007). If current trends continue, such expansion will cause loss of productive agricultural lands, forest cover, surface water bodies, and increasing levels of water pollution.

Lying in the rain shadow of the Rocky Mountains, the western Prairie Provinces are the driest areas of southern Canada. Scientists project that climate change effects will combine with cyclic droughts and rapidly increasing human activity to cause a crisis in future water availability. Alberta already experiences climate extremes, and the projected increase in average temperatures of 3 to 5°C over the next 40 years will amplify these extremes, increasing the risk of more severe and frequent droughts (Schindler and Donahue, 2006). Consequently, a reduction in average water supply is expected in the near future, already indicated by a trend of significant decrease in surface water in southern Alberta watersheds.

Managing water resources is therefore a critical issue requiring a comprehensive understanding of several interrelated factors, particularly land use, climate, and hydrological processes. The University of Calgary’s research team in GIS and Environ-

mental Modelling in the Department of Geomatics Engineering, in collaboration with Alberta Environment (AENV) and the Danish Hydrological Institute (DHI) in Cambridge, Ontario, has engaged in a GEOIDE P32 and other-funded project which aims at engaging stakeholders and providing decision makers with an integrated set of geo-spatial modeling tools. The goal is to anticipate changes in water availability, develop long-range plans to avoid adverse land-use and climate changes impacts on water supply, and make informed decisions to better prepare for the future.

The project's focus has thus been on the development and linkage of a land-use cellular automaton (CA) model with a comprehensive hydrological/climate model (MIKE SHE) to simulate future land development and climate change scenarios, and investigate their impacts on the major hydrological processes of the Elbow River watershed. An additional critical component of the modeling system consists of a web-supported agent-based model (ABM) designed to incorporate the perspective of different stakeholders concerned by water resource management issues in the watershed. The stakeholders represented as agents include citizens, planners, developers and different government and non-profit organizations. The ABM serves as a simulation laboratory through which the stakeholders are able to view and evaluate various scenarios of land development based on their values and preferences, examine how their perspectives are perceived by other stakeholders, and reach an acceptable agreement regarding the location of a proposed land development project. An easy-to-use web interface was developed to hide the complexity of the modeling environment and facilitate the interactions of the users with the system (Pooyandeh and Marceau, 2012).

The project has generated numerous outputs. Historical (1985-2010) land-use maps of the Elbow River watershed, produced from remote sensing images at a spatial resolution of 30 m, were used to identify the main factors driving and constraining land-use changes and development. The CA model was built to simulate land-use changes over the next 25 years based on projected population growth (Figure 4). The hydrological model, once adequately calibrated and validated, was linked to the land-use model to assess the impact of land-use changes on the key hydrological processes in the watershed (Hasbani et al., 2011; Wijesekara et al., 2012). The results revealed a potential significant negative impact on the sustainability of ground/surface water supplies and groundwater storages in the future in addition to an increased risk of flash floods. Ongoing research, with additional post-GEOIDE project funding provided by Tecterra, consists in integrating AENV datasets to conduct the simulation of five climate change scenarios using the MIKE SHE hydrological/climatological model to evaluate their influence on the watershed's hydrology.

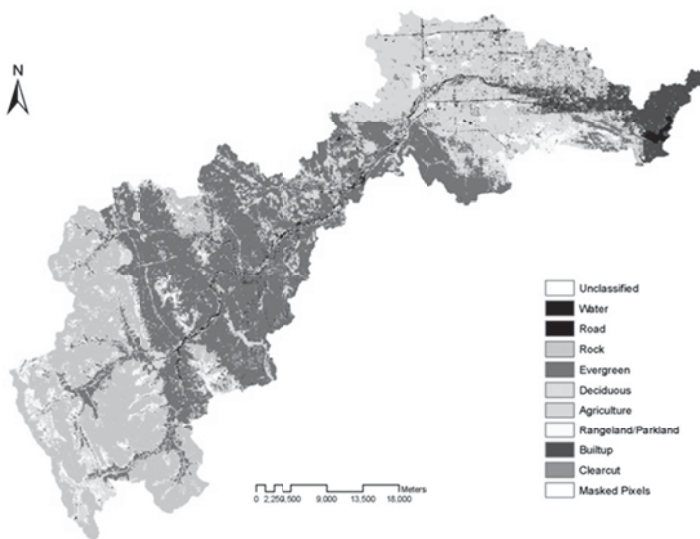


Fig. 4. P32 Calgary project: simulated land use map for the year 2016.

Furthermore, interviews were conducted with several stakeholders regarding water management issues in the watershed. This information was used to express their values and perspectives in the agent-based model that allow users to visualize maps of land development scenarios, conduct spatial analyses, and negotiate the most suitable location for land development in the watershed. Initial results conducted with a hypothetical land development plan indicate that the model is able to find the most satisfactory location for all agents (stakeholders) involved in the evaluation and negotiation process (Pooyandeh and Marceau, 2012). Work is in progress to run the model with additional agents and data corresponding to real land development scenarios to assess the utility of the proposed system in guiding decision making.

For the project's participatory process, the research team brought together representatives of various organizations, including the Calgary Regional Partnership, the Rocky View Municipal District, the City of Calgary, the Elbow River Partnership, the Implementation Committee of the Elbow River Basin Water Management Plan, Action for Agriculture, and Alberta Environment to openly share their perspectives on land development, climate change, and water management in the watershed. Two workshops with more than 40 participants were held at the University of Calgary in 2010 and 2011, allowing scientists and stakeholders to share opinions and expertise, along with providing feedback on the models being developed. These discussions generated several positive immediate social impacts. First, they allowed representatives of these organizations to express their views, sometimes conflicting, in an open academic environment considered as politically neutral. Second, they provided a rich data and information content that was required to understand the complexity of the environ-

mental and political issues in the watershed. An effort was made by the research team to avoid focusing on the technical sophistication of the models being developed, but rather to stimulate input from the stakeholders regarding the usefulness of the models at delivering meaningful results. A third and possible fourth workshop will be held in the near future with the stakeholders to present the final results of the modeling system and further assess its utility in terms of facilitating community engagement to achieve a common goal regarding water resource management in the watershed.

A major challenge in this project was the acquisition of various datasets to ensure the calibration and validation of the models being developed. Data sharing agreements between organizations were signed and numerous meetings were held to discuss dataset quality and adequacy. This critical step in the modeling exercise required far more time and expert resources than originally planned. However, resolving this issue is a fundamental positive component of the experience gained in this project.

A long-term outcome of the project is the opportunity for expanding this collaborative research. AENV considers the Elbow River watershed as a test bed and has indicated their interest in applying the study to the South Saskatchewan Regional Plan Area that includes the whole southern region of Alberta from Red Deer to the US border. Cross-case study questionnaires for this case study are being gathered, in order to substantiate researcher insights on outcomes.

In summary, this project has employed a participatory process with stakeholders that allowed for shared learning around different (and opposing) viewpoints about land-use change and water resource management. Key learnings have been that the acquisition of high-quality data necessary for modeling along with the development, testing and linkage of the models required more time than anticipated. The inclusion of climate change scenarios is in progress. Once the modeling exercise has been completed, the results will be presented and discussed with the stakeholders and an evaluation will be conducted regarding the utility of the models to increase awareness, public participation, and decision making about water resource management.

2.2 Toronto + Waterloo – Urban Adaptation and Mitigation Challenges

Over the past five years, the City of Toronto has taken several concrete steps to adapt to and mitigate local climate change impacts, ranging from conducting a city-wide inventory of greenhouse gas (GHG) emission sources, to site-specific efforts supporting low albedo and green roof retrofits (EcoRoof Incentive program). The Green Development Standard (City of Toronto, 2006; revised 2010) is particularly noteworthy as this bylaw requires new developments to satisfy performance metrics for air and water quality, GHG emissions, energy efficiency, and other factors relating to environmentally sustainable built form.

The Toronto GEOIDE case study sought to complement these efforts with geovisualization methods and tools that help policy-makers and, ultimately, the public, to ex-

plore where planning policy and mitigation efforts can best be targeted. Given the complexity of how macro-level climate change impacts are manifested spatially across urban settings and the limitations on local resources to mitigate these effects, geovisualization tools are particularly important as aids for learning, communication, and decision-making processes.

The case study team consisted initially of geovisualization, participatory GIS, and landscape architecture researchers from the Universities of Toronto and Waterloo, City of Toronto staff (Environmental Planning), Environment Canada, and a local NGO, the Clean Air Partnership (CAP). In keeping with TDAR approaches, two main research foci were identified through team discussions: a) reducing heat island effects and, b) increasing green energy production through rooftop photovoltaics. The heat island concern stemmed from the recent marked increase in summer temperature extremes observed in Toronto (and other large urban areas), and higher levels of mortality and hospital admissions among vulnerable populations (Toronto Public Health, 2005), and the threat of climate change worsening the problem. Interest in assessing the solar power potential of individual buildings resulted from the Ontario government's Green Energy Act (2009), which provides incentives for property owners to generate electricity from renewable sources and, ultimately, reduce greenhouse gas emissions from some conventional electricity sources (e.g. coal) as well as the need for future large scale power generation infrastructure. A key geovisualization challenge common to both research foci is that policies to reduce urban heat effects and promote renewable power generation are largely aspatial in nature even though the opportunities to make meaningful contributions to either issue varies spatially across the city. Hence, these visualization approaches were driven by a need to help decision makers (e.g. City staff, individual homeowners, etc.) to interactively explore spatial variability in heat and rooftop PV suitability, and to identify tangible linkages between policies and action strategies across multiple scales

In terms of tool development, addressing a complex issue such as local climate change within a multi-faceted environment that is typical of large urban centres provided several lessons regarding how geovisualization methods can support problem exploration and learning. From a technical perspective, access to spatial data of the appropriate resolution for representing phenomena such as temperature variations across space, building characteristics (e.g. height, roof configuration, etc.) and shading effects due to vegetation and structures proved to be challenging initially. A multi-scale approach (city, neighbourhood, property) was adopted to alleviate this problem by permitting some issues (e.g. surface temperature variations) to be represented at city-wide scales with comparatively coarse data (i.e. Landsat TM), while high resolution LiDAR data available for selected neighbourhoods was used to characterize built form and vegetation.

From the project process, an important, and initially least recognized, project learning was recognition of the broad range of objectives, preferred foci and ontologies within the study team for understanding both the urban environment and climate change

concerns. To a large extent, this simply reflects the complexity of urban scale climate change analysis and the varied analytical frames and responsibilities of different individuals and agencies; such challenges in inter-disciplinary work are well reflected in the literature (cf. Robinson, 2003). Interestingly, the early geovisualization outputs (see below) provided a common point of reference, solidifying the team's focus and ultimately providing a stronger base to capitalize upon the team's diverse expertise.

Initial discussions had been quite wide ranging and included issues rooted in existing policy initiatives or concerns such as increasing tree canopy coverage, renewal of residential towers to improve energy efficiency, heat-related health ailments, and the potential for flooding under feasible future climate scenarios, among others. The practical lens of initially limited data availability, particularly with regard to high resolution thermal imagery and downscaled climate projections for the City, spawned an iterative and informal process of developing, discussing and refining prototype visualization outputs (e.g. 3D images of modelled vegetation at street scales, mapping of Landsat thermal imagery across the City). Central to these efforts was a desire to investigate how macro climate change and GHG reduction concerns could be translated and visualized at the neighbourhood and property scales that local bylaws most often target.

The case study has generated two primary types of output, with divergent practical applications, from its first stage of exploratory visualization. The first type involved the mapping of variations in surface heat using various 2D and 3D cartographic approaches. On a city-wide scale, surface temperature variations were represented as topographic surfaces on which orthophotos were draped to highlight correspondence between land use and heat effects. In addition, detailed 3D visualizations of specific buildings and vegetation provided a basis to search for patterns in surface temperature variations and identify where mitigation strategies could have the most significant impact (Figure 5). For example, the Green Development Standard requires developers to construct green roofs on all new buildings greater than 2,000 square meters or provide cash in lieu; thus, current policy considers only the building, but not the building's context. The 3D visualizations enable context-dependent policy decisions about building-scale interventions. The visualizations therefore allow planners to consider whether it may be better to accept cash payments in locales with strong urban forests and apply the funds in other areas where the cooling impact is needed most.

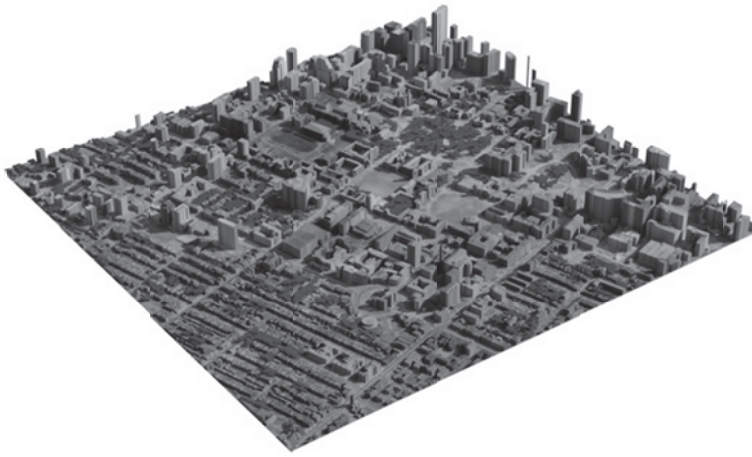


Fig. 5. P32 Toronto: 3D temperature map with urban forest canopy, University of Toronto area. The visualization combines remote sensed heat mapping, 3D urban form, ortho imagery and GIS Urban Forest data. It reveals, for example, the increase in heat from the new Varsity Stadium artificial turf, where there is no evapotranspiration.

The second broad type of output from this project was the development of a web-GIS application and associated solar modelling to allow users to explore solar panel feasibility on individual buildings. Solar insolation was modelled for two study areas within the city (broader Central Business District and the Black Creek area) using the ArcGIS Solar Analyst tools. Within an urban context, solar insolation on individual roofs varies primarily with topography, shading from trees and nearby buildings and the characteristics of the roof (e.g. roof slope, aspect, obstructions such as chimneys). These characteristics were captured in selected areas from LiDAR data provided by team partner Optech Inc. and 3D data derived from the City's Urban Design CAD model, and used to populate building footprints with height values and, where possible, to develop roof profiles. These data were used in a web-GIS tool built using ESRI's Flex API to allow users to interactively explore variations in solar potential across the study areas.

Users can easily retrieve estimates of the financial returns and GHG reductions associated with different solar panel configurations that they define interactively on specific buildings (Figure 6). Other capabilities of the web-GIS tool, including solar transects and land cover charting, were also developed to allow users with varying skill sets and interests to interactively explore existing spatial data sets (e.g. multiple Landsat thermal imagery snapshots, high resolution land-cover data derived from Quickbird imagery) that they otherwise would not be able to access and learn from.



Fig. 6. P32 Toronto: Prototype solar potential mapping application.

Formal testing of the visualization products and the web-GIS tools will take place in 2012 including the administration of cross case study questionnaires, which will allow for substantiation of some of the assumed impacts. In terms of longer term outcomes, this work aims to increase public awareness and understanding about urban micro-climates and how solar energy could contribute to improved implementation of urban heat island mitigation, GHG reduction, and reduced electricity costs to households and businesses participating in the Feed-in Tariff (FIT) and Micro-FIT incentive programs. Web-mapping techniques of this type are increasingly being used by governments as one way to complement and extend existing processes of public participation in decision making and, particularly, to reach out to individuals who are not able or willing to engage in traditional place- and time-specific meetings (Hall et al, 2010; Stern et al, 2009). Moreover, given that the City of Toronto's revised Green Development Standard (2010) includes specific performance measures related to tree shading and green roof provision for new development, there is further potential for tools of this type to be extended and integrated into routine planning practice.

Two important outcomes can be identified at this time: first, on-going networking has enabled the team and the research to be expanded to incorporate new partners, particularly the Toronto and Region Conservation Authority (TRCA). The new linkage with the TRCA has resulted in collaboration between University of Toronto landscape architecture students and private sector property owners, in order to develop green infrastructure design options for sites in the industrial and commercial district centered on Pearson International Airport. This collaboration has led to on-the-ground implementation of a green parking lot as a heat island mitigation measure. Second,

collaboration was also initiated with the TRCA to leverage the solar and heat mapping work for their Toronto and Brampton Sustainable Neighbourhood retrofit Action Plan (SNAP) sites, integrating testing and dissemination of results within an established community participation process.

In summary, the project process has illustrated some of the ontological and epistemic challenges in working with inter-disciplinary teams, and pragmatic challenges in integrating disparate data sets across multiple scales. Project outputs have led to new partnerships, with the potential to increase understanding of urban solar conditions for both planners and the public. Finally, project outcomes include implementation of a small-scale micro-climate adaptation project, as well as enhanced collaborative networks between academic researchers and Toronto environmental organizations for on-going, applied research. Five new small-scale micro climate change adaptation case studies have been funded for 2012 as part of the Toronto Region Conservation Authority's Partners in Project Green initiative that will utilize the visualizations, tools and data sets assembled as part of the GEOIDE study.

2.3 Clyde River – Planning for Growth in a Small Northern Hamlet

Clyde River, Nunavut, is a hamlet of approximately 900 residents on the North Coast of Baffin Island located just north of the Arctic Circle, and 750 km north of Iqaluit. There are no roads, power grid, or other physical infrastructure connections. Daily transport and travel to Clyde River is by air, with an additional summer sea-lift shipment. Electricity, heat and transportation energy are provided by diesel fuel and gasoline, imported during the summer sea-lift. Most major decisions for Clyde River are made within and paid for by territorial authorities in Iqaluit, which feed into sparsely distributed regional planning authorities as well as the local Hamlet office.

The Clyde River project used spatial planning, scenarios, 2D and 3D visualizations, as well as participatory processes (focus groups, community open houses, and community mapping, all working with translators) to bring together local and scientific knowledge, build social learning around planning issues, and visualize potential future resilient pathways for the community.

In terms of process, researchers at UBC partnered with Ittaq, the local Inuit research centre, as well as Natural Resources Canada researchers studying landscape hazards. Initially, the project focused on relationship building: UBC researchers (1 or 2 per trip) met with community members to explain the project, ask for feedback, and identify priority issues. They also met with Government of Nunavut staff, particularly Community and Government Services, the Department of Environment, the Nunavut Energy Secretariat, Qulliq Energy Corporation, and the City of Iqaluit's Department of Engineering, during the Iqaluit lay-overs on the way to or from Clyde River. These first two visits, along with a third trip for participatory community mapping, shifted the project's thematic focus from direct climate change related issues to include the locally-identified critical challenge of housing.

Scenario development was thus based on four dominant concerns: landscape hazards, housing (the current challenge, as well as how to plan for future population growth), walkability within the community (later broadened to cover multiple quality of life issues), and energy resilience. Following review by Hamlet staff and members of the community and Council, the four initial planning scenarios were refined by the UBC researchers to two final, spatially divergent scenarios (Figure 7) that explore different development alternatives while incorporating more resilient energy production and quality of life concerns in building design and arrangement.

Due to the long distances, and challenges in online communications, the scenario development process was carried out primarily by the university researchers, based on findings and community reviews during trips. Climate change was captured indirectly through hazards and energy resilience issues, rather than addressed directly as a scenario driver or indicator. This was for two reasons: first, community members expressed climate change “fatigue”, instead wanting researchers to deal with immediate issues such as housing; and, second, localized future projections for a secondary climate change impacts were not available (with the exception of sea level rise which is projected to be negligible for the Clyde River, as it is part of a region undergoing uplift). Data on current permafrost extents, for example, is still being mapped; preliminary, draft data was only available to UBC researchers towards the end of the project.

Outputs include community and expert mapping (done by hand during two workshops, and converted to GIS by researchers); a typology and 3D representation of current and possible future housing types, including low energy row houses; community planning scenarios with 3D visualizations; and, a simple integrated assessment of indicators for hazards, energy demand, quality of life, and housing units/population. These have been communicated using PowerPoint presentations and webinars, fostering rich researcher-community and researcher-Government staff discussions. A bilingual (English/Inuktitut) set of project posters will further enable project sharing with the community and various Government of Nunavut staff.

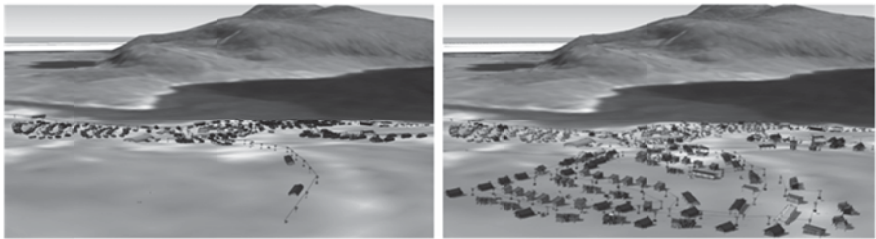


Fig. 7. P32 Clyde River: scenario visualizations contrasting future development options: compact Lower Town or solar-oriented Upper Town (image credit: Cheng, CALP).

The immediate impacts from the process and tools have been evaluated through researcher observation, participant comments, and by the cross-case study question-

naires. Researcher insights are that LCCV potentially bridges between local knowledge, scientific expertise, and government decision-makers, particularly for communities at a distance from territorial decision-making with additional language, cultural, and institutional barriers. Feedback from community partners suggests that the mapping exercises and 3D visualizations have fostered new conversations and understanding around the community's future and growth options. The cross-case study questionnaires are still being analysed, and longer-term outcomes cannot yet be measured; the final researcher trip to the community has yet to be completed.

The key learning has been that, given the complex set of environmental, socio-economic, cultural, and institutional conditions facing the far north, long-term resilience in Arctic communities such as Clyde River will be challenging to achieve, regardless of the availability of climate change projections or other scientific modeling. On-going planning processes will need to address many inter-related challenges, in addition to simply bringing added professional capacity, resources, and inter-departmental communication. Although the research team encountered dedicated and highly skilled practitioners throughout collaborating institutions in Nunavut, holistic and accessible processes may additionally bridge from residents and communities to practitioners and government, as well as fill a gap in official planning procedures.

2.4 Delta RAC – Operationalizing Adaptation

Building on the GEOIDE SII project, CALP continued to work with the Corporation of Delta on Project 32 in an alliance with Natural Resources Canada's Regional Adaptation Collaborative (RAC), in order to model, visualize and evaluate potential sea level rise and storm surge flood impacts and adaptation options. While the province of British Columbia has recently provided updated guidelines and tools for flood risk management, local governments must assess their own flood risk and vulnerability, and integrate these with planning policies to implement flood protection actions. The challenge facing local governments is that they must address adaptation planning within a context of scientific uncertainty, while at the same time building public support for possibly politically-contentious climate and flood adaptation policy and action.

For the project process, CALP researchers worked with a core group of five Delta staff (the local climate change "champions") and a citizen working group to identify sea level rise impacts and vulnerabilities, generate adaptation scenario options, determine environmental, economic, and social indicators, and review materials. Key experts (Environment Canada, the BC Inspector of Dikes, and engineering consultants) provided feedback on technical issues such as indicator measurement and dike infrastructure options. In addition, an engineering study was commissioned to specifically model the impacts, spatial flood extent, and water depth of possible breach events associated with 1.2 meters of sea level rise, the current BC Ministry of Environment high projection for Delta for 2100.

There are two key project outputs. First, a comprehensive graphic package of posters and presentation was produced to combine the risk and vulnerability assessments, 2D scenario mapping, indicator graphics, and 3D landscape visualizations. The work explores four flood management scenarios: Hold the Line, Reinforce and Reclaim, Build Up, and Managed Retreat. Managed Retreat is a potentially controversial adaptation option in which parts of the community are moved out of highly vulnerable areas. The package has been reviewed with the core staff team and the working group to assess policy implications and social acceptability. Second, two reports are being prepared: a technical report outlining the assumptions behind the scenarios and visualizations, and a Policy Implications and Recommendations report for Delta staff and Council. The second report used the visualization/scenario package to develop a set of detailed policy implications for each adaptation scenario across a range of themes, from agriculture to civic infrastructure. Shared, cross-scenario policy recommendations, as well as recommendations for community engagement around sea level rise planning, will be included. This project output, which directly engages with policy development, is posited to contribute to longer-term outcomes, particularly around policy-making and decision-support.

Further long-term outcomes are anticipated as UBC researchers have already been asked to provide staff workshops (beyond the core staff team) as a capacity-building tool within the municipality, along with a similar workshop for the Delta Mayor and Council, which may inform local decision-making in future. Additional project outputs include: a dedicated project website making the project materials publically available; use of the visuals by local and international media to explain potential sea level rise impacts, following a presentation at the American Association for the Advancement of Science's annual conference (Flanders 2012); and use of the materials by a provincial ministry in a national Adaptation Primer on sea level rise. The project materials, along with visualizations from earlier projects, are also being used in online courses for BC public servants. All of these are posited to contribute to raised public and government awareness, and increase knowledge about climate change, sea level rise, and adaptation options. This in turn builds local government capacity for climate change adaptation, supporting longer-term decision-making, although the outcomes have not yet been directly evaluated.

A final key outcome that has already been noted by researchers has been broadening the adaptation conversation to include a range of hard (infrastructure) and soft (non-engineered) approaches, particularly introducing new options that were previously off the table such as "Managed Retreat" (Figure 8).

The LCCV process in Delta seems to have created a robust tool for understanding and evaluating adaptation options; through the RAC partnership, this process is influencing best practice in the emerging field of adaptation planning in Canada.



Fig. 8. P32 Delta: 3D landscape visualization of managed retreat, shown here with a sea level rise and storm surge inundation event after relocation of most of the neighbourhood. With long-term planning, low-lying residential neighbourhoods could be converted to habitat areas (image credit: Flanders, CALP).

3 Discussion

3.1 Key Outcomes for Practice and Policy, SII to P32

Overall project results have been broad, with a wide variety of immediate impacts from the participatory processes and outputs, and on-going outcomes. Participatory, iterative processes, involving stakeholders throughout, have led to credible outputs (Moser, 2009), based both on underlying science, local knowledge (Rantanen and Kahila, 2009), and trust relationships with the research team. Participatory processes also seem to provide local capacity-building, particularly around awareness and understanding of the local impacts and response options related to climate change (Shaw et al., 2009). This should in turn lead to improved decision-making in the future. Strong local partnerships can lead, as shown by Toronto, to design and implementation of built projects. Taking the time to build trust in partnerships can lead to broader deliberation about more contentious issues, including moving the discussion to the public arena, as has been the case in the work between UBC researchers and the Corporation of Delta. However, questions remain about how to scale up and broaden the capacity-building, and embed enhanced tools and processes into mainstream planning procedures.

In terms of outputs, the projects have resulted in new modeling (all projects) and emerging integrated models (Calgary), as well as downscaled climate scenarios with local storylines and relevance – in some ways, anticipating the new direction in socio-economic modeling set out by the IPCC (Moss et al., 2010). Visual outputs include mapping, indicators, and 3D and virtual globe (e.g. Google Earth) visualizations of critical local climate-related issues and response options. In addition, production of the LCCV Guidance Manual, based on Kimberley as well as SII, was a major P32 output, available to case study teams in year two of P32.

Visualization evaluation has shown that visualizations can add value to data by effectively conveying salient information and helping to encourage discussion, build awareness, and improve understanding, particularly of local issues, risks, trends, and response/policy options (Sheppard et al., 2008; Tatebe et al., 2010; Burch et al., 2010b). The process and the tools taken together have had measurable impacts on participants, including increased awareness and understanding (Sheppard et al., 2008; Schroth et al., 2009; Cohen et al., 2012a).

In terms of scientific and practitioner impacts, multiple peer-reviewed journal articles, conference papers, book chapters, and other grey literature publications cumulatively point to an emerging field of local climate change planning and outreach, and an emerging Canadian research cluster. New research on the application of GIS spatial modelling and 3D visualization to climate change (SII), hybrid modeling (Calgary), the use of virtual globes in planning (Kimberley), and web-based interfaces (Toronto) are adding new scientific knowledge to their respective fields. Intensive research training has also been undertaken for Highly Qualified Personnel (HQP) ranging from undergraduates to post-doctoral fellows, in areas of growing demand for expertise that lie between traditional disciplines. The long-term project has offered both shorter term training, as well as the rare opportunity for some HQP to hone skills over successive project cycles in diverse settings.

In terms of outcomes, the many presentations, workshops, training sessions, and media coverage that have taken place beyond the initial participatory processes have served as a significant extension effort which would otherwise be difficult to fund, enabling researcher, practitioner, stakeholder, and public capacity-building. Local climate change visioning has thus contributed to longer-term outcomes, in particular a culture of change on thinking about and planning for climate change in several Canadian communities. The longest running project, the GEOIDE SII and P32 in Delta (2.1 and 2.3) illustrates the momentum of successive visioning and visualization projects that build long-term, on-going relationships. The continuation of projects beyond the GEOIDE funding period (Calgary, Toronto) suggest success in partnerships as well as tools.

The projects have attracted considerable interest and coverage in the media, particularly the more novel 3D landscape views of future conditions, with increased attention and wider appreciation of available and emerging geospatial and 3D tools available within the field, as suggested by Sheppard (2005). This suggests a latent and largely untapped demand for such products in envisioning community futures. Several visual project outputs have gained widespread and on-going use: for example, the BC Pacific Institute for Climate Impacts will be using LCCV visualizations in their online Impacts and Adaptation courses for BC public servants. This value-added outcome is a key benefit of working with geomatics and visual media in collaboration with other researchers, and of sharing the results.

There have been some unexpected results: reaching implementation (Toronto); intense media uptake of project outputs (SII, Delta P32); and that climate change planning work is becoming mainstreamed into planning practice. Community energy and GHG planning, and local adaptation planning are emerging areas within municipalities, to which resources and staff are being allocated. These various practices still need to be complemented with an integrated assessment to identify possible synergies and conflicts; our early projects (SII, Kimberley) in particular illustrate that a structured visioning process to convey the big picture of multiple choices and consequences is at least feasible.

3.2 Key Learnings, Challenges, and Recommendations for Further Research and Networking

As shown by the outcomes in 3.1, it is possible to engage with climate-related themes using inter-disciplinary research teams, modeling, and visualizations in participatory processes. Here, we discuss the learnings that apply to further research and management of collaborative and networked projects, as the GEOIDE SII and P32 projects have provided numerous insights to help run future projects.

Based on SII to P32 experience, we have found scenarios to be helpful in exploring and handling future uncertainty, and in demonstrating choices and consequences. Two divergent future directions warrant further testing. First, we recommend exploration of deeper collaboratively-generated scenarios, particularly a participatory approach to define key drivers (Bishop et al., 2007). Given that it may not be possible to explore the full range of scenarios (a resource-intensive approach), stakeholders could be asked to select the most locally relevant scenarios, in keeping with TDAR scholarship. For example, as compared to SII, the Kimberley bridging project focused on an adaptation/mitigation and an adaptation only scenario, rather than a full range of future scenarios. Other projects have moved into exploring multiple adaptation scenarios only (e.g. P32 Delta). Secondly, for current, known vulnerabilities in specific locations, that will be exacerbated by climate change in the future, such as urban heat islands in Toronto or wildfire in Kimberley, design solutions may be more effective than broader scenario-based projects, at least to support immediate, short-term decision-making. Further research into which scale, and in which planning phase, design rather than scenarios should be used would be helpful in accelerating implementation of local climate change responses.

In terms of data integration, modeling, and geospatial tools, the projects overall found that integrating climate science at the local level continues to be challenging, particularly in “data poor” areas. Downscaled climate projections and impacts data are still difficult to obtain, or may not yet exist; local climate projections and impacts data may need to be modeled on a project-by-project basis. The Kimberley and Clyde River case studies have demonstrated the value of using existing conditions data and currently available model outputs to advance community learning with better tools/processes. SII, Toronto, and Delta combined existing data sets and modeling

with project-specific data integration and/or modeling. Calgary has developed robust, project-specific, integrated models with diverse datasets, which has taken the most time. However, all of these approaches have taken longer than anticipated. Unless this is overcome through provision, for example, of centralized regional hubs of expertise that are available to communities, it represents an additional challenge to resource-limited planning jurisdictions.

In terms of data, we have also found that not all spatial data integration is successful (Toronto), neither should all spatial data be visualized in 3D due to the level of uncertainty in the data (snowpack projections, Kimberley). Volunteered geographic information (VGI), often discussed in relation to PPGIS, may enable new data sources and is worth exploring in future projects (Goodchild, 2007). Lastly, how to express uncertainty, particularly in visualizations (cf. Bizikova et al., 2011) still requires further research.

This project has engaged in two scales of collaboration: locally, with stakeholder/public participation and inter-disciplinary research teams, and nationally as externally networked projects across research institutions. The scientific process has been considerably enriched by input from local stakeholders who are non-technical or represent different disciplines than those on the research team. The networked case study approach has enabled process flexibility in order to adapt to and take advantage of local community and researcher expertise, with project goals and themes at least partially defined by partners.

One of our key learnings has been that face-to-face collaborations are easier to maintain in trans-disciplinary action research than long-distance collaborations, possibly a function of the number and ease of interactions. It is easier to consult when an expert is on the same campus, or a stakeholder is in the same region; informal meetings and social events also build the social networks supportive of collaborations (Yarnal et al., 2009). Web-based tools can be used to collapse distances (MacEachren et al., 2006); however, in some cases the infrastructure is not yet reliable (e.g. Nunavut, or rural community halls that do not have internet access). However, long distance collaborations across research teams face the additional challenges of finding time within multiple busy research and teaching schedules (see also Yarnal et al., 2009 for discussion of these challenges). Future networked projects would do well to structure consistent meetings, take advantage of as well as create opportunities to meet face-to-face, and take advantage of emerging web-based technologies (which also reduce carbon footprints), discussed below.

In terms of project failings, one of our biggest challenges came with developing sufficient inter-disciplinary capacity in our networked teams. While inter-disciplinary learning about modeling approaches, scales, and policy contexts has been advanced across the research teams through multiple joint workshops between 2008 and 2011, we were not able to successfully deal with how to build 3D capacity where 3D landscape visualization experts (predominantly but not exclusively landscape architects)

were not directly involved on the project team. Similarly, we were less successful in sharing specialized modeling. In other words, the networked research teams did not all have the same capacity, and working across distances and institutions made capacity-building across the teams more difficult. This may be a question of scale: the final P32 project involved, at the final case study stage, small, dispersed teams working on individual projects, rather than working on building a network. Resources could have been allocated differently, to directly build networking capabilities (e.g. software, etc, cf. Yarnal et al., 2009), but would have involved a trade-off in terms of individual case study outputs and potential long-term local outcomes (policy recommendations, new modeling techniques, built projects).

Web-based geotools may be able to provide an even stronger support of different-place collaboration (MacEachren et al., 2006) and it is recommended to further explore the potentials of emerging technologies such as collaborative web mapping tools and web resources for group work. Other solutions might include having HQP spend considerable time (several weeks to months) housed at alternate networked institutions, or engaging more directly in cross-team training. We were more successful in ensuring that experienced social scientists were available to advise, develop and analyze evaluation methods with participants. This may be due to the fact that social science materials are easily web-dispersed (word documents), while 3D visualizations and expert modeling require specialized software and hardware.

In addition to ensuring adequate time for data challenges, and building interdisciplinary team capacity, collaborative projects that are engaged in social outcomes research require more time, as well as researcher flexibility, than experimental projects that measure quantitative effects. Structured, well-managed, and flexible projects should allow for: exploration including dead-ends, time to solve data challenges, and the development of strong evaluation frameworks. It is important to plan for the additional project management and project time required for collaboration. Pohl, studying collaboration between natural and social scientists, found that “the pressure to produce usable results should be reduced if collaboration is to emerge” (2005: 1159), while Moser calls for “a clear understanding of the essential role of learning by all parties involved... and a clear policy of refusing to punish early mistakes” (2009: 19). Yarnal et al., 2009 detail the additional time it takes to set up collaborative projects.

We have found similar time results (see Pond et al., 2010a for a detailed breakdown of project steps): the first year of a cross-case study is spent setting up the research protocols, defining the goals and setting up workplans, inviting and organizing stakeholders, and building relationships. Data gathering may also begin in this phase. Depending on modeling depth, as well as data availability, the next few months to years may be spent on data and scenario development; visualizations also take time to develop, review, and refine. In a participatory process, the scenarios, design iterations, model development, integrated data, and visualizations all need to undergo iterative reviews with the wider team (partners, stakeholders, citizen working groups,

etc). This means that three years may be just enough time to start to see early results and outputs. In some cases, where relationships exist (e.g. Delta P32), or parallel processes are underway (e.g. Kimberley), project timelines may be tightened.

Therefore, the role of a federal funding agency that prioritizes collaborative and applied use of decision-making tools has been of considerable value to the partner communities, enabling in-depth engagement with researchers that contributes to policy development and social learning. A key benefit has been the ability of researchers to advance exploratory planning on issues considered too sensitive at the time for inclusion in formal planning processes. The GEOIDE network has facilitated sharing of geospatial technologies such as analyses based on LiDAR data, webtools, virtual globes, and hybrid modeling. As well, the nation-wide collaboration made it possible to test tools and processes in a range of typical contexts across Canada. And, the long-term funding made evaluation of social outcomes possible, often difficult for action research projects.

The final project challenge has been in the overall project evaluation in terms of process, tools/outputs, immediate impacts, and longer-term outcomes, for three reasons. First, while the teams developed an evaluative framework, it has proven overwhelming to document. Stronger research team protocols, developed and maintained from the outset, could aid in this. Secondly, the evaluation of longer-term outcomes requires post-project funding and time, which P32 funding provided for SII and Kimberley evaluation. The opportunity to think in terms of longer time frames in order to measure outcomes is critical, and likely the reason that so few projects evaluate social/institutional impacts over time. Thirdly, in term of methodology, impacts and longer-term outcomes are more difficult to evaluate than development results where one can count reports and papers, or measure immediate knowledge gain within a workshop. Mixed methods are recommended, with a focus on triangulating results (cf. Burch et al., 2010b; Schroth et al., 2009).

Geospatial tools need to be integrated within structured, iterative processes, although this may pose challenges for planning agencies with limited resources. All case studies showed that the political context, or rather the social-institutional constructs (Janowski and Nyerges, 2003), are of major importance. Even the most successful GIS aids cannot work around social-institutional barriers (Burch et al., 2010a) but depend on the political context. Therefore, it is critical that geovisualizations and PPGIS put adequate resources into the social-institutional framing of the tool application: the social process is as critical as tool development. This would include having skilled process facilitators, supporting local champions, and deliberately working across silos. The strength of the LCCV process rests largely in the capacity to build durable and inclusive collaborations that provide critical data and insights to shape scenarios and visualizations for enhanced community deliberation. These social learning processes may also serve to spur local climate change responses long after GEOIDE project completion.

4 Conclusions

The networked GEOIDE projects have led to the development of localized and downscaled climate change scenarios tied to local issues, the development of innovative spatial and hybrid models, the uptake of spatial planning tools and project outputs within communities, local champion support, and capacity-building around climate change planning and engagement. In framing climate change around local issues, “climate change” often becomes particularized into local themes such as urban heat islands, water availability, or energy resiliency, potentially a sign of climate change “mainstreaming” (Kok and de Coninck, 2007).

These projects have demonstrated that the geospatial models, maps, and visualizations generate discussion, insight, and change because they are embedded within facilitated, participatory processes. In all cases, the use of mapping, visual representation of numerical modeling, and images of possible futures, has generated discussion and insight that might otherwise be missed. Such discussion and insights happen, however, not because of the discrete geo-visualization artifacts by themselves, but through the facilitated relationship-building process built into the action-research.

While traditional planning has often been sectoral, effective climate change mitigation and adaptation requires integrated approaches and therefore tools that support interdisciplinary work and better decision-making. The GEOIDE projects on local climate change visioning have demonstrated the integrative capabilities and broad applicability of combined land-use, expert and stakeholder models; the utility of the resulting 3D landscape visualizations; and the communicative potential of geospatial webtools. The results suggest that such geospatial tools and participatory processes can bring considerable benefits in building capacity of community partners and supporting decision-makers facing climate change challenges, and warrant further research, development and application in practice.

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Does it make any difference to organize multi-disciplinary, multi-institutional projects? What is the value-added by the network form of collaboration? These questions are frequently asked but rarely answered.

*Over the past fourteen years, the **GEOIDE Network** (Geomatics for Informed Decisions) has mobilized 84M\$ in research effort across Canada. All participants in the Network over this period have a story to tell; and this book is the collection of these stories. Participants in the network have collaborated to contribute their viewpoints and their assessments. Some come from long-term participants whose activity spans the whole fourteen-year history, while others come from one particular moment, at the start or the end.*



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