FINAL REPORT – RIISQ FOURTH SCHOLARSHIP PROGRAM

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PROJECT SUMMARY

Project title

Paleoflood frequencies in the Ottawa River basin for the last two millennia

Project summary (300 words)

The severe floods that occurred in the Ottawa River Basin (ORB) in 2017 and 2019 resulted in the evacuation of approximately 14,000 individuals and incurred governmental expenses of around 1 billion dollars (Ministère des Affaires municipales et de l'Habitation, 2020). The damage caused by the 2019 flood in the ORB surpassed that of 2017 (Nolin et al., 2021a&b) which had already exceeded the flood levels witnessed in 1974 and 1976 (Ottawa River Regulation Planning Board, 2018). These floods were previously considered to be of a magnitude that would typically occur once in a century (Nolin et al., 2021a&b). The recurrence of such events has raised concerns, highlighting the need for a better understanding of these floods, including their connection to anthropogenic climate change and changes in land use. Unfortunately, the available flood records are limited in duration (Water Survey of Canada, 2021) and lack comprehensive data on unregulated tributaries (Centre d'expertise hydrique du Québec, 2021). Consequently, there is insufficient information to accurately estimate the natural occurrence of 100-year floods in the sub-basins (Reinders & Muñoz, 2021). However, it is possible to infer missing long-term data on the frequency and intensity of major floods by examining flood sediments, which exhibit distinct characteristics compared to sediments deposited under non-flood conditions (Oliva et al., 2016). In order to reconstruct and map past floods in the ORB, sediment cores will be obtained from oxbow lakes located in four tributaries of the basin. These sediment cores will be radiometrically dated and analyzed using various techniques such as X-ray fluorescence, magnetic susceptibility, particle size analysis, and organic matter content, among others. Additionally, the study will explore the impact of human-induced landscape changes and global warming on floods over the last century, in comparison to more natural floods experienced in the nineteenth century. This project tries to address concerns regarding the repetition of such damaging events in the future. Overall, the expected outcome is to enhance our knowledge of flood risks and vulnerabilities in the ORB, leading to improved spatial and long-term data on floods. This knowledge can help inform future flood mitigation strategies, reduce damage, and better prepare communities for potential flood events.

Axis(es) in which this project fits

☒ Axis 1 ☐ Axis 2 ☐ Axis 3 ☐ Axis 4 ☐ Axis 5

Sector(s) involved in this project

☒ Natural sciences and engineering ☐ Health ☐ Social Sciences, Arts and Humanities

PROJECT DESCRIPTION

Introduction (500 words) - This section should address the background of the research, the state of the art, the research questions and the significance of the study.

The Ottawa River Basin (ORB) has experienced severe flooding during the spring snowmelt period in various years, including 1974, 1976, 2017, and 2019 (Bourgeois, 2019; Ministère des Affaires municipales et de l'Habitation, 2020). The floods in 2017 and 2019 led to the evacuation of approximately 14,000 people and incurred governmental costs of around $1 billion (Ministère des Affaires municipales et de l'Habitation, 2020). It is evident that such costly losses cannot be sustained, and there is a pressing need for improved management of flood risks and vulnerabilities in the ORB. To address this, my project aims to create flood vulnerability maps on multi-centennial scales for different sub-basins within the ORB.

The research I am conducting addresses significant gaps in our understanding of flood risk vulnerability adaptation in the ORB. By utilizing long-term paleo-flood records obtained from naturally-flowing tributaries of the Ottawa River, we can enhance regional flood management in this densely populated area. Currently, the available instrumental records of regional floods are quite limited, starting only around 1910 (Water Survey of Canada, 2021). Moreover, there is a scarcity of streamflow gauges in the northern two-thirds of the ORB (Centre d'expertise hydrique du Québec, 2021), and most of the few existing gauges are located on regulated tributaries with records beginning at the time of regulation implementation. As a result, we lack sufficient data to accurately estimate the natural 50- and 100-year flood return periods in the diverse sub-basins of the ORB (Reinders & Munoz, 2021). This data gap prevents us from understanding longer-term flood frequencies and intensities across different sub-basins and their changing trends in today's climate influenced by global warming.

By filling this knowledge gap through the reconstruction of paleo-flood records, my research aims to expand our understanding of future flood risks in a changing climate. Additionally, it seeks to shed light on the potential occurrence of low likelihood and high impact (LLHI) events. These reconstructed records will provide valuable insights into the flood vulnerabilities associated with different sub-basins within the ORB and contribute to more effective flood risk management strategies in the face of a changing climate.

Regarding innovation until now, no research has utilized this specific approach to create a comprehensive spatial map of changing flood risks by mapping paleo-floods throughout the Ottawa River Basin (ORB) or in the province of Quebec. However, there has been a limited application of this approach within the ORB, specifically in reconstructing paleo-floods for a single tributary, the Désert River, which flows into the Gatineau River (Oliva et al., 2016). This prior work provides evidence that supports the feasibility of my project.

The general approach of inferring paleo-floods has been successfully employed in other regions as well. Previous studies have used this approach to reconstruct paleo-floods in diverse locations such as the Peace-Athabasca Delta (Wolfe et al., 2006; 2008a; 2008b; 2011), the Mississippi River (Munoz et al., 2015), and the lower Rhine (Toonen et al., 2015; 2016; 2020). These successful applications in different regions demonstrate the effectiveness and reliability of the paleo-flood inference approach.

This project aims to address the following questions: What are the inherent flood risks in different areas of the ORB, and how do they vary? Are there regions within the basin characterized by either

high or low flood risks? Is there evidence of emerging patterns or changes in floods across the ORB? Specifically, have floods become more frequent and severe in the past century due to significant human influences on the landscape, such as deforestation and land use alterations, in comparison to the preceding century when the natural state of the landscape was relatively less impacted by human activities?

Project objectives - Indicate the general and specific objectives of the research.

The objectives of my project involve enhancing flood risk management in the Ottawa River Basin (ORB) through the utilization of long-term data on flood occurrence and intensity, encompassing both anticipated consequences and the potential for Low-Likelihood, High-Impact (LLHI) events.

Methodology (400 words) - Provide a brief summary of the procedures and methods used and the setup of the experiments.

The study aims to address the issue of missing long-term data on the frequency and magnitude of major floods by utilizing sediment cores from oxbow lakes (Toonen et al., 2020). Oxbow lakes are known to capture floodwater sediments during flood events, which may differ from sediments deposited during non-flood conditions in terms of grain size distribution, magnetic susceptibility, sediment sources, and/or organic matter content. By analyzing sediment cores, dating them, and examining changes in sediment composition, past flood occurrences can be inferred (Toonen et al., 2020; Oliva et al.,2016; Wolfe et al., 2006; Munoz et al., 2015).

This approach has been successfully employed in Europe for the Rhine and Rhone Rivers, providing insights into the switching patterns between "active" and "inactive" flood phases and enabling a more accurate estimation of 500-year flood frequency curves (Toonen et al., 2020). Similarly, in Canada, Wolfe et al. (2006) have used oxbow lake sediment cores to reconstruct flood frequencies in the Peace River over the past 300 years, demonstrating high variability and a decrease in flood occurrences in the 20th century.

In the Ottawa River Basin (ORB), Oliva et al. (2016) reconstructed flood frequencies for the Rivière Désert (Gatineau River) using magnetic susceptibility, sediment grain sizes, carbon content, and radiocarbon dating of oxbow lake cores. The study revealed increased flood occurrences during the Dark Ages Cold Period and Little Ice Age, and decreased floods during the Medieval Warm Period.

In the current project, sediment cores will be obtained from oxbow lakes. The focus will be on reconstructing paleo-flood occurrences over the past 200 years across different sub-basins of the ORB and its near neighboring basins. The inferred paleo-flood records will provide insights into the variability of flooding in the ORB and establish a long-term baseline of flood frequencies.

Before conducting fieldwork, the coring sites will be examined using aerial photographs, remote sensing images, lidar data, early survey maps and Google Earth Engine to identify stable oxbow

lakes that have existed for at least the past century. In the laboratory, the sediment cores will be dated using various markers such as stratigraphic markers, lead-210, and radiocarbon dating. Age-depth models will be constructed using Bayesian modeling to date flood signals detected in the cores.

Different analytical techniques, including X-ray fluorescence analysis, computerized tomography scans, carbon and nitrogen content analysis, sediment particle size analysis, and magnetic susceptibility measurements, will be employed to detect changes in sediment composition that serve as indicators of past flood events.

The dated flood occurrences will be used to estimate flood frequencies and, if gauge data is available, flood magnitudes. The study will also investigate the switching patterns between "active" and "inactive" flood phases, which are often associated with major climate variability modes. Understanding the causes of these phases is crucial for accurate flood hazard assessment and provides insight into long-term climate drivers.

Furthermore, the long flood records will be correlated with climate oscillations and drought records to enhance understanding of the role of long-term climate factors in influencing flooding patterns.

Main results obtained (300 words)

In February 2023, I took sediment cores from three candidate oxbow lakes of the Rouge River near L'Ascension, Quebec. Two cores from two of the oxbows (Lac Burt and Lac Brach) have passed initial screening of suitability for analysis, that is they contain a sufficient depth of fine sediments deposited on top of the river gravel to be worth further examination as they probably contain at least a century of lake mud deposition. I have extracted terrestrial macro-fossils from both of these lakes and sent them to the Lalonde Lab, University of Ottawa, for radiocarbon dating which is needed to create age-depth models for these cores. Also for age-depth model construction, I have also sent in upper-core sediment samples for ^{210}Pb dating by our collaborator, Dr. Nicole Sanderson at Geotop at UQAM. I have done a preliminary 1-cm resolution magnetic susceptibility analysis of both cores. Encouragingly, I have found that both cores show definite variation in magnetic susceptibility, similar to that that would be expected if there are flood signals contained within. I am waiting on these radiometric results to come back before I proceed with further expensive analysis using XRF and high-resolution 1-mm magnetic susceptibility at INRS with our collaborator Dr. Pierre Francus.

While I am waiting for the radiometric results to come back, I am using GIS and the southern Quebec lidar from Foret Ouverte to choose two other coring sites in August 2023 during summer low flows. One site will probably be at the mouth of the Noire River, near Waltham, Quebec. The second site will probably be on the adjacent Assomption River, south of Joliette. By experience, we have learnt that a candidate site must contain many oxbows, as not all of them will contain a continuous record of lake sediments. Scouring and removal of sediments may occur when the oxbow reconnects with the mainstem during major flooding. Hence, in practice multiple oxbows must be cored at a site and examined for suitability and continuous sediment deposition. This necessity constrains our choice of sites.

Conclusion and discussion (300 words) - Specify how the project addressed flooding issues and the impacts of the project on society as a whole.

I aim to produce a better estimation of flood frequency in various basins of the ORB for the most recent 500-600 years. In particular, I would like to understand whether the land clearance starting in the 1830's on the northern bank of the ORB has changed the natural flood frequencies.

Furthermore, because I date the transition between the bottom of the oxbow mud and the underlying river gravel, I can date when the oxbow was formed and hence estimate river channel migration. To the best of our knowledge (and that of Prof. Pascale Biron of Concordia University), this has not been done anywhere in Quebec before (although it has been successfully done elsewhere, such as for the Rouge River, Manitoba and the Mississippi River, US). Having a better understanding of the rates of channel migration (and the closely related probability of avulsion occurrence as has occurred in the Rouge River north of L'Ascension) is extremely useful information in flood management and planning. An example of a location in Quebec where such information would have been very useful was during the recent flooding this spring in Baie-St-Paul, Quebec.

This basic background knowledge is of serious interest to supporting stakeholders of this project: the mayor and townsfolk of L'Ascension, the MRC of Antoine-Labelle, the Organisme de bassins versants des rivières Rouge, Petite Nation et Saumon (OBV-RPNS), the Agence de Basin Versant des 7, and the Bureau de projets de la rivière des Outaouais Ouest. All have supported our project in some fashion or another (in kind, with data or advice) and have requested to be sent our results when this multi-year project is completed.

Impact of the project on flood management for the partners and in Quebec (300 words)

Through my research, I aim to provide valuable insights into the spatial and temporal variations of natural flood risk baselines and emerging trends within the Ottawa River Basin (ORB). Additionally, I seek to assess the historical probability of Low-Likelihood, High-Impact (LLHI) flood events, which indicate potential severe risks in a changing climate. This study will contribute to our understanding of whether there have been major flood events exceeding the magnitude of the 2017/2019 floods in the past. Such findings will enhance our ability to anticipate extreme events in the coming decades and devise effective mitigation strategies to address them.

If possible, I will calculate improved flood magnitudes and determine the recurrence of 50- and 100-year floods in areas where gauge data is available, such as the Riviere Rouge (as has been done for the Rhine River in Europe). These findings will be valuable in providing a broader historical context of flooding in the Ottawa Basin for organizations and entities including the Ministère de la Sécurité publique, Ministère des Affaires municipales et de l'Habitation, la ville de Gatineau, and the Commission de planification de la régularisation de la rivière des Outaouais.

To effectively communicate my results to local communities, I will collaborate with Garde-Rivière des Outaouais, Organisme de bassins versants des rivières Rouge, Petite Nation et Saumon (OBV-RPNS), and the Agence de Basin Versant des 7. Together, we will determine the best methods for sharing the research outcomes, such as public talks, local newspapers, and informative newsletters. Given the significant financial impact this basin has had on insurers and residents, they recognize the importance of my research in terms of obtaining the missing long-term data on

natural flood frequencies and trends across the basin. I am grateful for the opportunity to apply my research to address urgent community needs.

Knowledge mobilization activities undertaken as part of the scholarship (e.g. participation in various events, such as conferences, workshops; writing (or participating in) scientific papers, etc.).

Conference Papers

- **Salemi, Fateme**, Jeannine-Marie St-Jacques and Matthew Peros, The frequency and intensity of flooding for the last two millennia in the Ottawa River basin using sediment cores, General assembly annual of ACG - 73nd edition, UQAM University, Montreal, Canada, May 8-12, 2023 (poster presentation).
- **Salemi, Fateme**, Jeannine-Marie St-Jacques and Matthew Peros, Paleoflood reconstruction of the Ottawa River Basin using oxbow lake sediments, Research that matters: Sustainability, biodiversity, and justice in a time of crisis, Loyola Sustainability Research Centre, Concordia University, Montreal, Canada, March 13-16, 2023 (oral presentation).
- **Salemi, Fateme**, Jeannine-Marie St-Jacques and Matthew Peros, Paleoflood reconstruction in the Ottawa River Basin, Canada, using sediment cores, NESTVAL 22, American Association of Geography (AAG), Salem State University, Salem, Massachusetts, November 4 &5, 2022 (poster presentation).

The final report must be sent at the following email address by May 31, 2023: poudrette.diane@uqam.ca