Title: Wetlands as Nature-Based Climate Solutions: A Socioeconomic Analysis of the Great Lakes-St. Lawrence River Basin

ECCC Project Number: GCXE24C298

Context

The crises of climate change and biodiversity loss are inextricably linked. Nature-based climate solutions—such as protection, conservation and restoration of wetlands—are uniquely suited to address both of these challenges. Canada is committed to nature-based climate solutions (NbCS) to build social and ecological resilience and to help Canada meet its 2030 and 2050 climate mitigation targets. The Nature Smart Climate Solutions Fund (NSCSF), administered by Environment and Climate Change Canada (ECCC), supports partner-led projects—focused on either place-based actions or sector-based policy—that result in the reduction of GHGs and increased carbon sequestration on Canadian soil using activities that also have biodiversity benefits. NSCSF activities during 2021-22 to 2030-31 will seek to reduce 2-4 megatonnes of GHGs per year from 2030 to 2050 and onwards. Several hundred million dollars will be invested in these projects across the country. Rigorous monitoring, accounting, and reporting of the projected and actual mitigation outcomes of individual projects as well as of the program will be essential to provide evidence to support NSCSF activities and to track progress toward achieving Canada's climate mitigation targets.

Canada does not have GHG projections for all categories in the land use, land-use change, and forestry (LULUCF) sector, particularly for the activities under the NSCSF related to wetlands. GHG projections rely on natural and social sciences to assess future activities under different climate, social, economic, and policy scenarios, and to quantify GHG emissions or removals associated with each scenario.

ECCC needs consistent and coherent (and hence comparable) integrated environmental, social, and economic impact assessment methods (1) to establish baseline carbon pools, and then (2) to evaluate and report on how different funded activities will affect the carbon pool under different climate, social, economic, and policy scenarios by 2030 or 2050.

Research Proposal

This proposal is designed to respond to ECCC's NSCSF need to create baselines and projections under different environmental, social, economic, and policy scenarios of the effectiveness of freshwater mineral wetlands as NbCS on agricultural landscapes of Canada, focusing on the Great Lakes-St. Lawrence River Basin.

In January, a ECCC NSCSF project ("Socioeconomic addition to the CAAF Wetlands as Natural Solutions Project for the Lake Winnipeg Watershed") was established to (1) identify drivers of wetland conversion, (2) explore the economic behavioural perspectives of stakeholders towards wetland drainage, restoration, conversation, and protection, (3) develop a model that incorporates behaviour to project wetland conversation rates under different social, economic and policy scenarios, (4) use the model to assess the efficiency of various policy instruments, and (5) assess the potential role of "leakage" of wetland associated emissions. This project is being conducted by Irena Creed, Patrick Lloyd-Smith (University of Saskatchewan), and John K. Pattison-Williams (University of Alberta), with the method being developed over a 3-month time frame (January-March 2023) and then applied to the entire Lake Winnipeg Watershed over a subsequent 2-year project (April 2023-March 2025).

In January, ECCC requested an additional proposal to modify/extend the analyses to be performed in the above-named project to the Great Lakes-St. Lawrence River Basin, an area in which intensive agricultural activities have been found for over a century and which has seen large numbers and areas of wetland conversion (Creed et al. 2022), with limited success in restoring and recovering wetland losses (e.g. Macrae et al., 2021; Liu and Brouwer, 2022).

For this additional proposal, we focus on two areas of inquiry.

First, a national wetland inventory and historical (1970 to present) rates of land use change and conversion of freshwater mineral wetlands in Canada will be developed. The development of a high-quality wall-to-wall inventory of wetlands in the agricultural landscapes of Canada has been a long-sought objective. The CAAF Wetlands as Natural Solutions Project (2022-2026) includes development of methods that will be used to create a freshwater mineral wetland inventory using satellite remote sensing techniques using "standardized" pixel-analysis of Landsat imagery (1984-present). Our preliminary analysis shows that use of standardized 30 m-pixel imagery is a coarse approximation of the number and size of freshwater mineral wetlands. Therefore, we propose work to explore the viability of using advanced machine learning techniques to enable sub-pixel analysis of the images that will generate finer resolution wetland inventories, and we propose work to use this machine learning technique to extend the wetland inventory from 1984-present to 1970-present. The advanced methods for wetland mapping that will be developed in this project will generate great value for expanding the national wetland inventory for use by ECCC practitioners.

Second, an integrated environmental, social, and economic impact assessment method will be developed and then applied to assess the effectiveness of the ECCC's NSCSF in achieving Canada's climate mitigation targets within the Great Lakes-St. Lawrence River Basin. This proposed project will be led by Irena Creed, George Arhonditsis (University of Toronto), Ben DeVries (University of Guelph), Geneviève Ali (McGill University), Roy Brouwer (University of Waterloo), and Jie He (L'Université de Sherbrooke). Through the leadership of Irena Creed, this project will work closely with the project team working on the Lake Winnipeg Watershed, sharing strategies and operationalizations, so that ECCC will receive a standardized integrated environmental, social, economic assessment method that can be used across Canada.

The following objectives are identified to conduct the requested project.

Objective 1. Evaluate methods of mapping wetlands and estimating historical rates of land use change and conversion of wetlands in the Great Lakes-St. Lawrence River Basin.

Personnel: Ben DeVries, Geneviève Ali, Irena Creed

Timeline: Year 1

The CAAF Wetlands as Natural Solutions Project (2022-2026) includes mapping of a wetland inventory in the Prairies using a combination of USGS Dynamic Surface Water Extent (DSWE) (Jones, 2019) and the European Commission's Joint Research Centre's Global Surface Water Extent (GSWE) (Pekel et al., 2016) maps. **This objective will evaluate whether more advanced methods of sub-pixel water detection (Sub-Pixel Water Fraction (SWF); DeVries et al., 2017) can improve wetland mapping in the Great Lakes-St. Lawrence River Basin. Development of these advanced methods will not only be applied to mapping wetlands in the Great Lakes-St. Lawrence River Basin but will**

also be used in the CAAF Wetlands as Natural Solutions Project to improve estimations in the Prairies and will eventually be used to generate long-sought high-quality wetland inventories in all the agricultural landscapes of Canada.

SWF is an automated algorithm for mapping sub-pixel water fractions over large areas and over long periods using Landsat images (DeVries et al., 2017). The algorithm has been tested in various wetland-dominated regions across North America, including a portion of the Prairie Pothole Region in Saskatchewan (DeVries et al., 2017; Zou et al., 2021). In the test regions, estimates of wetlands were found to be more sensitive to small, inundated features, to canopy-covered water features, and to those portions of features that are only partly inundated in space or time. It is expected that testing and calibration of SWF products will produce large improvements in the spatial and temporal accuracy of wetland inventories in Canada.

Task 1 (Year 1). Identify wetland inventories from governmental or non-governmental sources (e.g., DUC SOLRIS inventory) and reported estimates of uncertainty for these wetland inventories (i.e., minimum mapping size, spatial accuracy, omission/commission errors associated with wetland coverage methodology, unaccounted wetlands (i.e., those too small to be captured)).

Outcome: geodatabase of published reference wetland inventories.

HQP: Funded by ECCC CAAF grant

Task 2 (Year 1). In areas where validation wetland inventories are identified in Task 1, generate wetland inventories from (1) the combination of DSWE and GSWE maps used in the CAAF Wetlands as Natural Solutions Project and (2) SWF. These inventories will be compared to the validation inventories to determine the best available wetland mapping methods and to produce a report providing the limitations and uncertainties associated with both methods.

Outcome: geodatabase of wetland inventories in test areas generated through novel methodologies (DSWE+GSWE, SWF); report showing limitations and uncertainties of new wetland inventories ((i.e., minimum mapping size, spatial accuracy, omission/commission errors, characterization of wetlands that have likely been missed); journal article presenting products of novel methodologies (specifically SWF).

HQP: PhD 1 (UofG), PhD2 (McGill), Tech 1 (UofT)

Task 3 (Year 1). In the same areas, identify methods of land cover change detection (e.g., Kennedy et al., 2010; Zhu et al., 2022). We will use existing maps of land cover from 2000-2020 (AAFC Semi-Decadal Land Use Time Series; https://open.canada.ca/data/en/dataset/fa84a70f-03ad-4946-b0f8-a3b481dd5248) to evaluate performance of land cover change detection in these areas to be able to extend land cover change detection back to 1984 (beginning of Landsat time series). We will also use validated methods to extrapolate land cover changes back to 1970.

Outcome: database of land cover change in the Great Lakes-St. Lawrence River Basin.

HQP: PhD 1 (UofG), PhD2 (McGill), Tech 1 (UofT)

Objective 2. Create an inventory of wetlands and identify historical rates of land use change and conversion of wetlands in the Great Lakes-St. Lawrence River Basin.

Personnel: Ben DeVries, Geneviève Ali, Irena Creed

Timeline: Years 2-3

Task 1 (Year 2). Map wetlands using the methods tested in Objective 1, Task 3. Provide estimates of historical rates of conversion of wetlands in the Great Lakes-St. Lawrence River Basin. Wetland loss (or gain) will be mapped by applying a number of statistical analyses, including non-parametric Theil-Sen/Mann-Kendall trend tests, to each pixel in the SWF image stack. **These maps and rates will provide inputs into the next objectives and will also be provided as feedback to the CAAF Wetlands as Natural Solutions Project to improve wetland inventories in the Prairies and eventually to expand the national wetland inventory for use by ECCC practitione**rs.

Outcome: high-quality wetland inventory of the Great Lakes-St. Lawrence River Basin; report on methods to identify wetland loss/gain.

HQP: PhD 1 (UofG), PhD2 (McGill), Tech 1 (UofT)

Task 2 (Year 2). Estimate rates of wetland conversion. Once a wetland is lost, its follow-on land use and land cover will be classified using pixels drawn from a stratified random sample of change types (including strata of no significant change) using very high-resolution reference imagery. Classification of follow-on land use and land cover has been similarly used to identify drivers of forest change in the context of the United Nation's Reducing Emissions from Deforestation and Degradation (REDD+) strategy (Hosonuma et al., 2012). By performing this analysis on a stratified random sample, we will produce an unbiased areal estimate of follow-on land uses, which will inform further analysis of socio-economic drivers of wetland change.

Outcome: database of wetland conversion rates Great Lakes-St. Lawrence River Basin; journal article presenting wetland inventory obtained in Task 1 and methods for obtaining estimates of historical conversion rates.

HQP: PhD 1 (UofG), PhD2 (McGill), Tech 1 (UofT)

Task 3 (Year 3). Estimate changes from 1970 to present in wetland number, size, permanence, perimeter:area ratio, and perimeter width and distinctness (factors known to influence carbon cycling; Marton et al., 2015) at several assessment unit levels in the Great Lakes-St. Lawrence River Basin, including the Soil Landscapes of Canada (SLC) soil polygon database, which is currently being used to support the national GHG inventory. Estimate uncertainties associated with land cover change/wetland conversion rate (Olofsson et al., 2014).

Outcome: geodatabase of wetland inventory with calculation of additional attributes showing factors that have been shown to influence carbon cycling (wetlands and additional attributes identified and calculated at scale of different assessment units).

HQP: PhD 1 (UofG), PhD2 (McGill), Tech 1 (UofT)

Objective 3. Identify the main socio-economic drivers of wetland conversion and projecting how these drivers might change the rates of wetland conversion, and the resulting GHG emissions, over time in the Great Lakes-St. Lawrence River Basin.

Personnel: Roy Brouwer, Jie He, Irena Creed

Timeline: Years 1-3

Future agricultural wetland conversion projections directly incorporating socioeconomic considerations will be the product of this objective. Past conversion trends will be correlated to available socio-economic data and information and to policies to protect wetlands and increase agricultural production, making use of available global assessments (e.g., Van Asselen et al., 2013). For example, increases in agricultural commodity prices and input costs can be expected by 2030 and potentially beyond to 2050, which could be further expected to result in an increase in the rate of wetland conversion in the agricultural landscape of the Great Lakes-St. Lawrence River Basin. We will also survey landowners and farmers to identify which socio-economic and institutional factors influence their decisions to change land use or not, and to incorporate these behavioral feedbacks into making credible wetland conversion projections. These projections will allow for the assessment of the outcomes of the NSCSF using the best available natural and social science information. For this objective, Roy Brouwer will focus on Ontario and Jie He on Quebec, coordinating activities and making sure the same or similar research designs will be used. These research designs will be shared with the research team working on the Lake Winnipeg Watershed.

Task 1 (Year 1). Identify and describe the main drivers of wetland conversion in the Great Lakes-St. Lawrence River Basin based on existing data and literature (e.g., literature review and/or quantitative assessment using meta-analysis), and learning from the ECCC pilot project ("Socioeconomic addition to the CAAF Wetlands as Natural Solutions Project"). The latter will help identify assumptions that can be used to develop socioeconomic models of wetland conservation and conversion.

Outcome: report with wetland conversion rates for the Great Lakes-St. Lawrence River Basin and their underlying socio-economic drivers.

HQP: PDF1 (UWater), PDF2 (USher), PhD3 (UWater), PhD4 (USher), Tech1 (UofT)

Task 2 (Year 2). Work in parallel with the concurrent "sister" ECCC project ("Socioeconomic addition to the CAAF Wetlands as Natural Solutions Project") to design and implement a survey instrument to explore the economic behavioral perspectives of landowners and farmers towards wetland management and drainage in the Great Lakes-St. Lawrence River Basin, including the necessary institutional-economic terms and conditions for wetland protection and restoration, with reference to existing studies elsewhere including reforestation and afforestation to restore multi-service provision (e.g., Lienhoop and Brouwer, 2015; He et al., 2015; Brouwer et al., 2015; Santos et al., 2015; He et al., 2016).

Outcome: journal article with an estimated choice model explaining farmers' land use behavior, in particular wetland conversion, based on the survey.

HQP: PDF1 (UWater), PDF2 (USher), PhD3 (UWater), PhD4 (USher), Tech1 (UofT)

Task 3 (Years 2-3). Quantification and spatial mapping of the economic values of wetland ecosystem services in agricultural landscapes (e.g., Brander et al., 2013), linked to georeferenced biophysical characteristics of wetlands coming out of the previous two objectives. Key challenges are addressed, such as possible synergies and trade-offs between ecosystem services associated with the restoration and protection of wetlands in the Great Lakes-St. Lawrence River Basin. The ultimate aim is to map the total economic values of wetlands' protection and restoration, including use and non-use values, using state-of-the-art valuation methods (e.g., Johnston et al., 2017; Nobel et al., 2020), and test their transferability over space and time for use in cost-benefit analysis of future wetland conservation programs and as a basis for the development of payment schemes for wetlands ecosystem services (e.g., Nimubona and Pereau, 2022).

Outcome: journal article containing the economic value maps for the main wetland ecosystem services in agricultural watersheds in the Great Lakes-St. Lawrence River Basin (carbon sequestration, flood control, water quality regulation, and biodiversity/wildlife habitat).

HQP: PDF1 (UWater), PDF2 (USher), PhD3 (UWater), PhD4 (USher), Tech1 (UofT)

Objective 4. Cost-effectiveness and cost-benefit analysis of restoration and/or conservation of wetlands on agricultural lands as NbCS in the Great Lakes-St. Lawrence River Basin.

Personnel: Roy Brouwer, Jie He, Georgios Arhonditsis, Irena Creed

Timeline: Years 1-3

Conservation efforts in agricultural watersheds, including best management practices (BMPs) and NbCS, are typically evaluated based on their effectiveness in reducing, for example, erosion, sediment, or nutrient loads into rivers or streams. Including their cost of implementation helps to identify which combinations of measures are least costly in achieving environmental targets (e.g., Brouwer and De Blois, 2008; Taillardat et al., 2020). Evaluating BMPs on the basis of their environmental impacts only may result in the selection of overly costly measures, limiting their implementation under constrained government budgets and most likely reducing farmers' support for such costly measures. At the same time, the scope of the economic analysis has broadened in the context of environmental policy and decision-making to include both the private costs and benefits on agricultural plots to the wider public costs and benefits of wetland protection and restoration (e.g. Vermaat et al., 2016); see, for example, the Credit Valley Conservation Authority's Ecosystem Goods and Services program (https://cvc.ca/ecosystem-goods-services/) or the work in Canada on estimating the economic value of natural capital (L'Ecuyer-Sauvageau et al., 2021). Existing ecosystem services models such as InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) will be calibrated and applied to the Great Lakes-St. Lawrence River Basin to supplement the cost-effectiveness analysis with a cost-benefit analysis of different wetland protection and restoration scenarios, including the introduction of novel policy instrument mixes.

Task 1 (Year1- 2). Identify future policy scenarios and instruments for the Great Lakes-St. Lawrence River Basin and estimate their implementation costs, including the opportunity costs (benefits foregone) of wetland conservation and restoration.

Outcome: report with the costs of different wetland protection and restoration policies and policy instruments.

HQP: PDF1 (UWater), PDF2 (USher), PhD3 (UWater), PhD4 (USher), Tech1 (UofT)

Task 2 (Years 2-3). Develop spatial economic optimization procedures for wetlands as NbCS in the Great Lakes-St. Lawrence River Basin, based on cost minimization of the identified policy scenarios and instruments under climate change.

Outcome: journal article with the spatial optimization results for wetlands conservation and restoration as a cost-effective NbCS compared to the status quo and conventional best management practices.

HQP: PDF1 (UWater), PDF2 (USher), PhD3 (UWater), PhD4 (USher), Tech1 (UofT)

Task 3 (Year 3). Assess the potential role of "leakage" of wetland-associated emissions (i.e., displacement of emissions from avoiding an activity to another location). This task will assess the cost-effectiveness of wetlands as NbCS compared to alternative courses of action and then account for leakage and how this affects the outcome of the cost-effectiveness analysis (the expectation being that it will undermine the cost-effectiveness of wetlands as a NbCS). There are several agriculture-dominated watersheds in Ontario that will allow us to assess the potential leakage effects and policy implementation (in)efficiencies.

Outcome: journal article presenting a new methodology for cost-effectiveness analysis accounting for leakage effects of NBS.

HQP: PDF1 (UWater), PDF2 (USher), PhD3 (UWater), PhD4 (USher), Tech1 (UofT)

Task 4 (Year 3). Develop spatial optimization procedures to maximize the benefits of wetlands' ecosystem services associated with the policy scenarios and instruments (carbon sequestration, flood control, water quality regulation, and biodiversity), drawing on the collected survey data and existing ecosystem services models like InVEST (e.g., Harmáčková and Vačkář, 2015; Yang et al., 2018 ; Rahimi et al., 2020; Daneshi et al., 2021). The application of site and zonal selection models like Marxan will be explored here too (e.g., Pinto et al., 2019; Reis et al., 2019; Epele et al., 2021; Zhang and Li, 2022).

Outcome: journal article presenting a new methodology for cost-effectiveness analysis accounting for leakage effects of NbCS; journal article with the results of wetland conservation and restoration based on benefit maximization using spatial site selection models including the total economic values of wetlands ecosystem services.

<u>HQP</u>: PDF3 (UofT), PDF4 (UofT), PhD5 (UofT), PhD6 (UofT), Tech1 (UofT)

Task 5 (Years 2-3). Build an integrated decision-making tool that connects mechanistic ecosystem function models with ecosystem service models. Through the ECCC CAAF project, we are applying the Classic Model (Melton et al., 2020). Here, we will advance the analysis by developing a mechanistic model aimed to recreate the complex interplay among physical, chemical, and biological processes that shape GHG emission rates and carbon cycling in individual wetlands. We will the evaluate linkages between the two mechanistic models with both InVEST or ARIES (Artificial Intelligence for Ecosystem Services), as these can be used to (1) test spatially explicit scenario analyses, (2) support valuation in either monetary or non-monetary terms, and (3) be applied to multiple terrestrial and aquatic ecosystem services (Arnillas et al., 2021).

This ensemble of models offers an excellent foundation upon which relationships among human actions, wetland dynamics in space and time, multiple ecosystem goods and services, and associated changes in values will be depicted. The integration of mechanistic models with socioeconomic analyses will allow the rigorous evaluation of conservation actions and identification of options that allocate financial incentives (direct payments, tax credits, insurance, and stewardship certification benefits) cost-effectively by funding practices with high predicted ecosystem service benefits per dollar invested (Arhonditsis et al., 2019).

<u>Outcome:</u> integrated decision-making tool to estimate ecosystem services including GHGs but also others, to understand potential synergies and trade-offs; journal article and toolkit presenting explorations of socio-economic-political factors that influence the provision of these ecosystem services.

<u>HQP</u>: PDF3 (UofT), PDF4 (UofT), PhD5 (UofT), PhD6 (UofT), Tech1 (UofT)

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