Formal Title: Wetlands as nature-based climate-change solutions: Quantifying carbon-capture potential while building a stronger green economy.
ECCC Project Number: EDF-CA-2021i023

Project Summary

Project title	Wetlands as nature-based climate-change solutions: Quantifying carbon-capture potential while building a stronger green economy
Start date	2022-04-01
End date	2027-03-31

Project goals / objectives

Canada's greenhouse gas (GHG) reductions and carbon offsets to prevent warming above 1.5 °C need to be reported internationally in order to be recognized in global negotiations around climate change [ECCC, 2021a]. For this purpose, organic carbon (OC) accumulation and GHG emission estimates need to be reported in the national GHG inventory. However, the international community needs to be convinced that Canada's estimates are scientifically based. Any method for assessing carbon stock changes and GHG reductions must be demonstrated in the national GHG inventory, which must provide both information about activities accounted for in the estimates as well as the scientific reasoning behind the implementation of the accounting method itself.

According to the Pan-Canadian Framework on Clean Growth and Climate Change [ECCC, 2016], "forests, wetlands, and agricultural lands across Canada will play an important natural role in a low-carbon economy by absorbing and storing atmospheric carbon." Further, the report states that federal, provincial, and territorial governments will work together to protect and enhance Canada's carbon sinks, including wetlands. With growing local- and national-scale interest in wetlands as a Nature-based climate Solution (NbS), improved estimates of wetland OC sequestration and GHG flux across wetland types are required. While significant research has focused on carbon cycling in Canadian peatlands, few studies have investigated ecosystem-scale carbon cycling and GHG dynamics of freshwater mineral wetlands (hereafter, wetlands) in Canadian agricultural landscapes. While recent research suggests that avoiding conversion of existing wetlands and restoring others could play a significant role in helping Canada meet its emissions targets [Drever et al., 2021; Valach et al., 2021; Hemes et al., 2019], there is significant uncertainty associated with these estimates, which makes it challenging to incorporate wetlands in national GHG inventory reports [GOC, 2004-2019]. Further, this uncertainty is problematic when trying to develop carbon offset protocols focused on avoided conversion or restoration of wetlands.

Our GOAL is to determine the magnitude of and uncertainty in GHG estimates and generate tools (e.g., a GHG calculator) to predict GHG reductions through conservation and restoration of wetlands as NbS.

We suggest that a large source of the variability over time and heterogeneity over space in GHG estimates is attributed to properties of the hydrological landscapes that vary across the country.

To achieve this goal, we have FIVE OBJECTIVES (OBJs):

- OBJ 1: Develop authoritative estimates of landscape-scale density of wetland coverage for agricultural landscapes.
- OBJ 2: Develop authoritative estimates for rates of organic carbon accumulation, greenhouse gas fluxes to the atmosphere, and carbon transports to (and out of) wetlands to downstream waters.
- OBJ 3: Develop robust estimates of hydrological process controls on organic carbon accumulation and greenhouse gas fluxes.
- OBJ 4: Develop robust estimates of the synergies (and conflicts) of wetlands as nature-based solutions for carbon capture versus other benefits.
- OBJ 5: Use the authoritative and robust estimates of organic carbon accumulation and greenhouse gas fluxes to inform policy and practice tools to incentivize the use of wetlands as nature-based solutions for multiple benefits in agricultural landscapes.

These objectives are scaffolded; they progressively build towards the goal. OBJ 1 provides a first-of-its-kind standardized wetland coverage database for the national GHG inventory. The standardized wetland coverage database will form the basis for measurements (OBJ 2) and models (OBJ 3) of OC accumulation, GHG fluxes, and carbon transports into (and out of) wetlands. Together, OBJ 1, 2, and 3 will form the basis for comparing wetlands as NbS for carbon storage versus other ecosystem service benefits (including hydrological regulation, water purification, and biodiversity enhancement) (OBJ 4). Knowledge generated from these four objectives, individually and together, will be effectively transferred from academia to public and private sectors through an open science wetland information network, but it will also be translated to inform improvements to Canada's national GHG inventory reporting to the United Nations Framework Convention on Climate Change (UNFCCC), and, in turn, improvements to the design of farmers' carbon-smart agricultural management strategies in a way that is quantifiable at the national scale (OBJ 5). Finally, the knowledge will be used to educate and engage the next generation of climate champions interested in NbS.

The timeline for each OBJ is designed so that OBJ 1 and OBJ 2 feed into OBJ 3, 4, and 5. While there are clear linkages between the five OBJs, the first four OBJs have been designed to make substantive contributions individually and independently to improving the national GHG inventory by factoring in the role of wetlands as a NbS (OBJ 5).

Project description

INTRODUCTION:

The United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement strives to stabilize greenhouse gas (GHG) atmospheric concentrations worldwide to prevent enhanced anthropogenic interference with the world's climate [UNFCCC, 2015]. As part of the Agreement, Canada has committed to cut carbon emissions by 30% below 2005 levels by 2030 [ECCC, 2021a]. For Canada to meet this goal, the federal government's Nature-based climate Solution (NbS) fund has targeted tree planting and soil carbon gains as the means to achieve envisioned emission reduction targets [ECCC, 2021b]. Yet, agricultural wetlands (largely vanished in annual croplands [Watmough & Schmoll, 2007]) provide ample opportunity for "locking up" carbon and nutrients by protection, by conservation of wetlands that would otherwise be lost, or by restoration to the landscape of wetlands that have been lost [Badiou et al., 2011]. As part of Canada's commitments, governments are interested in the opportunity for wetlands to generate "carbon credits", where the ability of a wetland to sequester carbon can be used to offset GHG emissions.

Wetland protection, conservation, and restoration would increase organic carbon (OC) accumulation, resulting in net GHG reductions [Drever et al., 2021]. However, the scientific evidence in support of these benefits is cursory at best: it is scattered amongst different researchers throughout Canada based on different sites, different methodologies, and different timeframes. First and foremost, this project will provide scientific evidence (and estimates) of the role that wetlands provide for Canada to achieve its international commitments such as to the Paris Agreement.

RESEARCH DESIGN:

The proposed project will be conducted at three scales: wetlands, which represent the majority focus of wetland management in agricultural landscapes; watersheds, which are representative of different agricultural landscapes and are likely to yield highly valuable information for extrapolation across the agricultural landscape; and agricultural landscapes from coast to coast.

At the wetland scale, we will establish a network of about 100 wetland monitoring sites in agricultural landscapes across Canada (BC, AB, MB, SK, ON, QC, NB, NS). Our wetland sites will consist of small intact and restored wetlands as well as large freshwater impoundments, which represent the majority of wetland conservation programming nationally. Our wetland sites will be used to collect measurements to calibrate/validate wetland coverage data (OBJ 1) and wetland OC accumulation, GHG flux, and carbon transport into (and out of) wetlands (OBJ 2). At the watershed scale, we will select about five regional watersheds where we will use measurements from OBJ 1 and 2 to develop mechanistic models of hydrological process controls on wetland carbon cycling (OBJ 3) and statistical models of the synergies (or conflicts) of wetlands as NbS for carbon storage versus other ecosystem service benefits (OBJ 4). At the national scale, we will use measurements and models to extrapolate wetland coverage and our knowledge of process controls on wetland OC accumulation, GHG flux, and carbon transport into (and out of) wetlands to all agricultural landscapes within Canada.

Policy analysis is often made in the face of considerable uncertainty stemming from a multitude of sources. We acknowledge the need for a rigorous assessment of uncertainty and transparent communication of the inevitable risks associated with this uncertainty. In our measurements and models, we will incorporate estimates of uncertainty. This will allow policy analysts to consider both the state of our knowledge as well as the uncertainties in our knowledge. The precautionary spirit of our approach with the introduction of several layers of uncertainty will ensure robust decision-making processes.

METHODS FOR PROJECT CORE ACTIVITIES [HQP: 1-ECH/1-PDF/0-PHD/0-MSC].

The project's core activities are those foundational activities that support each of the project objectives. They include activities related to project management (including meetings with the project team, the international science advisory group, and the partner steering committee), the project's commitment to authoritative standardized estimates and uncertainties of wetlands as NbS, project activities related to knowledge mobilization (including both the transfer and translation of knowledge), and finally education and outreach.

PROJECT CORE ACTIVITY 1: PROJECT TEAM, INTERNATIONAL SCIENCE ADVISORY GROUP, AND PARTNER STEERING COMMITTEE MEETINGS AND WORKSHOPS.

- The project team will have regular science meetings (quarterly online) with at least one annual face-to-face meeting.
- In addition to the project team meetings, we will also convene annual meetings for our international science advisory group and for our partner steering committee.
- The international science advisory group will consist of science experts from the USGS (Dr. Sheel Bansal), the USEPA (Drs. Amanda Nahlik and Scott Leibowitz), Ducks Unlimited, Inc. (Dr. Ellen Herbert), and the Swedish University of Agricultural Sciences (Prof. Kevin Bishop).
- Our partner steering committee will include representatives from industry, government, as well as from other not-for-profit conservation organizations.

PROJECT CORE ACTIVITY 2: DECISION MAKING IN THE FACE OF UNCERTAINTY.

- The project team recognizes the need for authoritative measurements of wetland coverage and rates of wetland OC accumulation, GHG flux, and carbon transports that include rigorous assessments of uncertainty and transparent communications of the risks to decision making associated with this uncertainty.

- The project team will provide authoritative measurements that include estimates of uncertainty based on standardized protocols for all data that will become part of the Canadian Wetland INformation (CanWIN) repository.

PROJECT CORE ACTIVITY 3: KNOWLEDGE MOBILIZATION.

- The project team will mobilize the knowledge gained through this project to academic, government, industry, and civic society.
- The project team will transfer the knowledge to other scientists both in Canada and internationally through the CanWIN data, protocols, and tools that will be publicly available, through workshops with interested CanWIN users, through presentations at user workshops and conferences, through publication of peer-reviewed articles in scientific journals, and through presentations at scientific workshops and conferences.
- The project team will translate the knowledge into policy and practice through providing material in support of the national GHG inventory and Agriculture and of Agri-Food Canada's Holos GHG emission model and software [AAFC, 2020], and through providing evidence in support of the federal government's new Nature Smart Climate Solutions (NSCS) Fund [ECCC, 2021c] and of a proposed National Index on Agri-Food Sustainability [Protein Industries Canada, 2021].

PROJECT CORE ACTIVITY 4: EDUCATION AND OUTREACH.

- We will engage and educate diverse groups, creating the next generation of champions of wetlands as NbS.
- **We will engage youth.** Working **with Ducks Unlimited Canada (DUC**), we are uniquely positioned to leverage their award-winning education program to train and inspire youth across the nation using a combination of online learning and outdoor classrooms.
- Further, project results will be communicated through DUC's interpretive centres and project webinars to nearly 5,000 high school students nationally through DUC's 24 Wetland Centres of Excellence.
- **We will engage Indigenous Peoples.** We are committed to mutually beneficial collaborative partnerships with Indigenous Peoples across the country. We will leverage DUC's ongoing partnerships with Indigenous Peoples. We will seek and incorporate Indigenous perspectives into wetlands as NbS in the agricultural landscapes of Canada by inviting participation from Indigenous leaders to serve in an advisory capacity and by hosting a series of workshops and meetings with Indigenous communities. Where possible, we will work with Indigenous communities to quantify the carbon storage potential associated with Indigenous land management practices in and around wetlands, which could provide access to carbon offsets.

- We will engage wetland managers. We will share our research through the Wetland Knowledge Exchange, which is the official newsletter, webinar series, and social media account of the Canadian Conservation Land Management's Wetland Knowledge Portal (WKP). The Wetland Knowledge Exchange amplifies the voice of the WKP by increasing information sharing and fostering collaboration amongst diverse stakeholders interested in wetland conservation, restoration, and management.
- Finally, we will engage agricultural partners. As one of Canada's oldest and most respected conservation organizations, DUC has had the privilege to partner with farm groups and agricultural leaders to help elevate long term sustainability goals within the agricultural sector. A selection of these partnerships includes our partnering organizations as well as other industry and industry organizations. We believe that a thriving agricultural sector will be one that integrates wetland conservation and restoration to improve environmental sustainability while remaining competitive and profitable.

METHODS FOR OBJ 1: DEVELOP AUTHORITATIVE ESTIMATES OF LANDSCAPE-SCALE DENSITY OF WETLAND COVERAGE TO INFORM DECISION MAKING AT LOCAL, REGIONAL, AND NATIONAL SCALES [HQP: 2-TECH/1-PDF/2-PHD/0-MSC].

TASK 1.1: Compile Government/Non-Government Held Databases Of Wetland Coverage Across The Agricultural Landscapes Of Canada.

We will identify wetland inventories with coverage of agricultural landscapes in Canada from government and non-government holdings. We will compile these wetland inventories and create criteria for establishing estimates of uncertainty for these wetland inventories (i.e., minimum mapping size, minimum data inputs, minimum wetland classes or types, methodological rigor, relevant time periods, and spatial extents). We will identify the producers and users of these wetland inventories (e.g., DUC, provincial and federal government agencies, and Canadian academic investigators), and establish contacts with these groups for the purpose of establishing wetland inventory methods, accuracies, and limitations.

TASK 1.2: DEVELOP STANDARDIZED ESTIMATES OF LANDSCAPE-SCALE RATES OF WETLAND COVERAGE IN AGRICULTURAL LANDSCAPES OF CANADA OVER A TIME SERIES FROM 1984 TO PRESENT.

We will download and calibrate USGS Landsat Dynamic Surface Water Extent (DSWE) [Jones, 2015] and EU Joint Research Center (JRC) Global Surface Water Extent (GSWE) [Pekel et al., 2016] satellite remote sensing datasets from Google Earth Engine for all available years to develop standard "wall-to-wall" inundation maps for Canadian agricultural landscapes across a time series from 1984-present [Jones, 2019; Vanderhoof et al. 2020]. Thresholds of DSWE and GSWE classes for mapping annual inundation will be calibrated using the integrated wetland database developed in Task 1.1. We will then use the calibrated and thresholded satellite remote sensing products to develop standardized estimates of landscape-scale wetland coverage and wetland properties of agricultural landscapes of Canada. For this wetland coverage, we will include estimates of wetland number, size, permanence, perimeter: area ratio, and perimeter width and distinctness (factors known to influence carbon cycling). We will include estimates of uncertainty (omission/commission errors associated with wetland coverage methodology) as well as estimates of unaccounted wetlands (i.e., those too small to be captured). The wetland inventory will be available at several assessment units, including the Soil Landscapes of Canada (SLC) soil polygon database [Soil Landscapes of Canada Working Group, 2010; Du et al., 2015], which is currently being used to support the national GHG inventory.

TASK 1.3: DEVELOP STANDARDIZED ESTIMATES OF LANDSCAPE-SCALE RATES OF WETLAND LOSS (GAIN) ASSOCIATED WITH CLIMATE CHANGE AND HUMAN MODIFICATION OF HYDROLOGICAL LANDSCAPES (I.E., DRAINAGE DITCHES AND TILE DRAINAGE).

Wetland coverage is dynamic, with wetlands lost (via drainage, filling, or drying) or gained (via restoration or refilling by precipitation). We will estimate the rates of wetland loss (or gain) using the method of Serran et al. [2018]. This method establishes a power-law function of the natural log-log linear relationship between wetland size classes and uses the departure from the power-law function to characterize wetland loss (or gain) in terms of number and area at the watershed scale. The accuracy of wetland loss (or gain) estimates will be assessed in areas where DUC has evaluated wetland change (prioritizing the project's selected watersheds, if possible).

While the power-law function provides non-spatial estimates of wetland loss, we will also generate spatial estimates of wetland loss. We will generate maps of human modified wetlands resulting in their loss to inform land managers where there have been large losses of wetlands and where there are potentially restorable wetlands. Two main human modifications are surface drainage ditches (both in-field surface drainage ditches and municipal/provincial drainage ditches) and subsurface tile drainages. Farm surveys and municipal and provincial maps of drainage ditches will be used to calibrate drainage ditch maps derived from digital terrain analysis [Waz and Creed, 2017]. Data on tile drainages will be identified, compiled, and used to characterize wetland loss from this activity; because of the subsurface nature of this activity, explicit mapping will not be possible. The extent of tile drainage can be directly ascertained through the permitting process that exists in most jurisdictions, and the permitting process often goes back several decades. These permits specify the unit of land drained. Such information has been used to assess the potential impacts of tile drainage on GHG emissions [Burton et al., 1999]. The extent of tile drainage can also be indirectly ascertained through expert knowledge of the drainage required to change poorly and imperfectly drained soil (as indicated in the National Soil DataBase (NSDB) [AAFC, 2021]) to moderately drained, allowing the successful growth of crops such as corn. Similarly, irrigation often requires tile drainage to control soil moisture. Expert knowledge of soils, crop management, and irrigation permitting processes will therefore allow us to overlay water management techniques onto the SLC polygons to estimate wetland loss from tile drainages. Data on drainage ditches and tile drainages will be used to identify priority areas for wetland restoration.

TASK 1.4: SHARE AND DEMONSTRATE WETLAND COVERAGE DATA PRODUCTS WITH POTENTIAL USERS OF THESE DATA—INCLUDING GOVERNMENT

ORGANIZATIONS, NON-GOVERNMENT ORGANIZATIONS, AND FARMERS.

We will share and demonstrate wetland coverage products developed in Tasks 1.1-1.4 to potential users of these data, including provincial and federal government agencies, farmer unions or associations, wetland and watershed managers, conservation groups, and consulting groups. Socialization efforts will include an online portal to provide easy access to the data products, workshops to communicate the benefits of using the wetland database and information products, and writing articles or making appearances in public media forums. Continuous improvement of wetland databases and information will be made as new ground, aerial, and satellite data come online and as new methods are developed and investigated, and will be accompanied by continuous updates of the online portal.

LINK TO GOAL: We will generate standardized wetland coverage (including density) estimates linked to the SLC polygons that are needed to support the proposed revisions to the national GHG inventory that incorporate wetlands as NbS.

LINK TO OTHER OBJECTIVES: The standardized wetland coverage data will be used as the foundation for OBJ 2, 3, and 4. Further, by placing the wetland coverage data within the SLC polygons, these OBJs will have information on surficial materials that affect acidity/alkalinity and salinity and, in turn, OC accumulation and GHG production rates that can be incorporated into models. Finally, the standardized wetland coverage data will be placed in the CanWIN repository (OBJ 5).

METHODS FOR OBJ 2: DEVELOP AUTHORITATIVE ESTIMATES FOR RATES OF ORGANIC CARBON ACCUMULATION, GREENHOUSE GAS FLUXES TO THE ATMOSPHERE, AND CARBON TRANSPORTS INTO (AND OUT OF) WETLANDS [HQP: 6-TECH/ 0-PDF/ 4-PHD/ 6-MSC].

TASK 2.1: COMPILE PUBLISHED INFORMATION ON PROCESS CONTROLS OF WETLAND CARBON STABILIZATION AND PUBLISHED DATA FOR ALL COMPONENTS OF WETLAND CARBON BUDGETS, RECONCILING DIFFERENCES IN ESTIMATES DUE TO DIFFERENT TECHNIQUES/TOOLS.

We will compile and summarize published information on process controls influencing wetland carbon stabilization, and compile published data for all major components of wetland carbon budgets, including rates of OC accumulation, GHG fluxes to the atmosphere, and dissolved/particulate inorganic carbon (IC) and OC transports into (and out of) intact and restored wetlands. Additionally, we will reconcile differences in estimates associated with different sampling techniques both through application of standardized methodologies for the collection of new data, and by applying a Bayesian hierarchical modelling framework [Arhonditsis et al., 2018] that will allow comparing different estimates of wetland carbon storage and fluxes, assigning error values (uncertainty ranges), and estimating the minimum corrections needed to standardize the data at a national scale. Our approach will be based on standard methodological protocols of meta-analyses published in the peer-reviewed literature (e.g., weighting the available flux estimates by sample size, methods used to generate estimates, hydrological conditions, and landscape features). This exercise will provide carbon cycle fluxes suitable for the rigorous calibration and validation of wetland models. This is an essential piece of information to characterize wetland OC accumulation and GHG flux rates, determine the associated uncertainties, and minimize the likelihood of developing over-parameterized (under-identified) models that give "right results" for the "wrong reasons" [Beven, 2006].

TASK 2.2: DEVELOP STANDARDS AND PROTOCOLS TO MEASURE WETLAND OC ACCUMULATION AND GHG FLUX RATES.

We will develop a standard set of practices and protocols for measuring OC accumulation and GHG fluxes from wetlands and their riparian zones in agricultural landscapes of Canada. This will include standardization and recommended protocols for dissolved gas and chamber-based sampling techniques [Collier et al., 2014; Oertel et al., 2016; Butterbach-Bahl et al., 2016]. This will also include recommended protocols for the deployment of Eddy Covariance (EC) flux towers in freshwater wetlands, based on the expertise within our team but also the expertise from established flux networks. With respect to determining rates of OC accumulation and mechanisms of carbon stabilization we will also develop protocols aimed at standardizing coring techniques, sampling designs (number and location of cores), and laboratory extraction protocols to facilitate comparisons between wetlands across Canada [Janik et al., 2007; Chatterjee et al., 2009]. This will include recommendations aimed at facilitating radiometric dating (210Pb/137Cs) while reducing analytical costs.

TASK 2.3: USING STANDARDS AND METHODOLOGIES DEVELOPED IN TASK 2.2, MEASURE WETLAND OC ACCUMULATION AND GHG FLUX RATES.

At the pan-Canadian network of wetland measurement sites (n = 100), we will use a suite of sampling techniques, including ex-situ and in-situ methods, to determine OC accumulation and stabilization [Six et al., 2002; Zimmermann et al., 2007; Chatterjee et al. 2009]; we will also use chamber-based sampling [Cole et al., 2010] and dissolved gas sampling for measuring GHG fluxes [USEPA, 2017]. These wetland measurement sites will build on, and add to, an established network of wetland sites (n > 200) that have previously been sampled for OC accumulation and/or GHG flux rates by members of our team. At a subset of the wetland sites, we will collect sediment cores to quantify OC stocks and to determine OC accumulation rates using 210Pb/137Cs dating. Also, at four sites, we will establish wetland EC flux towers that will add to an existing set of three wetland EC flux towers sites operated and maintained by members of our team.

As the most complete and direct method to measure ecosystem-scale fluxes, EC data have an important role to play in determining the feasibility of wetlands as NbS [Hemes et al., 2021]. We will use EC flux towers to measure Net Ecosystem Exchange (measured as carbon dioxide (CO_2) and methane (CH_4) fluxes above the study wetlands. LiCOR EC systems will be equipped with an LI-7500DS open path CO_2/H_2O analyzer, LI-7700 open path CH_4 analyzer, and a sonic anemometer. EC flux towers will be strategically situated at each site to ensure that the flux footprint captures the wetland ecosystem as well as transitions between zones within the wetlands (i.e., meadow marsh, emergent vegetation, and open water zones). Our EC-measured fluxes for CO_2 and CH_4 will be supplemented with chamber-based and dissolved gas sampling to account for nitrous oxide (N_2O) emissions. EC data can also be used to determine the role of wetlands in cooling and humidifying the atmosphere [Zhang et al., 2021], and thereby capture the full potential of these ecosystems to serve as NbS [Hemes et al., 2018]. We will quantify the surface energy balance and rates of evapotranspiration for intact and restored wetlands and compare these to the agricultural landscapes in which they are embedded.

TASK 2.4: ESTIMATE LATERAL FLOWS OF CARBON INTO (AND OUT OF) WETLANDS.

Net ecosystem carbon budgets (NECBs) link terrestrial and aquatic carbon fluxes and therefore represents a critical step to developing integrated estimates of carbon cycling and carbon flows into (and out of) wetlands [Chapin et al., 2006; Webb et al., 2019]. NECBs can vary widely from one ecosystem to the next, and few such budgets exist worldwide, particularly for wetlands on agricultural landscapes [Webb et al., 2019]. Therefore, it is difficult to accurately represent the flow of carbon through wetlands and other ecosystems using existing information. Lacking relevant NECBs, we cannot answer with sufficient accuracy some of the most pressing questions relating to the use of wetlands as NbS or how the ongoing loss of wetlands may impact the carbon balance at a farm scale.

We will build comprehensive NECBs for a series of Canadian wetlands that will enable us to better define annual rates of carbon flux for the major components of the wetland carbon cycle. NECBs will be generated at key wetland sites where measurements of above- and below-ground carbon cycling will be conducted. We will follow the established approach that combines EC methods with OC accumulation [e.g., Forbrich et al., 2018; Bogard et al., 2020]. This approach will provide both estimates of the portion of carbon fixed by vegetation that remains on site and is buried over longer timescales (decades to millennia) plus the fraction of carbon fixed by wetland vegetation that is lost via lateral hydrologic export to downstream environments. Lateral export of carbon will be estimated from the difference between EC-derived Net Ecosystem Production [Odum, 1969] and estimates of site-specific long term carbon burial rates.

At selected wetland sites, we will collect measurements of carbon fluxes associated with shallow subsurface/groundwater exchange (i.e., recharge versus discharge) [Waletzko and Mitsch, 2013] and dissolved carbon concentration in the discharge to provide independent estimates of hydrological carbon export from wetlands [Bogard et al., 2020]. By identifying the composition of carbon exported from wetlands (as either organic or inorganic, particulate versus dissolved), we will be able to provide context as to the long-term fate of carbon leaving wetlands (i.e., mineralization of carbon and further GHG production versus retention of bicarbonate/carbonate in dissolved form and long-term storage of carbon). While wetland NECBs will necessarily have associated error and assumptions built in [e.g., Chapin et al., 2006], they represent an important next step in our understanding of the role of wetlands in landscape carbon cycling, as they go beyond the assumption that carbon fixed by wetland vegetation (as measured by EC and other methods) is equivalent to carbon retained in soils [Lovett et al., 2006].

TASK 2.5: DEVELOP MODELS TO PREDICT THE POTENTIAL FOR WETLANDS FOR OC SEQUESTRATION AND GHG REDUCTION.

We will use information from Tasks 2.1-2.4 to develop simple process-informed models that can be used to determine the potential for wetlands as NbS for OC sequestration and GHG reduction (e.g., how to maximize CO_2 removal and minimize CH_4 and N_2O release) at local (wetland/watershed) and national scales. We will collect information on key environmental drivers, including water levels (i.e., hydroperiod) that will be continuously monitored at a subset of wetland sites and supplemented with data from Task 1.3, water quality (i.e., temperature, sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), nitrate (NO_3^-), ammonium (NH_4^+)) that will be monitored at all wetland sites, and landscape properties in the catchment contributing areas of the wetland sites, that will be included in the simple models. For the landscape properties, we will use a combination of ground surveys at the wetland sites as well as the AAFC Annual Crop Inventory [AAFC, 2009-2020] and SLC database [AAFC, 2021] to compile information on the types of land management practices, crops, and soils within the contributing areas of our study wetlands. This will generate estimates of the implications of land management decisions associated with wetlands as NbS. These process controls will establish natural heterogeneity/variability in OC accumulation and GHG reduction, as well as how land management practices influence OC accumulation and GHG reduction within the wetlands and the surrounding agricultural land within watersheds.

LINK TO GOAL: Building on national agricultural wetland coverage information from OBJ 1, we will identify process controls on wetland carbon fluxes to enable prediction of heterogeneity and variability of wetland OC accumulation and GHG fluxes.

LINK TO OTHER OBJECTIVES: The standardized wetland OC accumulation and GHG flux data will be placed in the CanWIN repository (OBJ 5). The results generated through the combination of information gathered in OBJ 1 and 2 will be instrumental for the modelling work proposed in OBJ 3 and 4. Further, this information will form the foundation of the main deliverables in OBJ 5.

METHODS FOR OBJ 3: DEVELOP ROBUST ESTIMATES OF HYDROLOGICAL PROCESS CONTROLS ON ORGANIC CARBON ACCUMULATION AND GREENHOUSE GAS FLUXES FROM WETLANDS [HQP: 0-TECH/ 2-PDF/ 4-PHD/ 0-MSC].

TASK 3.1: USING DATA COLLECTED ACROSS OUR NETWORK OF WETLAND SITES, DEVELOP MECHANISTIC MODELS OF CARBON CYCLING.

We will develop mechanistic models of wetland carbon cycling to help understand the observations from OBJ 2. All biogeochemical processes will be considered to determine the fate of carbon (e.g., gas exchanges at the interface between wetlands and the atmosphere, seasonality of the organic matter decomposition under different redoxpotential regimes, photosynthesis and uptake by the autotrophic assemblages, autotrophic and heterotrophic respiration, particle settling, diffusive transport from the sediments, sediment resuspension, and advective mass exchanges within the wetlands). We will apply correction factors based on empirical linear regression equations from published studies to account for the presence of IC in soils and to avoid an overestimation of the amount of OC in soils and sediments [Nelson & Sommers, 1996; Skjemstad & Baldock, 2007; Kasozi et al., 2009; Wang et al., 2011]. These mechanistic models will be calibrated using data from OBJ 1 and 2. We will use a recursive approach, whereby the data produced from the project will be used to calibrate the mechanistic models following which the derived characterization of wetland processes along with the associated uncertainties will be used to dictate future data collection efforts or to identify compelling hypotheses that can be tested in the field.

The mechanistic models will provide the platform to run a series of “what-if?” scenarios, where we can predict the potential of wetlands as NbS under alternative scenarios (i.e., changes in weather predictions and frequency of extreme events, and changes in land management schemes). The mechanistic models will be used to generate information related to the potential role of wetlands in achieving national GHG reduction targets, and to enable adaptive management.

TASK 3.2: ESTIMATE THE HYDROLOGICAL CONNECTIVITY OF WETLANDS TO THE WATERSHEDS IN WHICH THEY ARE EMBEDDED.

We will develop a Canadian-scale map of groundwater table depth and combine this map with maps of watershed drainage networks and wetland coverage within the watersheds (OBJ 1) to estimate hydrological connectivity types (e.g., surface versus subsurface) and hydrological travel times of wetlands to their watershed drainage outlets in agricultural landscapes across Canada.

For the map of groundwater table depth, we will use knowledge of the hydraulic characteristics of shallow soils to estimate the rate, travel time, and pathway of soil drainage, and, ultimately, connectivity. Soil hydraulic characteristics depend on intrinsic properties of the substrate. Janssen and Ameli [in prep.] developed a novel statistical machine learning approach to combine the intrinsic properties of shallow (< 4 meters) and bedrock substrates taken from the global dataset developed by Dai et al. [2019] and Gleeson et al. [2014] with climatic, topographical, and geophysical landscape factors to develop a North America-scale map of static (and seasonal) groundwater table location and unsaturated pressure at 500-meter resolution. The soil hydraulic characteristics and associated groundwater table depth map will be used to quantify how fast, and through which flowpaths, soils could drain water. This dataset, combined with wetland coverage (OBJ 1), will be used to identify the wetland hydrological connectivity types (e.g., surface versus subsurface) and the timing (or travel times) of wetland connectivity across Canadian agricultural landscapes, using the methodology conceptualized by Cohen et al. [2016] and recently applied by Leibowitz et al. [in prep.] in the United States. As suggested by Leibowitz et al. [in prep], wetland connectivity types will include: (1) riparian wetlands connected to streams with persistent or frequent surface connections with short travel times and fast hydrologic connectivity; (2) non-riparian wetlands with surface flowpaths to streams and moderate hydrologic connectivity; (3) non-riparian wetlands with subsurface flowpaths but poorly-drained upland soils that promote saturation excess overland flow and moderate hydrologic connectivity; and (4) non-riparian wetlands with dominant subsurface flowpaths, due to well-drained upland soils, and with slow hydrologic connectivity. Hydrological travel times along the various connectivity types will be calculated as the least cost path from the wetland to the watershed surface drainage network.

TASK 3.3: DETERMINE THE INFLUENCE OF HYDROLOGICAL CONNECTIVITY ON THE ATMOSPHERIC VERSUS AQUATIC FATE OF CARBON FOR WETLANDS IN AGRICULTURAL LANDSCAPES.

Using wetland coverage data from OBJ 1, and potential wetland OC accumulation, flux, and transport rates from OBJ 2, we will model the relationship between hydrological connectivity of wetlands to the watershed surface drainage network and carbon export. We can trace carbon sources, pathways, and sinks, either directly, by using isotopes of carbon (13C and 14C) [e.g., Schiff et al., 1997; Raymond and Bauer, 2001; Koiter et al., 2018; McCallister et al., 2018; Rieffarth et al., 2019], or indirectly, by tracing water isotopes or biogeochemical properties of sediments [e.g., Boudreault et al., 2018; Koiter et al., 2018], but this is beyond the scope of the proposed project. This tracing will be pursued by other funding sources to the project team members. Our models will use statistical approaches to identify wetland hydrological connectivity types with predictive power and the strength of relationships. Our model outputs will be tested for uncertainty using reference data measured in OBJ 2.

TASK 3.4: DEVELOP WEB-BASED INTERACTIVE COMPUTER TOOLS TO EXPLORE THE RESPONSE OF WETLAND HYDROLOGICAL CONNECTIVITY TYPE AND TRAVEL TIME TO DIFFERENT CLIMATIC SCENARIOS.

We will develop a web-based interactive tool and provide online training workshops that will enable users to examine the effects of different scenarios of both climate change and wetland drainage/restoration on hydrological connectivity and ultimately the exacerbation or alleviation of carbon export to water resources.

LINK TO GOAL: By placing wetlands within the context of their hydrological landscapes, we will improve knowledge of the heterogeneity and variability of wetland OC accumulation rates and GHG fluxes, and of human modification of the hydrological landscape on wetlands as NbS.

LINK TO OTHER OBJECTIVES: The more complex mechanistic models generated in OBJ 3 will inform the simpler statistical models based on indicators in OBJ 4 that will enable exploration of synergies and conflicts between wetlands as NbS for carbon storage and other ecosystem service benefits.

METHODS FOR OBJ 4: DEVELOP ROBUST ESTIMATES OF THE SYNERGIES (AND CONFLICTS) OF WETLANDS AS NATURE-BASED SOLUTIONS FOR CARBON STORAGE VERSUS OTHER BENEFITS [0-TECH, 0-PDF, 2-PHD, 0-MSC].

TASK 4.1: COMPILE ECOSYSTEM SERVICE INDICATORS TO INFORM ASSESSMENT OF NON-CARBON ECOSYSTEM SERVICES IN WETLANDS.

We will compile indicators (e.g., Gleason et al. [2008]) of ecosystem services. In addition to the ecosystem service of carbon storage, we will focus on ecosystem services related to wetland hydrological regulation functions (e.g., flood and drought attenuation), water purification functions (e.g., nutrient retention or removal [Fisher and Acreman, 2004]); and biodiversity functions (e.g., habitat-supporting biodiversity). We will consult with wetland scientists on which indicators should be used and at which spatial scales (e.g., regional subwatersheds, ecoregions). Attention will be paid to incorporating agricultural uses (i.e., crop type) and climate as indicators (e.g., wetlands can mitigate floods or droughts, but hydrologic regulation can depend on crop type). The lists of indicators (including their rationales, limitations, and degrees of importance (i.e., weight)) will help inform development of indicator models.

TASK 4.2: DEVELOP A DESKTOP- AND INDICATOR-BASED TOOL FOR RAPID ASSESSMENT OF WETLAND ECOSYSTEM SERVICES RELATED TO HYDROLOGICAL REGULATION, WATER PURIFICATION, AND BIODIVERSITY ENHANCEMENT.

We will develop a desktop-based tool from indicator-based models for rapid assessment of wetland ecosystem services [e.g., GOA, 2011].

The Government of Alberta commissioned the development of an indicator-based model and desktop-based tool (i.e., Alberta Wetland Relative Value Evaluation Tool (ABWRET)) to implement their no-net-loss of wetland function policy [GOA, 2013]. We propose to adapt the ABWRET tool for application across all agricultural landscapes in Canada. We will divide the agricultural landscapes into homogeneous assessment units so that wetlands in similar landscapes can be assessed against each other to provide relative estimates of wetland function within that geographic region. For each homogenous assessment unit, we will develop a "CanWRET for agricultural landscapes" tool. This tool will be based on GIS and remote sensing data so that we can use it to assess wetland ecosystem services in all agricultural landscapes in Canada. Members of the team led the development of a GIS/remote sensing version of ABWRET and will bring this expertise and experience to this project [Creed et al., 2018; Accatino et al., 2018].

Policymakers and land managers can then use CanWRET to identify high (and low) functioning wetlands in terms of carbon storage and other ecosystem services at local and watershed scales.

TASK 4.3: IDENTIFY HIGHEST PRIORITY DATA GAPS FOR MEASURING INDICATORS AND FILL THEM.

We will use the CanWRET tool constructed in Task 4.2 and consult with project partners and other wetland scientists and managers to identify geographic regions that require additional data on wetland functions in terms of hydrological regulation, water purification, and biodiversity enhancements. We will then revise the tool. Leveraging data being collected for OBJ 2, we will collect data to reduce uncertainties in the indicator tool by filling in knowledge gaps where data is lacking and providing direct observations to estimate indicators.

TASK 4.4: IDENTIFY PRIORITY WETLANDS FOR PROTECTION OR RESTORATION TO INCREASE WETLANDS AS NBS FOR CARBON STORAGE AND OTHER ECOSYSTEM SERVICES.

We will use outputs from OBJ 1, 2, and 3 and the rapid assessment tool to identify the highest functioning wetlands in terms of carbon storage benefits. Synergies and conflicts among ecosystem services are common [Turkelboom et al., 2018] and features of a wetland may affect the relative contribution to carbon storage versus other ecosystems services [Hansson et al., 2005]. Therefore, we will also use the rapid assessment tool to estimate synergies and conflicts among the ecosystem services [e.g., Accatino et al., 2018; Hoffmann, 2020], and optimize wetland protection and restoration scenarios to maximize both carbon storage and other ecosystem services at watershed scales.

LINK TO GOAL: Estimates of synergies and conflicts between carbon storage and other ecosystem services (hydrological regulation, water purification, biodiversity enhancement) in wetlands in agricultural landscapes of Canada.

LINK TO OTHER OBJECTIVES: The CanWRET rapid assessment tool we generate in OBJ 4 will leverage carbon storage data from OBJ 1, 2, and 3. A key output from OBJ 4 will be identification of high priority wetlands for protection or restoration based on carbon storage (estimated from OBJ 1-3) and other ecosystem services (OBJ 4).
Identifying wetlands with synergies between carbon storage and other ecosystem services is necessary for directing policy and practice tools to incentivize use of those wetlands as NbS in agricultural landscapes (OBJ 5).

METHODS FOR OBJ 5: USE THE AUTHORITATIVE AND ROBUST ESTIMATES OF ORGANIC CARBON ACCUMULATION AND GREENHOUSE GAS FLUXES TO INFORM POLICY AND PRACTICE TOOLS TO INCENTIVIZE THE USE OF WETLANDS AS NATURE-BASED SOLUTIONS FOR MULTIPLE BENEFITS IN AGRICULTURAL LANDSCAPES [HQP: 1-TECH/ 0-PDF/ 4-PHD/ 0-MSC].

TASK 5.1: ESTABLISH AN OPEN SCIENCE CANADIAN WETLAND INFORMATION REPOSITORY TO SUPPORT SCIENTISTS AND DECISION MAKERS INTERESTED IN WETLANDS AS NBS.

We will form a Canadian Wetland INformation (CanWIN) repository with the aim of combining all past and current data, standards, protocols, methods (including from OBJ 1 to 4) in a single database and harmonizing the data and models according to CanWIN identified standards. The CanWIN repository will provide the opportunity for analyses of potential re-establishment of lost wetlands (potential sites) and their potential to contribute to Canada’s emission reduction targets in the form of NbS. CanWIN will be built in a stepwise fashion, starting with data, tools, and models from the core group of co-applicants on this proposal, which will also serve as a training opportunity for the working of the repository. Subsequently, CanWIN will be expanded to achieve national scope, and, ultimately, international scope, with partners across North America and Europe.

TASK 5.2: INTEGRATE WETLANDS AND THEIR ROLE IN OC ACCUMULATION AND GHG REDUCTION INTO THE NATIONAL GHG INVENTORY.

We will develop a statistical model to incorporate wetlands into the national GHG inventory. This statistical model will be developed using a similar approach to the national CO_2, CH_4, and N_2O methodologies [Rochette et al. 2008; VandenBygaart et al., 2008; Liang et al., 2020]. Using the CanWIN repository, a meta-analysis will permit the formulation of a statistical model that incorporates environmental and ecological conditions in the estimation of an output [Rochette et al., 2018]. The statistical model will include climate parameters as well as spatial location (ecoregion or ecodistrict), information of the wetland properties (e.g., number, size, perimeter-to-area ratio, permanence, as established in OBJ 1), and the state of the wetland (natural or managed as established in OBJ 2). Subsequently, the statistical model will be restructured to fit within the data availability constraints of the national GHG inventory database [Liang et al., 2020] with the help of the wetland map established in OBJ 1. The Bayesian foundation of our statistical model will enable quantification of the degree of confidence on the derived estimates. In doing so, Canada will take the leadership role in assessing and accounting for the wetlands as NbS.

TASK 5.3: DEVELOP APPROACHES TO QUANTIFY AGRICULTURAL IMPACTS ON WETLAND CARBON STORAGE AND GHG EMISSIONS TO ENABLE FARMERS TO CALCULATE ESTIMATES AT THE FARM SCALE SO THAT THEY CAN MAKE LAND DECISIONS THAT ARE CONSISTENT AND QUANTIFIABLE AT THE NATIONAL SCALE.

We will use the NEW national GHG inventory approach that accounts for agricultural wetlands as a basis for a NEW Holos model to enable farmers to calculate GHG estimates at the farm scale.

The Holos model is an Agriculture and Agri-Food sponsored whole-farm model that uses internationally acknowledged methodologies to calculate GHG (CO_2, CH_4, and N_2O) emissions of individual farms [AAFC, 2020]. The Holos model is based on the national GHG inventory data and calculations of IPCC Tier 2 emission factors (i.e., countryspecific empirical calculations that estimate GHG emissions as a direct fraction from an input, e.g., the fraction of nitrogen fertilizer that is lost as nitrous oxide [Eggleston et al., 2006]). However, in the Holos model, the emission factors are not static (as in the inventory) but remain dynamic for the purpose of estimating emissions factors under different management sciences. The Holos model has an interface designed to be usable by farmers and policymakers, asking for input data that are available to farmers, or at least readily measurable, and providing output data that can be reported from farmers to provinces and from provinces to the national GHG inventory, thus accounting for the efforts farmers conduct on a national level. Users can select the farm management practices that best describe their operation and then adjust these practices (e.g., change livestock feed, reduce tillage, or include perennial forages in rotation) to see the effect on GHG emissions.

The Holos model has been expanded with a carbon-budget approach, which enables exploring changes in soil carbon in response to changes in agricultural management practice [Kröbel et al., 2016]. An important missing component in the Holos model is the effect of wetlands on whole-farm GHG emissions and carbon storage. With the new national GHG inventory, the Holos model will be updated to integrate wetlands. For each farm, we will use OBJ 1 to establish what wetlands are on the farm and to characterize their properties (e.g., size, perimeter-to-area ratio, permanence). From OBJ 2 and 3, we will determine the type of vegetation in the contributing catchment and, thereby, the carbon input to the wetland. Alternative management practices will be considered that alter the type of vegetation (e.g., changes in vegetation surrounding and growing within the wetland) and, in turn, the farm's soil carbon stocks and GHG emissions. The Holos model interface will be updated to include wetlands, with farmer input to ensure its usability, and with default data for different regions and farms. This will permit policy makers to evaluate the effect of different policy scenarios. Model training will be provided to project participants and Holos model users throughout the project; this will garner input on model development to ensure its subsequent usability for all involved parties and provide input into the ongoing development of the national GHG inventory.

The Holos model will also allow wetlands and their carbon stocks to be incorporated into the United Nations Global Soil Partnership program and its recarbonization of soils initiative [FAO, 2021] to address multiple United Nations Sustainable Development Goals.

TASK 5.4: SUPPORT OTHER NATIONAL INITIATIVES FOR NATURE CLIMATE SOLUTIONS.

The outputs from Tasks 5.1-5.3 will support the goal of the federal government's new NSCS Fund to develop carbon-smart ecosystems. For example, they will: (1) provide the data required to better understand the rate of wetland conversion to other land use (e.g., agriculture) and the potential for wetland restoration; (2) allow for the identification and prioritization of priority wetlands for carbon reduction (e.g., wetlands located where soil conditions are optimal to maximize CO_2 sequestration and minimize CH_4 emissions); and (3) enhance the capacity of farmers to account for GHG emissions and reductions from wetlands at the project- and national-levels, thereby enhancing the capacity of farmers across Canada to implement carbon mitigation projects that qualify for programs such as the NSCS Fund or future opportunities associated with voluntary or regulated carbon offset markets. We will use the data generated by OBJ 1 to conduct a prototypical socio-economic analysis of the trends in land use changes and the drivers behind wetland degradation and destruction. Such information is instrumental in supporting the design and implementation of the NSCS Fund, for instance, by generating the data required to develop counterfactual baselines and projections to assess the impacts of the NSCS Fund on reducing GHG emissions.

TASK 5.5: INFORM CANADA'S PROPOSED NATIONAL INDEX ON AGRI-FOOD SUSTAINABILITY.

Our project will support other initiatives, such as Canada's proposed National Index on Agri-Food Sustainability, which is intended to benchmark Canada's performance as an agri-food provider in a world seeking to ensure that the way food is produced is sustainable. With an authoritative approach for calculating wetland OC accumulation and GHG emissions that will be integrated into the national GHG inventory approach and the Holos model, industry organizations will have a basis to establish their benchmarks for carbon storage/GHG reduction which is an integral part of the National Index on Agri-Food Sustainability. By being able to employ government sanctioned calculation approaches, the industry will be able to publish defendable metrics and benchmarks that are internationally recognized.

LINK TO GOAL: Use the CanWIN repository to integrate wetlands as NbS into the national GHG inventory as well as the Holos land management tool that will help guide GHG reductions based on the inventory information.

ANTICIPATED CONTRIBUTIONS TO THE FUND'S OBJECTIVES:

We firmly believe that our proposed project, "Wetlands as nature-based climate solutions: Quantifying carbon capture potential while building a stronger green economy", will be an important contribution to Canada's efforts to build a sustainable net-zero emissions economy by 2050. Our project, which is being proposed under Theme 1 ("Informing carbon sink enhancements: nature-based climate solutions"), will advance the quantification of, and reduce uncertainties in, our understanding of the current state and future potential of wetland carbon sinks on Canada's agricultural landscapes. The standardized protocols, measurements, and models gathered over the course of our project will inform and improve the reliability and consistency of Canada's reporting efforts related to wetlands as NbS. They will also inform opportunities to implement conservation, restoration, and management of wetlands as NbS to achieve net-zero GHG emissions in Canada. Further, our project will train tomorrow's scientists and practitioners, who will be instrumental in implementing wetland conservation and restoration, contributing to the creation of middle-class jobs for Canadians who work in science and technology, academia, and other related conservation organizations. Lastly, our work will support the development of offset protocols which will help improve the sustainability of the Canadian agriculture sector while contributing to economic incentives for agricultural producers.

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Project team experience

The project team includes nationally and internationally recognized scientists whose careers span a range of stages—twelve scientists in the early stages of careers and ten in the advanced stages, including two former (Irena Creed, David Lobb), three current (Jay Famiglietti, Lawrence Flanagan, Matthew Bogard) and one nominated (Ali Ameli) research chairs (see Attachment 1 for team members' biographies and their roles and responsibilities in the project and Attachments 4 and 5 for their CVs).

The project team has extensive experience in studying wetlands from science, policy, and management perspectives. They comprise a diverse group of researchers with expertise in hydrological, biogeochemical, ecological, agricultural, and soil sciences, geographic information system (GIS), remote sensing, modelling, and wetland assessment techniques, and socioeconomic and policy analysis to determine drivers of wetland change (see Attachment 1). Many team members have diverse skills in field-based and laboratory-based methods, GIS science, remote sensing methods, and modelling tools/techniques.

Our team which includes researchers from across the country; they have extensive experience communicating science to government, industry, non-government organizations, and the general public for the purposes of informing and promoting policy decisions and on-the-ground conservation programs.

In addition to the core activities, the project team will be clustered around five objectives:

CLUSTER FOR OBJ 1 (Creed, Li, Lobb, VandenBygaart):

This cluster will create a wetland coverage database – including wetland gain (and loss) estimates over the past 30+ years – for all agricultural landscapes in Canada (Creed, Li, Lobb, VandenBygaart).

CLUSTER FOR OBJ 2 (Badiou, Bogard, Bortolotti, Chmura, Flanagan, Knox, Lobb, VandenBygaart, von Sperber):

This cluster will measure the exchange of GHG fluxes (CO2, CH4, and N2O) between the atmosphere and the ecosystem, in wetlands in BC (Knox), AB (Bogard, Flanagan), MB (Badiou, Bortolotti), ON (von Sperber), QC (Chmura) and the Maritimes (Chmura). They will install chambers and eddy covariance tower in a wetlands and identify environmental drivers of GHG fluxes to inform models and management strategies for increasing wetland carbon storage and reducing GHG emissions. They will also collect cores to quantify carbon stocks and OC accumulation at a subset of the sites (Lobb, VandenBygaart).

CLUSTER FOR OBJ 3 (Creed, Ameli, Arhonditsis, Li, Lobb, Soolanayakanahally, VandenBygaart, von Sperber):

This cluster will bring their expertise in developing models of wetland carbon cycling (Arhonditsis, Lobb, Soolanayakanahally, VandenBygaart, von Sperber), erosion and runoff mediated carbon transport into and from wetlands (Li, Lobb, VandenBygaart, von Sperber), and hydrological processes affect carbon transport among wetlands and between wetlands and other water bodies (Creed, Ameli).

CLUSTER FOR OBJ 4 (Creed, Badiou, Bortolotti, Lobb, Paterson, VandenBygaart, von Sperber):

This cluster will bring their expertise in (1) measuring hydrological regulation, water purification and biodiversity benefits (Badiou, Bortolotti, Lobb, Paterson, VandenBygaart, Von Sperber); and (2) modelling ecosystem services to enable exploration of synergies and conflicts among them (Creed, Paterson).

CLUSTER FOR OBJ 5 (Creed, Badiou, Akhter, Famiglietti, Kröbel, Li, Lobb, Lorente, MacDonald, Peterson St. Laurent, Webb):

This cluster will bring their expertise in (1) developing data, tools, models for science and policy support related to incorporating wetlands into the national GHG inventory (Creed, Badiou, Famiglietti, Lobb, Lorente, MacDonald), (2) enabling farmers to explore agricultural impacts on wetland loss (or gain) and its impacts on the design of carbon smart landscapes (Creed, Badiou, Famiglietti, Kröbel, Lobb), and (3) designing beneficial management practices for managing wetlands to maximize their role as nature-based climate solutions (Akhter, Li, Soolanayakanahally). This cluster will also bring their expertise in conducting socio-economic analysis of the trends in land-use changes and the drivers behind wetland degradation and destruction, which will be used to support the design and implementation of the NSCS Fund (Peterson St. Laurent) and in the design of the proposed National Agri-Food Sustainability Index and explore ways that the project results can be included in this index (Webb).

Some members of the project team have a track record working with national GHG inventory scientists. Many members of the project team have established connections or collaborations with government agencies, farmers' associations, industry, industry organizations, not-for-profit organizations, and Indigenous communities, in addition to their connections and collaborations with other scientists from around the world.

The project team's expertise and experiences are essential not only to identifying GHG emissions from and the carbon capture potential of wetlands in Canadian agricultural landscapes but also to promote their use as nature-based climate solutions to governments, industries, and the public as a policy tool to help Canada meet its carbon reduction obligations.
Project delivery experience

Project delivery experience

Financial capacity

The project's (and the lead investigator's) institutional home, the University of Toronto, is highly supportive of this proposal and has provided substantial resources for its development and, if successful, to its implementation.

The University of Toronto is one of the largest universities in North America, with 95,000 students across three campuses and over $8.1 billion in net assets, including endowments, investments, and capital infrastructure. It is in a sound financial situation with consistent revenue growth over the past five years, including 2020, and net income gains each year. In 2020, U of T's researchers were awarded more than 16% of all federal tri-agency funding in Canada (NSERC, SSHRC and CIHR), funds that are managed through the portfolio of the Vice-President, Research and Innovation and Strategic Initiative (VPRI). The VPRI ensures that U of T fulfills its ethical, legal, and financial reporting obligations associated with research. It manages research risk for the University so that researchers and students can conduct research in a safe environment. As part of managing this risk, the VPRI also manages matters related to research ethics and environmental health and safety. With the assistance of faculty members, staff, and community volunteers, all the VPRI units work together to manage sponsor and regulatory requirements that accompany academic research. In 2020, the VPRI helped manage $525 M in awarded research funds from 1,600 funding programs to 2,700 principal investigators. As part of its oversight role, it created 8,400 financial and other related reports.

The project's co-lead investigator's home, Ducks Unlimited Canada (DUC), is also highly supportive of this proposal. DUC is the leading non-profit in wetland conservation, restoration, and management in Canada. Over the past 80 years, DUC has completed more than 11,890 projects and conserved, restored, and positively influenced more than 163.5 million acres of habitat. To accomplish these projects, DUC has partnered and collaborated with government, industry, non-profit organizations, and landowners across Canada. These projects have generated extensive science-based knowledge that has resulted in over 725 publications. Further, DUC's extensive network of connections and relations with experts, practitioners, and policy makers allows them to work closely with governments, industries, and landowners to quickly inform and implement on-theground conservation. DUC also strives to communicate the latest information on wetland and waterfowl biology and conservation to broaden support for wetland conservation and restoration through its national education program and communications department and via several platforms, including social media, the "Conservator" magazine, webinars, and scientific conferences. Given their unparalleled expertise in wetland ecosystems across the country, partnering with DUC is key to both improving and implementing our scientific understanding of wetlands as nature-based climate solutions and effectively communicating this science to a broad range of stakeholders.

The significance of the proposed objectives for the partner institutions, organizations, and government agencies united here is demonstrated by their financial commitments to this project. The team has secured $4.84 million in additional cash and in-kind contributions (45% of the total research costs: $1.99 million cash and $2.85 million in-kind) to ensure the financial viability of the proposed program in the short term and to ensure sustainable knowledge mobilization in the long term. Further, in partnering with DUC, we will be able to take advantage of and leverage additional resources through their national education program and communications department. As co-lead for the project, Dr. Badiou will be able to seek additional financial resources for the project via DUC's fundraising and development departments if required.

Project management capacity

A collaborative leadership model will be used in project design and implementation, jointly led by Irena Creed (University of Toronto) and Pascal Badiou (DUC), who will provide project oversight.

Creed has led many large cross-disciplinary collaborative research projects—including projects to provide scientific evidence to support policy decisions on watershed and wetland ecosystem services—of similar magnitudes involving multiple investigators and university, government, non-governmental, industry, and community stakeholders, including recently completed NSERC Strategic Partnership for Projects and Collaborative Research and Training Experience (CREATE) grants. Badiou has coordinated large national research initiatives requiring collaboration with investigators and stakeholders from various organizations focused on wetlands, carbon sequestration, and GHGs, and has been involved with carbon offset protocol development. As accomplished lead investigators who have worked productively together for the past ten years, Creed and Badiou have the experience needed for managing project governance, goals/objectives, and timelines, recruiting, training, and graduating successful highly qualified personnel, and managing budgets, committees, and communications throughout the life-cycle of projects. Both are internationally recognized wetland scientists who are strong advocates of the importance of wetlands to human and environmental health and of translating this into management, practice, and policy.

The six universities and the not-for-profit organization leading the Wetlands as Nature-Based Climate Solutions (Wetlands as NbS) project, including co-leads Creed and Badiou, have demonstrated knowledge and prior experience in the effective management of data generated through large, national, multi-site research collaborations, of staff and highly qualified personnel, and of governance. The project management plan, modelled on similar large scientific research networks such as RAEON (Real-time Aquatic Ecosystem Observation Network), is designed to achieve excellence in developing and operating the research program over time through robust data management, strategic staffing, and effective governance.

GOVERNANCE:

The Wetlands as NbS program will base its governance structure on those of successful networks in which we participate (see Attachment 2). In addition to the project team, the governance structure will include the following bodies: (1) an Executive Team, (2) an International Science Advisory Group, (3) a Partner Steering Group, and (4) a Data Management Committee.

1. EXECUTIVE TEAM

The core project team will be led by Creed and Badiou. Creed will provide oversight for the project's human and financial resources. Badiou will provide project oversight at the project team's regional research nodes (southern British Columbia, Prairies, southern Ontario and Quebec, Atlantic provinces), which are led by some of Canada's most well-respected wetland scientists with expertise in the quantification of carbon storage and GHG emissions.

Creed and Badiou will be responsible for ensuring that results are shared with relevant Canadian government agencies, industry groups, and not-for-profit conservation organizations. Creed and the University of Saskatchewan's Global Institute of Water Security (Famiglietti) and Global Institute of Food Security (Webb) will leverage their government and industry connections to ensure that the research outcomes achieve their impact potential. Badiou and DUC will work closely with DUC's partners within Canada and, via Ducks Unlimited, Inc. and Ducks Unlimited Mexico, across the continent to facilitate continental-scale policy development and implementation of wetlands as NbS. Creed and Badiou will be supported by a jointly appointed full-time project manager, supported by contributions from the lead institution, the University of Toronto, who will work with the co-leads to support project reporting, website design and maintenance, hiring, purchasing, meetings, logistics, and interactions with project advisors and partners.

2. INTERNATIONAL SCIENCE ADVISORY GROUP

The International Science Advisory Group is proposed to comprise science experts from Canada (Professor Tim Moore, McGill University), the USGS (Dr. Sheel Bansal), the USEPA (Drs. Amanda Nahlik and Scott Leibowitz), Ducks Unlimited, Inc. (Dr. Ellen Herbert), and the Swedish University of Agricultural Sciences (Professor Kevin Bishop). The Group will facilitate collaboration and the sharing of infrastructure and data among researchers and end-users to maximize the impact of the network. In particular, the Group will guide, advise, and, where possible and desirable, integrate the planning of Canadian and international inventory and nature-based solution projects. The chair of the Group will be a non-voting science director, suggested to be Tim Moore in the first year and then elected at the AGM in subsequent years. Creed and Badiou will be ex officio members. The Group will meet at least once a year at the AGM.

3. PARTNER STEERING COMMITTEE

The Partner Steering Group will include representatives from industry, government, and not-for-profit conservation organizations. The Group will provide strategic guidance on the development of the project's network and data/information repository (CanWIN) and other user-focused tools, databases, and products. The chair of the Group will be a non-voting partner, suggested to be Pat Kehoe in the first year and then elected at the AGM in subsequent years. Creed and Badiou will be ex officio members. The Group will meet at least once a year at the AGM.

4. MANAGEMENT OF THE DATA, TOOLS, AND MODELS

The Data Management Committee will comprise Creed and Badiou, co-applicants from three of the partner organizations on a biannual rotating basis, technical computing consultants from the University of Toronto; and a representative from a federal government partner (AAFC or ECCC). The Committee will meet once a year at the AGM and on an ad hoc basis during the rest of the year as needed. Its objectives will be to ensure that the network remains in compliance with the data management plan and to help facilitate the use of these data within the research and management/policy community.

Secure Data Storage: Ensuring the proper storage of the large volumes and varied types of data, protocols, and models generated by this program—held in the purposely designed CanWIN repository—is a priority for the Committee. Experience has shown that multiple locally and geographically distributed copies of digital files are required to keep information safe. A master copy of each digital file will be held in the CanWIN repository, and researchers will be expected to make duplicate copies upon collection. Data security will require data archiving at multiple locations—the lead applicant's institution and other (to be determined) secure servers—and data sharing agreements to ensure compliance with the data management plan.

Secure Data Access: Repository users will need to be able to easily find past and current raw data to expand the scope of their own investigations and to suggest new scientific/policy pathways. Project team members will provide appropriate metadata information on these digital files in an Extensible Markup Language (XML) format that will be linked to the digital files stored in the CanWIN repository. Metadata ensures that the data can be recognized and found by other researchers and improves knowledge transfer and accessibility among the research team and with users and stakeholders. All CanWIN data, protocols, and models will be properly collected, cross-referenced, and shared on a user-friendly web-based platform.

The project will provide support to the TECHNICIANS who will ensure effective and efficient collection and analysis of data. The technicians will be based at the participating academic institutions and will have relevant skills and expertise in the deployment, operation, maintenance, and troubleshooting of the flux towers and other essential equipment. The technicians will have theoretical knowledge, practical experience, and problem-solving skills, which they will share with all members of the project team. This will result in a shortened learning curve for researchers, enhanced support for trouble-shooting instruments, ensuring equipment will be properly maintained and calibrated, and supporting the analysis, formatting, and storage of the data generated.

We will hold regular online meetings (3x per year) and an annual face-to-face general meeting (AGM) (COVID-19 permitting) will be open to all stakeholders and provide the opportunity to learn about the research as the objectives develop, to identify opportunities for collaboration and cross-fertilization between themes to support management needs. Core management business conducted at the AGM will include reports and discussions on operations, future plans, and budgetary issues. To further facilitate interactions among the research team and to increase the participation of HQP, all project personnel (scientific research team and collaborators) will meet at least one other time each year to meetings to review reports, proposals, and progress, to share information and data, and more importantly, to ensure that all team members are included (as needed) in papers/manuscripts. We will lead inclusive meetings by adopting strategies that include sharing the agenda two weeks in advance so that there is enough time to prepare, monitoring closely for interrupters and dominators, and alternating meeting facilitators among the project team. The inclusion of partner organizations in these annual meetings will be particularly important to review progress, share research information, and coordinate upcoming research activities.

Stakeholders

Advancing climate change science and technology - 2021/2022

Project theme

Please identify the theme for which you are applying. Descriptions of themes can be found in the Eligible Project section of the Applicant Guide.

Theme 1: Informing Carbon Sink Enhancements: Nature-Based Climate Solutions

#	Type	Organization name	Organization Type	Name	Email
1	Supporting Applicant	Ducks Unlimited Canada	Not-for-profit non-governmental organization	Pascal Badiou	p_badiou@ducks.ca
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6	Supporting Applicant	University of Manitoba	Universities and academic institution	David Lobb	david.lobb@umanitoba.ca
7	Supporting Applicant	University of Toronto Scarborough	Universities and academic institution	George Arhonditsis	george.arhonditsis@utoronto.ca

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20	Partner	Agriculture and AgriFood Canada	Government	Raju Soolanayakanahally	raju.soolanayakanahally@agr.gc.ca

21	Partner	Agriculture and AgriFood Canada	Government	Bert VandenBygaart	bert.vandenbygaart@agr.gc.ca
22	Partner	Beef Cattle Research Council		Stacy Domolewski	domolewskis@beefresearch.ca
23	Partner	Canadian Forage and Grassland Association		Cedric MacLeod	cedric@canadianfga.ca
24	Partner	Canadian Roundtable for Sustaineble Beef		Monica Hadarits	hadaritsm@cattle.ca
25	Partner	Canadian Wetlands Roundtable		Pat Kehoe	p_kehoe@ducks.ca
26	Partner	Carry the Kettle Dakoda First Nation		Howard Adams	howardadams@live.ca
27	Partner	Ducks Unlimited Inc		Steve Adair	sadair@ducks.org
28	Partner	Farmers for Climate Solutions		Brent Preston	director@farmersforclimatesolutions.ca
29	Partner	Irving Oil		Ian Whitcomb and Sarah Irving	Julia.Atkinson@irvingoil.com
30	Partner	Nature Conservancy of Canada		MarieMichele Rousseau Clair	Samantha.Knight@natureconservancy.ca
31	Partner	Nature United		Ronnie Drever	cdrever@tnc.org
32	Partner	Nutrien		Michael Nemeth	michael.nemeth@nutrien.com
33	Partner	Environment and Climate Change Canada National Wetland Working Group	Government	Jacey Scott	Jacey.Scott@ec.gc.ca
34	Partner	Soil Conservation Council of Canada		Kier Miller	info@soilcc.ca
35	Partner	United States Department of the Interior US Geology Survey USGS		Sheel Bansal	sbansal@usgs.gov

36	Partner	Sveriges lantbruksuniversitet Swedish University of Agricultural Sciences		Kevin Bishop	Kevin.Bishop@slu.se
37	Partner	Ducks Unlimited Inc		Ellen Herbert	eherbert@ducks.org

Project "Elevator Pitch"

Freshwater mineral wetlands are integral features of Canada's agricultural landscapes. While there is general agreement about the potential of these systems to become a key component of a Canada's nature-based climate solution (NbS) strategy, there remain significant uncertainties about how to account for their contributions to this strategy.
These uncertainties stem from a lack of wetland coverage data and a lack of carbon stock and GHG data from these specific types of wetlands. These deficits must be resolved to accurately assess the contribution of wetland conservation and restoration to climate goals. The proposed partnership among universities, government agencies, industry, and not-for-profits will advance science and inform policy by measuring the potential of these wetlands to store carbon in agricultural landscapes. This will be achieved by developing authoritative estimates of wetland coverage, measuring wetlands' ability to store carbon and reduce GHG emissions, and by accounting for the potential synergies and/or conflicts that may arise when managing wetlands for carbon vs. other ecosystem services. This information will be used to establish the potential climate-change mitigating characteristics of wetlands and to support decision-makers with data, tools, and models to incentivize the use of wetlands as NbS. Without this project, the potential of agricultural wetlands to function as NbS while supporting a thriving agricultural sector will go unrealized.

Project management

The Wetlands as Nature-Based Climate Solutions project team has extensive experience working in multidisciplinary projects and has incorporated a multidisciplinary approach into the project design and its implementation (see Attachment 1).

Lead applicant Creed has experience leading numerous multidisciplinary research projects, including the Network of Centres of Excellence on Sustainable Forest Management, a NSERC Strategic Network Grant, an NSERC Strategic Partnership Grant, and multiple NSERC Collaborative Research and Training Experience (CREATE) Grants. She has also led federal and provincial contracts to provide evidence to support policy decisions on wetland and watershed ecosystem services. As an internationally recognized scholar, she has a reputation for creatively integrating physical and social science disciplines in collaborative projects for the purposes of advancing scientific understanding of the effects of regional, national, and global environmental changes on the environment and human health and wellbeing. Co-Lead applicant Badiou has similar experience. For example, he played a leadership role in the Agriculture and Wetlands Greenhous Gas Initiative, where he worked with a team of more than 20 natural and social scientists as well as individuals from the private and public sectors.

The project's goal of generating authoritative estimates of the potential of freshwater mineral wetlands as nature-based climate solutions requires a "systems thinking" approach such as that proposed—one that works across disciplines, techniques, and sectors. The project depends on expertise in a wide range of disciplines (e.g., hydrology, biogeochemistry, ecology, agricultural science, and soil science) and of techniques (field and laboratory research, GIS, remote sensing, modelling techniques, socio-economic analysis, and policy analysis). Creed and Badiou have assembled a team in which each member not only has impressive records of individual achievement in multiple disciplines and techniques but, as importantly, extensive experience working on multidisciplinary projects. The team includes members across a broad range of geography, from agricultural landscapes extending from British Columbia to the Maritimes. The project further includes members who specialize in assessing how to best integrate wetlands as nature-based climate solutions within agricultural landscapes. For example, Ducks Unlimited Canada is uniquely positioned to inform wetland conservation and restoration practices here in Canada as well as internationally via their engagement in continental conservation planning in conjunction with its sister organizations in the US (Ducks Unlimited Inc.) and Mexico (Ducks Unlimited de México).

Project Risks

Area	Risk	Mitigation Strategies
PROJECT MANAGEMENT	Inconsistent communication.	Central coordination ensured by a project management expert; calendar of meetings established in the first quarter of the project; shared document of resources and contact information; tracking of progress to achieve milestones; replacing departing members with new expertise drawn from extensive contacts of members.
ACCESS TO RESEARCH SITES	Failure to secure data collection at sites due to failed negotiations with private landowners, COVID-19	Frequent outreach and engagement to explain progress and potential findings to recruit new candidate sites as

	restrictions, or environmental phenomena.	necessary; planning field sampling over multiple years to minimize risk of unforeseen events.
DATA SECURITY	Proprietary datasets subject to risk of espionage, interference, or theft.	Online data portals and CanWIN repository hosted on secure servers; data sharing agreements established; data sharing protocols designed and distributed; members and personnel required to abide by terms of these agreements when sharing data and in publication or presentation of results.
INSUFFICIENT ADOPTION OF STRATEGIES INFORMED BY FINDINGS	Lack of conservation/restoration acceptance from farmers on whose properties most small or degraded wetlands are found.	Share findings with farmers through provincial and national associations; promote nature-based climate solutions

Environmental Risks

The environmental risks of the project are ex ante minimal and will be effectively managed using established safety and security protocols for minimizing the likelihood or impact of any risks. Monitoring and measuring activities at the wetland sites are expected to constitute the only possible environmental risks of the project; these activities will be designed to negate or mitigate any risks. Potential disturbances to wildlife will be mitigated by judicious and informed timing of measurement events. Potential disturbances to ecosystems will be mitigated by keeping infrastructure footprints to a minimum. For GHG measurements, the scaffolding for the eddy covariance instrumentation and the supporting micrometeorological instrumentation will be powered with a solar/battery power system. For soil, water, and gas measurements, destructive sampling will be kept to a necessary minimum and the amounts of material removed would not be expected to cause any environmental damage. Potential risks of infecting the surrounding cropland with disease will be mitigated using established bio-security protocols such as those established for decontaminating boots and waders by Canadian Wildlife Health Cooperative).

COVID-19 Risks

The team will adhere and adjust to any restrictions imposed by federal or provincial authorities in response to the COVID-19 pandemic.

RESTRICTIONS ON FACE-TO-FACE MEETINGS:

Regular meetings within and among members will be remote to facilitate accessibility and cost effectiveness. If necessary, the annual in-person general meeting will be replaced with an online event, hosted on one of the University of Toronto's meeting platforms.

RESTRICTIONS ON ACCESS TO FIELD SAMPLING SITES OR LABORATORY/COMPUTER WORKPLACES:

Members will assume responsibility for field sampling and laboratory analysis within their regions; to mitigate the risk of delays, they will incorporate archived data into collections and will repeat sampling over the multi-year project period so that a disruption to access will not limit the collection of a successful dataset. Team members and HQP will be equipped with computers that will allow GIS, remote sensing, and modelling activities to be continued uninterrupted in the event of disruption of facility access.

DEMANDS ON PERSONNEL AND/OR CAREGIVING ACTIVITIES:

Team members and HQP will be invited to respond to anonymized surveys about the effects of COVID-19 on their living-working-studying situations and will be made aware of resources available to address their needs. Team members will request individual workplans from their HQP, including assessments of COVID-related delays or interruptions and provisions of alternative arrangements.

Value

Value for Money

By identifying the return-on-investment in carbon storage and GHG reductions in agricultural wetlands across Canada, this project will improve the accuracy of the national GHG inventory's estimates and the efficiency of Canada's investment in nature-based climate solutions, which includes $631 million through the Nature Smart Climate Solutions Fund. Data, tools, and models will provide authoritative estimates in a timely and cost-effective manner. Integration of wetlands into the Holos model will enable users to efficiently account for GHG emissions at the local scale and will provide timely and cost-effective updates to the national GHG inventory. The project will take advantage of Canada's leading expertise in all aspects of wetland science. The project will incorporate geographic expertise from British Columbia to Nova Scotia and will generate usable data, tools, and models applicable to wetlands across the agricultural landscapes of the country. The project will train HQP from the same geographic breadth, including those working in academic institutions, government agencies, industry organizations, and local communities. By encouraging policymakers and practitioners to evolve wetland management, the project will drive an increase in the competitiveness and profitability of the agricultural sector, helping

Canadian agricultural producers be on the leading edge of sustainability transitions, which will, in turn, boost consumer confidence and market access.

Training and Development

If applicable, describe how your proposal plans to train highly qualified personnel (HQP) and/or enhance Canadian expert scientific capacity. Your response may be up to 1500 characters (including spaces) in length.

The project will use cutting-edge research, employing new techniques and technologies to advance science and to mobilize this science into policy and practice in areas related to nature-based climate solutions. In this process, the project will integrate and amplify existing expert scientific capacity across academic institutions, government agencies, industry organizations, and not-for-profits. At the same time, the project will increase that capacity by training a new generation of HQP. The project team will train a minimum of 6 Masters, 14 PhDs, 6 postdoctoral researchers, and 10 technicians with skills that are essential to Canada's commitment to reducing the impact of climate change.

They will engage with our First Nations community partner to learn how they interact with wetlands in their territories, and to provide training in wetland science and management skills they can use to support their communities. The exceptional training environment for our HQP includes opportunities to work directly with the network of project team members and their facilities, international advisors, government scientists, and industry practitioners. These training experiences will make the HQP excellent candidates for positions in academia, government, and industry. By creating a community of practice, a growing talent pool, and exceptional resources, the project will expand the current Canadian ability to understand and use scientific data to act on nature-based climate solutions.

Federal, Provincial, Territorial and/or Municipal Involvement

If applicable, describe how your proposal leverages government expertise, resources, data, and/or science infrastructure. Your response may be up to 1500 characters (including spaces) in length.

The project team includes 36% (8/22) government researchers and will benefit from their expertise, data, and other resources. From the ECCC, three researchers include:

(1) a scientist and policy advisor responsible for production of national estimates of GHG emissions from agriculture, forestry, and other land uses;
(2) a scientist who will assure the integration of nature-based climate solution science into the GHG inventory objectives and methodologies; and
(3) a scientist and policy advisor who will develop land use baselines and projections to enable the calculation of GHG flux rates on land affected by the federal government's new Nature Smart Climate Solutions program.

From AAFC, five researchers include:
(a) scientists who will contribute knowledge on wetland carbon cycling, influence of erosion and runoff transport process on wetland carbon functions, and best management practices to simultaneously optimize wetland carbon storage and adjacent agricultural land productivity; and
(b) the developer of the Holos model (a wholefarm modelling platform used to estimate farm-scale carbon storage and GHG flux rates) who will integrate wetlands into the Holos model. Federal, provincial, and municipal governments will be approached to gain insights into perceived or real barriers to the adoption of nature-based climate solution policies around agricultural wetlands and to learn how these barriers can be overcome.

Communication and knowledge mobilization

Which audiences does your project intend to reach?

A key outcome will be a wetland information network and repository that will provide easy and no-cost access to data, tools, and models to:

(1) GOVERNMENT EMPLOYEES: Federal government agencies responsible for establishing national climate targets (policy advisors) and generating the data and information needed to provide evidence that those targets are met (scientists), and counterparts at provincial agencies—these have an urgent need for authoritative data, models, and tools to design efficient strategies that will shape Canada's response to climate change and its international obligations.

(2) WETLAND AND WATERSHED MANAGERS: Provincial managers, conservation authorities, and other conservation bodies responsible for making decisions regarding wetland restoration and management—these will benefit strongly from identification of where their conservation and restoration resources will most efficiently be allocated.

(3) NOT-FOR-PROFIT CONSERVATION ORGANIZATIONS: Not-for-profit that play a role in wetland conservation and restoration, including the co-lead organization of the proposed project, DUC, one of Canada's largest not-for-profit conservation organizations.

(4) LANDOWNERS: Agricultural landowners, including farmers and industry groups, who will be able to use project results to improve management and to apply to carbon markets for financing.

(5) SCIENCE COMMUNITY: Scientists seeking to improve understanding of climate feedbacks associated with wetlands.

(6) GENERAL PUBLIC: Members of the general public interested in learning about nature-based climate solutions as a precursor to embracing policies based on the project findings. The repository will be designed to expand to include institutions in Canada and internationally to ensure that science gained

during the project benefits and will continue to benefit from data and ideas from science and management peers, and to put a spotlight on Canada's climate action plans.

What will be communicated both during the project and once it has been completed?

The goal of the project's knowledge mobilization activities will be to share information regarding the role of wetlands as a nature-based climate solution (NbS) for Canadian decision making. We will communicate

(1) scientific evidence;
(2) the availability and usefulness of decision-support data, tools, and models developed by the project; and
(3) the broader importance of wetlands in addressing climate change.

(1) During and after the project, we will share the scientific evidence developed through our research objectives, including:

- The first-of-its-kind standardized wetland coverage database for agricultural landscapes in Canada;
- Authoritative estimates of wetland carbon storage, GHG fluxes, and carbon transport into and from agricultural wetlands;
- Mechanistic and statistical models;
- The CanWIN repository, through which our data, protocols, models, and tools will be accessible in a public-facing portal.

(2) The science will be mobilized through decision-support data, tools, and models to inform the conservation, restoration, and management of wetlands. These will include:

- CanWRET: a rapid-assessment tool for policymakers and land managers to target wetlands for protection/restoration based on maximizing carbon storage and other ecosystem service benefits;
- An updated version of the Holos model that will enable farmers and industries to examine the effects of farm management practices on wetland carbon storage and GHG fluxes;
- Improvements to the National Index on Agri-Food Sustainability and similar tools used by academia, government, industry, and civic society to make decisions about the agricultural sector.

(3) More broadly, our scientific network and partners will communicate the importance of wetlands as NbS to a broad audience:

- Workshops on the CanWIN data, tools, and models;
- Youth outreach activities led by partner organization DUC;
- Building and expanding CanWIN to reach and benefit from data and knowledge acro

If applicable how do you plan on leveraging or creating knowledge mobilization infrastructure/relationships (e.g., networks, working groups, expert workshops, targeted briefings, seminars, or conferences) to communicate results?

This project's goal requires leveraging existing and creating new knowledge mobilization pathways.

EXISTING KNOWLEDGE MOBILIZATION PATHWAYS:

Our project will draw on the wide breadth of skills and expertise and the connections with our public and private partners, and connections with our not-for-profit and a First Nations community partner. In collaboration with our federal government partners at AAFC and ECCC, we will improve existing decision supports by developing wetland data, models, and protocols that will integrate seamlessly into federal initiatives. These initiatives include the national GHG inventory, the Holos model, the Nature Smart Climate Solutions Fund and the proposed National Agri-Food Sustainability Index. Members of our partner organizations will sit on the science advisory group and the partner steering group, to provide guidance to ensure the scientific data is shared in the most effective and useful ways for these many different stakeholders, and to communicate our science both nationally and internationally.

NEW KNOWLEDGE MOBILIZATION REPOSITORY AND NETWORK:

This project was inspired by the desire to create a national network of wetland researchers, one that would create a community of practice to better integrate wetland data into the national GHG inventory and beyond. We will develop a Canadian Wetland Information (CanWIN) repository, where our data, tools, and models will be shared through a public facing web portal and a series of workshops. In addition, we will develop a CanWIN network that will form a "community-of-practice" for wetlands as nature-based solutions.

Through the repository and network, the knowledge developed through our research will be transferred to and translated for end-users, particularly policy-makers and land managers. The more than 30 HQP trained through this program will further help develop pan-Canadian expertise in freshwater wetlands as nature-based climate solutions.

Equity, diversity, and inclusion

Team composition and recruitment processes.

Equity, diversity, and inclusion (EDI) are accelerators of excellence, leading to better, more impactful, and more innovative research. The project team includes members with expertise in EDI in science,

including lead applicant Creed. The project's commitment to EDI principles started with a deliberate approach to the composition of the team, which is purpose-built to leverage existing and to build new expertise, recruiting for diversity of perspectives and lived experiences across disciplines, genders, career stages, and career sectors. This will continue by recruiting researchers from diverse backgrounds, especially underrepresented groups in the natural sciences and engineering, and by working with end-users from small-scale to large-scale government and industry organizations. All members of the project team will complete the Canada Research Chairs'
Unconscious Bias training module and commit to informing themselves about inclusive and equitable training practices. All members of the project team will model behaviour that demonstrates the importance of the principles of EDI throughout the term of the project. The project co-leads commit to ensuring that all project team members are valued, respected for their contributions, and supported throughout the duration of the collaboration irrespective of any differences. They also commit to extending equitable communication and collaboration to all partners and communities with which they engage.

Training and development opportunities.

The project team will prioritize on advancing diversity and equity goals in our recruitment of HQP by seeking individuals who come from underrepresented or disadvantaged groups—positions will be advertised with invitations to apply to Indigenous people, women, racialized persons, LGBTQ2S+ persons, and those with disabilities, and advertisements will be shared with networks that support equity-deserving groups including the Canadian Black Scientists Network and Indigenous Graduate Student groups at partner institutions. Members will coordinate with EDI experts at human resources departments to create postings that avoid gendered, exclusionary, or biased language. HQP will be encouraged to pursue EDI training tailored to their positions and needs through resources available at participating institutions. The project team commits to providing an inclusive space for all HQP and will accommodate individual needs as much as possible (e.g., allowing flexible schedules). Training and development opportunities will be designed to ensure equitable access to mentors, resources, supports, and communication opportunities (e.g., networking forums, conferences, publications). A team EDI lead will be appointed to report on progress towards identifying and meeting EDI performance indicators and to advertise to HQP their availability for reporting or discussing concerns. Quarterly meetings will discuss reported or potential workplace concerns and develop plans to address them.

Inclusion.

The project team commits to ensuring inclusive participation in the project at all stages and in all practices. The project co-leads are committed to ensuring that all members share strong beliefs in building a research culture where all differences of culture, identity, and beliefs are valued and respected. The project team will adopt a code of conduct that will include guidelines on inclusion, cultural sensitivity, community engagement, and accountability, based on one of several such documents recently developed by professional societies (e.g., Canadian Society for Ecology and Evolution). Project events and meetings will be informed by accessibility and inclusion principles, drawing on the Council of Ontario Universities’ Planning Guide and other similar documents. Inclusion will be considered in invitations to speak at events, workshops, seminars, and other presentations. The project team is sensitive to how our research questions and findings will apply to the needs and experiences of underrepresented groups and will pay attention to these needs and experiences in the project’s socioeconomic analyses. The project team will pay special attention to engaging with Indigenous communities to invite perspectives, seek advice, discover collaboration opportunities, and communicate findings through workshops and meetings and with a view to benefiting Indigenous access to funding opportunities. Written findings will be translated into French.

Project work plan:

Objective	Task	Activity	Methods	Node	Outcome	Outputs	Start Date	End Date
Core	Activity 1	Project management, financial management, and quarterly reporting to the funder.	Project team will hold quarterly science meetings (online) and one annual meeting face-to-face. Project team leadership will also hold one annual face-to-face meeting with our international science advisory group and a partner steering committee.	UToronto	Project performance tracked throughout the funding period.	Meetings	April 1, 2022	March 31, 2027
Project Core	Activity 2	Decision making in the face of uncertainty.	Develop authoritative measurements that include estimates of uncertainty based on Core standardized protocols for all data that become part of the Canadian Wetland Information Network (CanWIN) data repository.	UToronto	Policy analysts and practitioners can incorporate uncertainty into their decision making.	Calculator to estimate uncertainty for measurements in the CanWIN data repository.	April 1, 2022	March 31, 2024
OBJ 1	Task 1.1.	Compile database of wetland coverage across the agricultural landscapes of Canada.	Meet with Canadian wetland mapping producers and users; compile available wetland inventories; establish common criteria of uncertainty in wetland maps (i.e., minimum mapping size, minimum data inputs, minimum wetland classes or types, methodological rigour, relevant time periods, spatial extents); quantify uncertainty using common (i.e., Task 1.1 standard) criteria and reference data (i.e., estimate spatial accuracies using reference points identified from reference data and confusion matrices).	UToronto	Identification of available wetland inventories and documents on wetland inventory methods, accuracies, and limitations.	Wetland coverage database that will be used to inform, calibrate, and produce uncertainty estimates of the standardized wetland inventory.	April 1, 2022	September 30, 2022
OBJ 2	Task 2.1	Compile published	Compile and summarize published information on	DUC, UBC, ULethbrid	Improved understanding of	Standardized database of wetland carbon accumulation	April 1, 2022	March 31, 2023

		information on process controls influencing wetland carbon stabilization and published estimates for all components of wetland carbon budgets fluxes to (and from) wetlands, reconciling differences in estimates due to different techniques/ tools.	process controls influencing wetland carbon stabilization, and compile published data on estimates for all major components of wetland carbon budgets. Reconcile differences in estimates associated with different sampling techniques, assign error values (uncertainty ranges), and estimate the minimum corrections needed to standardize the data at a national scale.	ge, UManitoba, UToronto, McGillU	local and regional process controls on wetland carbon accumulation and GHG fluxes.	and GHG flux measurements in Canada; reports on methods used to standardize measured values.		
OBJ 2	Task 2.2	Develop standards and protocols to measure wetland OC accumulation, GHG fluxes.	Review and make recommendations for standards for OC accumulation and GHG flux rate determination. Draw upon expertise within our team as well as international expertise.	DUC, UBC, ULethbridge, UManitoba, UToronto, McGillU	Establishment of protocols for measuring and reporting standards for wetland OC accumulation and GHG flux rates	Develop a standard set of practices and protocols for measuring OC accumulation, OC stabilization, and GHG fluxes from wetlands and their riparian zones in agricultural landscapes of Canada.	April 1, 2022	March 31, 2023
OBJ 2	Task 2.3	Measure wetland OC accumulation and GHG flux rates.	Create a pan-Canadian network of wetland measurement sites, creating new (n=100) and building on existing (>200) wetland measurement sites, where GHG fluxes and OC accumulation and stabilization rates will be measured. Add four wetland Eddy Covariance (EC) flux tower sites to the existing three flux towers sites	DUC, UBC, ULethbridge, UManitoba, UToronto, McGillU	Establishment of pan-Canadian wetland freshwater wetland network for determining OC accumulation and GHG flux rates for agricultural landscapes.	Standardized database of wetland OC accumulation and GHG flux rates for all agricultural landscapes.	April 1, 2022	October 15, 2026

			operated and maintained by members of our team to measure Net Ecosystem Exchange (NEE; measured as carbon dioxide (CO_2) and methane (CH_4)) fluxes above the study wetlands. Measure key environmental drivers of GHG fluxes and OC accumulation/stabilization, including AAFC Annual Crop Inventory and the Soils Landscapes of Canada database, to compile information on the types of crops and soils that are within the contributing areas of the measurement wetlands and the water's physical and chemical parameters.					
OBJ 3	Task 3.1	Develop mechanistic models of carbon cycling.	Develop a model of wetland carbon cycling to elucidate the mechanisms underlying wetland OC dynamics. We will apply correction factors based on empiric linear regression equations from previous literature to account for the presence of inorganic carbon in soils and to avoid an overestimation of the amount of OC in soils and sediments. These models will be calibrated using data compiled/collected from OBJ 1 and 2. We will use a recursive approach between modelling and data collection/field experimentation, whereby the data produced from the project will be used to calibrate and validate the mechanistic models, after which the derived characterization of wetland processes along with the	UToronto	Estimation of the potential role of wetlands in achieving national GHG reduction targets while having synergistic benefits for agriculture	An interactive measurement-modelling framework and a platform to run a series of “what-if?” scenarios representing alternative climate conditions and management schemes to project the potential role of wetlands as NbS.	April 1, 2022	March 31, 2024

			associated uncertainties can be used to dictate future data collection efforts or to identify compelling hypotheses that need to be tested in the field.					
OBJ 3	Task 3.2	Estimate the hydrological connectivity of wetlands to the watersheds in which they are embedded.	Develop a Canadian-scale map of groundwater table depth. Combine this map with maps of watershed drainage networks and wetland coverage within the watersheds (from OBJ 1) to estimate hydrological connectivity types (e.g., surface vs subsurface) and hydrological travel times of wetlands to their watershed drainage outlets in agricultural landscapes across Canada. Hydrological connectivity types will include: (1) riparian wetlands connected to streams with persistent or frequent surface connections with short travel times and fast hydrologic connectivity; (2) non-riparian wetlands with surface flowpaths to streams and moderate hydrologic connectivity; (3) non-riparian wetlands with subsurface flowpaths but poorly-drained upland soils that promote saturation excess overland flow and moderate hydrologic connectivity; and (4) non-riparian wetlands with dominant subsurface flowpaths, due to well-drained upland soils, and with slow hydrologic connectivity. Hydrological travel times will be estimated by distances between wetlands and the closest stream.	UBC, UToronto	Estimation of the hydrological flowpaths and travel times flowing into and from wetlands to watershed drainage outlets in agricultural landscapes of Canada.	Map of hydrologic connectivity type and travel time of wetlands to watershed drainage outlets.	April 1, 2022	March 31, 2024
OBJ 4	Task 4.1	Compile indicators	Review peer-reviewed and grey literature on wetland	UToronto, DUC	Identification of indicators of three	Full preliminary list of indicators (including their	April 1, 2022	March 31, 2023

		of wetland ecosystem services (hydrological regulation, water purification, biodiversity)	ecosystem services. Consult experts on ecosystem service indicator selection and scale of application.		non-carbon wetland ecosystem services (hydrological regulation, water purification, biodiversity) for use in the development of models for a rapid assessment tool.	rationales, limitations, and degrees of importance (i.e., weight)) and a final list of indicators (post-consultation with experts) for use in Task 4.2.		
OBJ 4	Task 4.2	Develop a desktop- and indicator-based tool for rapid assessment of wetland ecosystem services.	Generalize desktop- and indicator-based Alberta Wetland Relative Value Evaluation Tool (ABWRET) for application across all agricultural landscapes in Canada (CanWRET) using data from Task 4.1. Divide agricultural landscapes into homogeneous assessment units so that wetlands in similar landscapes can be assessed against each other to provide relative estimates of a wetland's ability to produce ecosystem services within that assessment unit. Apply the CanWRET tool to wetlands in these homogeneous assessment units.	UToronto, DUC	Assessment of synergies (or conflicts) of wetlands as NbS for carbon versus other ecosystem services.	A tool for rapid assessment of hydrological regulation, water purification, and biodiversity ecosystem services from wetlands in agricultural landscapes of Canada.	April 1, 2022	March 31, 2025
Project Core	Activity 3	Knowledge mobilization.	Transfer knowledge to other scientists both in Canada and internationally through the CanWIN data, Project protocols, and tools; through workshops with interested CanWIN users; through presentation at scientific workshops and conferences; through publication Core of peer-reviewed articles in scientific journals; and through presentation at scientific workshops and conferences.	UToronto	Transfer and translation of knowledge related to wetlands as a Nature-based climate Solution (NbS).	CanWIN repository of data, protocols, and tools; user workshops; scientific conferences and peer-reviewed journal articles. Knowledge integration into national GHG inventory, Holos model, Nature Smart Climate Solutions Fund, and National Index of Agri-Food Sustainability.	July 1, 2022	March 31, 2027

			Translate knowledge into policy and practice.					
OBJ 1	Task 1.2	Develop standardized estimates of landscape-scale rates of wetland coverage for agricultural landscapes of Canada over a time series from 1984 to present.	Download and calibrate satellite remote sensing data to develop a standardized "wall-to-wall" wetland coverage for Canadian agricultural landscapes across a time series from 1984-present. From this wetland coverage, derive estimates of wetland number, size, and other properties that may influence wetland organic carbon (OC) accumulation and GHG flux rates.	UToronto	Standardization of wetland coverage for agricultural landscapes of Canada.	Maps of wetland coverage (1984-present); reports on the uncertainties of these maps.	October 1, 2022	March 31, 2024
OBJ 1	Task 1.3	Develop standardized estimates of landscape-scale rates of wetland loss (and gain) associated with climate change and human modification of hydrological landscape (i.e., drainage ditches and tile drainage).	Generate estimates of wetland loss (and gain), both aspatial (using powerlaw function technique) and spatial (using time series analysis). Generate maps of human-caused wetland loss including in-field and roadside drainage ditches and tile drainage	UToronto	Standardization of wetland loss (and gain) for agricultural landscapes of Canada.	Maps of wetland loss due to climate change or human modification of agricultural landscape (drainage ditches, tile drainages); reports on the uncertainties of these maps.	April 1, 2023	March 31, 2025
Project Core	Activity 4	Educate and engage the next generation	We will engage youth, Indigenous leaders, wetland managers, and agricultural partners, leveraging DUC's long	DUC	Informed private, public, and civic society on wetlands as NbS.	Advisory circle to engage public and private partners; lectures, seminars, and	April 1, 2023	March 31, 2027

		of champions of wetlands as Nature-based climate Solutions (NbS).	history of working with their private and public partners and civic society.			webinars to engage civic society.		
OBJ 3	Task 3.3	Determine the influence of hydrological connectivity on the atmospheric vs. aquatic fate of carbon for wetlands in agricultural landscapes of Canada.	Model the relationship between hydrological connectivity of wetlands to downstream waters and carbon export, identifying indicators with predictive power and the strength of the relationships.	UBC, UToronto	Estimation of the influence of hydrological connectivity type and timing on wetland OC accumulation, GHG flux, and carbon export rates under different climate change scenarios and wetland drainage/restoration scenarios in agricultural landscapes.	National-scale model of hydrological connectivity type and timing of wetlands on agricultural landscapes.	April 1, 2023	March 31, 2025
OBJ 2	Task 2.4	Estimate lateral flows of carbon into (and out of) wetlands.	Build comprehensive net ecosystem carbon budgets (NECBs) for a subset of the pan-Canadian network of wetlands; existing models will be used to provide estimates of both the portion of carbon fixed by vegetation that remains on site and is buried over longer timescales (decades to millennia) and the fraction of carbon fixed by wetland vegetation but lost via lateral hydrologic export to downstream environments. Lateral export of carbon will be estimated indirectly as bulk carbon loss from the difference between EC- derived NEE and estimates of site-specific long term carbon burial rates. Where feasible, direct				April 1, 2023	October 15, 2026

			hydrologic measurements of discharge and dissolved carbon concentration will be paired to provide independent estimates of hydrologic carbon export from wetlands. By identifying the composition of carbon exported from wetlands (as either organic or inorganic, particulate versus dissolved), we will be able to provide context as to the long-term fate of carbon leaving wetlands.					
OBJ 4	Task 4.3	Identify highest priority data gaps for measuring indicators and fill them.	Evaluate CanWRET tool performance and consult with project partners and other scientists to identify priority assessment units (with priority given to wetland watershed monitoring sites) that require additional data for indicators of hydrological regulation, water purification, and biodiversity. Fill knowledge gaps in water quality with water samples of nutrient content at study wetlands. Fill knowledge gaps on biodiversity using acoustic recording units at study wetlands.	DUC	Enhanced and additional data to improve performance of the rapid assessment tool for estimation of wetland ecosystem services.	An improved tool for rapid assessment of hydrological regulation, water purification, and biodiversity ecosystem services from wetlands in agricultural landscapes of Canada	April 1, 2023	March 31, 2026
OBJ 5	Task 5.1	Establish an open science Canada Wetland Information Network (CanWIN) to support scientists and decision makers interested	We will form a Canadian Wetland Information Network (CanWIN) that aims to combine all past and current data, standards, protocols, methods (including from OBJ 1 to 4) in a single database and harmonize the data and models according to the CanWIN identified standards. The CanWIN database will provide the opportunity for analyses of potential re-establishment of lost wetlands and their potential to contribute to	UToronto	A community of practice for wetlands as NbS.	A centralized, standardized database of measurements and models in support of wetlands as NbS.	April 1, 2023	March 31, 2027

		in wetlands as NbS.	Canada's emission reduction targets in the form of NbS. CanWIN will be built in a stepwise fashion, starting with a core group of co-applicants on this proposal, which will also serve as a training opportunity for the working of the network. Subsequently, the network will be expanded to achieve national scope and, ultimately, international scope, with partners across North America and Europe.					
OBJ 5	Task 5.2	Integrate wetlands and their role in OC accumulatio n and GHG reduction into the national GHG inventory.	Develop a modelling framework to incorporate CanWIN wetlands into the national GHG inventory. This approach will be developed using a similar approach to the national CO2, CH4, and nitrous oxide methodologies; specifically, we will develop a statistical model that relates environmental and ecological conditions to the estimation of GHG flux rates, follwed by uncertainty analysis of the developed model.	UToronto /ECCC	Inclusion of agricultural wetlands in Canada's national GHG inventory.	A methodology to include agricultural wetland OC accumulation and GHG flux rates in the national GHG inventory.	April 1, 2024	March 31, 2027
OBJ 5	Task 5.3	Develop approaches to quantify agricultural impacts on wetland carbon storage and GHG emissions to enable farmers to calculate estimates at the farm scale so that they	We will use the new national GHG inventory approach as a basis for a new Holos model to enable farmers to calculate OC accumulation and GHG flux rate estimates at the farmscale. The Holos model interface will be updated to include wetlands, and the Holos model will include default data for different farm systems and agricultural landscapes, which will permit policy makers to evaluate the effect of policy implementation. Holos model training will be provided to project participants and	UToronto /AAFC	Empowerment of farmers to estimate the effects of their farm management practices on wetland OC accumulation and GHG flux rates.	A methodology to include the effects of farm management practices that alter wetland OC accumulation and GHG flux rates in the Holos model.	April 1, 2024	March 31, 2027

		can make land decisions that are consistent and quantifiable at the national scale.	potential users to ensure its subsequent usability for all involved parties and provide input into the ongoing development of the national GHG inventory.					
OBJ 4	Task 4.4	Identify priority wetlands for protection or restoration to increase wetlands as NbS for carbon storage and other ecosystem services.	Compare predicted carbon storage using data from OBJ 1-3 and predicted ecosystem services using revised rapid assessment tool from Task 4.3 to identify wetlands ranked in highest 5-10% for all ecosystem services.	UToronto, DUC	Increased understanding of the heterogeneity in and synergies (or conflicts) between ecosystem services provided by wetlands.	A list of priority wetlands for protection or restoration to provide NbS for both carbon storage and other ecosystem services.	April 1, 2024	March 31, 2027
OBJ 2	Task 2.5	Develop models to predict the potential of wetlands for OC sequestrati on and GHG reduction.	Develop simple process-informed models that can be used to determine the potential for wetlands as NbS for OC accumulation and GHG reduction at local (wetland/watershed) and national scales.	DUC, UBC, ULethbrid ge, UManitob a, UToronto, McGillU	Predictive understanding of the natural heterogeneity/variabi lity in OC sequestration/GHG reduction as well as how land management practices influence OC sequestration/GHG reduction within the wetlands and the surrounding agricultural land within watersheds.	Process informed models to predict environmental controls on wetland OC accumulation and GHG flux rates.	April 1, 2024	October 15, 2026
OBJ 3	Task 3.4	Develop web-based interactive	Develop web-based interactive computer application that will enable users to explore the	UBC	Knowledge transfer of the importance of hydrological	Webbased interactive computer applications to predict hydrological	April 1, 2024	March 31, 2027

		computer tools to explore the response of applications on wetland hydrological connectivity type and travel time response to different scenarios.	effects of different scenarios of both climate change and wetland drainage/restoration on hydrologic connectivity, and whether these scenarios ultimately exacerbate or alleviate carbon export. Hold workshops to explain potential scenarios of climate change and wetland drainage/restoration in different environmental settings.		connectivity type and timing in determining the potential of wetlands as NbS.	connectivity under different climate change scenarios and wetland loss/restoration scenarios in different environmental settings. Online training workshops for potential users of the web-based interactive computer application.		
OBJ 1	Task 1.4	Share and demonstrate wetland coverage data products with potential users of these data, including government organizations, non-government organizations, and farmers.	Develop online portal to provide easy access to data products; host workshops to communicate the benefits of using the wetland database and information products; write articles or make appearances in public media forums.	UToronto	Private and public use of standardized maps of wetland coverage and wetland gain/loss.	Online data/map repository and workshops/forums to inform potential users of the data/maps.	October 1, 2024	March 31, 2025
OBJ 5	Task 5.4	Support other national initiatives for nature climate solutions (e.g., the new Nature Smart Climate Solutions (NSCS) fund).	Develop decision support tools to support carbon-smart ecosystems. We will: (1) use the data generated by OBJ 1 for a socio-economic analysis of the trends in land-use changes and the drivers behind wetland degradation and destruction; (2) identify wetlands for carbon reduction that should be protected, conserved, or restored; and (3) enhance the capacity of farmers to implement carbon-mitigation	UToronto/ECCC/AAFC/USask (GIWS)	Enhance the capacity of farmers across Canada to implement carbon mitigation projects that qualify for programs such as the NSCS Fund or future opportunities associated with voluntary or regulated carbon offset markets.	Decision support tools for carbon-smart agricultural ecosystems	April 1, 2025	March 31, 2027

			projects that qualify for programs such as the NSCS fund. DUC will communicate the value of wetlands as NbS to government, industry, and the public, and develop decision support tools to help target wetland protection and restoration strategies to maximize wetland ecosystem services.					
OBJ 5	Task 5.5	Inform Canada's new National Index on Agri-Food Sustainability for Canada's agri-food sector.	The authoritative approach for calculating wetland OC accumulation and GHG flux rates with the national GHG inventory approach and the Holos model will be used to provide industry organizations a basis to establish their own benchmarking and branding for marketing purposes. By being able to employ government-sanctioned calculation approaches, industry will be able to publish defendable metrics and benchmarks that are internationally recognized.	UToronto /USask (GIFS)	Enhance the capacity of industry organizations to establish their own benchmarking and branding of NbS for marketing purposes.	Harmonized approaches to calculating wetland OC accumulation and GHG flux rates between academia, government, and industry.	April 1, 2025	March 31, 2027

Evaluation plan and performance measures

Expected results

We will provide the scientific evidence in support of freshwater mineral wetlands as a nature-based climate solution on agricultural landscapes and the decision-support tools to inform the protection, conservation, restoration, and management of wetlands to maximize organic carbon accumulation and GHG reductions as well as other nature-based solutions.

We will produce the first-of-its kind standardized wetland coverage database for agricultural landscapes in Canada, identifying wetlands > 0.36 ha for the period from 1984 to present. Drawing on this database, we will include a record of wetland loss (and gain) due to the cumulative effects of climate change and human modification of agricultural landscapes (drainage ditches, tile drainages). Using this standardized wetland coverage database, we will provide authoritative estimates of wetland organic carbon storage, vertical fluxes of GHG to estimate their potential for GHG reduction, and horizontal fluxes of carbon into and from wetlands on agricultural landscapes. These data will be used to develop mechanistic and statistical models that can be used to explain what we expect to be substantial heterogeneity (over space) and variability (over time) in wetland organic carbon accumulation and GHG reduction. As a singular focus may lead to unintended consequences, we will develop a rapid-assessment tool for wetland ecosystem services that will be able to discern where wetland management strategies lead to co-benefits of carbon and other ecosystem services, including hydrological regulation, water purification, and biodiversity enhancement, and where there may be conflicts. We will identify priority wetlands for protection or restoration that will provide the most effective nature-based solutions for both carbon storage and other ecosystem services.

Through an interactive measurement-modelling platform, our models will allow users to explore the effects of alternative climate change scenarios on the potential role of wetlands as nature-based climate solutions and of alternative land-management scenarios (or wetland drainage/restoration scenarios) that would maximize the benefit of wetlands as a nature-based climate solution while supporting a thriving agricultural economy.

Our results will be integrated into Canada’s national GHG inventory. In turn, this inventory will be mobilized to support a harmonized approach to decision-support tools used by academia, government, industry, and civic society for the design of carbon-smart agricultural landscapes. For example, the Holos model that integrates wetlands will enable farmers and industries to examine the effects of farm-management practices on wetland organic carbon accumulation and GHG flux rates. Farmers can thereby implement carbon-mitigation projects that qualify for programs such as the Nature Smart Climate Solutions Fund or future opportunities associated with voluntary or regulated carbon-offset markets. Further, industries can benchmark and track their carbon footprints for the proposed National Index of Agri-Food Sustainability.

All the results from our research program as well as the products generated will be held in the Canadian Wetland Information Network (CanWIN) data repository, a centralized, standardized repository of data, protocols, models, and tools. As a public-facing resource, CanWIN will be extremely valuable for all those involved in wetland research as well as those involved with their management as a vital natural resource.

Project evaluation plan

The proposed project is designed to make fundamental contributions to understanding the potential role of freshwater wetlands in helping Canada achieve its international commitments under the UNFCC Paris Agreement. The project's core project activities and its five inter-related and inter-dependent objectives will produce authoritative data, tools, and models for evaluating wetlands as nature-based climate solutions. The project executive will lead the evaluation plan, including the tracking of inputs, activities, outputs, and outcomes, with QUARTERLY evaluation points to identify and mitigate risks associated with the successful completion of the individual objectives to ensure their interdependencies do not create risks to the entire project's success. The project executive will submit ANNUAL progress reports, where we will report on the progress to achieving our goal and objectives. Below are the key elements of our evaluation plan and how they contribute to the goal of informing the national GHG inventory and other associated benefits.

PROJECT CORE ACTIVITIES

INPUTS:

- Hire project manager.
- Hire a postdoctoral researcher who will be responsible for developing protocols for determining uncertainty estimates for all data, tools, and models generated during the project.
- Establish the international science advisory group and the partner steering committee and education and outreach committee.

ACTIVITIES:

- Hold biannual meetings of the project team to ensure that all members remain focused on the project goals and are committed to the project's requirement to inform and integrate wetlands as nature-based climate solutions into policies and practices.
- Hold annual meetings of science advisory group and partner steering committee to ensure that the project remains aligned with government and industry priorities.
- Identify and remove any barriers to project progress and the achievement of project goals and objectives.
- Mobilize (transfer and translate) knowledge through workshops, conferences, and publications.
- Communicate the role and value of wetlands to government, industry, and public and the decision support data, tools, and models being developed to help target wetland protection and restoration strategies to maximize wetland ecosystem services.

OUTPUTS:

- Website and social media outlets specifying project purpose and progress.
- Data, tools, models to assess wetlands as nature-based climate solutions.
- Workshops to train end-users on the data, tools, and models.
- Position papers on wetlands as nature-based climate solutions.
- Articles on wetlands as nature-based climate solutions in DUCs "Conservator" magazine.

IMMEDIATE OUTCOMES:

- Improved understanding and access to data, tools, models developed in the five project objective areas (see below) to estimate the potential of wetlands as nature-based climate solutions.

OBJ 1:

INPUTS:

- Hire 2 GIS/remote sensing technicians, 1 PDF, and 2 PhD students.
- Organize equipment (GIS, remote sensing, modelling) and physical space are in place to support creation of the standardized wetland coverage database.

ACTIVITIES:

- Conduct the GIS/remote sensing analysis to create the standardized wetland coverage database.
- Conduct quarterly inspections on progress and identify and mitigate any barriers to completion of the standardized wetland coverage database by end of Year 3.
- Share interim wetland coverage data product with government and industry partners and incorporate their feedback into the final wetland coverage data product.
- Survey the degree of adoption by project team, partners, provincial and federal government agencies, industry and industry associations, and conservation organizations for program planning.

OUTPUTS:

- First-of-its-kind national freshwater mineral wetland inventory – including number, size, and other morphological properties of wetlands – which will provide a foundation for assessing wetlands as nature-based climate solutions on agricultural landscapes at a national scale.

IMMEDIATE OUTCOMES:

- Improved understanding of freshwater mineral wetland coverage through the application of developed data, tools, and models to monitor; and a 30+ years assessment of the loss/gain dynamics in agricultural landscapes in Canada.

OBJ 2:

INPUTS:

- Hire 6 field and laboratory technicians, 4 PhD, and 6 MSc students.
- Organize field equipment that will be deployed to build the network of wetland monitoring sites that will be used to support the creation of the standardized wetland coverage database.
- Organize laboratory equipment that will be deployed to measure dissolved, particulate, and gaseous precursors and products of greenhouse gases.

ACTIVITIES:

- Conduct the field/laboratory analysis to create the standardized wetland organic carbon storage and greenhouse gas flux rates database.

- Conduct quarterly inspections on progress and identify and mitigate any barriers to completion of the standardized wetland organic carbon storage and greenhouse gas flux rates database by end of Year 5.
- Share the interim wetland coverage data and model products with government and industry and incorporate their feedback into the final wetland organic carbon accumulation and greenhouse gas flux rates data and model products.
- Once standardized wetland organic carbon storage and greenhouse gas flux rates database completed, build process informed models to predict spatial heterogeneity and temporal variability of wetland organic carbon storage and greenhouse gas flux rates.
- Share the process informed models of wetland organic carbon accumulation and greenhouse gas flux rates to predict the spatial heterogeneity and temporal variability of these storage and flux rates.
- Compare the nature-based climate solutions estimate of wetland organic carbon accumulation rates (stocks) and greenhouse gas reduction estimates (emission factors) generated from our project to other default stock- and emission-factors currently used, comparing the robustness of the estimates and uncertainties in these estimates.
- Survey the degree of adoption by project team, partners, provincial and federal government agencies, industry and industry associations, and conservation organizations for program planning. In particular, we will perform an assessment of the process-informed wetland carbon stock and greenhouse gas emissions factors used in Canada's national greenhouse gas inventory reports to develop carbon offset and GHG emission reduction protocols.

OUTPUTS:

- First-of-its-kind national freshwater mineral wetland organic carbon accumulation and greenhouse gas flux rates data products for agricultural landscapes in Canada, together with process-informed models to predict the spatial heterogeneity and temporal variability of these storage and flux rates for wetlands in agricultural landscapes across Canada.

IMMEDIATE OUTCOMES:

- Improved understanding of and data, tools, and models to inventory current wetland carbon stocks and organic accumulation rates of freshwater mineral wetlands on agricultural landscapes in Canada.

OBJ 3:

INPUTS:

- Hire 2 PDF and 4 PhD students.
- Organize modelling facilities to support creation of mechanistic and statistical models.

ACTIVITIES:

- Develop a mechanistic model of wetland carbon cycling.
- Develop a statistic model to determine the influence of hydrology on wetland carbon cycling processes and wetland carbon export to downstream waters.

- Assess the accuracy of these models for predicting wetland organic carbon accumulation and greenhouse gas emissions rates, and the usability of these models for understanding hydrological controls on the spatial heterogeneity and temporal variability in these rates.
- Share the interim models with government and industry and incorporate their feedback into the final models.
- Evaluate the degree of adoption of model or model results by project team, partners, provincial and federal government agencies, industry and industry associations, and conservation organizations for program planning. These activities will further our assessment of the applicability of the model-informed wetland carbon stock and greenhouse gas emissions factors used in Canada's national greenhouse gas inventory reports.

OUTPUTS:

- A mechanistic model of wetland carbon cycling and a statistical model of hydrologic process controls on wetland carbon cycling.

IMMEDIATE OUTCOMES:

- Improved understanding of (and data, tools, and models for):
- (1) how wetland carbon storage and wetland carbon accumulation rates are influenced by surrounding landscape processes (runoff and erosion as influenced by land use and land management) at local and regional scales; and
- (2) how wetland drainage and restoration affect hydrology and carbon movement among wetlands and to downstream waters.

OBJ 4:

INPUTS:

- Hire 2 PhD students.
- Organize modelling facilities to support creation of the rapid assessment tool for wetland ecosystem services.

ACTIVITIES:

- Develop a rapid-assessment tool for wetland ecosystem services.
- Assess the accuracy of the rapid-assessment tool for wetland ecosystem services.
- Share the interim tool with government and industry and incorporate feedback into the final tool.
- Survey the degree of adoption of the tool by project team, partners, provincial and federal government agencies, industry and industry associations, and conservation organizations for program planning. We will enhance our assessment of the tool-informed understanding of synergies and conflicts of wetlands as nature-based solutions for carbon versus other ecosystem services with regards to Canada's national greenhouse gas inventory reports and to develop carbon offset and GHG emission reduction protocols.

OUTPUTS:

- A desktop- and indicator-based tool for rapid assessment of wetland ecosystem services in agricultural landscapes in Canada.

IMMEDIATE OUTCOMES:

- Improved understanding of the potential synergies and conflicts of restoring wetlands for the ecosystem service of organic carbon accumulation and greenhouse gas reduction versus other ecosystem services including hydrological regulation, water purification, and biodiversity enhancements, in agricultural landscapes in Canada.

OBJ 5:

INPUTS:

- Hire 1 database manager and 4 PhD students.
- Organize data, tools, and models storage and access facilities to support the community of end-users.

ACTIVITIES:

- Develop a Canadian Wetland Information data repository.
- Transfer knowledge from the repository to end-users, tracking the extent of data, tool, model downlands from the CanWIN repository.
- Translate knowledge from the repository for end-users, tracking the number of applications of the knowledge in policy and practice (including the national greenhouse gas inventory, the Holos model, the Nature Based Climate Solutions fund, and the proposed National Agri-Food Sustainability Index).
- Conduct inspections to identify and mitigate any barriers to access and use of the data.
- Conduct surveys of end-users, in terms of usefulness and usability of the repository.
- Report on growth of the Canadian Wetland Information network and usage of its data, tools, and models in the Canadian Wetland Information repository.
- Assess public's general knowledge regarding wetlands as nature-based climate solutions.

OUTPUTS:

- The Canadian Wetland Information network workshops and Canadian Wetland Information repository of data, tools, and models for evaluating wetlands as naturebased climate solutions.

IMMEDIATE OUTCOMES:

- A centralized repository of scientific evidence of wetlands as nature-based climate solutions to support change in policy and management by:
- (1) quantifying wetland organic carbon accumulation rates in natural, intact, and restored wetlands; and
- (2) identifying target areas for wetland conservation or restoration to maximize accumulation of organic carbon accumulation, reduction in greenhouse gas emissions, and reduction in carbon loading to downstream water bodies.

ULTIMATE OUTCOMES:

- CANADA recognizes wetlands as nature-based climate solutions. CANADA provides leadership to other countries in data, tools, and models that lead to authoritative estimates of wetlands potential to store carbon and reduce GHGs in the atmosphere. In CANADA, wetland protection and restoration activities are embraced by the public and private sectors that influence or are influenced by agriculture. These activities contribute to meeting IPCC's targets of reducing greenhouse gas emissions by 45% from their 2010 levels by 2030 and to achieve net zero emissions by 2050, as reported in the IPCC's 2018 report, "Global Warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty." In addition, provincial government agencies develop wetland policies to encourage wetland protection and restoration activities, and in turn, these wetland protection and restoration activities create wealth, via the formation of new markets for farmers who restore wetlands on impacted agricultural landscapes, and via increased competitiveness for industries that buy crops from farmers who restore wetlands and sell them to socially conscious consumers of agricultural products. We will produce HQP who will be in high demand in academia, government, and industry, and who will make knowledge-based decisions on how to better engage agricultural landscapes to reduce climate change risks.