Carbon Accounting and Climate Change Adaptation: A Review of the Benefits of Floodplain Wetland Restoration in British Columbia

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GEOG 405 Capstone Report 2026

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CARBON ACCOUNTING & CLIMATE ADAPTATION BENEFITS OF WETLAND RESTORATION

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Abstract

Floodplain wetlands play an integral role in regulating carbon dynamics and supporting climate adaptation; however, many systems in British Columbia have been significantly altered through diking, drainage, and agricultural conversion. These modifications disrupt natural hydrological processes, reducing carbon storage capacity and increasing greenhouse gas emissions. As a result, there is growing interest in wetland restoration as a solution for climate mitigation and ecosystem recovery. This report evaluates how carbon emissions and sequestration differ across natural, restored, and diked floodplain systems, focusing on identifying the conditions under which restoration provides net climate benefits. Overall, this report finds that wetlands restoration is a net-positive climate strategy when hydrological connectivity is effectively re-established and systems are evaluated over appropriate time scales.

Research Approach

Literature Search

Accumulated relevant academic and government sources

Refinement

Narrowed scope by keywords and geographical bounds

Data Selection

Used Python script to select and extract relevant carbon data for analysis

Natural

Naturally connected to river systems, these areas experience regular flooding that supports diverse habitats, nutrient cycling and dynamic landscape processes.

Restored

Altered systems that have been reconnected to natural water flow that improves habitat quality, enhances biodiversity and restores ecological functions.

Diked

Floodplains isolated from rivers by infrastructure and often used for agricultural development with reduced natural flooding and limited ecological function.

Coastal

Tidal environments such as salt marshes that provide critical habitat, protect shorelines from erosion and supports high biological connectivity.

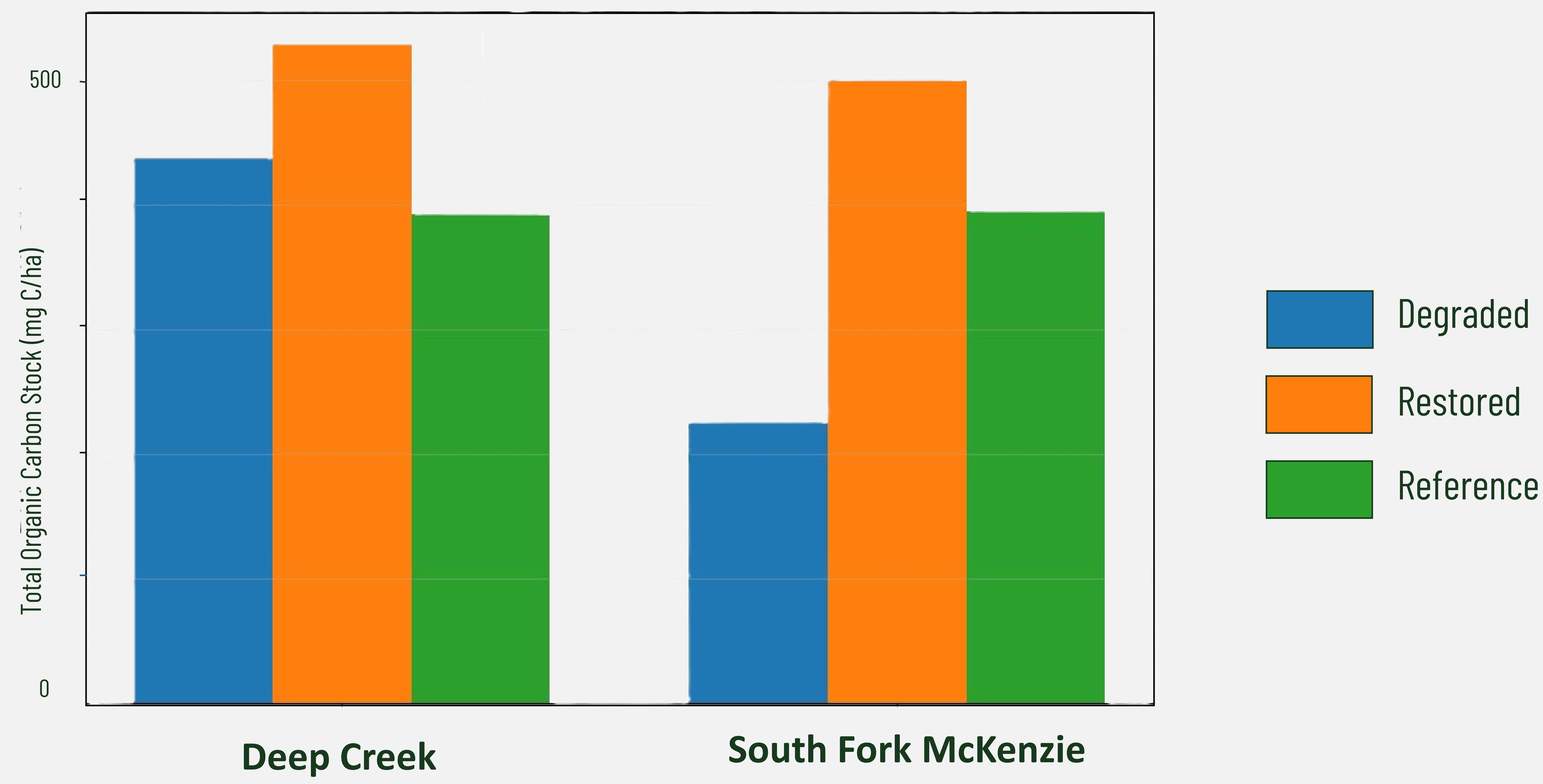

Figure 1. Freshwater floodplain carbon stocks in degraded, treated, and natural floodplains

Climate Co-Benefits

Drought Resilience[3]

Baseflow Maintained

Water Storage

Flood Mitigation[3]

Controlled Peakflow

Increased Infiltration

Biodiversity[4]

Channel Connectivity

Removed Invasive Species

Habitat Creation/Restoration

Controls on Sequestration & Emissions

Hydrology

Controls CO2 vs CH4

Time

Young = Unstable
Old = Efficient

Management

Grazing, Vegetation, Water control

System	Hydrology	Carbon Implication
Natural	Stable	Balanced
Restored	Variable	CO_2 ↓ / CH_4 ↑
Diked	Dry	CO_2 ↑

Conclusions

Wetland restoration is a net-positive climate strategy,

However…

Wetlands are complex carbon systems that will not react equally to restoration and management.

Therefore…

Hydrology, time, and site management must be considered to create the best restoration outcomes and make the most out of the associated climate co-benefits.

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Executive Summary

Floodplain wetlands play an integral role in regulating carbon dynamics and supporting climate adaption; however, many systems in British Columbia have been significantly altered through diking, drainage, and agricultural conversion. These modifications disrupt natural hydrological processes, reducing carbon storage capacity and increasing greenhouse gas emissions. As a result, there is growing interest in wetland restoration as a solution for climate mitigation and ecosystem recovery.

This report evaluates how carbon emissions and sequestration differ across natural, restored, and diked floodplain systems, focusing on identifying the conditions under which restoration provides net climate benefits. A targeted literature review of 25 academic and peer-reviewed sources was conducted, all with a direct focus on carbon fluxes, environmental drivers, and system characteristics.

The findings show that hydrology is the dominant control on carbon processes across all systems. Natural floodplains act as stable long-term carbon sinks due to continuous sediment inputs and saturated soil conditions. Diked floodplains are typically net carbon sources, as disconnection from natural flooding promotes soil oxidation and sustained carbon loss. Restored floodplains stand in between diked and natural, often having short-term increases in emissions followed by more carbon storage over time.

Although restoration generates short-term emissions from construction and machinery use, these costs are limited and outweighed by long-term carbon accumulation. Evidence from both freshwater and coastal systems demonstrate that restored floodplains can

offset initial carbon costs within short timeframes while continuing to provide ongoing sequestration benefits.

Overall, this report finds that wetlands restoration is a net-positive climate strategy when hydrological connectivity is effectively re-established and systems are evaluated over appropriate time scales. For Ducks Unlimited Canada, the key implication is that maintaining diked and degraded floodplains also acts a carbon cost, which is something to keep in mind. However, restoration can provide a pathway toward long-term carbon storage, improved ecosystem function and increased climate resilience.

1.0 Introduction

Floodplain wetlands are among the most dynamic and ecologically important systems for carbon storage, playing a central role in regulating greenhouse gas emissions and hydrological processes. These environments function as major carbon sinks by accumulating organic matter in saturated soils, where low oxygen conditions slow decomposition and allow carbon to be stored over long time scales. At the same time, wetlands are also sources of greenhouse gases, particularly methane (CH_4), creating a complex balance between carbon sequestration and emissions.

In British Columbia, many floodplain wetlands have been modified through diking, drainage, and land conversion for agriculture and development. These interventions have altered natural hydrological connectivity, disrupting sediment deposition, reducing organic matter inputs, and increasing soil oxygenation. Simultaneously, these changes have decreased floodplains' ability to provide essential ecosystem services, such as flood regulation, water storage, and habitat support.

Wetland restoration aims to reverse these impacts by re-establishing hydrological connectivity and restoring ecological function. Restoration efforts typically involve reconnecting floodplains to river systems, reintroducing natural flow regimes, and supporting vegetation recovery. While these interventions have clear ecological benefits, their carbon implications are more complex. Restoration can initially increase greenhouse gas emissions due to soil disturbance and rewetting, which raises important questions about the short-term versus long-term climate benefits of these projects.

This report explores how carbon dynamics vary across natural, restored, and diked floodplain systems, with a focus on identifying the conditions under which restoration provides net climate benefits. Specifically, the goal of this of this report is to strengthen Ducks Unlimited Canada's carbon accounting framework, improve understanding of carbon fluxes and net emissions/sequestration in floodplain wetlands, and identify climate adaptation co-benefits of wetland restoration. This will be achieved through the following objectives:

- To compare carbon emissions and sequestration across natural, restored and diked floodplains
- To evaluate the short-term carbon costs associated with wetland restoration activities
- To identify the environmental management conditions that influence long-term carbon storage and climate mitigation outcomes
- To assess the broader climate adaptation co-benefits of wetland restoration, and biodiversity enhancement

Ultimately, this report aims to support decision-making by Ducks Unlimited Canada and other stakeholders by providing a clear, evidence-based assessment of the carbon implications of floodplain restoration. Understanding how hydrology, time, and management interact to control carbon processes is essential for ensuring that restoration efforts deliver meaningful and sustained climate benefits.

2.0 Research Approach

This report focuses on evaluating the carbon dynamics and climate adaptation benefits of floodplain wetland restoration with a geographic emphasis on British Columbia, Canada. The scope of this research includes peer reviewed journal articles, government publications, reports presented by Ducks Unlimited Canada and other relevant information from environmental organizations examining carbon fluxes, greenhouse gas emissions and sequestration processes in floodplain environments with emphasis on natural floodplains, restored floodplain wetlands and diked floodplains utilized for agriculture and or water storage.

A targeted literature review was conducted using academic databases including PubMed, Scholarly, ScienceDirect and other databases to gather information based on this topic. Search terms included combinations of "floodplain carbon sequestration", wetlands restoration emissions", "diked floodplain carbon flux" and "wetland greenhouse gases" with a focus on carbon dioxide, methane, nitrous oxide and other potent emissions. Studies were included in this write up if they reported quantitative and qualitative assessments of carbon fluxes and storage, focused on floodplain and wetland systems and were conducted in temperate or comparable climatic regions with the opportunity to research on wetland systems located nationally and internationally. Preference was given to studies that were published after the year 2000 to ensure relevance to current restoration practices and carbon accounting frameworks while foundational studies were included where necessary to support key concepts in wetland biogeochemistry.

This approach was selected to ensure a balance between field studies and large-scale syntheses allowing for a robust comparison across floodplain systems. By focusing on both greenhouse gas emissions and long-term carbon storage the analysis captures key trade-offs that are central to evaluating the net climate benefits of wetland restoration.

This project includes several integrated deliverables designed to support both academic and applied outcomes. First, an excel dataset was developed to compile carbon related data from the literature including carbon sequestration rates, greenhouse gas emissions and environmental variables such as hydrology, vegetation type and land use. This dataset enables cross study comparison and supports the identification of trends across natural, restored and diked floodplain systems.

Second, this report synthesizes the findings from the literature and dataset to evaluate differences in carbon dynamics across floodplain types, assess the emissions associated with restoration activities and to identify conditions under which restoration provides net climate benefits. Additionally, this report integrates climate adaptation co-benefits including flood mitigation, water storage and biodiversity enhancement.

Third, a presentation was developed to communicate key findings in a clear and concise format to the projects partner, Ducks Unlimited Canada (DUC). This presentation highlights the major conclusions and supports decision making related to wetland restoration and carbon accounting. Finally, a visual infographic was created to summarize the key insights in an accessible format for broader audiences including policymakers and stakeholders. Together, these deliverables ensure that the findings are both scientifically robust and applicable to climate resilient land management.

3.0 Methodology

3.1 Literature Search

The process began with the search for literature, which turned out to be quite the journey for the group. The initial search was explicitly restricted to the University of Waterloo library, where a solid collection of sources was identified right away. However, a notable challenge arose early on - a large portion of those sources were not geographically located in British Columbia, which is the specific focus of this literature review. To work through this, the search was expanded to include the libraries at Wilfrid Laurier University and the University of Guelph, which turned out to be a very successful approach. The additional searches yielded sources that hit exactly what the group was looking for. While broader repositories such as Google Scholar were available options, the group made a conscious decision to rely exclusively on academic library databases. By only sourcing materials housed across three reputable Ontario universities, the group was able to heavily reduce the likelihood of incorporating unreliable or non-peer-reviewed material into the review.

3.2 Literature Review and Discussion

After the extensive search process, the group took on another considerably involved task - reading all 30 selected papers from start to finish. Given the sheer volume and research depth of the literature, this took a fair bit of time for everyone involved, as it required more than just a surface-level read. Each member needed to fully understand the material and ensure that everything in the final 30 sources was up to the standard expected for a deliverable intended for Ducks Unlimited. Once all 30 pieces of literature had been read, the group held a formal discussion where members went back and forth on what to include and exclude from the review. This discussion also served as an opportunity to flag key data points that would be useful for generating figures and providing meaningful, evidence-based insights in the final report.

3.3 Data Analysis and Figure Generation

With the relevant data accumulated from the previous step, it was time to take that information and turn it into visually informative figures that the reader will encounter later in this report. Following the group's final meeting, the most important data points were consolidated into a CSV file. From here things get a little technical, so feel free to skip ahead to Section 3.4 — some of what follows requires a degree of computer literacy to fully follow along.

Once all the compiled data was organized within the CSV, a series of Python scripts were developed to get the data looking exactly how the group wanted it, and to handle the necessary unit conversions to ensure consistency across all figures. The process involved setting up a project folder on a local machine, placing the CSV file within it, and navigating that directory through the terminal. From there, a total of four Python scripts were written - one for each of the figures produced for this report. As mentioned, the scripting process allowed the group to standardize units across sources and produce polished, accurate visualizations that would not have been as easily or effectively achieved by inputting raw values directly into Excel. Once the code was finished, each CSV file was run through its corresponding Python script via the terminal, delivering the exact graphical output the group was after for each figure.

3.4 Report writing

Once the data analysis was wrapped up, the group moved on to producing the written report that the reader is working through right now. This was a very time-consuming process that took a fair chunk of time to get through. At its core, it involved combining the data analysis work from the previous step with the notes gathered from the literature, and using both to form insightful, evidence-based conclusions from everything the group had researched and analyzed. The writing process an involved effort from everyone — work was distributed equally, with each member taking ownership of agreed-upon sections. Throughout the writing process, the group held weekly meetings to make sure everyone stayed on the same page, as many of the individually written sections directly reflected one another, making collaboration critical at every stage. The report went through many drafts and required numerous revisions from all members, with each person reading through the full document multiple times and contributing revisions to not only their own sections, but their colleagues as well. By the time of submission, the process had been thoroughly seen through and the methodology brought to a close.

4.0 Literature Review

4.1 Types of Floodplain Systems

4.1.1 Natural Floodplains

Natural floodplains function as significant long term carbon sinks due to their high primary activity, regular sediment deposition and saturated soil conditions. Periodic flooding delivers organic matter and nutrients which enhance vegetation growth and promotes the accumulation of soil organic carbon. In these waterlogged environments anoxic conditions slow microbial decomposition allowing carbon to be stored over extended time scales (Mitsch and Gosselink, 2015).

Carbon sequestration in natural floodplains occur through both plant biomass and externally derived sediments and organic matter inputs. Sequestration rates in wetland systems are commonly estimated in the range of approximately 100 Cm-2yr-1 to 300gCm-2yr-1; however, this varies depending on hydrology and vegetation (Mitsch and Gosselink, 2015). These systems, however, further emit methane due to anerobic decomposition processes. Methanogenesis occurs under low oxygen conditions creating a trade-off between carbon storage and greenhouse gas emissions (Bridgham et al., 2014).

Despite methane production natural floodplains are typically net carbon sinks as long-term carbon accumulation exceeds total greenhouse gas emissions. (Kayranli et al., 2010). Comparing this to altered systems, their intact hydrological connectivity maintains a balance between carbon inputs and outputs supporting stable carbon storage over time.

4.1.2 Restored Floodplains

Restored floodplains aim to re-establish hydrological connectivity and ecological processes that support carbon sequestration. Following restoration, these systems often experience a short-term increase in greenhouse gas emissions due to soil disturbances, rewetting, and microbial activity. This initial phase results in elevated carbon dioxide and methane fluxes as previously oxidized soils become saturated and organic matter decomposition accelerates (Moreno-Maeteos et al., 2012).

Overtime restored floodplains regain their function as carbon sinks as vegetation begins to re-establish itself and sediment deposition resumes while soil carbon begins to accumulate. Studies indicate that restored wetlands approach the carbon sequestration capacity of natural systems within decades however, recovery rates depend on site conditions, restoration design and hydrological reconnection (Nahlik and Fenessy, 2016).

Compared to diked floodplains restored systems exhibit significantly greater carbon storage potential due to reduced soil oxidation and increased organic inputs. For example, restoration efforts in British Columbia such as those at Bummers Flats and Moberly Marsh have focused on reconnecting floodplains to natural flow regimes demonstrating how hydrological restoration supports both carbon sequestration and broader ecosystem recovery (Ducks Unlimited Canada, 2020). While restored systems temporarily act as carbon sources they generally transition to net carbon sinks over longer timescales.

4.1.3 Diked Floodplains

Diked floodplains are characterized by reduced or removed hydrological connectivity which fundamentally alters carbon cycling processes. Flood control infrastructure prevents regular sediment deposition and limits organic matter inputs, effectively reducing the system's capacity for carbon sequestration. (Knox et al., 2015). Additionally, these systems are often drained or artificially managed lading to more oxygenated soils that accelerate decomposition and increase carbon dioxide emissions. The previously stored soil carbon contributes to land subsidence and long-term carbon loss (Deverel and Leighton, 2010).

Although methane emissions are typically lower due to reduced soil saturation however, this does not offset the substantial carbon dioxide emissions associated with soil degradation. As a result, diked floodplains are considered as net carbon sources. Compared to natural and restored systems diked floodplains exhibit the lowest carbon storage and the highest rates of carbon loss. This makes them a critical baseline for evaluating the potential climate benefits of wetland restoration particularly in regions such as British Columbia where agricultural conversion of floodplains is widespread.

4.1.4 Coastal Systems

Coastal floodplain wetlands including salt marshes and estuarine environments are among the most efficient carbon sinks globally and are commonly referred to as “blue carbon” systems. These environments benefit from high primary productivity and continuous sediment deposition driven by tidal processes which promote the rapid burial of organic carbon in saturated soils (Mcleod et al., 2011).

In contrast to freshwater systems, salinity in coastal wetlands suppresses methane production resulting in lower methane emissions and enhancing overall carbon storage efficiency (Chmura et al., 2003). Coastal floodplains therefore provide a valuable point of comparison highlighting how hydrological conditions and biogeochemical processes influence carbon fluxes across wetland types. In coastal regions of British Columbia these systems further contribute to climate adaptation by buffering against sea level rise and storm surges further reinforcing the importance of wetland conservation and restoration for both mitigation and resilience.

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4.2 Restoration Activities

4.2.1 Restoration techniques

For Ducks Unlimited Canada, restoration activities in B.C. floodplain and wetland systems should be understood as the suite of physical interventions used to re-establish the hydrologic, geomorphic, and ecological functions that were lost through diking, drainage, channel incision, shoreline armouring, and floodplain disconnection. The literature shows that these activities commonly include reconnecting floodplains to rivers through levee removal or setback, dam or barrier removal, aggrading incised channels, channel reconstruction, re-meandering, reconnecting or constructing side channels, ponds, and wetlands, as well as riparian planting and placement of logs, logjams, boulders, or other structures that restore habitat complexity and overbank connectivity. More site-specific examples from the literature include dense placement of large wood across a floodplain, lowering high alluvial surfaces, filling incised channels to reconnect channel and floodplain processes, reinstating tidal flows onto formerly agricultural floodplain land, breaching dikes to restore estuarine exchange, and placing dredged sediment to raise marsh elevation where coastal wetlands are threatened by erosion or sea-level rise. In the DUC context, these actions are not simply “habitat enhancements”; they are engineered landscape modifications intended to shift a degraded floodplain or wetland back toward a wetter, more connected, and more carbon-retentive state.

4.2.2 Emissions from Heavy Machinery Use

Wetland and floodplain restoration projects generate direct carbon emissions during implementation because earthworks rely on diesel-powered heavy machinery. For a conservative first-pass estimate, this report assumes the use of one Cat 336 excavator and one Cat D3 dozer. Under the lower-use scenario, each machine operates for approximately 2 hours per day over a 10- to 20-day project window. Based on the hourly emissions rates used in this report, the excavator is estimated to emit roughly 79.7 kg CO_2 per operating hour and the dozer about 30.7 kg CO_2 per operating hour, for a combined total of 220.8 kg CO_2 per day. This would result in approximately 2.21 t CO_2 over 10 workdays and 4.42 t CO_2 over 20 workdays. Under a second scenario, where each machine operates for 3 hours per day, combined emissions would rise to about 331.2 kg CO_2 per day, or 3.31 t CO_2 over 10 workdays and 6.62 t CO_2 over 20 workdays. These values should still be interpreted as lower-bound estimates because they exclude hauling, equipment delivery, idling beyond active work time, and any additional support machinery used on site.

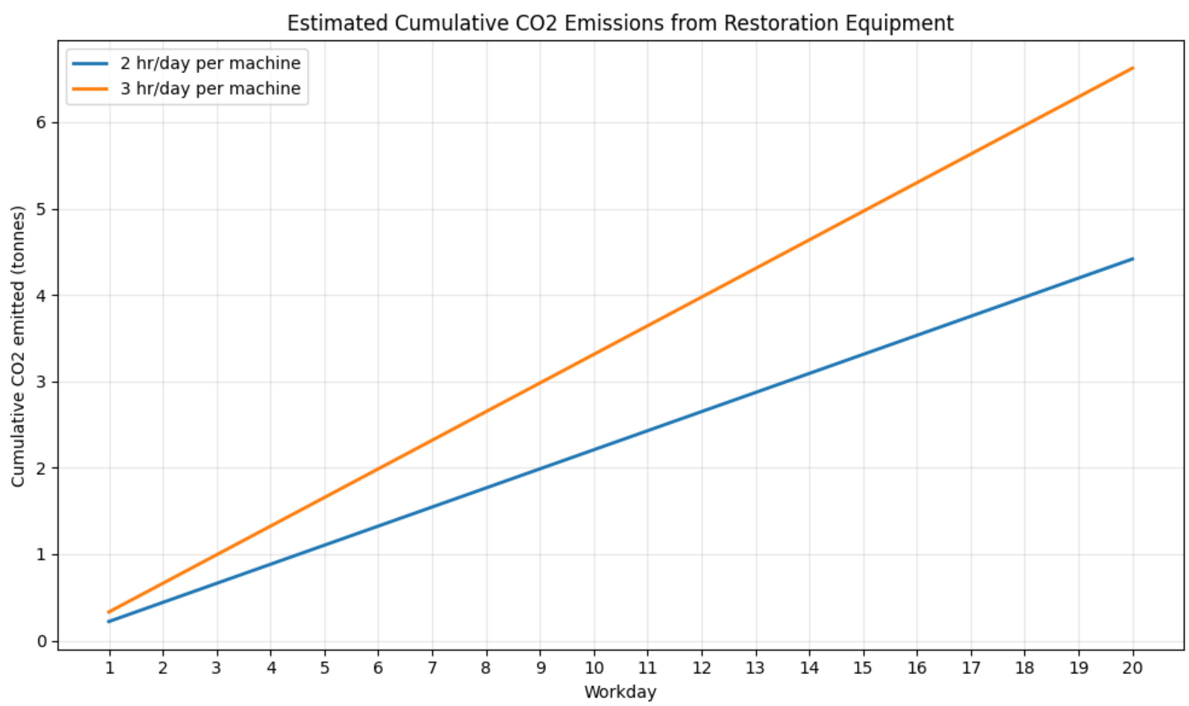

Figure 1: Author-generated figure based on estimated carbon emissions based on the number of hours an excavator and dozer supplied by the manufacturer Cat are used over a workday (Caterpillar Inc, 2026)

4.2.3 Emissions from Earthmoving and Construction

Earthmoving and construction emissions represent the immediate carbon cost of restoration, since excavation, grading, and channel or wetland re-configuration require fuel combustion before any ecological benefits are realized. In Ducks Unlimited floodplain projects, these emissions are best understood as an up-front implementation cost rather than an indicator that restoration is carbon-negative overall. The more material that must be excavated, pushed, shaped, imported, or removed, the larger this short-term carbon cost becomes. However, the literature suggests that restoration should be evaluated over a longer time horizon, because rewetting and hydrologic reconnection can reduce the persistent carbon losses associated with drained and degraded wetlands and support the recovery of soil carbon storage and floodplain function over time. As a result, construction-phase emissions need to be accounted for explicitly, but they should be compared against the long-term avoided emissions and sequestration benefits expected from a successfully restored wetland.

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4.3 Systems Comparisons

4.3.1 Emissions Comparison

Across the literature, the main distinction between diked, restored and natural floodplains is how the hydrology in each system regulates carbon inputs, storage and emissions. Natural systems have strong hydrological connectivity, which means there is continuous sediment deposition and sustained carbon accumulation. In contrast, diked systems are hydrologically disconnected, which limits organic input, consequently promoting aerobic soil conditions that increase decomposition and carbon loss (Mitsch & Gosselink, 2015; Knox et al., 2015). Restored floodplains lie in the middle of these two states, as the reconnection of hydrology re-establishes carbon storage processes over time, which is an extremely important factor to consider for restored floodplain status (Moreno-Mateos et al., 2012; Nahlik & Fennessy, 2016).

A key trade-off across all systems is the balance between CO_2 and CH_4 emissions. Diked floodplains tend to have higher CO_2 emissions, but low CH_4 emissions (Deverel & Leighton, 2010). In comparison, natural floodplains have decreased CO_2 emissions and increased CH_4 emissions due to the saturated and low-oxygen conditions that characterize them (Bridgham et al., 2014). This means that natural systems tend to have the most balanced greenhouse gas dynamics. Restored systems often experience short-term increases in CH_4 and shifting CO_2 reactions immediately following rewetting, making them the most variable system of the three (Moreno-Mateos et al., 2012). This highlights that hydrology is the most important control on greenhouse gas fluxes across all systems.

4.3.2 Sequestration Comparison

Carbon sequestration capacity also differs consistently among systems due to variations in sediment supply and vegetation productivity. Natural floodplains are efficient long-term carbon sinks due to constant organic matter inputs and slow decomposition rates (Kayranli et al., 2010; Mitsch and Gosselink, 2015). Diked systems have the lowest ability to sequester greenhouse gases due to restricted flooding which prevents sediment deposition and intensified carbon loss through soil oxidation (Knox et al., 2015). Over time, restored floodplains improve their sequestration capacity as vegetation re-establishes and sediment inputs continue to grow (Nahlik & Fennessy, 2016). Therefore, time since restoration plays a critical role in determining whether these systems are net carbon sources or sinks.

4.3.3 Net Carbon Benefits and Trade-offs Between Systems

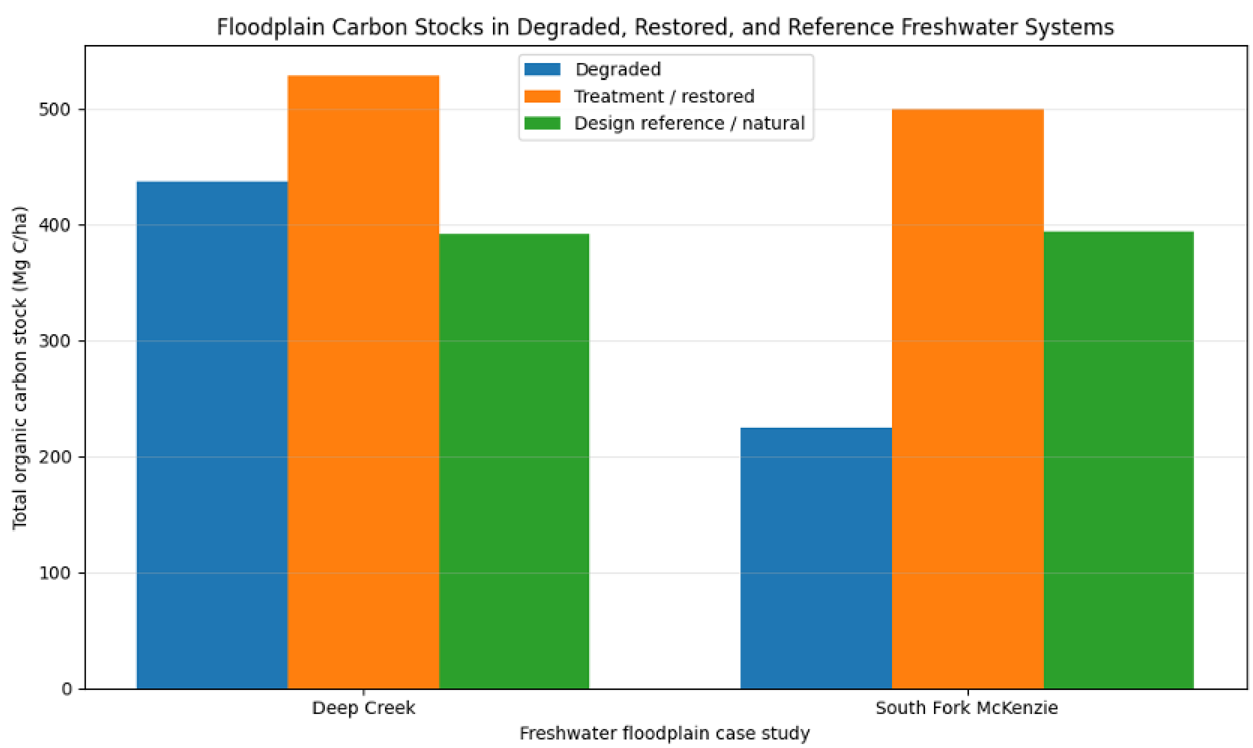

Figure 2: Author-generated figure based on total organic carbon stock data reported by Hinshaw and Wohl (2021, Table 3). The figure compares degraded, treatment/restored, and design reference floodplains at Deep Creek and the South Fork McKenzie River, with total organic carbon reported in Mg C/ha.

This is the comparison that actually matters for Ducks Unlimited. The Fraser problem is not a salt-marsh problem first; it is a diked, drained, freshwater floodplain problem. That is why the freshwater carbon-stock figure carries the most weight in this section. In the best analogue from our source set, Hinshaw and Wohl (2021) showed that the restored treatment reaches outperformed the degraded reaches at both case-study sites. At Deep Creek, total organic carbon stock rose from 437 Mg C/ha in the degraded floodplain to 528 Mg C/ha in the treatment reach. At the South Fork McKenzie, it rose from 225 Mg C/ha to 500 Mg C/ha. That is not a small bump around the edges. That is a serious shift in floodplain carbon storage after reconnection, regrading, and restoration of structural complexity. It also lines up cleanly with the Fraser baseline in Rosenau and Angelo (2007), who describe a floodplain system reshaped by dikes, drainage ditches, pump stations, land levelling, riparian clearing, and the loss of historically wetted side channels and wetlands. Their report notes that agriculture drove the draining of Sumas Lake, removing roughly 10,000 acres of shallow lake and wetland habitat, and that more than 100 km of secondary channels had been blocked by human activity. That is the benchmark Ducks Unlimited should be thinking about: not a neutral agricultural landscape, but a heavily altered floodplain that has already paid a major ecological cost for being kept dry and disconnected (Hinshaw & Wohl, 2021; Rosenau & Angelo, 2007).

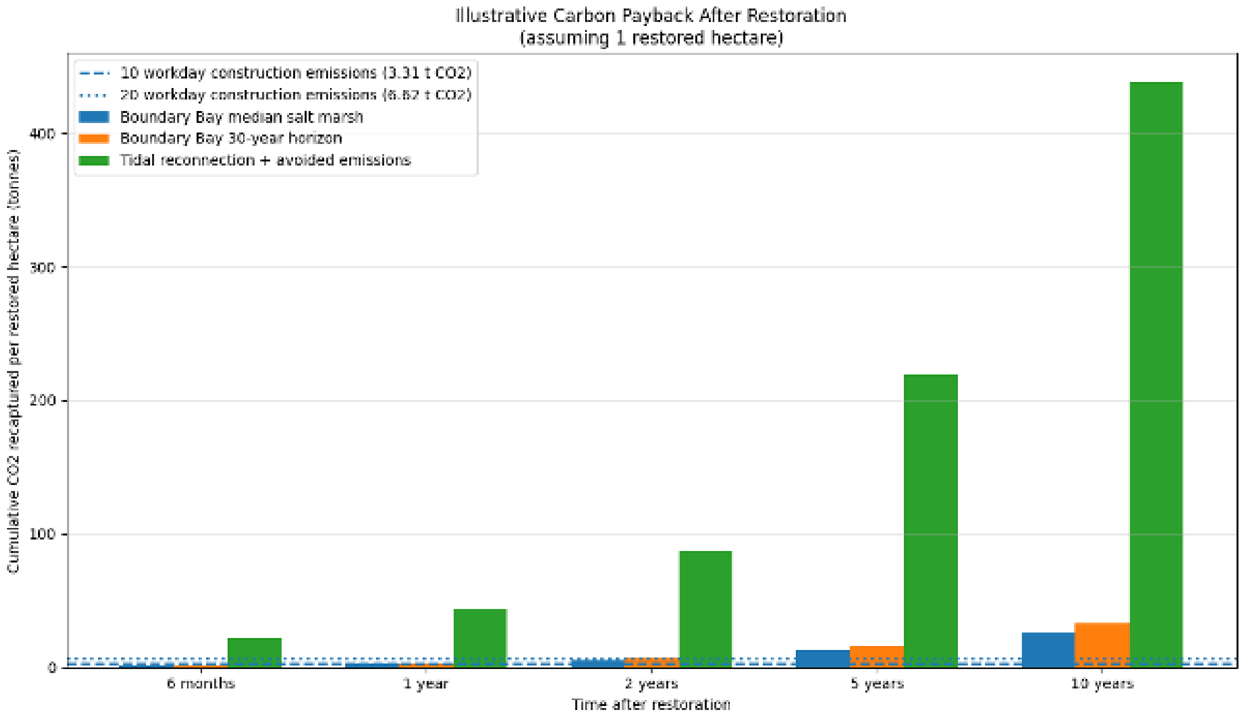

Figure 3: Author-generated figure comparing cumulative post-restoration carbon recapture per restored hectare against estimated construction emissions of 3.31 t CO2 for a 10-workday project and 6.62 t CO2 for a 20-workday project, using the higher-use machinery scenario of one excavator and one dozer operating 3 hours per day each. The restoration trajectories shown are based on the Boundary Bay median accumulation rate, the Boundary Bay 30-year horizon rate, and a tidal reconnection plus avoided-emissions scenario from Hagger et al. (2022).

The point of the full payback graph is scale. Restoration does create an upfront carbon debit through machinery use and earthmoving, but that debit is finite. Under the heavier-use construction scenario used here, the project emits 3.31 t CO2 over 10 workdays and 6.62 t CO2 over 20 workdays. Against that, the literature shows that restored systems can continue accumulating carbon after the machines leave. The coastal cases were useful for building that payback frame because Gailis et al. (2021) provide clear B.C. accumulation rates from Boundary Bay, while Hagger et al. (2022) show what happens when restoration also avoids emissions tied to degraded agricultural land use. That is why the tidal reconnection bar in the full graph is so much larger: it is not just measuring sequestration; it is also capturing avoided emissions. That makes it valuable as an upper-end comparator, but not the one-to-one freshwater analogue. For Ducks Unlimited, the more important takeaway is the logic of the comparison itself: construction emissions happen once, while carbon gains continue to build if restoration returns the site to a wetter, connected floodplain state. That logic gets even stronger when you remember what happens in altered freshwater floodplains that stay dry. Batson et al. (2015) found that a short-hydroperiod floodplain wetland with limited wetness had annual soil CO_2 emissions of 1091 g C m^{-2} yr^{-1} and a net soil carbon balance of −338 g C m^{-2} yr^{-1}, meaning it was acting as a carbon source rather than a sink. In plain terms, doing nothing is not free either (Batson et al., 2015; Gailis et al., 2021; Hagger et al., 2022).

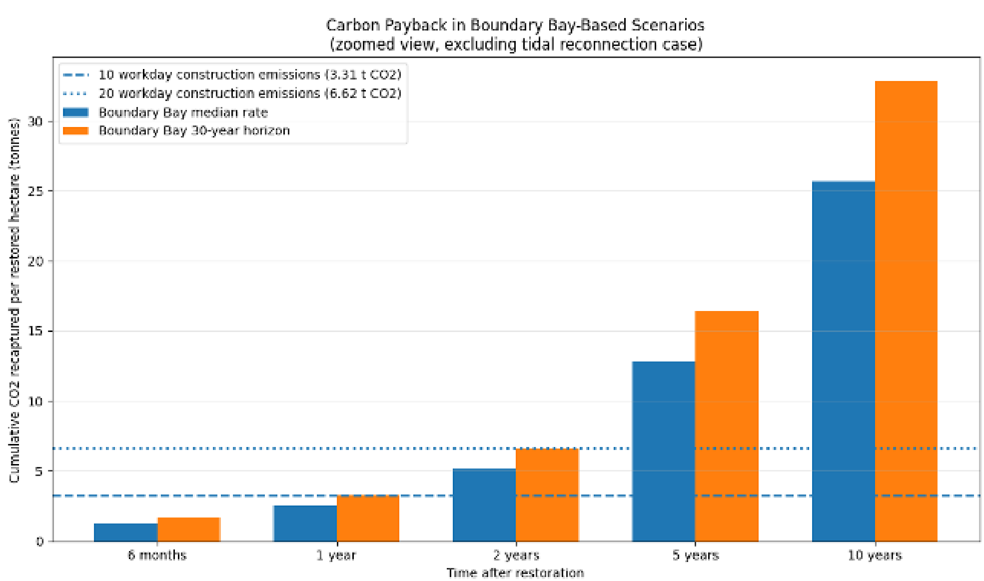

Figure 4: Author-generated figure showing only the two Boundary Bay-based accumulation scenarios, with the 10-workday and 20-workday construction-emissions lines retained for easier visual comparison. Values are standardized to 1 restored hectare.

The zoomed payback graph is where the argument becomes easier to read and harder to argue with. Once the oversized tidal reconnection case is stripped out, the two Boundary Bay scenarios show that even relatively conservative B.C. carbon-accumulation rates can overtake the estimated construction emissions on management-relevant timelines. Using the median Boundary Bay accumulation rate, a restored hectare would offset the 3.31 t CO_2 construction case in about 15.5 months and the 6.62 t CO_2 case in about 30.9 months. Using the stronger 30-year Boundary Bay rate, those payback windows tighten to about 12.1 months and 24.2 months. Those are coastal numbers, so I would not pretend they are a direct plug-and-play forecast for a Fraser freshwater floodplain. But they are still useful because they show the tempo of payback once a system is functioning again. And the freshwater literature in our own review points in the same direction. Napora et al. (2023) found that restored floodplain soils became wetter and stored more carbon, nitrogen, and phosphorus as restoration aged, with restored sites eventually outperforming even low-impervious “reference” streams. That is exactly the kind of trend Ducks Unlimited needs to lean on: the upfront emissions are real, but they are temporary; the restoration gains build with time if the hydrology is right (Gailis et al., 2021; Napora et al., 2023).

Put together, the case is strong. The Fraser literature gives the degraded baseline: diked, drained, simplified, and cut off from the wet floodplain processes that used to define the system. The freshwater restoration literature gives the direction of travel after intervention:

more wetness, more retention, more carbon, and better floodplain function. The broader payback analysis shows that the construction-phase carbon cost is not the headline; it is the entry fee. For Ducks Unlimited, the smart framing is that restoration is a net-positive floodplain investment. It reduces the long-term costs of keeping a system dry and disconnected, and it puts the site back on a trajectory where carbon storage, hydrologic function, and ecological value all improve over time. That is the comparison worth making, and on that comparison, restoration wins (Batson et al., 2015; Hinshaw & Wohl, 2021; Napora et al., 2023; Rosenau & Angelo, 2007).

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4.4 Climate Adaptation Co-Benefits

Wetlands are widely regarded as key nature-based solutions (NbS) when it comes to mitigating the environmental effects of climate change due to their status as carbon sinks but also because of their importance to the hydrological and biological functions of ecosystems (Goyette et al., 2023). Wetland restoration has the potential to return or strengthen these essential functions, leading to a number of climate co-benefits including flood mitigation, drought resilience, and biodiversity improvement.

4.4.1 Flood Mitigation

Wetlands contribute to flood prevention by storing excess water and reducing the power of stormflow while maintaining baseflow throughout the system (Ameli & Creed, 2019). These effects are achieved through both the presence of riparian vegetation as well as the waterlogged nature of wetland soils. Highly porous soils catch and store incoming flow from precipitation and nearby river systems (Ziemba, 2014). While wetlands have been associated with flood mitigation in many regions, climate change-driven storm events create conditions that exacerbate wetland loss with intense precipitation that often exceeds the mitigative capacity of the system (Ameli & Creed, 2019). Coastal floodplain systems play a particularly important role in mitigating flood risk due to projected sea-level rise, but their efficacy remains in question as climate variables continue to shift over time (Familkhalili et al., 2023).

Floodplain restoration has the potential to mitigate flood risk associated with storm surges even under projected increases in storm intensity due to climate change. Hydrological modeling can be used to predict the effects of wetland loss on flood mitigation under different climate scenarios. A 2019 study was able to use aerial imagery provided by DUC to model Alberta watersheds under different scenarios of wetland loss, determining that stormflow peaks can be reduced through restoring wetlands closer to first order streams (Ameli & Creed, 2019) for an overall reduction in flooding. Another paper examined the effectiveness of coastal wetland restoration in maintaining land cover under different sea-level rise scenarios by modelling and projecting the percent change in the land/sea cover ratio by 2100 (Familkhalili et al., 2023). Under the three projected SLR scenarios – intermediate, intermediate-high, and high – it was determined that restored coastal wetlands retain land cover for longer compared to degraded systems, but delayed wetland loss still occur. Overall, wetland restoration has short- and mid-term benefits for flood reduction while long-term effects remain uncertain due to unpredictable climate conditions.

4.4.2 Drought Resilience & Water Storage

Wetlands are essential in many hydrological systems for their water storage capacity which promotes drought resilience in regions across the world. As mentioned in the previous section, wetlands act to store excess water from stormflow and maintain baseflow within the hydrological system. Vague assumptions about drought risk resulting from wetland loss can be made using the knowledge that wetlands are an important regulator of baseflow, however, there are fewer academic studies available specifically related to the co-benefits of wetland restoration on drought resilience. The same paper that modelled stormflow in an Alberta watershed under different wetland loss conditions also examined how restoration in those areas would benefit drought resilience. The authors determined that while flood prevention requires restoration to occur in locations adjacent to rivers, drought resilience can be achieved by restoring wetlands at any point within the local watershed (Ameli & Creed, 2019). Another 2018 paper employed remote sensing technology and a multicriteria selection approach to determine the best locations for wetland restoration with the specific goal of mitigating the negative impacts of drought (Maleki et al., 2018). This study was the first of its kind to implement remote sensing imagery to guide practitioners in drought-resilient wetland restoration, and while the wetlands examined where in Afghanistan there is potential for the methodology to be applied to more relevant locations in Canada as well.

4.4.3 Biodiversity & Habitat Restoration

Wetland ecosystems are significant supporters of plant and animal biodiversity, accounting for 40% of all species on Earth despite only covering ~7% of the planet's surface (Wetlands International, 2022). Wetlands provide habitats for a wide range of species while also acting as migratory zones and connective channels for others. Loss of these systems contributes to a major decrease in global biodiversity for species ranging from invertebrates to birds to mammals (Wood et al., 2024). The 2022 Living Planet Report by the World Wildlife Foundation found that between 1970 and 2018, freshwater biodiversity experienced a decline of up to 83% as a result of habitat loss including wetlands (WWF, 2022).

One of the greatest risks to wetland species posed by habitat loss is an inability to adapt to other conditions. The aquatic nature of wetlands requires species to adapt both behaviourally and physiologically to waterlogged, anoxic conditions (Wetland Conservancy, 2026). In reptiles and amphibians, this can present as physical characteristics such as webbed feet or as subtle evolutionary traits like respiratory systems that function in oxygen-depleted systems (Batzer et al., 2025). Wetland plants, known as hydrophytes, are specially adapted to grow in waterlogged conditions (Queensland Government, 2021). These wetland-specific adaptations make it incredibly difficult for these species to relocate and thrive in new environments if the wetland habitat is lost or destroyed (Gibbs, 2001). Restoration does not always involve constructing or altering the morphology of a wetland; in some cases, a wetland ecosystem may be threatened by invasive plants or aquatic species. In British Columbia's wetlands, these species can include yellow flag iris (*Iris pseudacorus*) and purple loosestrife (*Lythrum salicaria*) (Nicholas, 2015), which are considered priority invasive species by the Province of British Columbia as of January 2026.

Wetland restoration has been shown to have a variety of benefits for ecosystem health and biodiversity. Some identified main outcomes of wetland restoration on species diversity include providing areas of connectivity between freshwater and terrestrial habitats and creating more areas suitable for reproduction (Hagger et al., 2022). A 1997 restoration project in the Fraser River, British Columbia, found that transplanted marshes had a species richness among fish nearly identical to those of natural (undisturbed) wetlands (Levings & Nishumura, 1997). A similar result was seen with amphibians in the Okanagan Valley, B.C., where small ponds were either constructed or restored to determine whether at-risk amphibious species would colonize these environments as a replacement for lost wetland habitats. The study found that 86% of the constructed/enhanced ponds were successfully colonized by Great Basin spadefoot frogs, allowing them to thrive and reproduce (Ashpole, 2015). Another restoration project in the Tl'chés watershed developed a comprehensive plan to remove invasive species which accounted for ~43% of total plant cover in the wetland. The intention of the project is to restore native biodiversity and increase the water storage capacity of the wetland (Nicholas, 2015). The projected outcome of this restoration would see the watershed return to pre-disturbed conditions in which invasive European species do not outcompete native flora and fauna for key resources.

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5.0 Synthesis

5.1 How do carbon emissions and sequestration differ among natural, restored, and diked floodplain systems?

When you look across all three systems, the biggest thing driving the differences in carbon emissions and sequestration is hydrology — it really is the key factor that ties everything together. Natural floodplains are consistent long-term carbon sinks, sequestering somewhere in the range of 100 to 300 g C m^{-2} yr^{-1} through regular sediment deposition, organic matter inputs, and the slow decomposition that comes with waterlogged, anoxic soils (Mitsch & Gosselink, 2015; Kayranli et al., 2010). They do produce methane through methanogenesis under those saturated conditions, but the long-term carbon accumulation generally outweighs those emissions (Bridgham et al., 2013). Diked floodplains are basically the opposite story. Cutting off hydrological connectivity limits organic inputs, promotes aerobic soil conditions, and speeds up decomposition — turning these systems into net carbon sources rather than sinks (Knox et al., 2015; Deverel & Leighton, 2010). Lower methane emissions in diked systems do not come close to offsetting the CO_2 losses from degrading soils. Restored floodplains sit somewhere in between, and where exactly depends on how far along recovery has gotten. Right after rewetting, emissions can actually go up as oxidized soils saturate and microbial activity picks up (Moreno-Mateos et al., 2012), but over time, restored systems move in the right direction — Hinshaw and Wohl (2021) documented carbon stocks rising from 437 to 528 Mg C/ha at Deep Creek and from 225 to 500 Mg C/ha at the South Fork McKenzie after restoration. That is not a small difference. For Ducks Unlimited, the takeaway is clear —

keeping floodplains diked and drained is not a neutral choice, but an ongoing carbon cost, and the literature is consistent on that.

5.2 What are the carbon costs associated with wetland restoration activities?

The carbon costs that come with restoration activities are real, but they are finite, and that is the important thing to keep in mind. The most direct source of emissions during a project is the diesel-powered heavy machinery needed for earthmoving and site preparation. Based on a conservative two-machine scenario with one Cat 336 excavator and one Cat D3 dozer running three hours per day, combined daily emissions come in at around 331.2 kg CO_2 — adding up to roughly 3.31 t CO_2 over a 10-workday project and 6.62 t CO_2 over 20 workdays (Caterpillar Inc., n.d.). Those are lower-bound estimates that do not account for hauling, equipment delivery, or any additional machinery on site. Beyond the machinery itself, the earthmoving and construction phase — excavation, grading, channel reconfiguration — carries its own upfront carbon cost, and the more material that needs to be moved, the bigger that cost gets (Batson et al., 2015). But again, these emissions happen once. A successfully restored wetland starts accumulating carbon after the machines leave, and that accumulation keeps building over time. Using B.C.-specific rates from Boundary Bay, a restored hectare would offset the 3.31 t CO_2 construction case in about 15.5 months and the 6.62 t CO_2 case in roughly 30.9 months under median accumulation, tightening further under stronger sequestration scenarios (Gailis et al., 2021). The upfront carbon cost is the entry fee to get the site back on the right trajectory — it is not the argument against doing it.

5.3 Under what conditions does wetland floodplain restoration provide carbon mitigation and long-term sequestration of carbon and other greenhouse gas emissions?

The literature is clear that restoration delivers real, lasting carbon benefits when the right conditions are in place, and the most important one by far is genuine hydrological reconnection. Without it, the processes that drive carbon accumulation — sediment deposition, organic matter inputs, waterlogged anoxic conditions — just do not come back. Restoration efforts that successfully reconnect floodplains to natural flow regimes, like those at Bummers Flats and Moberly Marsh in British Columbia, show exactly what is possible when that foundation is in place (Ducks Unlimited Canada, 2020). Time is the other big factor. Restored floodplains are variable in the short term and will often act as carbon sources right after rewetting before making the shift to net sinks as vegetation re-establishes and sediment inputs build up (Moreno-Mateos et al., 2012; Nahlik & Fennessy, 2016). Napora et al. (2023) found that restored floodplain soils got progressively wetter and stored more carbon as restoration aged, eventually outperforming reference streams — which is exactly the kind of long-run trend that makes the investment worthwhile. Site conditions also play into it; how degraded the site was to begin with, soil type, vegetation history, and restoration design all influence how quickly recovery happens. For the Fraser River context, Rosenau and Angelo (2007) lay out just how far degradation has gone — dikes, drainage ditches, pump stations, over 100 km of blocked secondary channels, and the full draining of Sumas Lake. The more disconnected and drained a site has gotten, the longer the road back, but the carbon argument for leaving it alone gets weaker the longer that degradation continues (Batson et al., 2015). Coastal systems are worth noting separately — salinity suppresses methane and tidal processes drive rapid carbon burial, making blue carbon restoration highly efficient when the conditions line up (Mcleod et al., 2011; Chmura et al., 2003). All in all, restoration hits its strongest carbon outcomes when hydrology is genuinely restored, vegetation is given time to come back, and the site is assessed over a long enough window to capture the full sequestration gains.

5.4 Knowledge Gaps

While the literature reviewed here gives a solid foundation for evaluating carbon dynamics across floodplain systems, there are a fair few gaps worth flagging for Ducks Unlimited going forward. Long-term, site-specific carbon monitoring data from British Columbia freshwater floodplains is still fairly limited, which makes it difficult to apply sequestration rates from comparable regions without some degree of uncertainty (Nahlik & Fennessy, 2016; Hinshaw & Wohl, 2021). Methane flux data from restored freshwater floodplains — particularly in that transitional window right after rewetting — is also inconsistent across studies, which makes net greenhouse gas accounting more complicated than sequestration figures alone would suggest (Bridgham et al., 2013; Moreno-Mateos et al., 2012). More field-based research in B.C.-specific systems, paired with longer post-restoration monitoring windows, would go a long way toward tightening the carbon accounting that Ducks Unlimited can actually rely on.

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6.0 Conclusion

This report demonstrates that carbon dynamics in floodplain systems are primarily controlled by hydrology, time, and management, rather than restoration status alone. Natural floodplains function as stable long-term carbon sinks due to continuous sediment inputs and saturated soil conditions that slow decomposition, while diked floodplains represent a persistent carbon cost driven by hydrological disconnection, soil oxidation, and reduced carbon inputs. Restored floodplains often have short-term increases in greenhouse gas emissions following rewetting but progressively recover their carbon storage capacity as vegetation re-establishes and sediment deposition resumes. Across all systems, hydrology has shown to be the dominant control, influencing both greenhouse gas emissions and long-term carbon sequestration outcomes.

Although wetland restoration generates short-term carbon emissions during construction, these impacts are finite and are outweighed by long-term gains in carbon storage and avoided emissions. When evaluated over appropriate time scales, restored floodplains consistently demonstrate net climate benefits while also supporting broader ecosystem functions, including flood mitigation, water storage, and biodiversity enhancement.

For Ducks Unlimited Canada, the key implication is that maintaining diked and degraded floodplains is not a neutral option, but an ongoing environmental cost. In contrast, restoring hydrological connectivity provides a clear pathway toward long-term carbon sequestration, improved ecosystem resilience, and more sustainable floodplain management.

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Appendix A

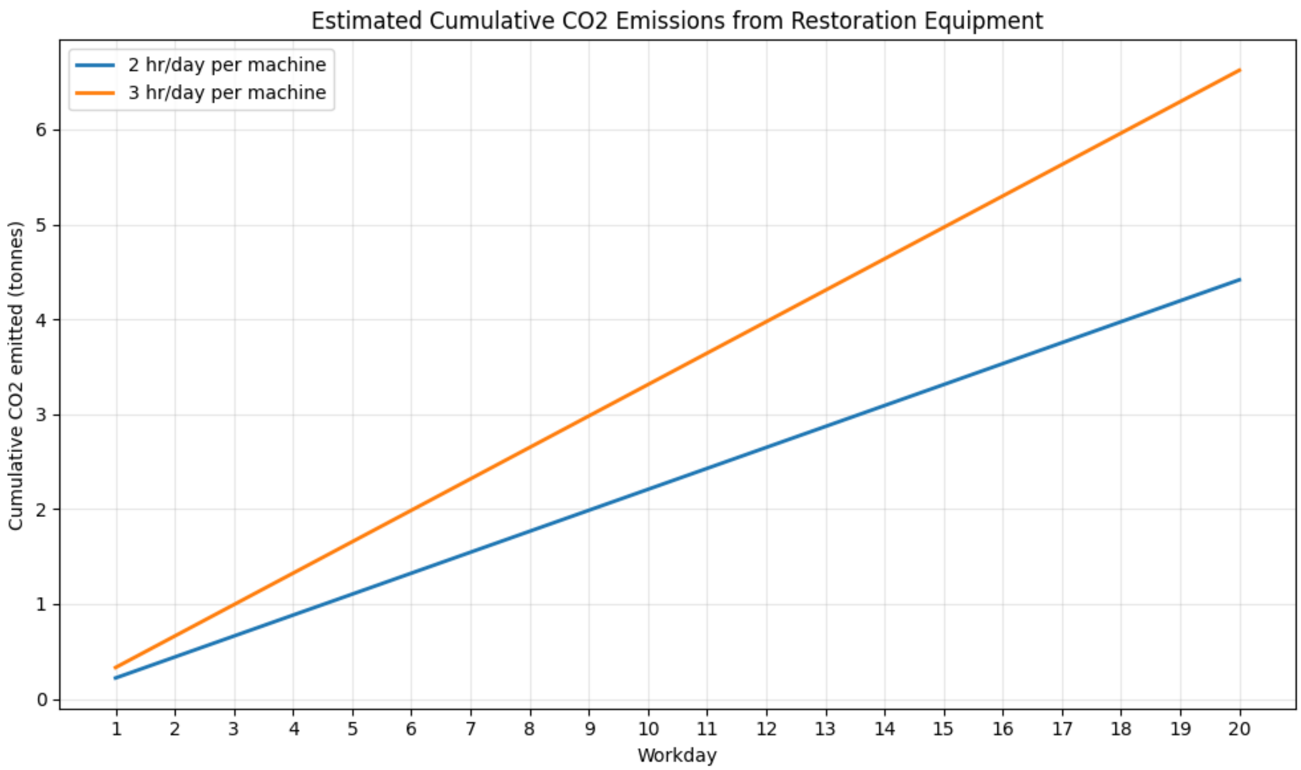

Figure 1: Estimated Daily Carbon Emissions from Heavy Machinery by Operating Hours

This figure was author-generated based on estimated carbon emissions data pulled directly from manufacturer specifications provided by Caterpillar Inc. for the Cat 336 excavator and Cat D3 dozer. The figure shows how daily CO_2 emissions scale with the number of hours each machine operates over the course of a workday, giving a pretty clear picture of just how quickly construction emissions add up depending on how long equipment is running on site (Caterpillar Inc., n.d.).

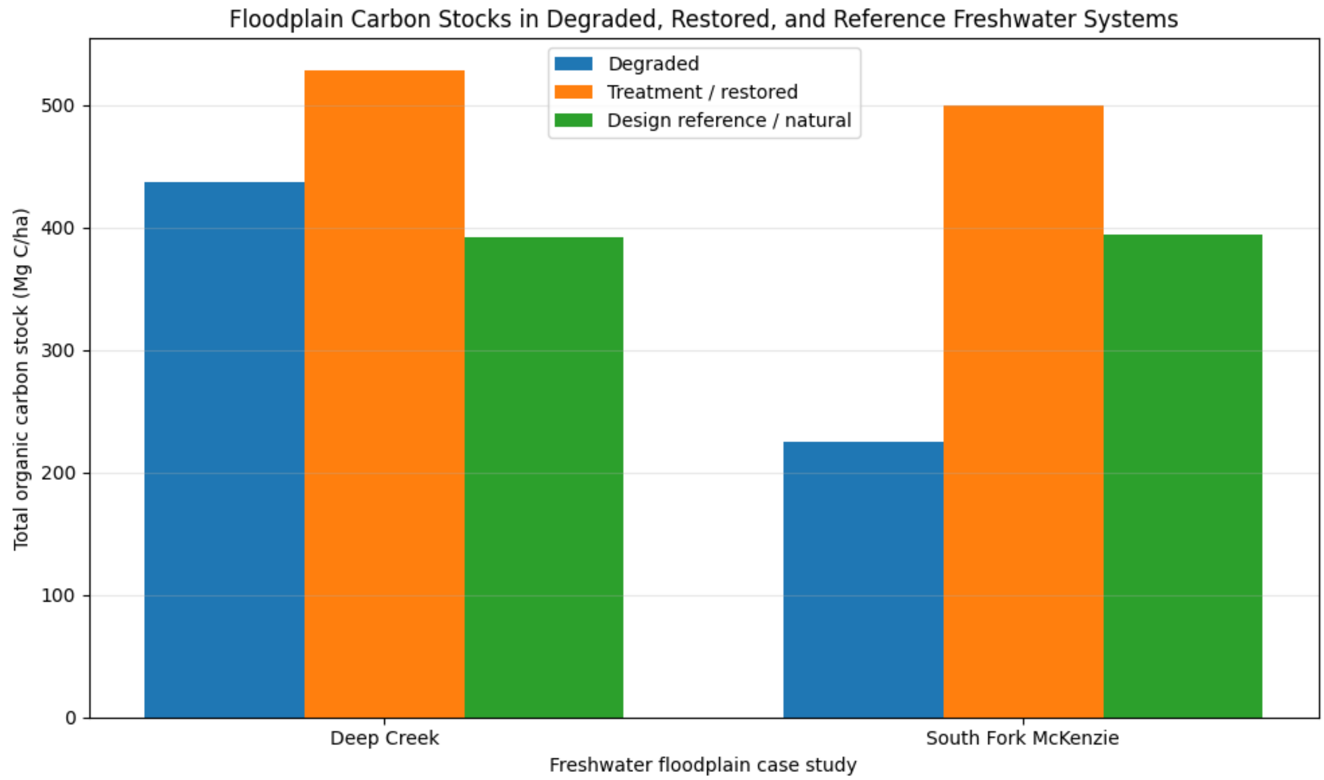

Figure 2: Total Organic Carbon Stock Comparison Across Degraded, Restored, and Reference Floodplains

This figure was author-generated based on total organic carbon stock data reported in Table 3 of Hinshaw and Wohl (2021). It compares carbon stocks across degraded, treatment/restored, and design reference floodplains at two case study sites — Deep Creek and the South Fork McKenzie River — with all values reported in Mg C/ha. The comparison does a good job of showing just how significant the carbon gains are once a floodplain goes through restoration, and it is one of the more compelling figures in the report for making that argument to Ducks Unlimited (Hinshaw & Wohl, 2021).

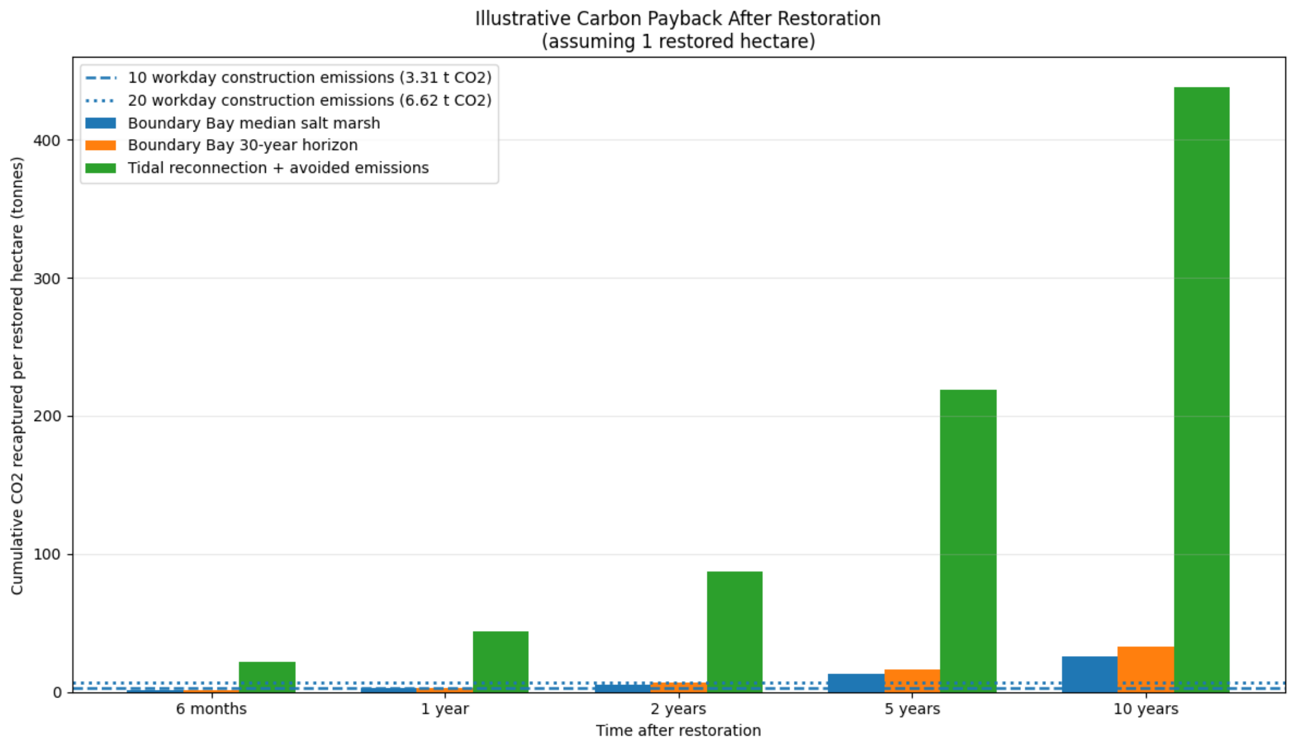

Figure 3: Cumulative Post-Restoration Carbon Recapture vs. Construction Emissions Per Restored Hectare

This figure was author-generated and compares cumulative carbon recapture per restored hectare against the estimated construction emissions from a higher-use machinery scenario — one excavator and one dozer each running three hours per day — producing 3.31 t CO_2 over a 10-workday project and 6.62 t CO_2 over a 20-workday project. The restoration trajectories shown are built from the Boundary Bay median accumulation rate, the Boundary Bay 30-year horizon rate, and a tidal reconnection plus avoided-emissions scenario, giving a fairly thorough look at the range of payback timelines a restored site might realistically follow (Gailis et al., 2021; Hagger et al., 2022).

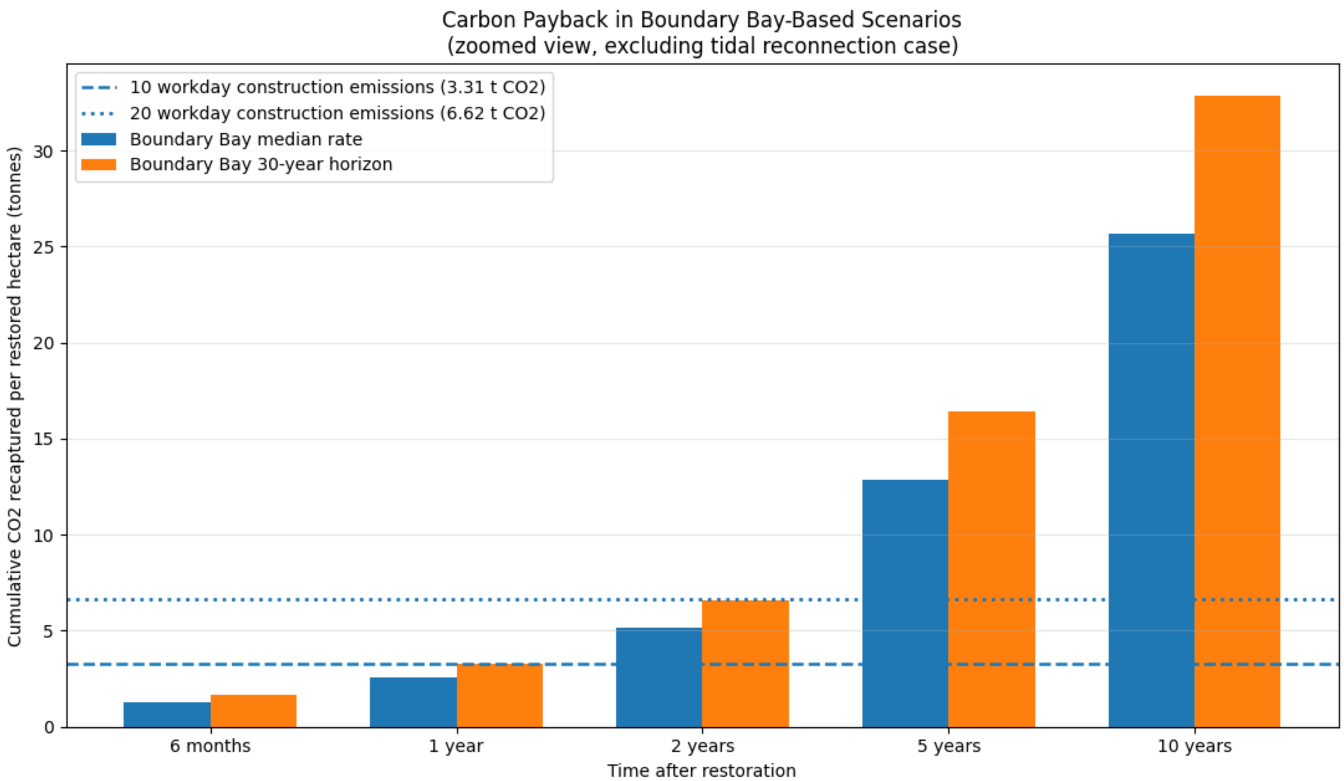

Figure 4: Zoomed Payback Comparison Using Boundary Bay Accumulation Scenarios

This figure was author-generated as a cleaner, more focused version of Figure 3, stripping out the tidal reconnection scenario to make the comparison easier to read. It shows only the two Boundary Bay-based accumulation scenarios plotted against the 10-workday and 20-workday construction emission lines, with all values standardized to one restored hectare. Pulling out the oversized tidal case makes the payback timelines a fair bit easier to follow and drives home the point that even relatively conservative B.C.

accumulation rates can overtake construction emissions on timelines that are actually relevant to land management decisions (Gailis et al., 2021).

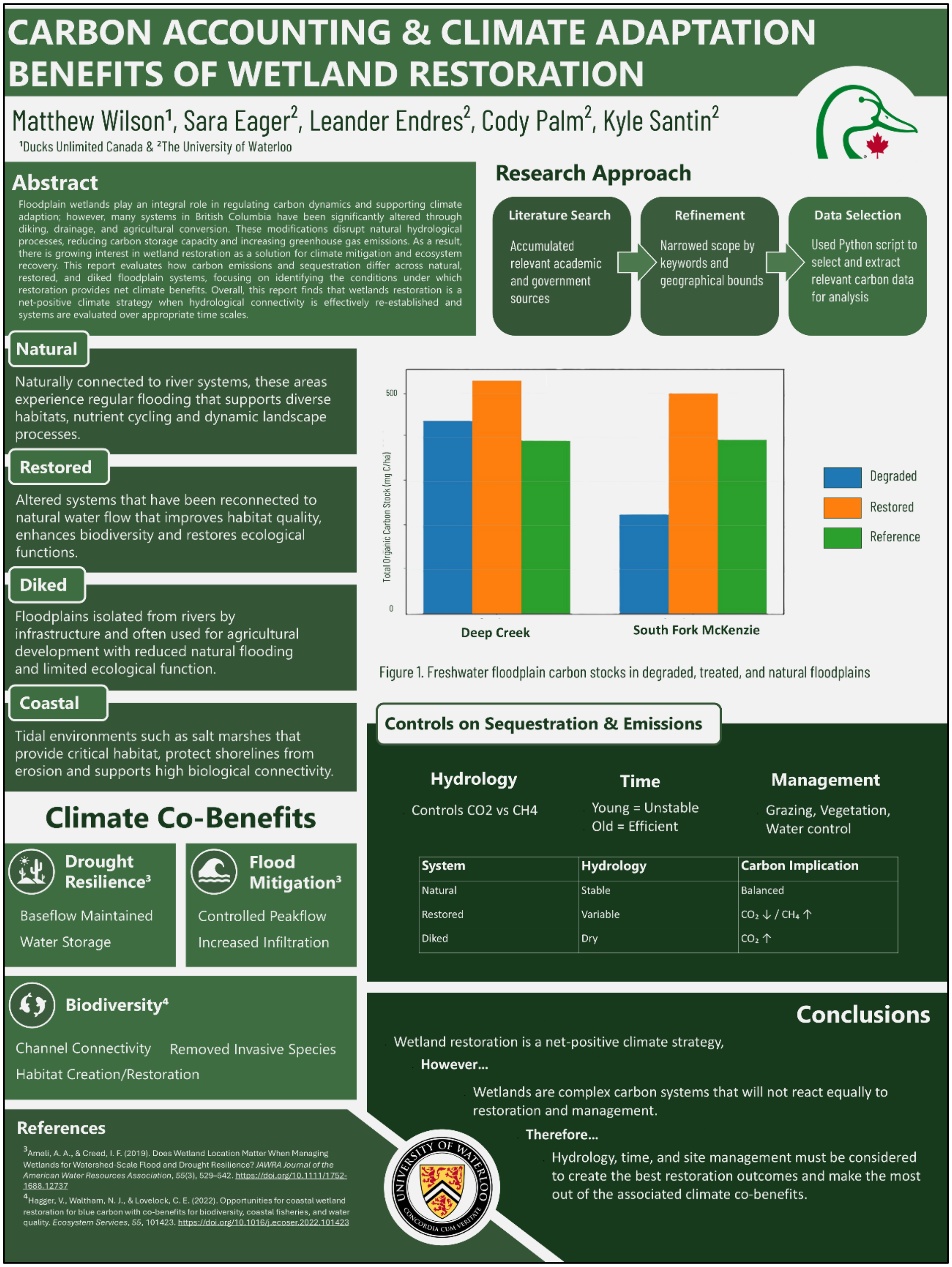

Figure 5. Infographic developed for Ducks Unlimited Canada based on information from this report and presentations for GEOG 405.