Chapter 3: Isolated-Wetland Contribute Little to Stream Carbon but Support Lateral Carbon Export: Mapping the Carbon Cycle in “Wetlandscapes”.

Landscape hydrology predicates that hydrologic and biogeochemical changes in one region of a watershed have the potential to cascade across the entire basin (Winter, 1980). Through the lens of landscape hydrology, the watershed is viewed as a singular, system, encompassing micro-ecosystems that collectively contribute to the basin’s distinct biogeochemical and hydrologic fingerprint (Winter, 1980.). However, the relevance of "landscape hydrology" is watershed specific, dependent on the basin's connectedness or how water flows and is stored between inland waters (Evenson et al., 2018; McLaughlin et al., 2014; Mitsch et al., 2013). This landscape "connectedness" is largely dependent on wetland area, namely geographically isolated wetlands (GIWs) density (Evenson et al., 2018; McLaughlin et al., 2014; Zarnetske et al., 2018). GIWs disrupt the flow of watershed runoff. Instead of flowing down elevation and being exported to streams, runoff is intercepted and held within GIWs (Evenson et al., 2018). Here, it is either released into the atmosphere, stored within the watershed, or exchanged with the local surficial aquifer (SAq). Through this wetland-aquifer exchange, GIWs modulate the SAq by sourcing and receiving groundwater, buffering flow extremes, and dictating downstream baseflow (Evenson et al., 2018; McLaughlin et al., 2014). The SAq acts as a vector for hydrologic connectivity, facilitating transport between inland waters even in the absence of overland connectivity. Thus, the chemical and hydrologic fingerprint of a landscape results from the "wetlandscape," or the energy exchange between the SAq and inland waters.

GIWs are global hot spots; the anaerobic conditions, long residence times, and extended hydroperiods of GIWs encourage the re-mineralization and storage of carbon (Saunois et al., 2016) while simultaneously exporting processed waters downstream through groundwater or overland flow ("spill-and-fill") (Abril & Borges, 2019; Raymond et al., 2016). However, in the literature, direct observations estimate GIWs' contributions to stream carbon is small. Only 15-30% of total stream carbon is sourced by GIWs, with the remainder assumed to be sourced from riparian wetlands (Casson et al., 2019; Solano et al., 2024; Zarnetske et al., 2018). These studies, though useful for finite carbon budgeting, undermine GIWs' role in global carbon cycling by (1) sampling from overland, intermittent flow paths while excluding subsurface export, and (2) failing to interrogate GIWs' influence on watershed-level carbon export. Despite model estimates, current research has not directly explored the cumulative impacts of landscape hydrology on carbon export, particularly concerning carbon cycling. As mentioned, GIWs modulate the surficial aquifer, performing an ecological function that is integral to the broader energy and water dynamics within the “wetlandscape (Evenson et al., 2018; Leibowitz et al., 2018; Zarnetske et al., 2018).” Energy exchange through the wetlandscape functions as a chain reaction: water and its contents runoff into GIWs, where they diffuse into the surficial aquifer. The surficial aquifer then exports water to riparian wetlands and streams as baseflow (Evenson et al., 2018; McLaughlin et al., 2014) (FIGURE #). These interactions determine downstream water quality, surface-groundwater exchange, watershed inundation, and carbon export and storage. While the surficial aquifer acts as the transport network of the wetlandscape, GIWs serve as its "capacitors (McLaughlin et al., 2014)." Even as soils dry, GIWs can sustain the surficial aquifer and its streams into the early seasons of drought. The longer the watershed remains inundated, the greater the potential for carbon storage in wetlands and carbon export to streams.

For the third chapter of my dissertation, I will estimate both direct and indirect carbon contributions from GIWs to streams by longitudinally sampling for DIC, DOC, and POC from three BEF streams within basins of various wetland densities. Thus far in my PhD, I will have explored stream carbon temporal dynamics and RC fluxes in fluctuating hydrologic settings. By coupling my longitudinal sampling results with the findings from Chapters 1 and 2, I can isolate the influence of isolated wetlands. Assuming RC fluxes and stream productivity responses to fluctuating discharge are homogeneous throughout the reach, I can investigate how nearby GIWs influence stream carbon as water accumulates downstream. Research has yet to observe GIW carbon contributions, and none have included observed RC fluxes in addition to stream metabolism models. I hypothesize:

1. I hypothesize that each stream will gain carbon, increasing in DIC, DOC, and POC as water flows downstream.
2. Although I expect depressional wetlands to directly contribute to the stream carbon, I hypothesize the RC will remain the dominant carbon source.
3. However, during flooded conditions, I anticipate GIW contribution will be greatest due to a shallower surficial aquifer and overland flow.
4. Lastly, I expect streams in watersheds with greater wetland areas to have higher total carbon (TC) concentrations across wetland, RC, and stream boundaries.

By synthesizing my results from Chapters 1 and 2 with my results from Chapter 3 I aim to holistically map stream carbon sources and fluxes, allowing me to draw detailed inferences on low-relief, “wetlandscape” carbon budgets. By testing these hypotheses and developing a carbon budget, I aspire for this chapter to offer both an improved understanding of low-relief carbon cycling and practical applications. Specifically, my objective for Chapter 3 is to inform management decisions on how to optimize landscape hydrology for carbon storage.

Methods:

*Sites:*

As mentioned, BEF's low-relief terrain fosters a dense cluster of GIWs that support an extensive surficial aquifer (SAq), serving as a transport network between GIWs and streams. For this chapter, I will longitudinally sample streams 5, 6, and 9, which have RC wells from Chapter 2 and high-frequency sensor packages from Chapter 1. Sampling locations will depend on the UCA estimate (see Chapter 2: Methods) and ease of access.

*Sampling and processing:*

Streams will be longitudinally sampled during various discharge conditions to encapsulate the hydrologic landscape under changing flow regimes. Each sampling location will be tested for DOC, DIC, POC, and FDOM. Point-CO2 measurements will not be recorded due to time-of-day dependency; instead, high-frequency CO2 readings from the Chapter 1 sensor package will be used as the assumed reach average. Point-pH and temperature readings will be recorded for potential CO2 interpolation and quality control.

FDOM, DIC, DOC, and POC processing will follow the methods outlined in Chapter 1. FDOM results from Chapters 1, 2, and 3 will be used to investigate carbon quality changes as it is exported across aquatic boundaries.

*Data Analysis and Carbon Budgeting:*

Synthesizing my results from Chapters 1 and 2, and assuming RC carbon fluxes have an identical relationship along the entire stream channel, sources of stream carbon will be parsed. Using the UCA analysis conducted in Chapter 2, all carbon samples (DOC, DIC, and POC) and CO2 recordings will be transformed into fluxes. By subtracting RC fluxes from the longitudinal estimates, the remainder is assumed to be sourced from GIWs. The BEF belongs to a confined aquifer unit; therefore, deeper groundwater seepage can be considered negligible.

*Statistical Analysis:*

To test hypothesis 1, that streams will gain in carbon as water flows downstream, a simple linear regression between the length of the stream and the sample location will be conducted. Similarly, to test hypothesis 3, GIW exports will be greatest during floods, a linear regression between estimated GIW-sourced carbon and discharge will be used. Additionally, to test hypothesis 4, that streams with more "wetlandscapes" will have higher total stream carbon (mol/L) across RC and GIW sources, stream carbon will be regressed with discharge. Lastly, to explore hypothesis 2, the RC will nonetheless contribute more significantly to stream carbon, I will use a ternary plot between riparian carbon (RC – ER), respiration carbon, and estimated GIW carbon to observe changes with fluctuating flow regimes during high discharge.