Chapter 1: Temporal and spatial carbon dynamic in Flatwood, Blackwater Streams: the Chimney-Reactor Pendulum

* Streams link terrestrial and marine environments, transporting, storing, and transforming terrestrial carbon before it reaches the world’s oceans.
* Terrestrial carbon enters small, low-order streams and accumulates in large, high-order rivers before eventually discharging into coastal marshes.
* Traditionally, this transport from low to high-order streams and rivers was viewed as passive, with minimal biogeochemical activity.
* Currently, streams and rivers are understood to play an active role in global carbon cycling. Less than half of terrestrial carbon inputs reach the oceans; the rest is mineralized or stored as water flows toward the coast.
* Furthermore, the total stream carbon flux is often greater per unit area than that of the surrounding terrestrial uplands. Despite only half of terrestrial carbon entering streams, CO2 emissions from global streams are equivalent to terrestrial net ecosystem productivity creating an imbalance between carbon inputs and stream carbon outputs.
* This imbalance creates major uncertainties in regional and global carbon budgets with stream carbon sources debated within the literature.
* From a global perspective, this gap is attributed to CO2-rich groundwater inputs degassing from the stream channel. However, other sources, such as riparian or internal carbon production, are insufficiently explored nor the processes that drive these fluxes.
* An area of stream carbon that is inadequately researched but increasingly vital is the contribution of low-order, headwater streams to global carbon cycling.
* Small streams encompass less than 1% of Earth’s terrain yet drain ~75% of watersheds and are the largest portion of all rivers and streams.
* Small, low-order streams are hypothesized to streams play a disproportionately active role in global carbon cycling.
* Smaller headwater catchments have higher DOC concentrations the high-order, downstream waters, and 36% of stream and river CO2 is predicted originate from small streams (0.93 Pg-C/yr).
* However, CO2 emissions and carbon dynamic with headwater streams are severely, insufficiently explored.
* Most research endeavors investigate carbon dynamics in stream four orders or higher, overlooking first, second, and third order, often perennial, flowing waters.
* Yet numerous models have predicted gas transfer velocity and stream area has negative relationship.
* These models estimate CO2 emissions from stream order 1-3 are concentration three times the global stream average and potentially drastically underestimating global stream CO2 emissions.
* Small streams have the potential to majorly influence global carbon cycling relative to the area they occupy but these estimates are largely preliminary.
* Observed estimates of small stream carbon fluxes, and the processes and mechanisms driving the high biogeochemical activity, are relatively few and largely speculative.
* This partially due to most headwater streams located in remote, undeveloped areas, making remote sensing delineation challenging and access energy intensive. Additionally, scaling limitations, especially for gas exchange rates and discharge estimates in “infinitely small,” perennial streams, create inaccuracies that hinder comprehensive global estimates.
* Carbon that enters high-order streams, like oceans, is the byproduct of numerous biogeochemical reactions across meters to kilometers of low-order streams. The processes in low-order streams that have transformed into higher-order stream carbon is unknown.

*What is understood, but nonetheless poorly constrained, is that stream carbon is fated for two pathways: the chimney or reactor pathway.*

* *The chimney pathway involves the passive transport of externally sourced carbon (predominately from soil or groundwater) that exits the stream through CO2 degassing with minimal downstream transport.*
* *In contrast, the reactor pathway involves the mineralization of organic carbon through respiration or anaerobic processes, producing CO2 as a byproduct.*
* *As mentioned, more CO2 is degassed from streams then what terrestrial inputs and internal production (the reactor pathway) can account for.*
* *Therefore, this “gap” within stream carbon budgeting is “filled” with chimney carbon, assumed to be sourced from groundwater inputs*
* *However, the reactor pathway, the internal production of carbon via mineralization, in itself is poorly constrained with publications contributing anywhere from 12% to 40% of total stream carbon to stream respiration, nor have other external sources been investigated*
* *The prominence of each pathway depends on the spatial and temporal factors linked to landscape hydrology.*
* *Seasonal changes, like temperature and precipitation, can enhance the rate of biogeochemical reactions while perennial flow regimes impacting residence times with high flows disrupting the streams’ ability process carbon.*
* *Dually, landscape slope, soil permeability, and wetland area impact lateral, overland, and subsurface carbon export, modulating the reactors pathway influence.*
* *Soil carbon is known to mobilize when the surficial aquifer level, and Kirk and Cohen 2020 observed the chimney pathway dominated in unconfined watershed whereas reactor pathways contributed 94% of stream carbon in confined watersheds.*
* *Streams swing between chimney and reactor states dictated on the hydrologic landscape temporal and spatial fluctuations.*
* For my first chapter, I will investigate carbon temporal and spatial dynamics within low-order, flatwood streams over-multi annual time scales, focusing on the response to flow extremes seasonal fluctuations and landscape hydrology.
* To explore these dynamics, I have selected nine remote, flatwood streams within Bradford Experimental Forest (BEF), and their higher-order receiving river (The Sampson River) to deploy high-frequency, long-term sensor packages containing CO2, dissolved oxygen (DO) and methane sensors.
* Most stream carbon studies rarely include high-frequency data especially on multi-annual scale, creating uncertainties in stream carbon dynamics across time.
* However, the advent of high-frequency, durable sensors—many of which are cost-effective and efficient—presents an opportunity to observe carbon dynamics across seasonal fluctuations, disturbances, and "hot moments."
* In addition to high-frequency observations, I will collect monthly samples for dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), and particulate organic carbon (POC).
* For this chapter, I aim to parse stream-carbons seasonal and flow-induced fluctuations into the reactor and chimney pathways, a perspective rarely explored in current literature.
* I hypothesize that (1) the chimney pathway dominates in flatwood streams, but the reactor pathway becomes more prominent during baseflow conditions when residence times are longer, and external contributions are minimal.
* I also expect (2) streams in basins with greater wetland areas have more influential chimney pathways whereas streams in basins with less wetland area exhibit a more prominent reactor pathway.
* Lastly, I hypothesis (3) the low-order streams will have greater carbon concentrations (DOC, DIC, and POC) than its receiving higher-order river due to burial, biogeochemical activity, and passive degassing.
* My objective for the research is provide greater insight into headwater, low-order stream contributions to regional, as well as global carbon cycling, and provide evidence on how landscape hydrology can influence stream carbon dynamics

Methods: