CO_2 Flux From Grassland Headwater Streams

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Introduction

Problem:

- Headwater streams often have a high gas transfer velocity(k) due to turbulence caused by shallow depths and higher velocities (Generaux & Hemond, 1992).
- Intermittent rivers account for more than half the length of rivers and streams in the United States and globally. Despite this they are often underestimated by remote sensing techniques, and left out of large studies due to difficulty in characterizing them (Datry & Tockner, 2014).
- Groundwater is supersaturated in CO_2 . In baseflow driven streams the CO_2 equilibrates with the atmosphere.
- Rivers in the temperate areas of the continental United States are estimated to release around 0.5 Pg C to the atmosphere each year (Butman & Raymond, 2011).
- Increasing carbon dioxide inputs into streams fed by groundwater can have significant effects on in stream pH which further affects stream biology, metal mobilization (Choi et al., 1998), and other chemical processes in the stream.

Importance:

- **Quantifying the rates involved in shallow aquifer storage could be crucial to determining long-term accurate carbon budgets.**

Previous Research

- The Konza Prairie Long-Term Ecological Research Site and Biological Station (Konza) has shown a steady increase in the concentration of CO_2 dissolved in groundwater over the last several decades (Macpherson et al., 2008)
- Groundwater often provides baseflow discharge to perennial streams at the Konza (Steward et al., 2011) which allows the supersaturated baseflow to equilibrate with the atmosphere.
- Measurements of gas exchange rates between water and the atmosphere are important, but are error prone (Datry & Tockner, 2014) and often neglect aspects of local hydrology.
- Many calculated measurements using stream velocity and depth have proven inaccurate in shallow turbulent streams (Genereaux & Hemond, 1992)
- Chemical tracers have been used in multiple studies for small streams, but this method is costly and time consuming (Morse et al. 2007), and requires a stream reach where little or no groundwater inflow occurs (Hauer, 2007 & Kilpatrick et al, 1989).

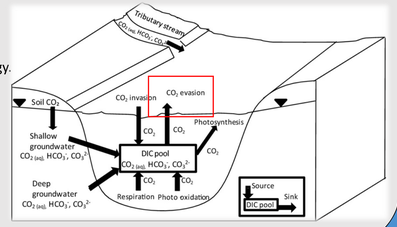
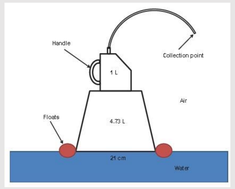


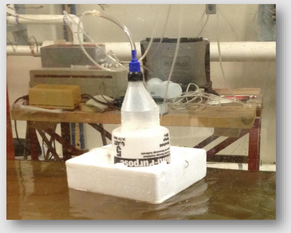
Diagram of carbon dioxide movement through streams from Wallin 2011

Floating Chamber

The floating chamber method may provide an accurate method of measuring gas transfer velocities in shallow streams, and will take into account groundwater inputs and complications from local hydrology. It has been used in a variety of gas studies in lakes, oceans, estuaries, and streams, but has not been thoroughly tested to evaluate critiques (Cole et al., 2010) of the technique in streams. We tested a floating chamber design in a laboratory simulated stream environment.



Schematic of the floating chamber from Liu et al., 2013



Chamber based flux measurements(calculated below) were taken at multiple velocities and compared to flume-based fluxes over the same reach. The chamber is attached to a recirculating infrared gas analyzer to obtain a continuous measurement of CO_2 in the chamber.

$$F_{CO2} = k\,(C_{water} - C_{air})$$

*F_{CO2} is carbon dioxide flux from the water surface, k is the gas transfer coefficient(L/T), C_{water} is the CO_2 concentration in the water, and C_{air} is the CO_2 concentration in the atmosphere above the water

Consider, k = f(turbulence)

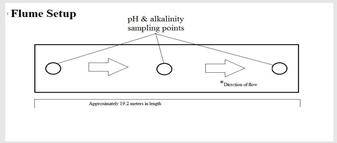
Artificial Stream(Flume)

The University of Kansas Water Resources Laboratory flume system simulates a simplified headwater stream environment. The flume has a recirculating water system with a constant head tank supply of water that feeds to a 0.76 m x 19.2 m channel. Diffusing CO_2 into the water reservoir system simulates a supply of supersaturated groundwater, and precise measurements of discharge are allowed in the controlled environment of the flume.

Water Resources Laboratory Large Flume

Flume-based Flux:

Dissolved CO_2 was determined by measuring pH, alkalinity(HCO_3^-), and temperature at the upstream and the downstream portion of the flume(below). The measurements taken, with known reaction constants to the reaction series show below, determined dissolved CO_2 levels.



$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

$$Flume\ Based\ Flux = \left(\frac{\Delta CO_2(\text{flume length})}{(\text{Surface area})}\right) \div Avg.Residence\ Time$$

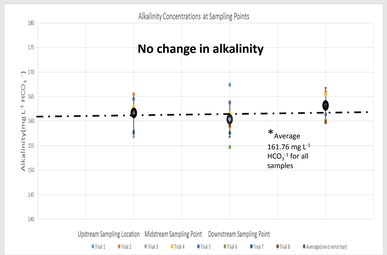
Precise measurements of hydraulic geometry and discharge are taken

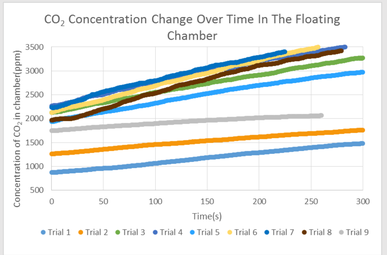
Chamber-based Flux: All of the floating chamber based measurements demonstrated an expected positive slope with a strong correlation ($R^2 > 0.95$) as the concentration in the chamber increased over time due to degassing from the CO_2 supercharged stream. Using the equation from Alin et al.(2011) we calculated a chamber-based flux for each trial. The slopes did not correlate well to increases in flume velocity (below).

$$Chamber\text{-}based\ Flux = \left(\frac{dC(CO_2)}{dt}\right)\left(\frac{Chamber\ Volume}{(R * Temperature * Surface\ Area)}\right)$$

Results: Alkalinity, CO_2 Degassing, or both?

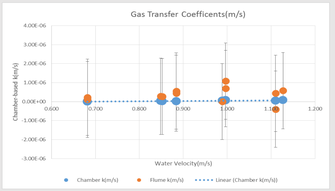
We can assume that pH changes are induced by flux of CO_2 into or out of the flume water. Alkalinity(HCO_3^-) remains constant throughout the study and does not change over the length of the flume. Since we know the water is supersaturated with CO_2 we assume that calcite and other minerals are under saturated (due to it being treated water).

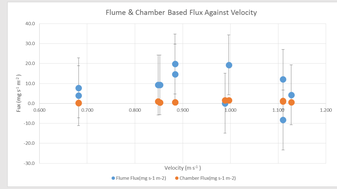


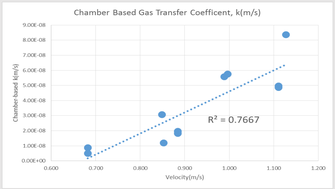


Results: Flux & Gas Transfer Coefficients

The chamber-based flux measurements shown in the figure below(left) fall within a reasonable estimate of the flume-based flux measurements. Normalizing for the concentration gradient between the water and air, and calculating the gas transfer coefficient(k)(figure on top right) also provides values consistent between the flume and chamber methods . The k values also increase with increasing velocity(bottom right) as would be expected.







Conclusions

Further trials are needed to confirm the initial trend displayed in the above results. The results of laboratory experiments indicate that the floating chamber method may provide an adequate means of measuring gas flux in a headwater stream environment. This measurement technique could prove a crucial component to determining the impact of headwater streams and shallow groundwater in the global carbon cycle.

Future Research

- Further comparison using gas transfer coefficients to normalize the data is needed. To do this we need to account for atmospheric CO_2 changes that occur over the duration of the experiment that affect the degassing rate for the entire flume.
- More in flume testing at different velocities, and with different chamber designs is needed. In particular, testing of the suspended chamber design used by Crawford and others in 2013 will conducted.
- If lab work shows promise, side by side comparison with a tracer study in the field at the Konza will be conducted sometime in the future.

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