Design of a low-cost floating flux chamber to quantify emissions from small urban waterbodies

Conception d'une chambre de flux flottante à faible coût pour quantifier les émissions provenant de petits plans d'eau urbains

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RÉSUMÉ

Les petits plans d'eau urbains artificiels (PEUs), tels que les bassins de gestion des eaux pluviales, les lagunes d'eaux usées et les carrières réhabilitées, sont des infrastructures courantes dans de nombreuses collectivités. Alors que les efforts mondiaux pour quantifier les émissions de gaz à effet de serre (GES) s'intensifient, les PEU ont été identifiées comme des sources potentielles de dioxyde de carbone (CO_2) et de méthane (CH_4). Une chambre de flux flottante à faible coût avec des capteurs de CO_2 et de CH_4 en temps réel a été conçue et construite avec des pièces imprimées en 3D et des matériaux de quincaillerie pour 1150 $ CA afin de résoudre les problèmes associés aux méthodes de surveillance typiques, tels que la contamination des échantillons, la faible fréquence d'échantillonnage et la négligence de la variabilité spatiale. Les capteurs ont été calibrés et validés en laboratoire en injectant des volumes connus de gaz et en les comparant à des échantillons de seringue analysés par chromatographie en phase gazeuse (CPG), rapportant 99,62 % (R^2 = 0,9950) et 99,22 % (R^2 = 0,9987) des valeurs mesurées par la CPG pour le CO_2 et le CH_4, respectivement. La chambre a été déployée dans un bassin d'atténuation à Almonte, en Ontario, le 20 août 2025 afin de calculer le flux de CO_2 dans une PEU réelle. Des relations exponentielles et linéaires ont été appliquées aux concentrations enregistrées, donnant des flux de 28,12 mg m^2 min^{-1} et 22,19 mg m^2 min^{-1}, respectivement. Des essais supplémentaires seront réalisés avec la chambre de flux au printemps 2026 afin de déterminer la variabilité spatiale des émissions dans les PEUs.

ABSTRACT

Human-made small urban waterbodies (SUWs), such as stormwater management ponds, wastewater lagoons, and reclaimed quarries, are common infrastructure assets throughout many communities. As global efforts to quantify greenhouse gas (GHG) emissions intensify, SUWs have been identified as potential sources of carbon dioxide (CO_2) and methane (CH_4), although there is large variation in the way emissions are measured. A low-cost floating flux chamber with real-time CO_2 and CH_4 sensors was designed and constructed with 3D-printed parts and hardware store materials for $1,150 CAD to address problems associated with typical monitoring methods, such as sample contamination during syringe sampling, failing to capture the true flux due to low sampling frequency, and neglecting spatial variability due to the high cost of GHG analyzers. The sensors were calibrated and validated in the laboratory by injecting known volumes of gas and comparing with syringe samples analyzed using gas chromatography (GC). Validation experiments showed that the real-time sensors reported 99.62% (R^2 = 0.9950) and 99.22% (R^2 = 0.9987) of the values the GC measured for CO_2 and CH_4, respectively. The chamber was deployed in an attenuation pond in Almonte, Ontario, on August 20th, 2025, to provide proof of concept and calculate CO_2 flux in a real SUW. Exponential and linear fits were applied to the recorded concentrations, giving fluxes of 28.12 mg m^2 min^{-1} and 22.19 mg m^2 min^{-1}, respectively. Additional field tests will be performed with the flux chamber in Spring 2026 to determine how emissions vary spatially across SUWs.

KEYWORDS

Greenhouse gas emissions, low-cost floating flux chamber, real-time sensors, small urban waterbodies (SUWs), stormwater management

1 INTRODUCTION

Small urban waterbodies (SUWs) have been identified as sources of carbon dioxide (CO_2) and methane (CH_4), even as municipalities use them to manage stormwater and build climate resilience. Holgerson & Raymond (2016) estimated that while small ponds (surface area of less than 1,000 m^2) represent only 8.6% of the global surface area of lakes and ponds, they account for 15% of all CO_2 and about 40% of all diffusive CH_4 emissions from lentic freshwater sources. As SUWs continue to gain popularity, it is important to accurately quantify their emissions, as they may be a significant yet underrecognized source of GHG emissions. While calculating emissions from waterbodies has been performed for decades, there is a large variation in measurement techniques which can therefore produce different results.

Historically, closed static chambers were placed on a waterbody and gas samples drawn with a syringe every five to ten minutes for 30 to 60 minutes (Weishampel & Kolka, 2008). However, this introduces an opportunity for sample contamination during the collection, transportation, and processing (Livingston & Hutchinson, 1995) of the syringes as they are returned to the laboratory and analyzed using gas chromatography (GC). Gas analyzers have been developed recently to provide high-frequency sampling (e.g. every second) at a high sensitivity (e.g. 1 ppb) but can cost tens of thousands of dollars and are likely limited to a single trial at a time due to their high cost, making it unlikely more than one analyzer is owned (Rodriguez-Garcia et al., 2023).

Real-time sensors placed directly inside the chamber were proposed as a solution to remove the potential errors associated with sampling, increase the sampling rate, and allow for more chambers to be deployed simultaneously without huge cost implications, thus allowing research on spatial variability. The objectives of this study were to (i) design and construct a low-cost floating flux chamber with real-time CO_2 and CH_4 sensors, (ii) validate that the system performed accurately in the laboratory, and (iii) deploy the flux chamber onto an attenuation pond to calculate the flux from a SUW.

2 METHODOLOGY

2.1 Flux Chamber Design and Calculations

A flux chamber was designed using 3D-printed parts and hardware store materials to simplify construction (Figure 1 (a)). The total cost to build the system was $1,151 CAD. An ExplorIR-M CO_2 sensor, INIR-ME100% CH_4 sensor, SCCRDNT 1.6BAA3 silicon pressure sensor, DS18B20 1-wire digital thermometer, and a small fan were placed on the inside of the chamber lid to record the real-time change in CO_2 and CH_4 concentration, pressure, and temperature over time. The chamber was placed in a hole cut into a polyethylene board to float on the surface of the SUWs and allow emitted gases to accumulate in the chamber. An electronics box containing a Raspberry Pi, LCD screen to display the concentrations, and a battery pack was also placed on the floating board. The flux of gases from the water surface was calculated using Eq. 1 (Dai et al., 2015):

$$J = \frac{dC}{dt}\frac{V}{A} \text{ [Eq. 1]}$$

Where J is the flux (mg m^{-2} d^{-1}), $\frac{dC}{dt}$ is the change in concentration over time using a linear or exponential approach (depending on the fit of the data), V is the chamber volume (4,184.38 cm^3), and A is the surface area of the chamber (314.16 cm^2). To give traditional flux units of mg m^{-2} d^{-1}, the ideal gas law and molecular weight must be applied; hence, the pressure and temperature inside the chamber were also recorded.

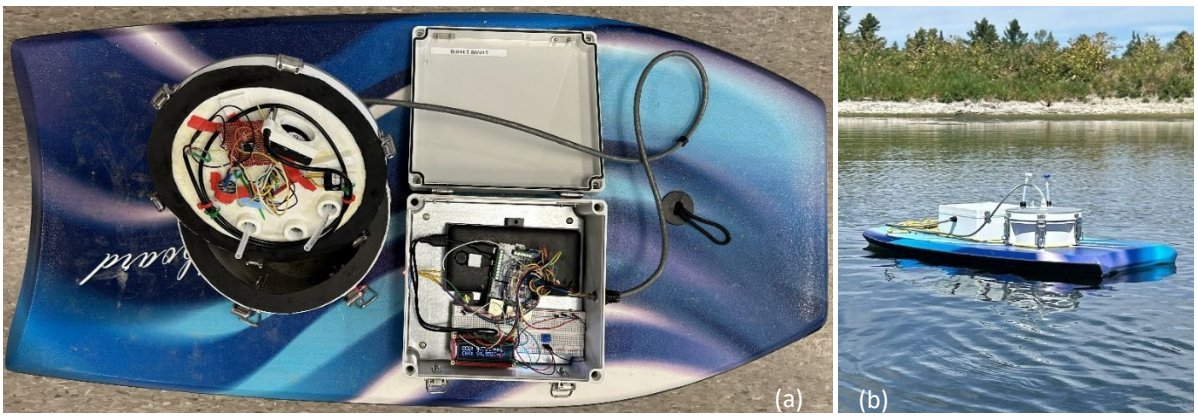

Figure 1: (a) the assembled flux chamber and electronics box on the floating board and (b) the floating flux chamber deployed in an attenuation pond

2.2 Laboratory Calibration and Validation

Calibration and validation experiments were performed in the laboratory to ensure that the flux chamber worked in a controlled environment before deployment in the field. Known quantities of gas were injected into the chamber (2 mL of pure gas every 5 minutes for a total of 12 injections using a gas-tight syringe with needle into a septum port in the chamber lid) and samples drawn (3 mL drawn, 3 minutes after an injection) to compare the concentrations reported by the real-time sensors with those reported by a GC (Scion 8500 GC with three thermal conductivity detectors). Triplicate tests were performed for each of CO_2 and CH_4 and calibration curves created from the pooled results (38 and 39 pairs of sensor and GC concentrations for CO_2 and CH_4, respectively). The same experiment was performed with the calibration curves applied to each sensor to validate their performance. The pressure and temperature sensors were validated using other sensors in the laboratory.

2.3 Field Deployment

The floating flux chamber was deployed on August 20th, 2025, in an attenuation pond at the Mississippi Mills Wastewater Treatment Plant in Almonte, Ontario (Figure 1 (b)). While the pond was only used during overflow events at that time, sludge was still present at the bottom, and small bubbles, plant matter, and algae were noted. For the purpose of this abstract, one CO_2 trial was selected for presentation. A shallow (0.8 m deep) lentic location was chosen to minimize wind effects and increase the likelihood of detecting emissions. A kayak was used to paddle to the selected area, and a rope and anchor were used to maintain the deployment spot. The sensors were turned on 15 minutes prior to the experiment commencement, and a sampling frequency of 1 Hz was selected to maximize data collection. An eighth-order Butterworth filter with a cutoff frequency of 0.01 Hz was applied using Matlab to smooth the sensor noise.

3 RESULTS AND DISCUSSION

3.1 Sensor Validation

The results of the validation experiments are given in Figure 2, showing the concentration reported by the GC plotted against the concentration recorded by the sensor. The 1:1 line (black) demonstrated that the trends between the GC and the sensors were very close, as shown by the slopes of 0.9962 (R^2 = 0.9950) and 0.9922 (R^2 = 0.9987) for CO_2 and CH_4, respectively, indicating that the real-time sensors reported 99.62% and 99.22% of the value the GC measured. A multiple linear regression model was performed on the validation results to determine if the slopes reported by the GC and the sensors were statistically different. The interaction between time and measurement method had a p-value of 0.899 and 0.803 for CO_2 and CH_4, respectively, indicating that there was no significant difference ($p > 0.05$) between the slopes reported by the GC and the sensors and that the calibrated real-time sensors accurately measure concentration.

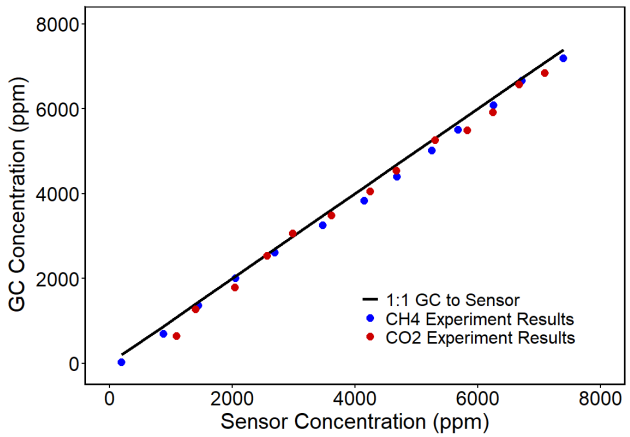

Figure 2: Laboratory validation results for CO_2 (red) and CH_4 (blue)

3.2 Field Results

The system was run for 86 minutes. The Butterworth-smoothed sensor data with a frequency of 1 Hz and 60-second average (rounded to the nearest recordable concentration) sensor concentration every 30 minutes ("Sensor Point Concentration") are given in Figure 3 (a). An initial spike in concentration was noted in the first two minutes, prompting an investigation into the flux immediately after lid closure (Figure 3 (b)).

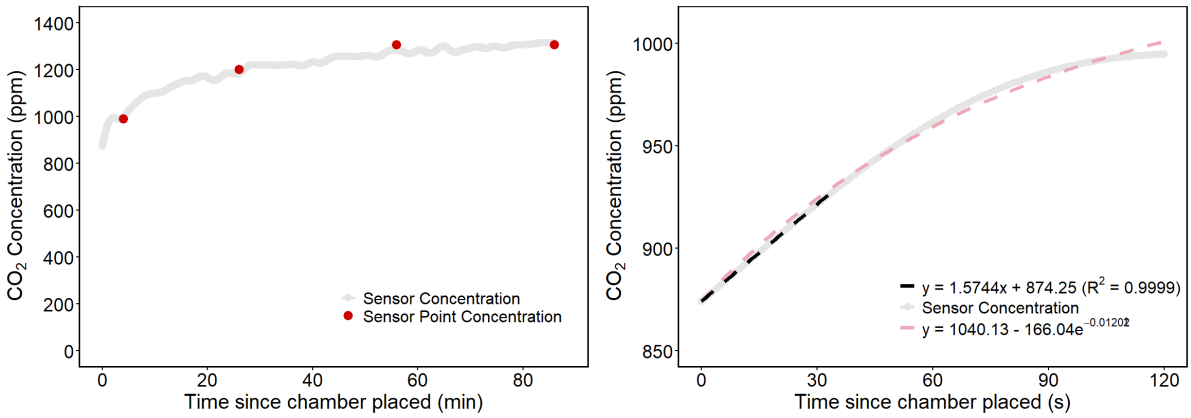

Figure 3: Butterworth-filtered CO_2 sensor concentration (light grey) with (a) the 60-second averaged sensor point concentration every 30 minutes for the 86 minutes the chamber was deployed and (b) a zoom in on the first 120 seconds, with the linear trend from 0 – 35 seconds (black) and the exponential trend from 0 – 120 seconds (pink)

An exponential curve was fit to the Butterworth-filtered data for the first 120 seconds, which was when the concentration began to approach an asymptote as the concentration in the chamber approached equilibrium with the water. The initial slope was found to be 1.995 ppm per second. Linear regression was performed for the first 35 seconds, as this was the limit to where the concentration increased linearly, producing a value of 1.574 ppm per second (R^2 = 0.9999). The initial pressure in the chamber was 0.987 atm and the temperature was 27.0°C. The flux calculated using the exponential and linear fits were 28.12 mg m^{-2} min^{-1} and 22.19 mg m^{-2} min^{-1}, respectively. For the duration of the deployment (86 minutes), this totaled 2,418 mg m^{-2} and 1,908 mg m^{-2}. If the fluxes were scaled to the estimated surface area of the pond (78,800 m^2), the amount of CO_2 released throughout the experiment totaled 191 kg by exponential fit and 160 kg by linear fit (-21.1% difference).

However, scaling from an area of 0.031416 m^2 to 78,800 m^2 is likely not good practice when fluxes from no other locations are known. This is an important benefit of this low-cost flux chamber, as many chambers can be constructed and simultaneously deployed across SUWs, resulting in larger spatial coverage for a much lower cost. In addition, the flux occurred in the first 120 seconds, which syringe sampling every 5 to 10 minutes would have failed to capture.

4 CONCLUSIONS AND FUTURE WORK

A floating flux chamber was designed, constructed, validated in the laboratory, and deployed in the field to measure CO_2 and CH_4 emissions from SUWs for $1,150 CAD. It is the authors' aim that this flux chamber will be used by researchers and municipalities to further the understanding of how SUWs can be an effective tool against the impacts of climate change while themselves contributing to the emissions that cause it. The system will be used in the extensive monitoring of several SWM ponds in Ottawa, Ontario to gain more insight into CO_2 and CH_4 emissions. A study of how emissions vary spatially across SWM ponds, particularly at the inlet, sediment forebay, main wet cell, and outlet, will be carried out in Spring 2026 and presented at the conference. Future work will include how emissions vary for ponds with different water quality levels (such as DO, turbidity, and specific conductivity, both at the surface and using depth profiling) and how emissions differ between SWM ponds with different characteristics and features (such as age and depth).

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