Flow Distribution in the Container ABR

SUSTAINABLE SANITATION IRES 2015

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ABSTRACT

This paper describes the tracer test conducted at the Anaerobic Baffled Reactor (ABR) of the Decentralised Wastewater Treatment System (DEWATS) of the Newlands-Mashu site. Each chamber of street 1 and street 2 contains the same amount of water (estimated to be 3,000 L), but have different properties such as water to solids ratio that might affect the flow rate of the chamber. Few motivations of this project includes: analyzing how the flow on each chamber differ, to analyze the flow rate of the ABR, to determine if there was a significant difference in the removal of COD, and to determine the performance of the ABR under a high hydraulic loading. This project utilized fluorescein and lithium based tracers to determine the flow distribution inside the ABR chambers. The goal of this project is not only to study the flow of water throughout the streets but also to compare the two tracers. The methods used in this experiment include fluorescence for the fluorescein tracer and the concepts of hydraulic retention time (HRT) and mass balance. Some interesting findings from this research includes the change of the flow pattern between the streets from the month of May to July. The concentration readings of the fluorescein is always greater in the inlet of the chamber than the outlet. The tracer test implications in the engineering field is that it is used to monitor the flow at each stage of a system. The flow data acquired can then be use to study different parameters in the system that are affected by flow rate.

INTRODUCTION

The ABR of Newlands-Mashu site consist of 3 streets. The first and second streets contain seven chambers and the third street consist of only 4 chambers. The first 3 chambers of Street 3 are double the size of the other chambers. The chambers on street 1 and street 2 are estimated to carry a water volume of about 3000 liters but they vary in dimensions and properties such as the wastewater to sludge ratio, giving each chamber a unique flow distribution.

Flow rate is an essential factor because the upflow rates determine the contact time between the microbial sludge, this affects the amount of the total solids that degrades to volatile solids. Flow rate also has an influence to the degradation of the organic matter in the system which has an effect on the correlation between particulate and the soluble COD. Initially when the ABR system was still in development, one of its research phase involves using the same flow rate to determine if there was a significant difference in the quality of the effluent between the two identical streets and the third street with larger ABR compartments. (Mwale and Pillay, 2014).

A series of tracer tests were conducted to study the flow of water in each of the chamber. Tracers are compounds or isotopes that can be used to outline flow paths and estimate time of travel (USGS). An ideal tracer is easily detectable, flows with the water, does not chemically react, and does not alter the properties of the water (Soeder, 2011). Fluorescent dye and Lithium ion based tracers were used in this experiment.

Fluorescein tracer has a maximum excitation of 492 nm, maximum emission of 513 nm, is cheap, and binds with the microbial sludge. According to the EPA tracer test design guidelines, fluorescein has "*low toxicity, relatively conservative behavior and a high degree of accuracy of analysis*" (EPA). One disadvantage of using fluorescein sodium tracer is that it tends to "photodecay", so excess exposure of the tracer to sunlight may affect the total mass recovery.

Lithium tracer on the other hand does not absorb onto sludge particles, does not intercept with anaerobic bacteria, and would not be taken as a nutrient by microorganisms (Anderson et al., 1991; Tomlinson and Chambers, 1979). In addition, the recovery rates of lithium based tracers are also generally greater than those reported for fluorescent dyes or biological spores (EBS). Disadvantages of the lithium base tracer are that it's more expensive and more toxic.

Sampling tracers presents difficulty depending upon the behavior of the tracer. Some of the knowledge gaps prior to starting the experiment include questions like: how will the binding of the fluorescein with the microbial sludge affects the fluorimeter reading? How will the flow rate affect the tracers? How consistent is the flow rate of the ABR?

The concentrations of the tracers used for the experiment were based on the detection limits of the equipment used to analyze them. The concentration of the fluorescein tracer used was 5 mg/L and the concentration for the lithium base tracer was 100mg/L. Data for fluorescein was gathered using an in-situ set-up of the fluorimeter. For the lithium tracer, grab samples were taken and were brought in the lab to be analyzed using a spectrophotometer. The theoretical principle used in this project is the concept of theoretical retention time. The goal of this study is to analyze the flow distribution in each chambers of the ABR. Identify how the varying flowrates on each chamber affects the quality of the effluent of the ABR.

METHODS

A pattern of flow data was analyzed before a tracer test was started. Because the flow meter was not accessible to read the exact flow rate at the exact moment, theoretical hydraulic retention time (HRT) were calculated using a very recent flow data. HRT was calculated using the equation:

$$\text{Theoretical Retention Time: } \frac{\text{V } (liters)}{\text{Q } (l/hr)} = \text{HTR (hr)}$$

Where Q (liters/hour) is the flow rate acquired from a very recent flow data and V is the estimated volume of each chamber = 3000 L.

Fluorescein Sodium and Lithium Bromide tracers were used on this test.

Fluorescein Sodium

1 L of 5 mg/L of fluorescein sodium tracer were injected in the inlet of the chamber in every experimental run. The Geomagnetism Group University of Neuchatel Fluorimeter (GGUN-FL) was set up to catch the initial peak at the inlet of the chamber at about 160 cm deep from the surface where it logs data every 10 seconds. Once the initial peak was catch and the concentration readings were continuously decreasing, the fluorimeter was moved to the outlet of the chamber. The fluorimeter set up is shown in Figure 1.

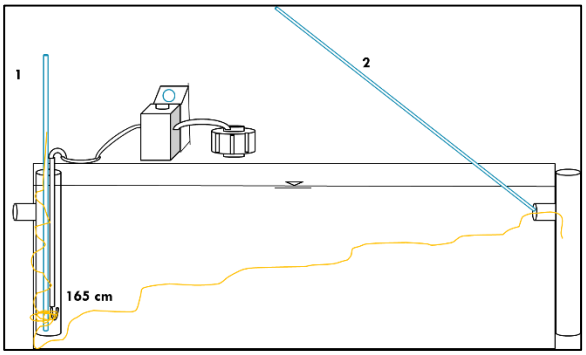

Figure 1: Schematics of the Fluorimeter setup

The fluorimeter was moved around the inlet and outlet of each chamber. On Wednesday (15/07/15), the fluorimeter was left over night and was set to do readings every 30 seconds.

Lithium Bromide

For the lithium tracers, 1L of 100 mg/l of the lithium bromide tracer were injected in the inlet of the chamber in every experimental run. Samples were taken using an improvised grab sampler. Nine 10 ml samples were taken every 2 hours at the first day of the lithium tracer test. Samples were taken at different sections and depths of the chamber. This sample plan was decided so that the dead zones and the movement of the tracer can be analyzed.

The sample plan was changed the next day. Instead of sampling in 9 different sections, it was changed to 3 sections of the chamber and the sampling integration time was changed to every 30 minutes. The samples were kept in the fridge and were brought to the lab the next day to be analyzed. Samples that were gathered from the bottom of the chambers had high sludge content and had to be put in the digester first. The Microwave Plasma Atomic Emission Spectrophotometer (SMP-AES) was set up to detect the lithium concentrations in each samples at wavelength ~670 nm. Both sample plans for the lithium tracer are shown in figures 2 and 3.

Sampling duration for the lithium tracer varies but generally, samples were collected 3-4 times before the theoretical retention time.

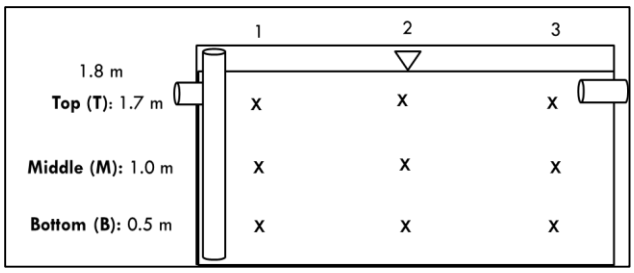

Figure 2: Sample Plan #1 to identify the route that the lithium tracer took

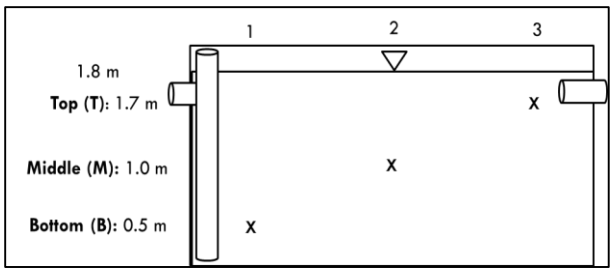

Figure 3: Sample Plan #2 for lithium tracer

After the data were gathered, time vs concentration graphs were plotted for both the tracers.

RESULTS

Flow rate data

One of the interesting findings in this study is that during the months of May and June street 1 had a higher flow rate than streets 2 and 3. But in July, street 3 started having the highest flow rates as shown in figures 4a-4c.

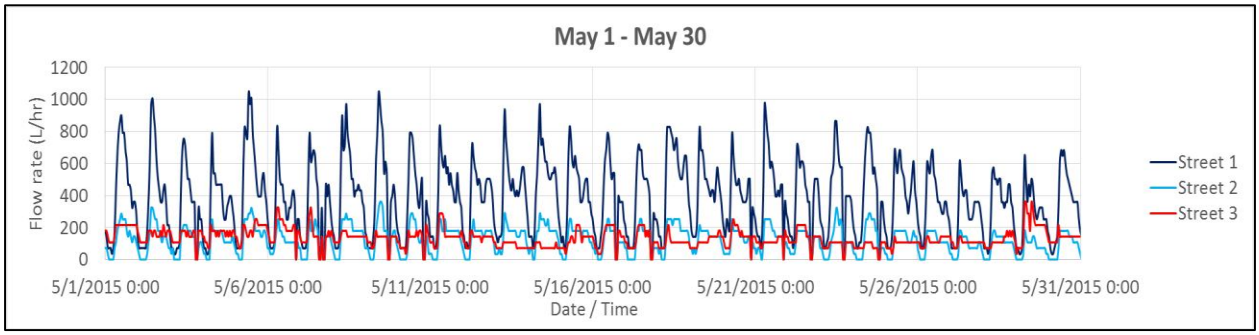

Figure 4a: Flow pattern for May

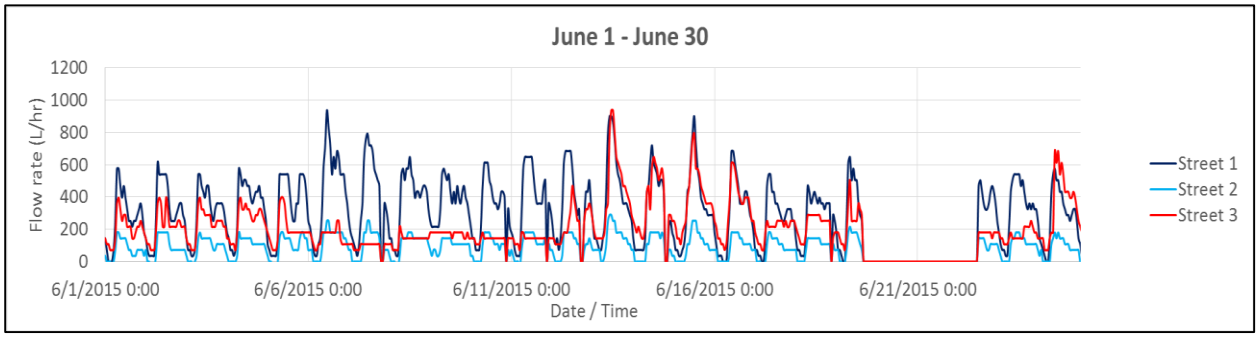

Figure 4b: Flow pattern for June

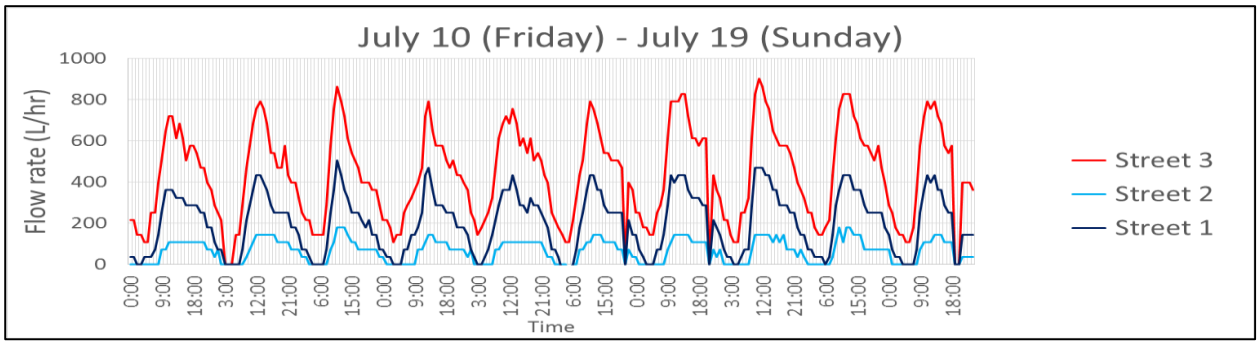

Figure 4c: Flow pattern for July 10 - 19

Calibration

Calibration data for the fluorimeter.

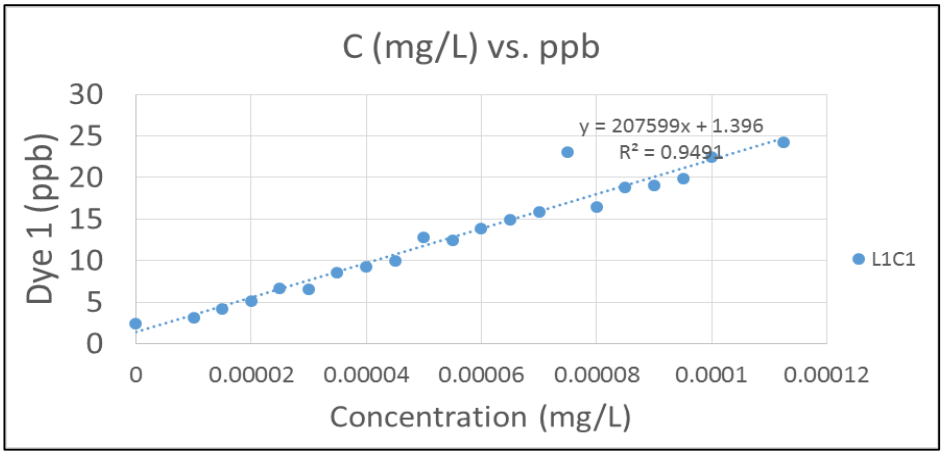

Figure 5: Calibration curve for the GGUN-FL fluorimeter using the fluorescein dye.

Fluorescein Sodium

Data From: July 13, 2015

The tracer was injected at 11:00 am and the fluorimeter was reading at 1.60 m of the inlet to catch the initial peak. Fluorimeter was set up to do readings every 10 minutes and was changed to every 10 seconds.

Findings: it takes about 1 hour and 40 minutes for the fluorescein to travel about 160 cm in the inlet because it peaked at around 13:39:42 with a concentration of 17.51 ppb.

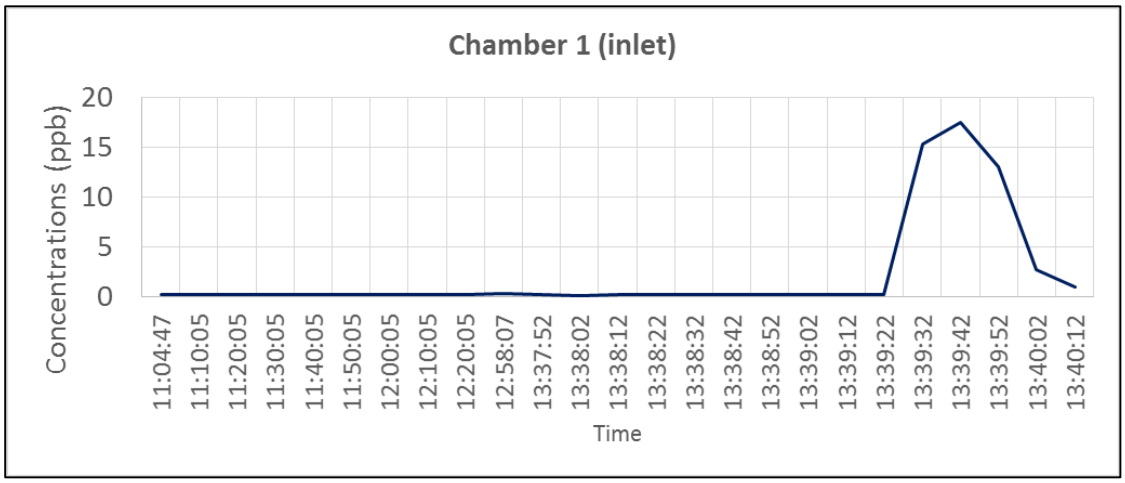

Figure 6: Catching the initial peak of the fluorescein tracer at the inlet of chamber 1.

At the outlet, it peaked with 2.6 ppb at 14:42:52. It stopped reading fluorescein at around 15:50 with lowest concentration at 0.19 ppb.

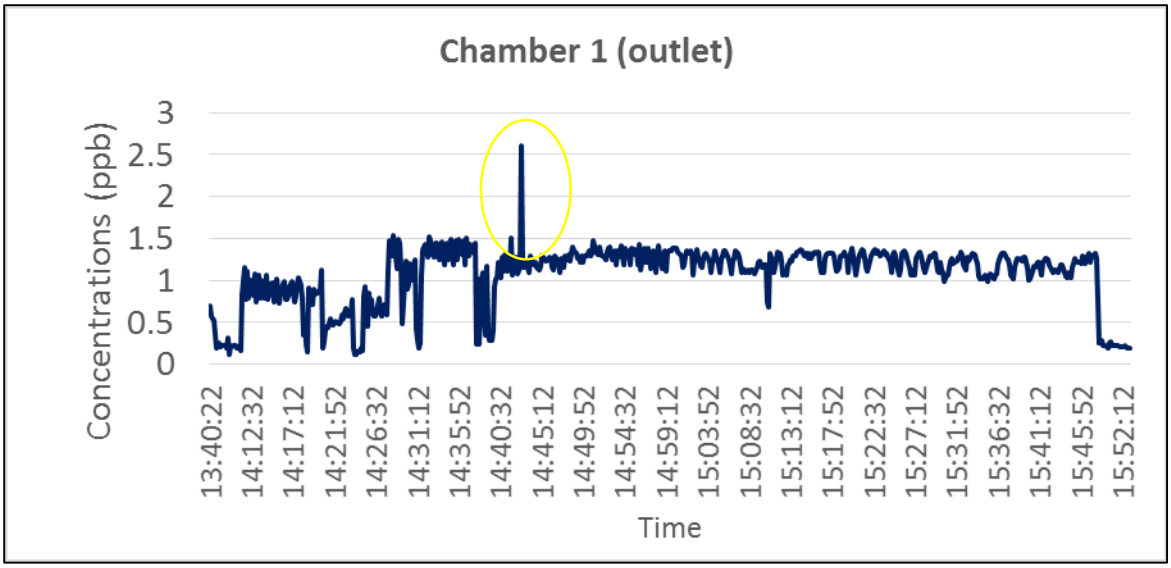

Figure 7: Catching the peak of the fluorescein tracer at the outlet of chamber 1.

Data from: July 15, 2015

The flow rate for 15/07/15 is 504 L/hr. Using the HRT equation: $\frac{3000\ \text{L}}{504\ (\frac{\text{L}}{\text{hr}})} = 5.952$ hours

Fluorescein was injected at chamber 3 inlet at 9:25 am and after the initial peak was logged. The fluorimeter was moved to the outlet waited for the flow at the outlet of chamber 3 and at 15:38:04 a peak of 7.18 ppb was read. That's about 6 hour difference.

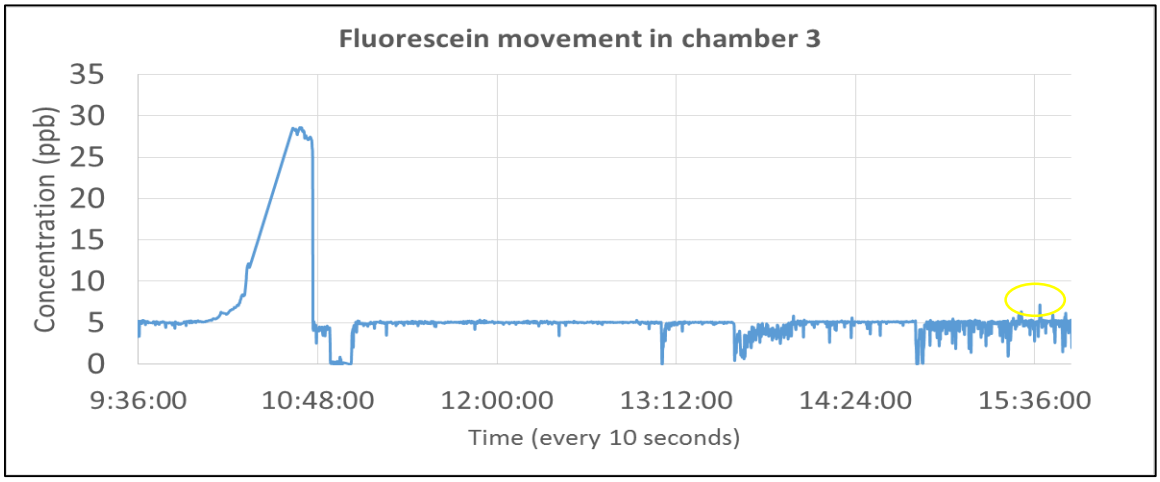

Figure 8: Fluorescein movement in chamber 3.

Data from: July 17, 2015

The tracer was injected at 8:45 am at the inlet of chamber 7 and the fluorimeter was reading at 162cm of the inlet of chamber 7 to catch the initial peak.

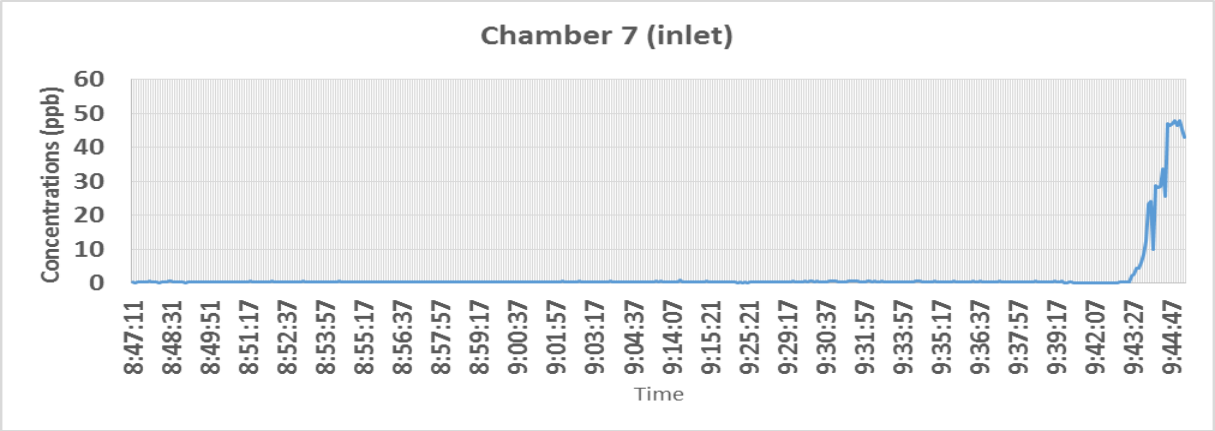

Figure 9: Catching the initial peak of fluorescein at the inlet of chamber 7.

Findings: it takes 1 hour for the tracer to travel 162cm in the inlet of chamber 7. The fluorimeter was moved to the outlet of chamber 7 at 9:45 am and was left there till 11:59 am.

The fluorescein peaked at 2.96 ppb at 10:09:47 and at around 11:59 the fluorescein never went above 0.6 ppb.

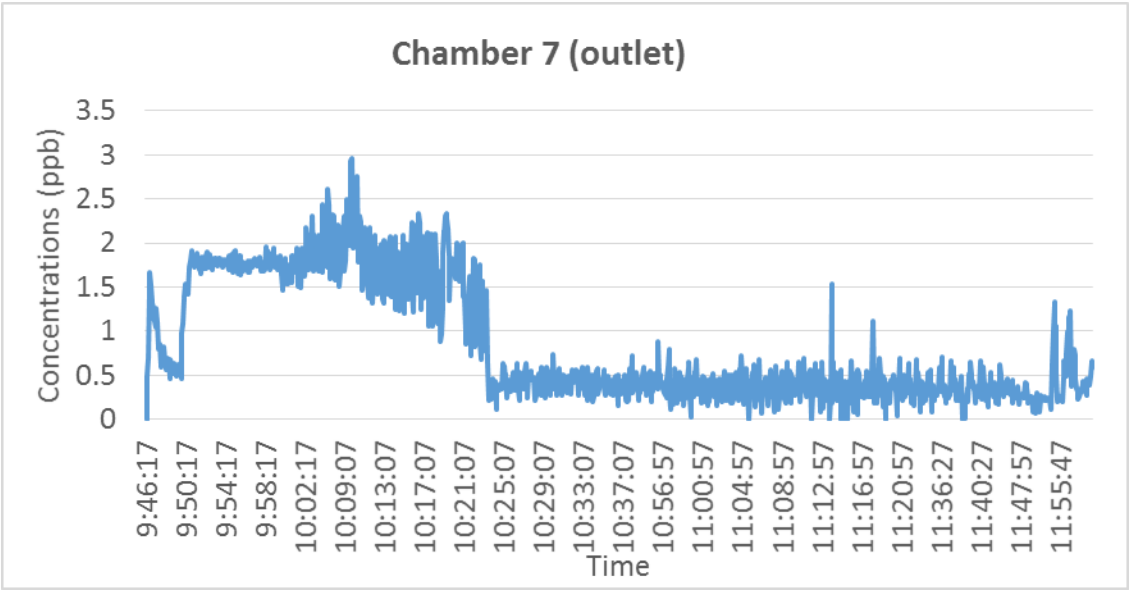

Figure 10: Catching the peak of fluorescein at the outlet of chamber 7.

The concentration measurements of the fluorescein is always greater at the inlet than the outlet. As shown in figures 11 and 12.

At 11:59 1L of 5mg/L fluorescein tracer was injected at chamber 4 inlet. Fluorimeter was set to do readings at 172 cm depth from the surface of the inlet.

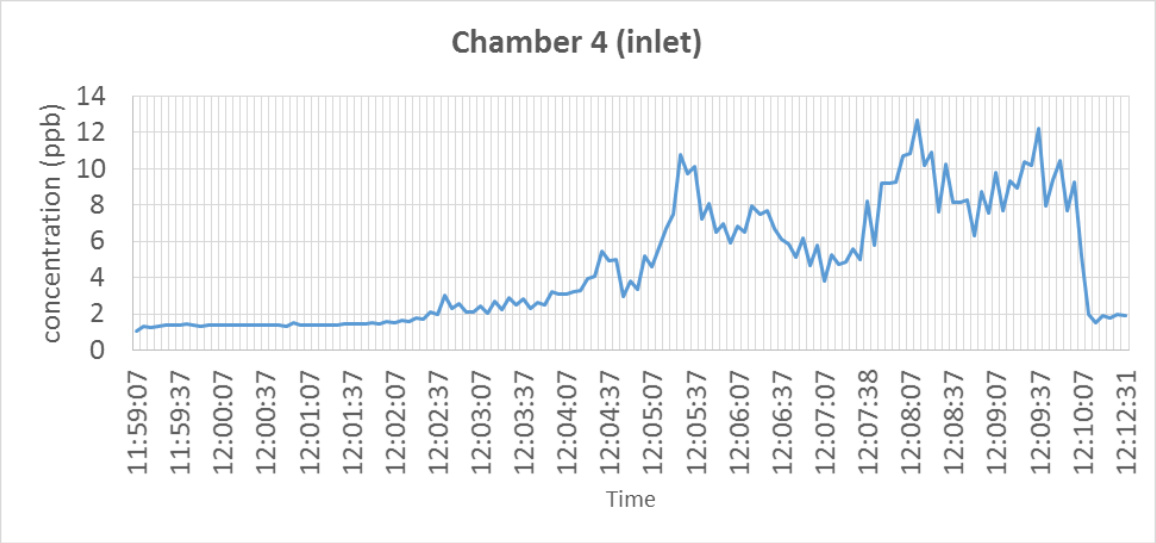

Figure 11: Catching the peak of fluorescein at the inlet of chamber 4.

After 12:12, it was moved to the outlet of chamber 4.

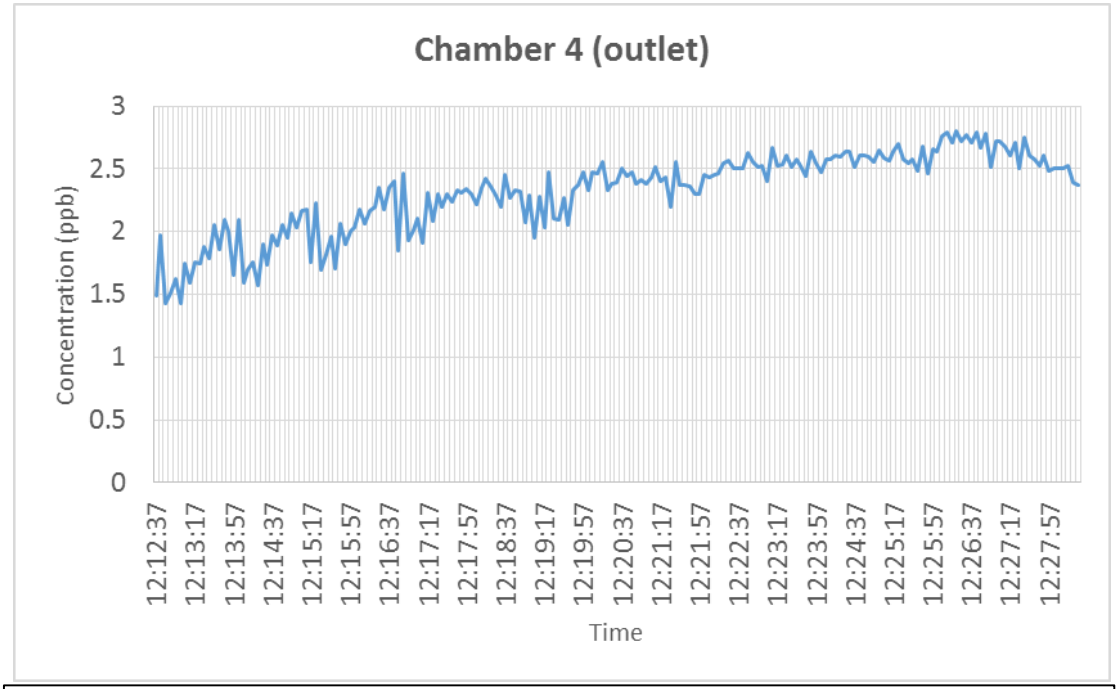

Figure 12: Catching the peak of fluorescein at the outlet of chamber 4.

Lithium Bromide

Was not able to run all the samples acquired.

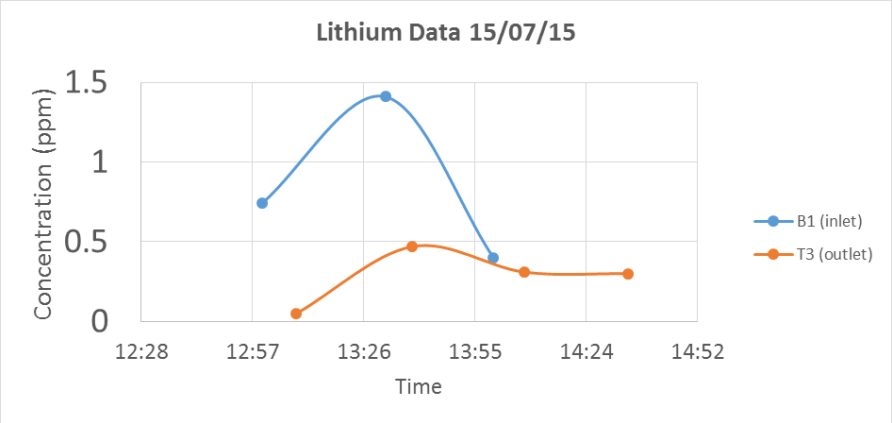

Figure 13: Movement of the lithium tracer at the inlet and outlet of chamber 3.

DISCUSSION

There are different factors explaining why the fluorescein readings at the outlet of the chambers gradually decreased from the initial concentration readings from the inlet. First is the fluorescein's binding property with the microbial sludge that can affect the fluorimeter's accuracy. Second is its dispersion property which makes it disperse into the 6 outlets of each chamber. The fluorimeter is connected to a pump and that pump can only do readings from one outlet, unless it's possible to pick up all the tracers going at different outlets it's impossible to do a mass balance in this experiment. Another properties of fluorescein that might have caused this error is the failure to account its absorbance changes with pH and its "photodecay" characteristics. Fluorescein tend to have a non-conservative behavior when it is introduced to a water system with pH greater than 9. It is also best for the samples with fluorescein to be protected from bright light because sunlight degrades fluorescein quickly but even hot samples are stable if kept in the dark (Smith and Pretorius, 2002).

Some recommendations for this experiment includes: starting with chamber 7 first when analyzing the tracer movement per chamber. That way when the chamber is accidentally contaminated with the tracer, it's easier to move to the previous chambers so that there won't be any confusion with the concentration readings. For lithium tracer have more than 2 people collect sample and have more samples per time than space. Use a little bit higher concentration for tracer and try to use auto-sampler for collecting samples for the lithium tracer.

CONCLUSION

The recovery rate for the fluorescein tracer is really small because it's impossible to do a mass balance in each chambers for the fluorescein tracer test using this in-situ fluorimeter. There are 6 outlets and there is no way to catch all the tracer going out of the system.

The relevance of these results can be helpful in modeling an ABR. Tracer studies are a powerful diagnostic tool in studying the flow in different systems. Tracer recovery is also

important because elution patterns can be tested using different mathematical models to quantify the flow character, and the total amount of recovered tracer is used as a validity and accuracy of the system.

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