ANALYSIS OF ABR HYDRAULICS

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Contents

1. Abstract

Studies on the hydraulic behavior of Anaerobic Baffled Reactors (ABR) is extremely important for both design and analysis of the system. Hydraulics effect many aspects of the system including hydraulic retention time, degree of mixing, and overall efficiency. This paper analyzes the flow rate and flow distribution of the ABR in Newlands. Both flow rate and flow distribution have changed dramatically over the past two years. These changes highlight how important context is when conducting experiments on this system. Hydraulic loading rates (HLR) were calculated using the flow rate data. HLR trends generally followed those of flow rates, due to the direct influence of flow rate in the HLR calculation. Total HLR of the system has seemingly gone through three distinct phases. The HLR was relatively stable for the first 8 months, followed by 11 months of significantly lower HLR, and lastly 7 months of HLR between the first two phases. The relationship between HLR and precipitation and temperature were also analyzed. Precipitation only had a significant impact on HLR if there was more than 50mm of rain in one day. Historically there has been little evidence of a correlation between HLR and temperature. However, this should be continuously monitored, because more recent data may suggest a correlation. Additional tracer tests were performed in the ABR. These tests indicated short circuiting and losses in the system.

2. Introduction

The Newlands ABR treats domestic wastewater from a nearby community of 84 households. Wastewater from these houses is directed through the ABR where it undergoes biological treatment processes before being distributed to a constructed wetland for additional nutrient removal.

Flow through the ABR is directed through one of 3 different paths called streets. An aerial view of the ABR can be seen in Figure 1. Streets 1 and 2 both have seven baffled treatment chambers with a volume of 3,000 L each. Street 3 consists of four larger treatment chambers with an approximate volume of 6,000 L each. Flow varies between each street and is measured using a flow censor at the outlet of each street. These variations give each street unique hydraulic characteristics.

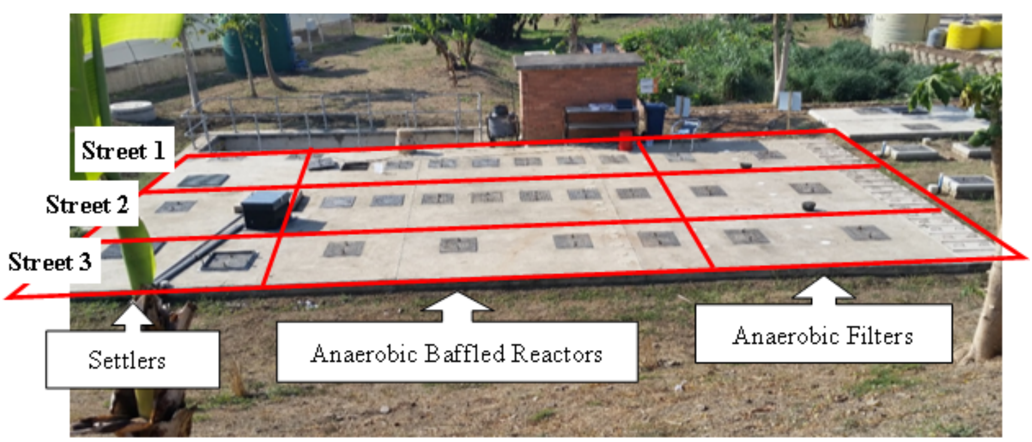

Figure 1. ABR Layout Design

Hydraulic behavior is extremely important and influential when designing waste water treatment systems. Hydraulic characteristics affect parameters including hydraulic retention time, zones of stagnant flow, contact between substrate and bacteria, degree of mixing, and overall efficiency of the system. Figure 2 illustrates a typical cross section schematic of an ABR. Design of the ABR accounts for factors such as flow rates, hydraulic loading, strength of waste water, temperature, efficiency, and treatment goals (Feng et al., 2008; Renuka et al., 2016). While accepted design parameters can be established, the reality is that the ABR is a dynamic system. Parameters affecting design can change over years (hydraulic loading), months (temperature), and even days (flow rate). Given these constant variations, hydraulic behavior is not as clearly understood in for the ABR as other treatment systems.

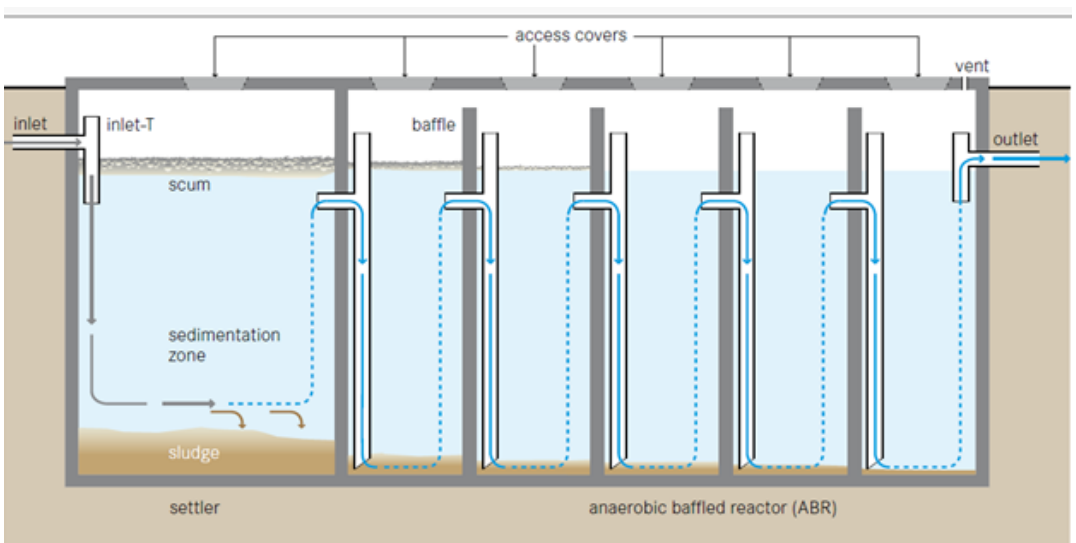

Figure 2. Schematic of a typical Anaerobic Baffled Reactor. *Source: Tilley et al. 2014.*

The focus of this project is to identify how hydraulic loading rates, flow rates, precipitation, and temperature change over time and their relationship with hydraulic behavior over days, months, and years. Data analysis was conducted on weather data, water meter readings, and flow meter data in order to establish long term trends affecting the ABR. A tracer analysis was conducted on Streets 1 and 3 in order to establish the relationships between mixing patterns and chamber size.

3. Methods

3.1 Hydraulic Data Analysis

Understanding the daily, monthly, and yearly changes in hydraulic behavior is fundamental for an accurate analysis of the ABR at Newlands. A solid understanding of hydraulic behavior is beneficial when describing treatment, providing context to any studies performed on the ABR, and for providing accurate data for any future designs. Flow distribution and HLR are important design parameters that require comprehensive knowledge of hydraulic behavior.

Flow data was collected using magnetic flow meters at the outlet of each street. Volume of water passing through each flow meter was recorded every hour beginning on April 22, 2014. Flow distribution between streets is calculated by determining the volume of water passing through an individual street per hour in relation to the total volume of water passing through the system per hour.

HLR was calculated as the ratio of flow to the area of the capture basin (Q/A), and in this case is presented in units of Liter per Day/m^2. The entire surface area of the each street is equivalent to the capture basin in this study. Surface area of each chamber is calculated using the known values of chamber volume and chamber depth. Surface area per chamber is multiplied by the number of chambers to determine the total surface area per street. Table 1 provides the street dimensions of each street in the ABR. HLR is calculated using both the total surface area and the flow rate data.

	Total Chamber Volume (L)	Depth (m)	Surface Area per Chamber (m^2)	Number of Chambers	Total Surface Area (m^2)
Street 1	3000	2	1.5	7	10.5
Street 2	3000	2	1.5	7	10.5
Street 3	6000	2	3	4	12
				System Surface Area =	33

Table 1. Dimensions of the ABR

3.2 Tracer Tests

Tracer tests were only conducted in the first chamber of the ABR in Streets 1 and 3. The reasoning behind this was concerns of long HRT per chamber and changing flow characteristics throughout the system. Estimated HRT for one chamber in all three streets was on the order of hours, during which, flow rates can change significantly. By running the experiment in only chamber 1, the change in flow rate during experimental runs would be minimized and multiple tests could be run in one day. Results of the tracer tests run in the first chambers can be applied to each additional chamber, as hydraulic behavior should be consistent for each additional chamber with identical size and flow rate. Streets 1 and 3 were selected because they are currently operating at similar flow rates, but Street 3 has double the chamber size of Street 1. Effects of chamber size on hydraulic behavior can be observed by comparing the tracer tests run on these two streets.

1L of fluorescein tracer was injected into the inlet pipe of chamber 1. Injection concentration of the fluorescein tracer was 250mg/L in both streets. An additional test was run in Street 3 with a fluorescein injection concentration of 500mg/L. Injection of the tracer was achieved by pouring the fluorescein through a syringe with tubing attached, directly into the flow stream. This method is referred to as the pulse injection method, and is the standard method when conducting tracer tests (Chen et al., 2010). Injection time of 1L was approximately 2 minutes. Figure 3 provides a visual schematic on the injection method.

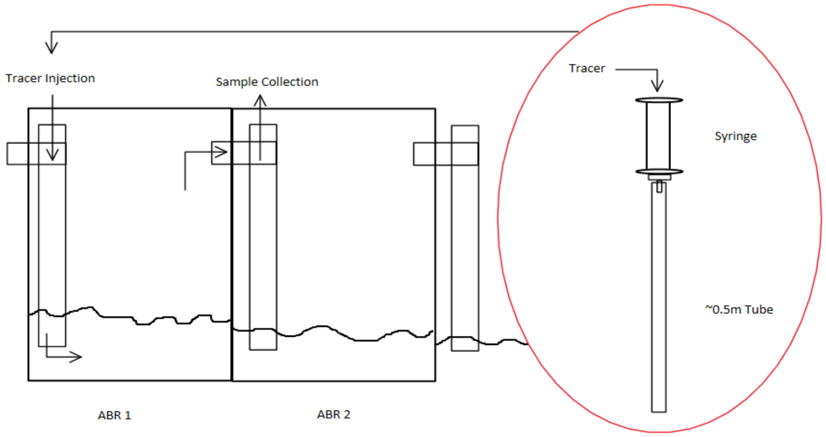

Figure 3. Tracer Injection and Sampling Location Schematic

Concentration of fluorescein was measured from the outlet pipe of chamber 1. Wastewater was pumped from the outlet pipe of chamber 1 through an Albillia GGUN-FL02 field fluorometer for surface waters at a rate of 7.2 L/hr. The GGUN-FL02 was connected to a datalogger that recorded the time and concentration of fluorescein as mV. Measurements were collected every 10s. Calibration of the fluorometer was necessary to convert the mV readings to ppb concentrations. Calibration was achieved by filling the GGUN-FL02 with ABR wastewater spiked with a known concentration of fluorescein. Measurements obtained were used to create a calibration curve, which can be seen in the Appendix as Figure A1. The entire setup is displayed in Figure 13. Flow meter data was graphed and analyzed in excel.

Figure 4. Complete Tracer Test Setup

4. Results

4.1 Flow Rates

Flow through the ABR was measured using flow meters at the outlet of each street every hour beginning in April 2014. The total volume of water flowing through the ABR each day was calculated using these readings, and can be seen in Figure 5. The most recent flow data indicates a total average daily flow of around 5000L/day. Flow through the ABR is primarily dominated by Streets 1 and 3 with Street 2 carrying less than 1000L/day. Analysis of flow data over time is also highlights how dynamic the flow through the ABR is. In spring 2014, flow was around 7000L/day with Street 2 accounting for the majority of the flow. After a brief shut down period, the ABR reopened with Street 1 accounting for the majority of flow through the system. Between January and October 2015 the system experienced an average flow of around 3000L/d which is significantly lower than the current flow of around 5000L/d.

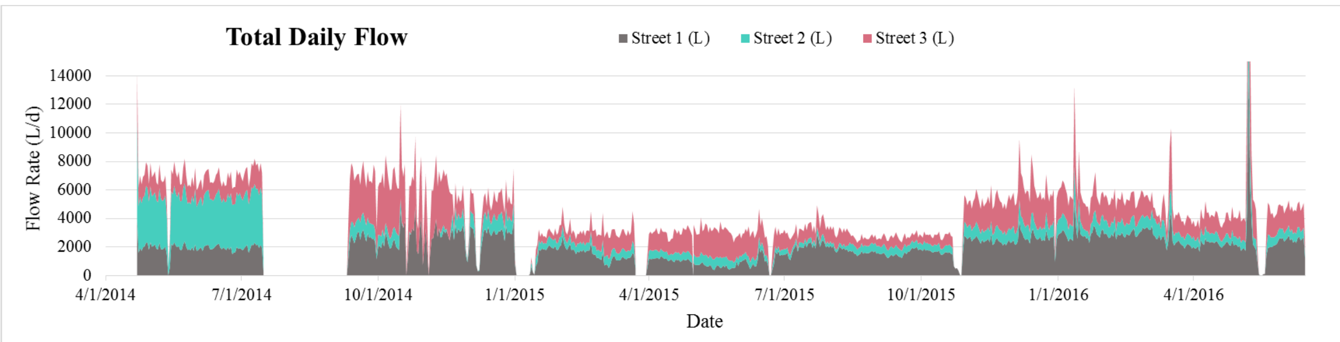

Figure 5. Daily Flow Through the ABR at Newlands

Further analysis was conducted to determine how flow rate changes in the ABR throughout the day. Figure 6a-c represents the hourly flow through the ABR during an arbitrary weekday in June 2014, 2015, and 2016 respectively. While these graphs differ in peak flow and flow distribution, there are notable similarities. Flow in the ABR begins to increase significantly around 5:00AM peaking around 7:00AM on weekdays. This has been true since the installation of the system. Flow significantly decreases around 11:00PM and decreases continuously until around 4:00AM, when there is very little flow through the ABR.

Figure 6a-c. ABR Hourly Flow Rate

4.2 Distribution of Flow

Figure 7a-c represents the hourly flow distribution throughout the ABR in June of 2014, 2015, and 2016 respectively. In 2014 distribution was dominated by Street 2. In mornings during hours of low flow, there was no flow through Street 1. By 2015, flow was dominated by Street 1. During times of low flow, there was no flow through Street 2. Current flow is distributed with 50-55% of flow through Street 1, 10-15% of flow through Street 2, and 30-35% through Street 3.

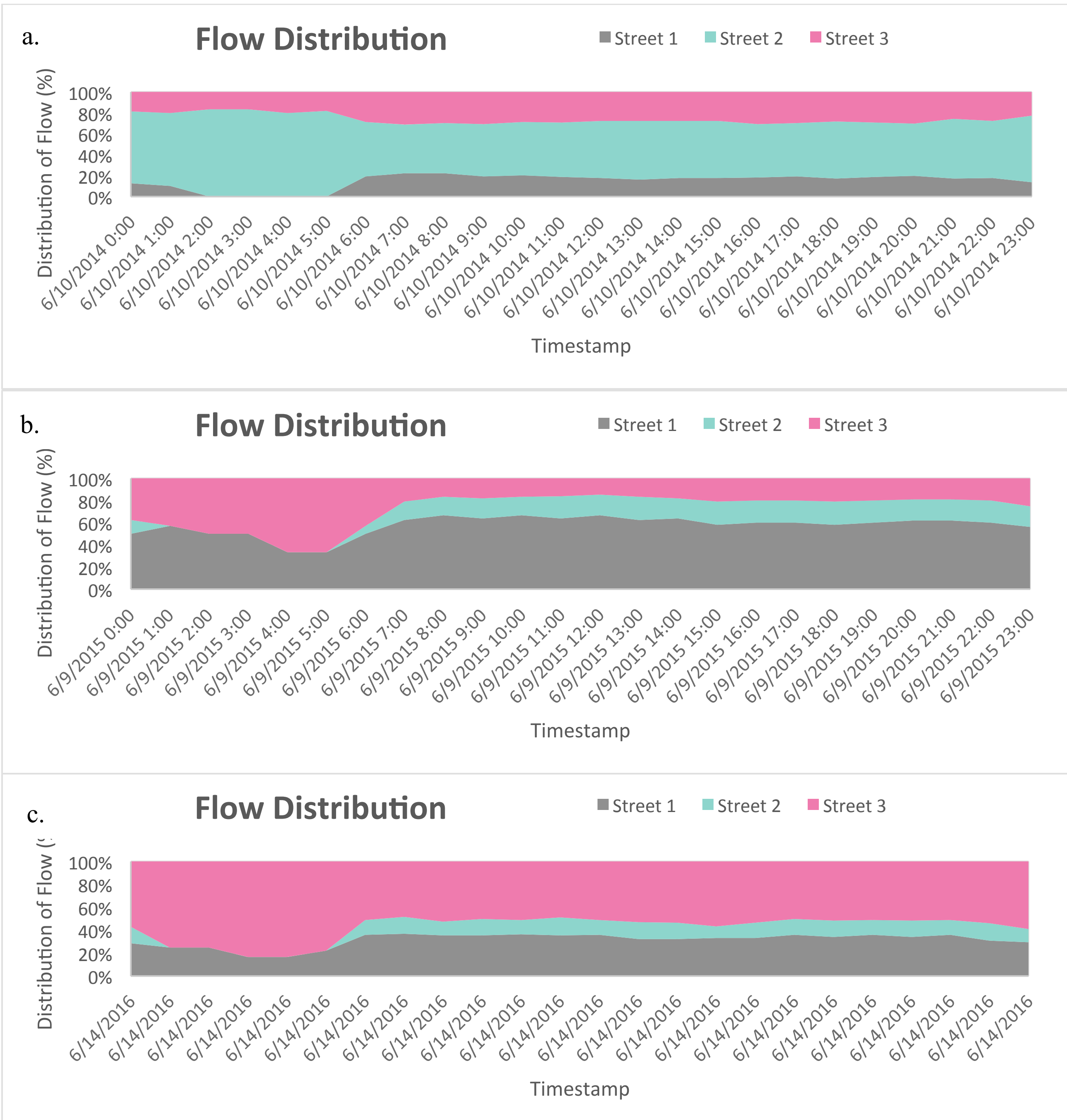

Figure 7a-c. ABR Hourly Flow Distribution

4.3 Hydraulic Loading Rates

Figure 8 represents the HLR history of the system at Newlands. Flow rate and basin size are the two parameters affecting HLR. Total HLR of the entire system is between 400-450 liters per day/m^2 currently. Trends in the HLR are similar to those of the flow rate with one major exception. HLR is lower for Street 3 due to the larger chamber size, and surface area of the basin.

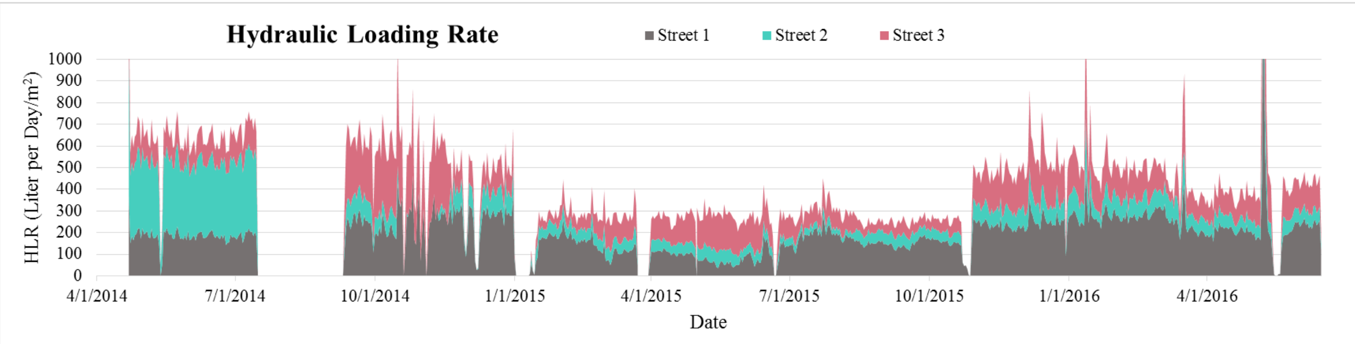

Figure 8. Hydraulic Loading Rates in Each Street

Another point of interest is how weather affects HLR of the system. Precipitation was plotted along with HLR to observe any relationships between the two. Rain events can be broadly categorized into events lasting several days with low amounts of rainfall and events one or two days with rainfall above 50mm/day. The events with constant, low amounts of rain have relatively little overall effect on HLR. These events occur in February 2015 and in October 2015 in Figure 9. However, once the rainfall exceeds 50mm/day, HLR rises dramatically. Three of these events occur between January and May 2016. These relationships indicate that major storms will have a significant impact on HLR in the ABR.

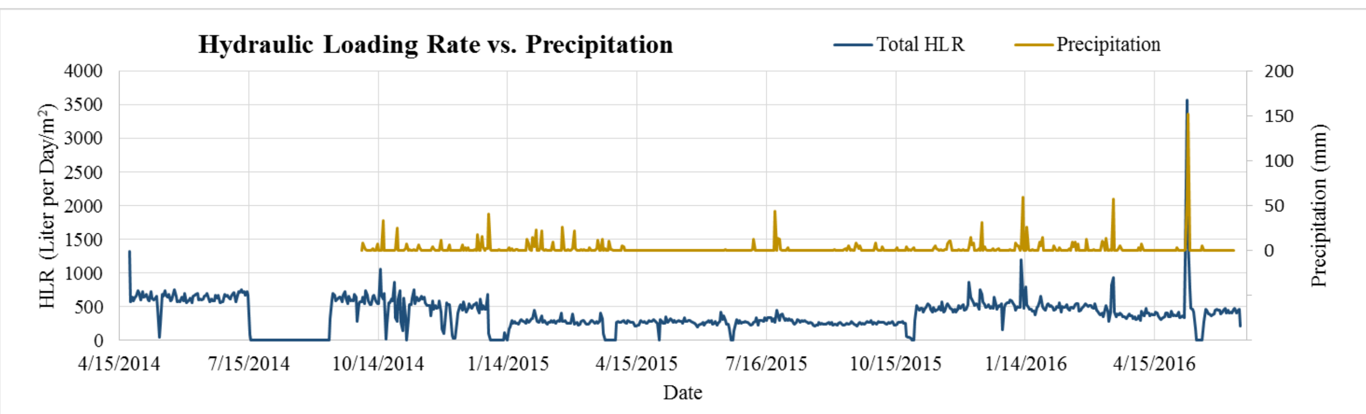

Figure 9. Hydraulic Loading Rates v. Precipitation

Average monthly temperature is another parameter that was modeled against average monthly HLR. It was anticipated that HLR would follow the same trend as average temperature.

This would prescribe to the idea that more water is used during the warmer months than during the colder months, since HLR is directly related to flow rate. However, Figure 10 shows that this correlation has not been true throughout the history of the system. This may be due to 3 months of 'startup' and adjustments of the ABR, followed by the 10 months of unusually low flow rates. As of November 2015, the correlation between HLR and temperature can be better observed. Analysis of future HLR and weather data should be conducted to further study this relationship.

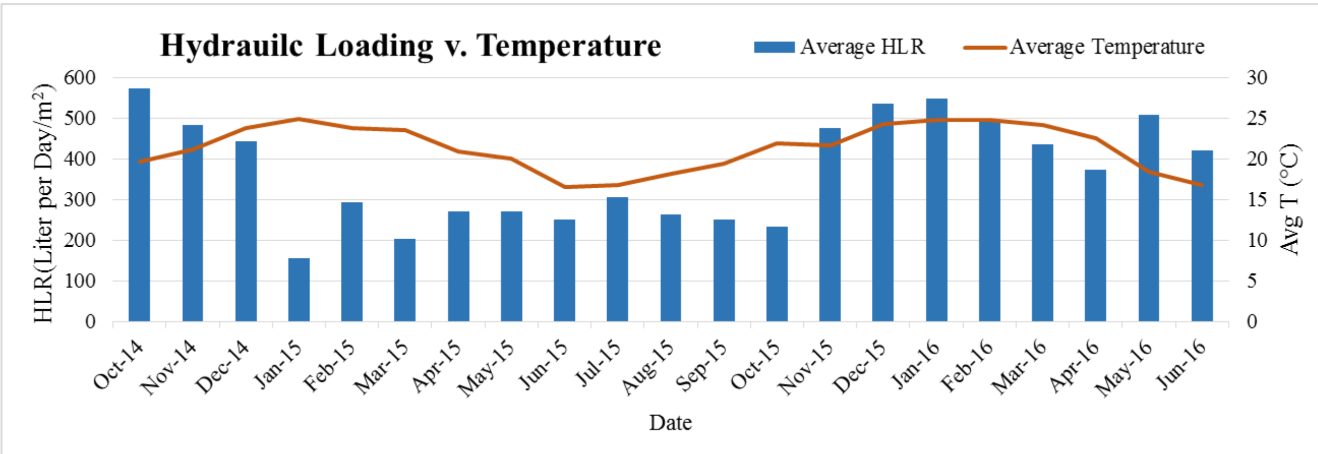

Figure 10. Average HLR v. Average Temperature

4.4 Tracer Tests

Both tracer tests conducted in Street 1 used 1L of 250mg/L fluorescein stock solution. Figures 11 and 12 show the results of these tracer tests with the x-axis beginning at the time of injection. In tests I and II, fluorescein is detected after 15min and 19min respectively. Tracer concentration begins to stabilize between 100-150ppb approximately 30 minutes after the initial injection .

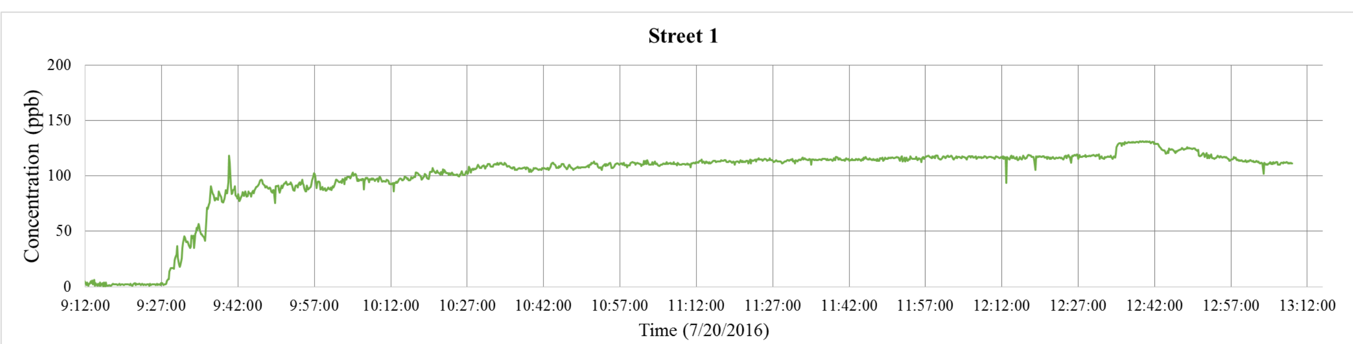

Figure 11. Street 1 Fluorescein Tracer Test (I)

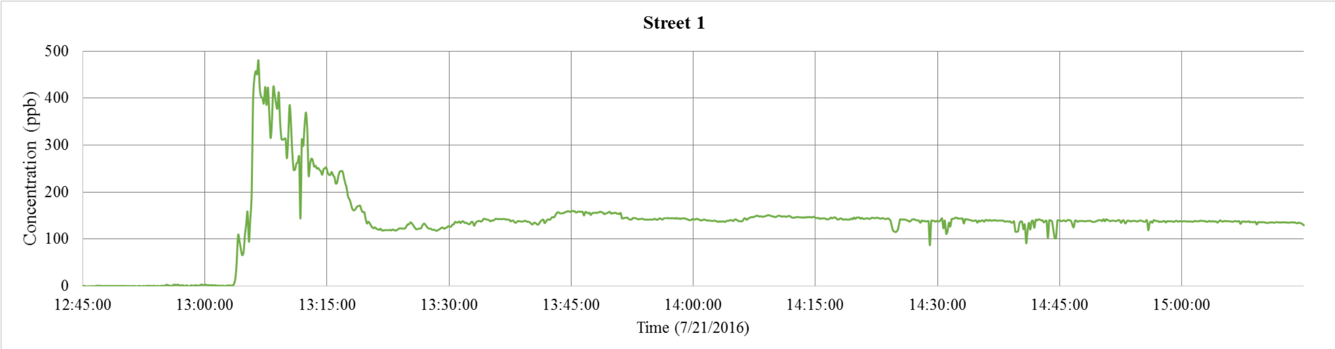

Figure 12. Street 1 Fluorescein Tracer Test (II)

The first tracer test in Street 3 (Figure 13) also used lL of 250mg/L fluorescein stock solution. Fluorescein was also first detected around the 15 minute mark after injection in Street 3. While this is still significantly less than any anticipated HRT, the curve increases at a slower rate and more closely resembles traditional tracer test curves. This may indicate that while short circuiting also occurs in Street 3 is may be less significant than in Street 1. The anticipated fluorescein concentration in Street 3 was half that of Street 1 due to double the chamber volume in Street 3.

Figure 13. Street 3 Fluorescein Tracer Test (I)

The second tracer test run in Street 3 (Figure 14) used 1L of 500mg/L fluorescein tracer. Fluorescein is detected 22 minutes following injection. Due to the injection concentration of 500mg/L (twice the injection concentration of Tracer Test (I)) it was expected that the tracer concentration in the second test would be greater than that of the first.

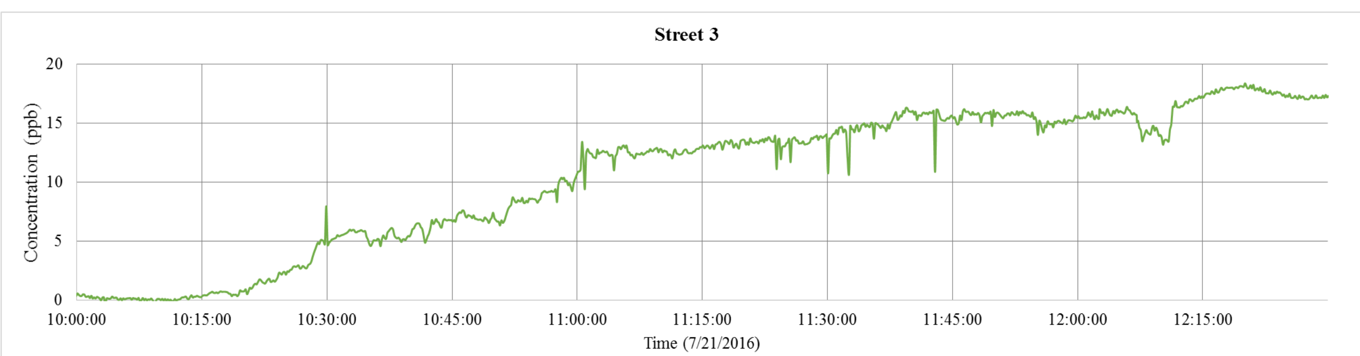

Figure 14. Street 3 Fluorescein Tracer Test (II)

5. Discussion

5.1 Hydraulic Analysis

Many studies on the relation of hydraulic behavior and the ABR have been conducted under steady state conditions (Barber and Stuckey, 1999; Grobicki and Stuckey, 1991). The results of the hydraulic analysis show just how dynamic this system really is. This is significant because both flow and HRT have been shown to affect the efficiency of the ABR. ABR efficiency increases with lower flow rates and a higher HRT (Renuka et al., 2016). Over years the efficiency of the ABR at Newlands may be changing according to the changes in flow rate. The average total daily flow rate in June 2016 is larger than the average total daily flow rate in June 2015, but less than the average total daily flow rate in June 2014. This indicates that ABR efficiency may be different for each of these time periods.

Studies have shown that flow rate and HRT effect efficiency, but not on a daily or hourly scale. This data indicates that flow rates through the ABR vary significantly by the time of day, and should be considered when determining design parameters. Flow peaks are in the morning and evening when most people are using water in their homes, but no consulted studies have determined typical daily flow patterns.

It should be noted that HLR is a commonly accepted formula for calculating particle capture, and is a major design component in many common waste water treatment systems. HLR is dependent on both flow rate and system size. Understanding flow patterns is just as important to understand HLR. Precipitation does have an effect on HLR, especially when precipitation exceeds 50mm per day. This is likely due to an increase in flow rate through the ABR from storm water intrusion.

Temperature has no direct effect on HRT or HLR. However, there is some evidence that loadings are higher when water usage is greater (i.e. warmer months) (Feng et al., 2008). The average monthly HLR vs Temperature analysis does not show a clear link between the two. This may be due to the infrequent flow patterns, shut down periods, and major rain events over the course of the analysis.

5.2 Tracer Tests

One consistent trend seen throughout these tracer tests is the relatively quick detection of fluorescein tracer. Bigelow et al. (2016) reported an HRT of approximately 6 hours per chamber. Even with higher flow rates, anticipated HRT would not be shorter than 3 hours. In all four of these tests, the tracer was detected in less than 30 minutes. Short circuiting is a likely case when residence time is significantly shorter than designed HRT. Short circuiting is indicative of large zones of stagnant flow. Stagnant zones typically account for 5-10% of the ABR, but in this study the zones are likely much larger. Previous studies have shown that the percent of stagnant zones increases as HRT decreases (Feng et al., 2008; Langenhoff and Stuckley, 2000; Ren et al., 2009).

Tracer tests were not performed long enough to determine when the fluorescein tracer fully exits the chamber. A mass balance, in this case, would not be useful to determine how much of the tracer was recovered. Chamber inlets of the ABR consist of 4 up flow pipes, and in this case the fluorometer was located in only one of those pipes. Fluorescein tracer will inevitably be distributed between up flow pipes and small fractions will be lost due to substrate binding.

6. Conclusions

Data analysis of the ABR provided significant insight into hydraulic behaviors of the ABR at Newlands. The ABR is quite a dynamic system with significant daily, monthly, and yearly changes. Initial flow in 2014 through the system was around 7000L/day with flow primarily being channeled through Street 2. The ABR system then underwent about 10 months of significantly low flow between January and October 2015, which was primarily channeled through Street 1 due to…?. Currently, the ABR has an average flow of 5000L/d with flow distributed primarily through Streets 1 and 3, with low flow through Street 2 due to…?. These changes are significant and emphasize the importance for context when studying this system. Checks should be done to ensure that the experiments are representative of the long term hydraulic behaviors.

Current total HLR of the system is between 400-450 Liters per Day/m^2. HLR is directly associated with flow rate and generally follows the same trends due to this relationship. HLR is also directly impacted by surface area of the chamber, therefore HLR in Street 3 will be lower than HLR in Streets 1 and 2 at the same flow rate. Small rain events have relatively low impacts on HLR. However, rain events with more than 50mm of precipitation per day will cause HLR to briefly but dramatically increase as well. Temperature did not have any long term correlation with HLR but there is evidence that that may be changing. This relationship should be monitored in the future to determine if any significant correlation between temperature and HLR exists.

Tracer tests were conducted in Streets 1 and 3. Short circuiting of the system was evident due to early detection of the fluorescein tracer. The shape of the concentration curve in Street 1 was atypical of traditional tracer curves. This curve indicates possible binding of the fluorescein to substrate in the system. More tests and modeling are needed to verify this. Tests run in Street 3 were more representative of traditional concentration curves, but did also provide evidence of short circuiting. The concentration of fluorescein theoretically should have been half as much as Street 1 due to double the chamber volume. This was not the case and may indicate losses in the system. Future tests should consider a lithium or bacteriophage tracer test to minimize losses and substrate binding (Chen et al., 2010; Langenhoff and Stuckley, 2000).

Overall these analyses provide necessary context to experiments conducted on this system. Understanding how this system changes will help to improve future design and testing methods. The tracer tests also provides ground work to build on in the future. With additional modeling and analysis, hydraulics in the system may be even better understood.

7. Appendix

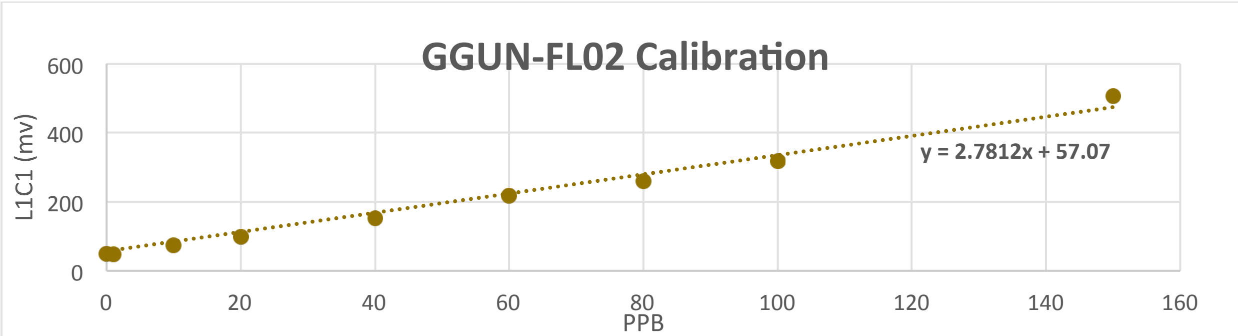

Figure A1. GGUN-FL02 Calibration Curve

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