Analysis of Hydraulic Retention Time for Modeling Removal of Pollutants in a Bioretention Basin

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Abstract:

Due to their large quantities of impervious surfaces, urbanized areas experience substantial pollutant runoff into lakes and streams. Bioretention basin are a common tool designed to combat this problem. These man-made sites naturally filter out key pollutants like COD, Nitrogen, and Phosphorous. The amount of time water spends in the system is known as hydraulic retention time (HRT), and is an important factor in proper removal of these pollutants. Using current methods, however, this parameter can only be found experimentally and, as a result, is rarely measured outside of research universities. This project uses continuous storm water data collected from pumping data at the Farm Lane bioretention site. Using this information, changes in HRT can be determined by (1) Quantifying HRT, (2) Determining HRT dependencies, and (3) Modeling a relationship between HRT and its dependencies.

Current Challenges:

- Before HRT can be characterized, flow into the system needs to be determined
- Because the flow is very high, it blew out flow meters at the site
- Data analysis revealed very high levels of groundwater intrusion
- The high levels of groundwater intrusion overwhelm pumps on rainy days, causing significant data loss

Problem Statement:

1. Quantify groundwater intrusion on dry days
2. Quantify amount of water entering the system on rainy days
3. Determine flow through the system on rainy days based on groundwater intrusion and precipitation
4. Determine energy expended by pumps as a result of groundwater intrusion

Site History and Background:

Located at the northeast corner of the intersection of Farm Lane and Service Road on Michigan State University campus, the 2500 ft^2 bioretention basin (Figure 1) is fed by a 40% impervious, 12.8-acre watershed[1]. Water is collected into a large tank, and the level is controlled by 3 pumps that trigger when the level is approximately 8.2 feet. After triggering, the level is pumped down 3 feet, which is 11,016 gallons per cycle. Before its completion in 2010, the Farm Lane Bioretention site was beset by a host of complications. The initial soil installed was extremely compacted and consisted of 40% clay topsoil instead of the specified 85% sand, and the base layer was road aggregate instead of gravel[1]. Although the mixture was eventually changed to the correct specifications, raw manure was also added to the bioretention media without tests to ensure initial phosphorus concentrations were within required limits[1]. Additionally, the outflow pipe was supposed to be laid under Service Road, but steam tunnels in the area forced the pipes to instead be laid parallel to the road before connecting to the stormwater sewer pipe on Farm Lane. Doing this increased the pipe length by 280 feet and resulted in an extremely gradual slope of only 0.002ft/ft[1]. Additionally, instead of using rigid piping material as specified, a flexible PVC was installed. As a result, slow drainage has been an issue for this site.

Figure 1: Farm Lane Bioretention Basin and Flow Map

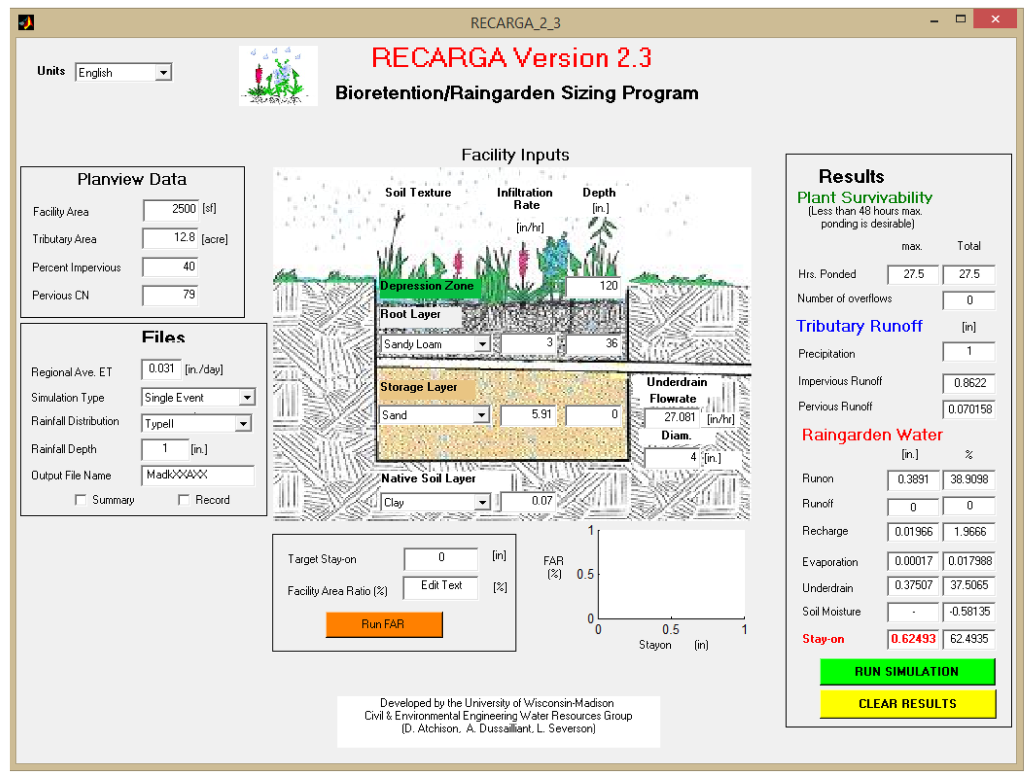

Figure 2: RECARGA inputs and analysis

Methods:

Pump data was taken from HVAC Central Control between 11/1/2016 12:00 pm to 2/25/2017 12:00pm. Rainfall data was taken from the Enviro-Weather station located in East Lansing (HTRC), Michigan in daily and 5-minute intervals between 10/28/2016 and 2/25/2017.

Excel data analysis

"Dry" days were characterized as days in which precipitation had not been recorded for at least three consecutive days, while "wet" days were those marked by active precipitation. Days that did not fall into either category were marked as "Neither". The tank diameter is 25 feet in diameter, and holds 3,672 gallons per foot of depth. Flow was calculated by multiplying the change in level (feet) by 3,672 gal/ft and dividing by the change in time (seconds). Dry day data was trimmed to exclude extreme flow values, which were defined as being the highest 5% of values. It was assumed that for dry days, all water entering the bioretention basin was the result of groundwater intrusion. To find this average rate, data could be filtered to only include days classified as DRY, pump status classified as OFF, and excluding changes in time equal to 0. "Wet" days were those characterized by active rainfall. Days without data loss were analyzed similarly by excluding the highest 5% of data points, filtering out changes of time equal to zero, and only selecting points when the pump was off. The total system flow on wet days was then averaged so that the average groundwater intrusion could be subtracted to find the average runoff. The average runoff entering the bioretention site on days with and without data loss was determined using a weighted averaged.

RECARGA analysis for precipitation data

RECARGA modeling software (Figure 2) was used to determine the amount of water entering the system as a result of precipitation. By adding this value to the average groundwater intrusion rate, the average flow through the system could be determined for pump records that were incomplete due to data loss. The curve number used was 79, based on the Michigan LID handbook, and an average reference potential evapotranspiration of 0.031 was found using data from the Enviro-weather station located in East Lansing (HTRC), Michigan. For points that did not experience data loss, flow through the system from precipitation could be determined by subtracting the average rate of groundwater intrusion from the total flow. The simulation type for REGARGA was "Single Event", and the facility was characterized by a 120 in depression zone, a 36-in sandy-loam root layer, a clayey native soil layer, and underdrain diameter of 4in.

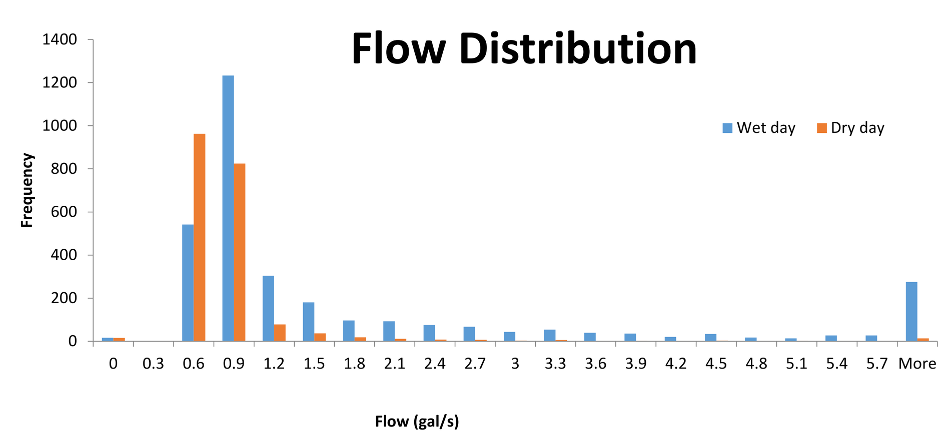

Figure 3: Floe Distribution on rainy vs dry days

Results and Discussion:

On average, the rate of groundwater intrusion was 0.74 gal/s, causing the pump triggered ON 3-5 times a day at a rate of every 4.5 hours. Average total flow on rainy days without data loss was 2.02 gal/s, and runoff into the systems was 1.28 gal/s after factoring out background groundwater intrusion. Using RECARGA analysis, average total flow on rainy days with data loss was 1.09 gal/s. Based on this information, the average flow into the system from runoff was determined to be 1.14 gal/sec. On averages, the pumps trigger on 9 times a day during rainy days.

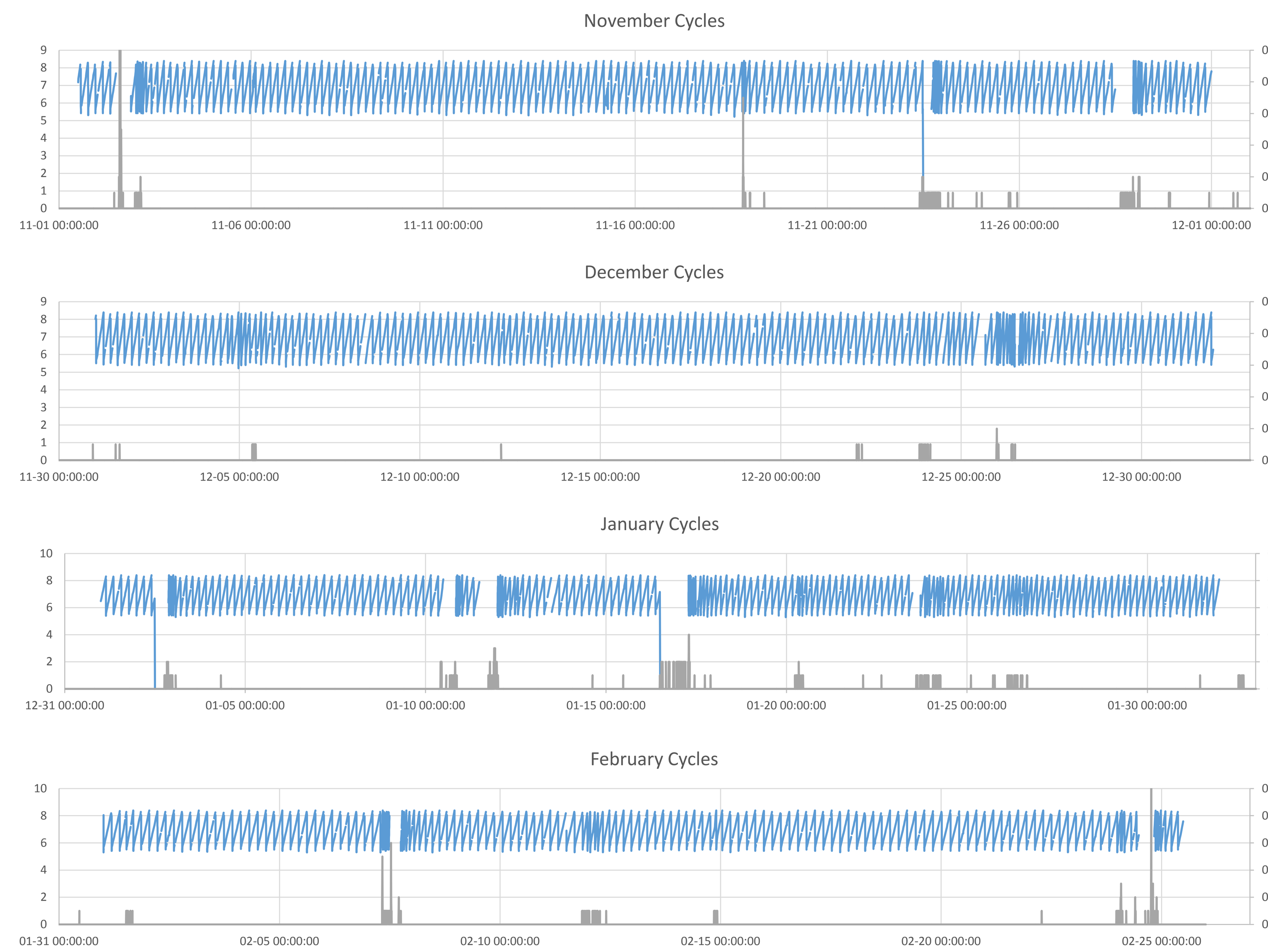

Figure 4: Pump cycles for January through February plotted with rainfall (in) data in grey

Conclusions:

At 0.74 gal/ sec, the high rate of groundwater intrusion into the system was concerning, as it may have adverse effects on system efficiency and performance. After running preliminary RECARGA analysis to compare the bioretention site with and without groundwater intrusion (Figure 5), it was determined that runoff values were significantly increased for the simulation including groundwater. Because the rate of intrusion into the system is so high, the next steps for this project will be to develop pumping strategies and conduct an energy analysis on the pumps to make recommendations for improving the system efficiency. This will help to extend the life span of the pumps and reduce the cost of pumping groundwater through the system, while improving system performance. Additionally, a tracer study will be conducted using potassium bromide to experimentally find Hydraulic Retention Time.

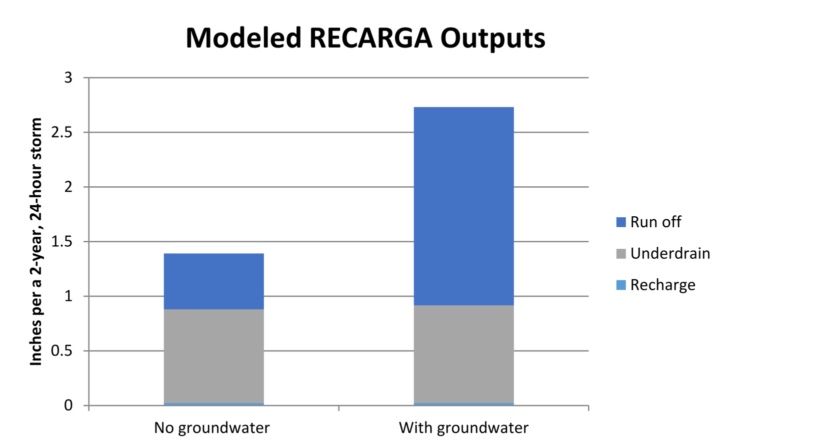

Figure 5: Comparison of system performance with and without groundwater intrusion

Acknowledgements:

This work was financially supported by the College of Agriculture and Natural Resources (CANR) at Michigan State University. Special thanks to Dr. Steve Safferman for help with pump energy analysis, and Matthew Banach for help with data analysis and structuring.

References:

Thode, A. G. (2013). Evaluation of the Farm Lane Bioretention Research Facility Stormwater Treatment Performance (Unpublished master's thesis). Michigan State University, East Lansing, MI.