GRAYWATER WETLAND TREATMENT FOR A LIVING BUILDING

Phillip L. Thompson[1]

ABSTRACT

This paper discusses the graywater treatment wetland performance data for the Bullitt Center which is a six-story, 4645 m^2 (50,000 ft^2) office building located in Seattle, Washington. Graywater from sinks, dishwashers and showers is stored in a 1514 L (400 gal) tank in the basement. Graywater is pumped every four hours to a 44.5 m^2 (479 ft^2) recirculating gravel filter system (RGFS) wetland located on a third floor balcony. The wetland was designed to treat an average daily flow of 1305 L (345 gal), and it must meet a regulatory standard of 30 mg/L for both total suspended solids (TSS) and biochemical oxygen demand BOD_5. The wetland was also required to meet a total fecal coliform concentration of 200 CFU/100-ml sample. After approximately three days of treatment, the graywater is discharged to an adjacent 325 m^2 (375 ft^2) drain field amended with a 1.07 m (42 in) mixture of C-33 sand and 35-40 percent compost. Due to low effluent flows that approached one-tenth of the design flow throughout the year, the wetland was able to meet mass discharge limits for both BOD_5 and TSS. The system achieved concentration limits for BOD_5 during the growing season. Decreasing the TSS loading on the system by adding a settling basin or pre-filter may enable the system meet BOD_5 and TSS discharge concentration limits throughout the year. Ultraviolet light disinfection may also be required to meet fecal coliform discharge limits during the winter months.

INTRODUCTION

The Bullitt Center is a six-story, 4645 m^2 (50,000 ft^2) office building located in Seattle, Washington that opened on April 22, 2013. To meet the Living Building Challenge's net-zero water requirement (CCBC 2011), graywater from the Bullitt Center's sinks, dishwashers, showers and floor drains is collected in a 1514 L (400 gal) storage tank located in the basement and is pumped to a recirculating gravel filter system (RGFS) wetland on a third floor balcony. The 44.5 m^2 (479 ft^2) RGFS wetland (Figure 1) was designed by 2020 Engineering (Bellingham, WA) to treat an average daily flow of 1305 L (345 gal). The filter is layered with 0.53 m (21 in) of a activated ceramic filtration medium (ES Filter, Coalville, UT), followed by a 10.2 cm (4 in) gravel underdrain layer and a 0.76 mm (30-mil) high-density polyethylene (HDPE) liner. The underdrain layer has a storage volume that is approximately three times the daily flow or 4164 L (1100 gal). Raw influent graywater is applied every four hours and recirculated graywater from the underdrain system is applied to the RGFS every 30 minutes via one-inch diameter, perforated pipes that are located six inches below the wetland surface. The wetland also contains approximately 100 water horsetail plants (*Equisetum fluviatile)*.

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[1] Phillip L. Thompson, Seattle University, Seattle, WA.

The wetland effluent overflows from the underdrain layer to a 325 m^2 (375 ft^2) drain field located in the right-of-way boarding McGilvra Place park. Effluent infiltrates six inches below grade via 14.5 mm (0.57-inch) ID Netafim Bioline drip lines (Netafim USA, Fresno, CA). The flow is split between two 2.4 m by 5.2 m (8 ft by 17 ft) dispersion zones that are 1.07 m (42 in) deep and amended with a 60:40 (v:v) soil mixture containing C-33 sand and compost. The amended layer is separated from the underlying native, sandy soils by a 15 cm (6 in) washed-gravel drainage layer.

FIGURE 1: The Bullitt Center's 44.5 m^2 (2.6 m x 17.0 m) recirculating gravel filter wetland system was designed to treat 1305 L per day.

The wetland effluent was permitted by the Washington State Department of Health with discharge limits of 30 mg/L for 5-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS). These allowable concentrations were multiplied by the average daily design flow of 1305 L per day and resulted in a permitted mass discharge of 39 g per day for both BOD_5 and TSS. The wetland was also permitted to discharge a maximum fecal coliform concentration of

200 CFU per 100-ml. This paper summarizes the performance data for the graywater wetland treatment system, and compares it to other graywater treatment wetland data from the literature.

ANALYTICAL METHODS

Water samples were analyzed by a team of students and faculty from Seattle University and by the King County Department of Parks and Natural Resources' environmental laboratory. For the first month of operation, water quality samples were taken on a weekly basis, at least once every three weeks for the subsequent five months of operation and then once per month thereafter. For each sampling period, four liter grab samples were taken at the untreated grey water storage tank and at the RFGS overflow. Samples were immediately analyzed for the following water quality parameters: temperature, pH, TSS, dissolved oxygen, BOD_5, chemical oxygen demand (COD), *E. coli* (fecal coliform), and total nitrogen.

E. coli was quantified with the Coliscan membrane filtration technique (Micrology Laboratories, Goshen, IN). COD was measured with mercury-free, low-range test kits (Chemetrics, Midland, VA). Total nitrogen was measured with Hach low-range test kits (Hach Co., Loveland, CO). All other parameters were analyzed according to standard methods (APHA, 2005). For quality control, samples were analyzed in triplicate and all instruments were calibrated daily with external standards.

RESULTS AND DISCUSSION

The effluent flow rate from the wetland averaged approximately 144 ± 107 L per day over the first 404 days of operation which was approximately one-tenth of the design flow. During the colder months of October through April, effluent flows averaged 170 ± 95 L per day (45± 55 gal per day). During the warmer months of May through September, the average daily flow was approximately one liter per day (0.34 gal) due to evapotranspiration. These relatively low flows resulted in mass loadings for BOD_5 and TSS that were well below those that were permitted.

Untreated graywater for the Bullitt Center had a larger range of concentrations of BOD_5 and TSS but comparable fecal coliform concentrations than those reported elsewhere (Gross et. al 2007; Jokerst et al. 2011; Paolo et al. 2009). Gross et al. (2007) evaluated a recirculating vertical flow wetland with a pre-treatment settling basin for solids removal and a loading rate of 75 L/m^2-d compared to the design loading of 30 L/m^2-d in the present study. In addition, their graywater was artificially prepared by using laundry detergent, boric acid and raw kitchen sink effluents. Paolo et al. (2009) also used a settling basin prior to using a horizontal flow wetland followed by vertical flow wetland in series to treat a design flow of 700 L per day and an initial BOD_5 of 500 mg/L for a household of nine people. Jokerst et al. (2011) conducted a temporal study of graywater treatment by two wetlands in series (a free water surface wetland and a subsurface flow wetland) utilizing graywater that did not include waste from kitchen sinks and thus had low influent concentrations of TSS. Table 1 compares the raw graywater influent water quality parameters from the Bullitt Center to those reported by Jokerst et al. (2011) and Gross et al. (2007).

TABLE 1. Influent water quality data ranges for Bullitt Center compared to literature values.

	Bullitt Center	**Jokerst et al. 2011**	**Gross et al. 2007**
BOD_5 (mg/L)	30 – 4860	31 - 162	280 - 688
TSS (mg/L)	29 – 424	7 - 28	85 - 285
Temp (°C)	17.5 - 22.4	0.4 - 22	No data reported
pH	4.8 - 8.9	6.0 - 6.8	6.3 - 7.0
COD (mg/L)	96 - 8817	No data reported	702 – 984
DO (mg/L)	1.5 - 10.3	0 - 0.6	No data reported
Fecal Coliform (CFU)	1.1×10^3 - 2.1×10^6	0 – 1×10^5	9×10^4 – 1×10^8
Total Nitrogen (mg/L)	7.3 - 30.5	5.7 - 34	25 – 45

The effluent water quality for the Bullitt Center graywater treatment system had a significantly broader range of values for BOD_5 and TSS (Table 2) which was likely due to the higher influent values, particularly for TSS. The overall removal of BOD_5 averaged 89±13 % over the entire period and the treatment goal of 30 mg/L was met during the late spring and summer months (Figure 2). However, effluent BOD_5 concentrations did not meet the allowable concentration limits (but did meet the mass discharge limits) during the fall and winter months, most likely due to decreased biological activity as was reported by Jokerst et al. (2011). The overall BOD_5 in the effluent would also be decreased if the TSS concentrations in the influent and effluent were lower since approximately one-third of the BOD_5 can be attributed to TSS loads (David and Cornwell 2012).

TABLE 2. Effluent water quality data ranges for Bullitt Center compared to literature values.

	Bullitt Center	**Jokerst et al. 2011**	**Gross et al. 2007**
BOD_5 (mg/L)	6.6 - 400	1 - 55	0 – 15
TSS (mg/L)	16 - 508	1 – 22	0 – 6
Temp (°C)	11.1- 26.4	5.2 – 18.9	0 - 4.5
pH	6.0 - 9.1	No data reported	7.0 - 8.0
COD (mg/L)	34 - 660	No data reported	60 – 220
DO (mg/L)	8.7 - 14.6	No data reported	No data reported
Fecal Coliform (CFU)	33 - 2.6×10^4	1 – 1.1×10^3	3×10^2 – 7×10^5
Total Nitrogen (mg/L)	1.3 - 8.3	0 - 8.2	0 - 4.5

The effluent concentrations of TSS were generally well above the 30 mg/L permitted concentration throughout the testing period (Figure 3). In several cases, the effluent TSS concentrations were higher than those measured in the influent which was likely due to the

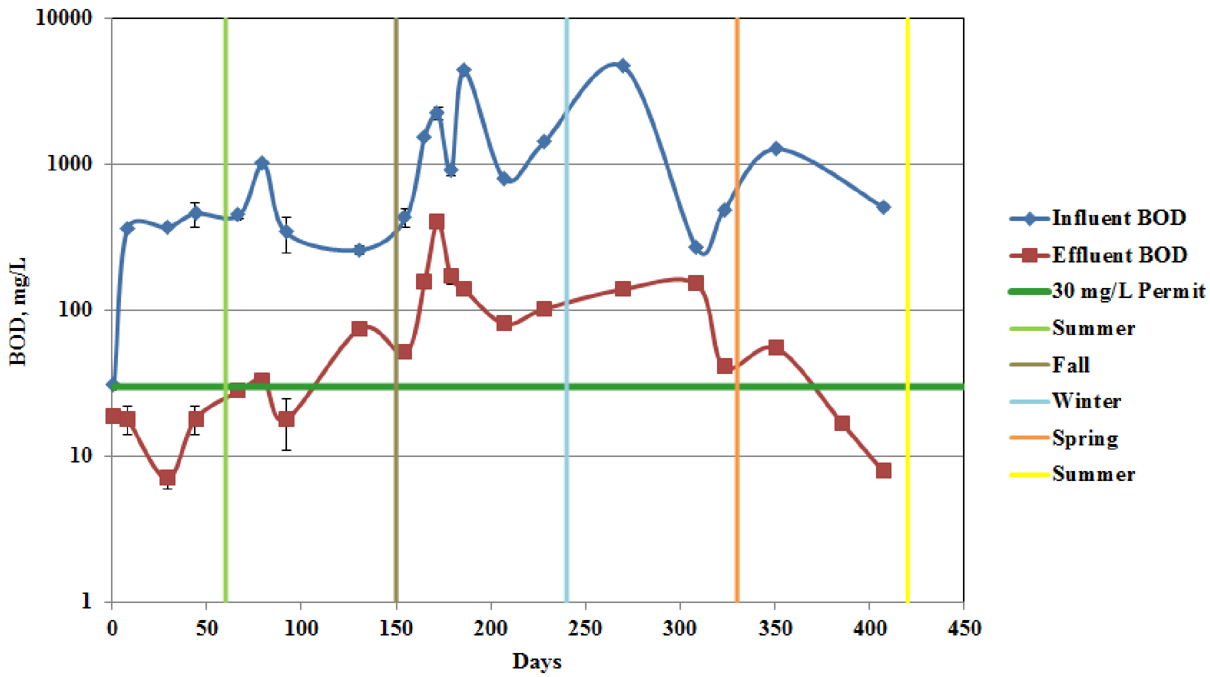

FIGURE 2: Influent and effluent 5-day biochemical oxygen demand (BOD) concentrations for the Bullitt Center constructed graywater treatment wetland between April 23, 2013 and June 10, 2014.

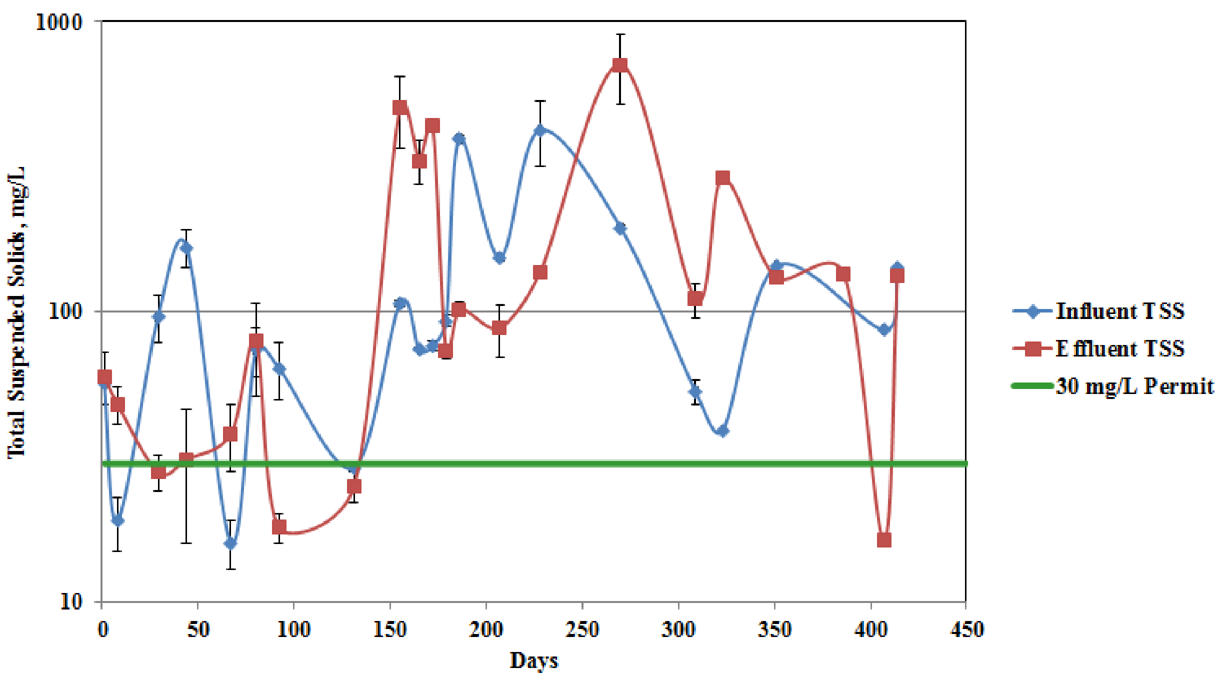

FIGURE 3: Influent and effluent total suspended solids (TSS) concentrations for the Bullitt Center constructed graywater treatment wetland between April 23, 2013 and June 10, 2014.

sloughing of biological solids production within the wetland. Decreasing the recirculation rate to the wetland could decrease the sloughing of solids, but it might also increase the risk of clogging to the system. To meet the permitted limits, it may be necessary reduce the solids loading by adding a pre-treatment settling basin as done by others (Gross et al. 2007; Paolo et al. 2009) or by adding an in-line pre-filter.

The Bullitt Center wetland was rarely able to meet the target effluent fecal coliform (*E. Coli*) concentration of 200 CFU per 100 ml (Figure 4), a phenomenon that was observed for comparable graywater treatment wetlands (Gross et al., 2007; Jokerst et al. 2011; Paulo et al. 2009). However, the three times that it was able to meet the coliform limits occurred in the late spring at the end of the first year of plant growth. These results are encouraging, however it is anticipated that the system will still have difficulty meeting these limits during colder months (USEPA 2012). Should this be the case, an ultraviolet light disinfection unit could be used to sterilize the effluent prior to discharge to the drain field.

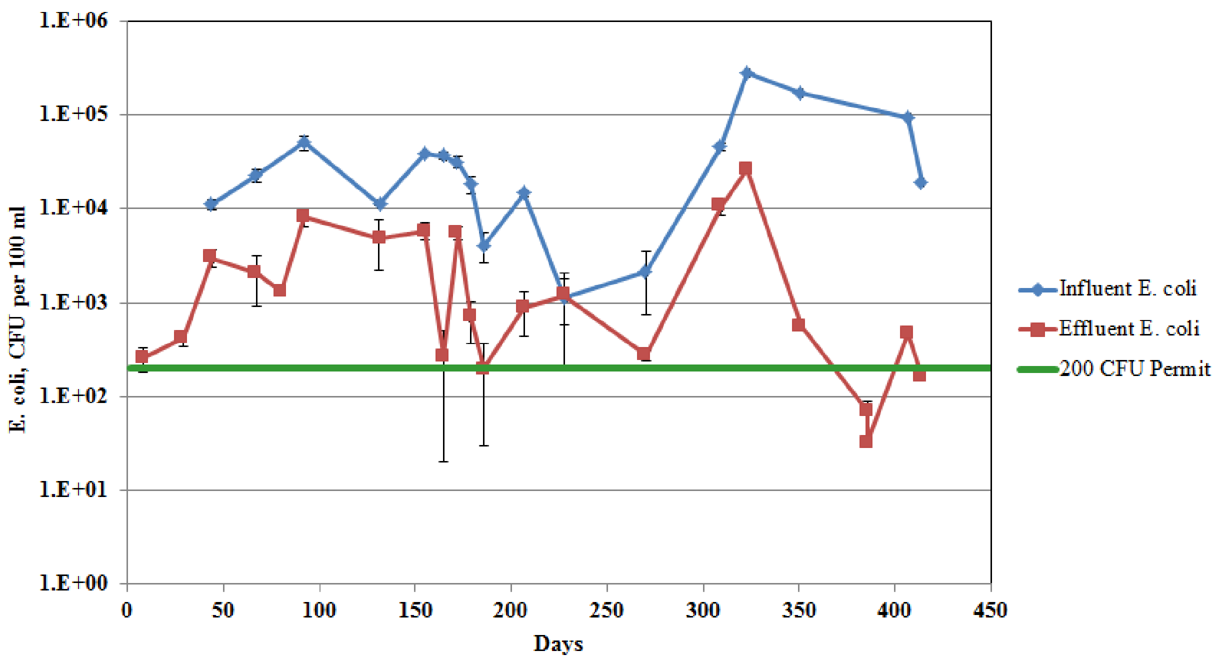

FIGURE 4: Influent and effluent *E. coli* concentrations for the Bullitt Center constructed graywater treatment wetland between April 23, 2013 and June 10, 2014.

CONCLUSIONS

The Bullitt Center has an RGFS wetland system that treats the building's graywater as mandated by the Living Building Challenge. Due to the relatively low effluent flows, the wetland was able to meet the mass discharge limits for BOD_5 and TSS. The wetland met the allowable discharge concentration of 30 mg/L for BOD_5 during the late spring and summer months when biological activity was presumably higher, but this concentration limit was not met during the colder fall and winter months. Decreasing the solids loading on the system could help achieve the 30 mg/L BOD_5 discharge concentration goals.

The influent graywater was significantly higher in TSS than that of systems reported in the literature. In addition to helping achieve the target BOD_5 limits, decreasing the solids loading by using a settling basin or in-line bag filter may also help the system achieve the 30 mg/L TSS discharge concentration limits. Finally, the system was rarely able to meet the allowable fecal coliform concentrations of 200 CFU per 100 ml. However, data after one growing season indicates that these limits are achievable during the growing season. Should the system continue to have difficulty meeting the fecal coliform concentrations during the colder months as observed by others, an active form of disinfection such as ultraviolet light sterilization may be required.

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