Abstract

Conventional subsurface-flow constructed wetlands (SFCW) for wastewater treatment are typically designed as horizontal plug-flow vegetated beds. Limited oxygen, provided mostly by slow transfer through air–water interface, turns these systems anaerobic, thus requiring a long hydraulic retention time (HRT) to achieve desired effluent quality. A SFCW treatment system with biofield effluent disposal has been designed and constructed for the highway I-70 rest area station near Greenfield, Indiana. A number of features were incorporated into the design of this system in an effort to enhance oxygen transfer. They include 1) a pair of parallel wetlands that can be operated in a cyclic “draw-and-fill” scheme – allowing filling of one wetland while draining the other, and 2) a vertical filter with coarse gravel at the front section of each wetland cell. It is expected these modifications can significantly improve biological oxygen demand (BOD) and nitrogen removal, therefore reducing the HRT of the system. This paper presents details of the modified design, flow and treatment data from the first year of operation, and early experience gained during this period.

Introduction

Subsurface-flow constructed wetlands (SFCW) have increasingly found applications in small- to medium-sized wastewater treatment systems throughout the United States. Many of these systems have been utilized in treating wastewater from a number of diversified sources, such as agriculture, municipality, industry, landfill, stormwater runoff, and contaminated surface or groundwater. A properly designed SFCW offers high performance in removing biochemical oxygen demand (BOD) and suspended solids with relatively short hydraulic retention time (HRT), even in colder climates. However, the efficiency of nitrogen removal can be quite poor, especially during winter months when temperature dips below sub-freezing.

Two major pathways exist in the treatment of nitrogen within wetlands (Hseih and Coultas, 1989). First is storage, a non-renewable pathway, in which nitrogen is being
assimilated into the biomass through uptake of vegetation/bacteria as well as adsorption to the wetland medium (i.e. soil or gravel substrates). Unless wetland plants are being harvested or medium replaced, temporarily stored nitrogen will eventually recycle back into the bulk solution. Second is the removal of nitrogen through nitrification–denitrification mechanism supported by microbial activities (Benham and Mote, 1999). Nitrification requires oxygen for nitrifying bacteria to convert ammonia (NH₃ and NH₄⁺) into nitrite (NO₂⁻) and subsequently nitrate (NO₃⁻) nitrogen, while denitrification reduces nitrate into gaseous nitrogen (N₂) under anoxic conditions with sufficient carbon source. This two-step process is sequential – nitrification transforms the nitrogen and denitrification then completes the removal through the release of gaseous products. Unfortunately in most conventional horizontal SFCWs, anaerobic conditions prevail throughout the water column in the wetland cells, except at near the water table and at the plant roots. In fact, typical values of dissolved oxygen (DO) in SFCW systems (for wastewater treatment) are usually below 1.0 mg/L (US EPA, 2000; Behrends et al., 2001). At such DO levels, oxygen becomes the limiting nutrient and nitrification slows to a halt (Metcalf and Eddy, 1991). Coupled with cold temperature, nitrogen removal efficiency becomes very low during winter months.

A number of alternative SFCW systems – both laboratory and field scale – have been designed, built, and operated, with various design modifications to enhance oxygen transfer and hence nitrogen removal efficiency. Cottingham et al. (1999) showed improvement (50%) in nitrification rate by direct aeration of laboratory scale wetlands. Aeration system has also been successfully applied at the field scale (Wallace et al, 2001). Many researchers have found that periodic raising and lowering of water level in experimental systems improves ammonium (NH₄⁺-N) removal (Moorhead and Reddy, 1990; Busnardo et al., 1994; Tanner et al., 1999). However, one study by Hunter et al. (2001) reported evidence contrary to previous studies. Hunter et al. (2001) found that microcosms with water level drawdown performed significantly worse in terms of NH₄⁺-N removal than ones without drawdown. The inferior removal performance, as pointed out by the authors, can be attributed to the plant stress caused by the water level fluctuations. It appears that the primary ammonium removal mechanism in their systems is through plant uptake. The fill–drain cycle spans two times the designated HRT (2 or 6 days). Such a long cycle not only causes stress to the plants, but it also fails to promote adequate oxygen transfer for nitrification.

The fill-and-drain concept has, however, been successfully demonstrated in the field scale systems. A unique and patented reciprocating SFCW system was developed by scientists at Tennessee Valley Authority (TVA), in which paired wetland cells are filled and drained alternately in a rapid (~2 hours per cycle) and recurrent basis (Behrends, 1999). This particular technology has been shown to achieve very high ammonia removal performance for a variety of waste streams (Behrends et al., 2001). A three-cell SFCW system at the Village of Minoa, NY, has also shown success in applying the fill-and-drain concept (US EPA, 2000). In that system, two parallel cells operated in an alternating fill-and-drain mode, followed by a conventional flow-
through cell. It was found that this mode of configuration produced effluent quality significantly better than other operating modes (such as three cells in series). The success of the fill-and-drain cycles lies in the diffusion of oxygen through thin films of water that are surrounding the plant roots and the biofilms on the wetland substrates during the drain cycle and the subsequent re-exposure of the biofilms to anoxic wastewater during the fill period (Behrends et al., 2001). Given the large surface area presence in the SFCW due to plant roots and substrates, the oxygenation of the rhizosphere and the substrate biofilms is substantial and rapid. This can potentially decrease the long HRT required for nitrogen removal associated with the conventional SFCW systems.

A SFCW system is often regarded as a low-cost and low-maintenance alternative to conventional wastewater treatment technologies. Promising results in its nitrogen removal capability (with design modifications) make the SFCW system an even more attractive one. As a result, the objectives of this study are to apply various design features to a SFCW system in hope to enhance nitrogen removal, and also to demonstrate the SFCW technology in the treatment of high-strength wastewater generated at a highway rest area facility in the State of Indiana. This paper presents the modified design, flow and treatment data from the first year of operation, preliminary modeling of the hydraulics of the wetland system, and early experience gained during this period.

Greenfield Rest Area Constructed Wastewater System

Chan et al. (2004) identified four major challenges facing wastewater treatment at highway rest area facilities: 1) remote location; 2) high wastewater strength; 3) high variability in wastewater flow; and 4) limited personnel. The Greenfield Rest Area, located along interstate highway I-70 near Indiana SR-9 in Hancock County, IN, encounters similar problems with the exception that it has access to a sanitary sewer that connects to the nearby city of Greenfield. An onsite SFCW system with a biofield disposal system was designed, built, and has been in operation for more than a year. The details of the design were provided in Chan et al. (2004). Here, a brief summary is given and design features pertinent to the nitrogen removal enhancement are discussed in more detail.

System Design. The Greenfield wetland system was designed based on a peak flow rate of 10,000 gpd (37.85 m³/day). Wastewater influent was found to contain 450 mg/L 5-day biochemical oxygen demand (BOD₅), 150 mg/L total ammonia nitrogen (NH₃-N), and 180 mg/L total suspended solids (TSS). The high strength wastewater is due to the use of flow-restrictive faucets and low-flush toilets. The schematic of the wetland system is shown in Figure 1. Wastewater influent from north and south buildings is first passed through two 10,000 gal. (37.85 m³) septic tanks (ST-1 and ST-2) in series. Dosing chamber LS-1 feeds wastewater into either one of the wetland cells (W-1 and W-2), each with a basal area of 56 ft by 56 ft (17 m by 17 m), 3 ft (0.9 m) in depth, and a side slope of 1 to 3. The actuator valves ACT-1 and ACT-2 control the filling and draining, respectively, of the wetland cells. Two
manual valves located in ACT-2 control the drain rate of W-1 and W-2 respectively. This “draw-and-fill” scheme operates on a time-based switch such that while W-1 is filling, W-2 is draining and vice versa. The switch occurs once a day from Tuesday to Friday, and twice a day from Saturday to Monday due to the expectation of higher flow rates during weekends. Wastewater exiting the parallel wetlands will pass through a flow distribution box (DBOX) where up to 83% of the effluent is diverted back to the second septic tank (ST-2). Such recirculation effectively turns ST-2 into an anoxic chamber for denitrification, along with the traditional functions of solid settling and anaerobic decomposition. The remaining 17% of the effluent flows by gravity through a third wetland cell (W-3) – a conventional flow-through SFCW cell. This cell serves as a polishing step and also a backup storage in the event of pump failure or heavy rainstorm. A small portion of the treated wastewater from W-3 – 20 ft (6.1 m) wide, 40 ft (12.2 m) long, and 2 ft (0.6 m) deep – is diverted to the biofield for disposal via evapotranspiration and infiltration to the subsoil. The bulk of the treated effluent is sent to the Greenfield wastewater treatment plant through the existing sewer.

Each wetland cell in the system contains a front and a back section. The front section consists of an elevated unplanted gravel (1.5–3 in. or 3.8–7.6 cm) bed that serves as a vertical filter. Smaller size (1–1.5 in. or 2.5–3.8 cm) gravel is used in the (back) horizontal flow section. In the back section, a 6 in. (15.2 cm) layer of pea gravel is laid on top to support vegetation growth and another layer of peat moss on top to provide thermal insulation. All of the gravel used in the system is mixed in with 10% by volume of crushed lime stone to ensure adequate alkalinity for nitrification.

At the writing of this paper, a surge tank is being constructed upstream of the first septic tank (ST-1), which will eventually control the dosage of wastewater into the wetland system.
**Instrumentation.** As shown in Figure 1, a number of flow measuring devices are placed in strategic locations to acquire a complete picture of the hydraulics of the system. A V-notch weir and a couple of Palmer-Bowlus flumes were installed for open-channel flow measurements. Magnetic flow meters were used to measure pressurized flows. Four automatic samplers were also installed to collect wastewater samples at various points in the system. A weather station was also installed to provide data on rainfall, wind speed, temperature, and estimates of evapotranspiration.

**First Year in Operation.** The wetland cells were planted on August 12, 2003. Clean water with fertilizer was initially used to promote plant growth and development. Wastewater was introduced early October of the same year. During the startup period (from October 2003 to June 2004), the cyclic draw-and-fill operating mode was replaced by an over-flow mode where water levels in the parallel wetland cells (W-1 and W-2) were maintained constant at full level and water was overflowing from both cells through two level adjusting pipes at the ACT-2 chamber. The constant water depth allows plants to establish better and it also protects the young root mass against the cold winter temperature. For most of the startup period, wastewater from only the north building was fed to the system and recirculation was also disabled.

In the middle of June 2004, the operation of the parallel cells was switched into draw-and-fill mode. Recirculation (at 83%) was started at the same time and only the north building was supplying wastewater to the system. At the beginning of October, the wetland system began full operation, receiving water from both north and south buildings.

**Flow Measurements Results**

Recognizing the lack of extensive flow data available on other similar wetland systems in the US, it was decided that extensive flow monitoring efforts should be undertaken at the Greenfield wetland system. Data of good temporal resolution are also needed to understand the hydraulics of the system as it incorporates a rather complex flow scheme that is dramatically different from a conventional horizontal-flow system.

Several problems were encountered, mainly with the open-channel flow measuring devices (F-1, F-2, and F-3), during the first year of operation. Besides occasional equipment failure, we realized the measurement errors associated with the weir and flume flow meters are quite large for the range of flow rates (0 to 15 gpm or 0 to 56.78 L/min) that were typically encountered. These devices consist of an ultrasonic level sensor and the corresponding flow measuring apparatus (either a weir or a flume). While the level sensor has a rather fine resolution of 0.01 ft (3 mm), the corresponding error in flow measurement can be very large especially at low flow rates. For a flow rate of 2 gpm (7.57 L/min), the relative error for the weir (F-1) is ~16% and for the flumes (F-2 and F-3) ~50%. In hind sight, tipping bucket type device should have been used due to flow intermittency and low flow rates of the system. Compounding the problem is the frequent clogging of the filters installed in septic tank 2 (ST-2). Clogged filters prevent ST-2 from overflowing properly, thus
flooding the F-1 chamber. Also, infiltration of groundwater into the system was observed especially after several consecutive rainfall events causing high groundwater table. Since currently the inflow to the system is being measured by F-1, its inaccurate measurements, plus the unknown rate of infiltration, prevent an accurate and complete water balance of the system from being calculated. A surge tank will be installed upstream of the first septic tank during the Spring of this year and the accompanying magnetic flow meter will eventually provide the much needed inflow information.

Flow measurements from the magnetic flow meters in the system are believed to be accurate and they can be used to adjust and correct the flume measurements. Figure 2 shows the daily total flows recorded by F-1, F-2, and M4 from October 15, 2004 to December 16, 2004. The drinking water (DW) usage and the rain total are also plotted. Measurements from F-2 were corrected by matching to those from M-4 since measurements from the two meters should be very close on dry days. (The flow contributing to the biofield and water loss due to evapotranspiration are negligible during that period.) Data from F-1 seem to match the drinking water data quite closely except on December 7 and 14 where the flow measured by F-1 is much higher than that of the drinking water. This indicates that the filters at the second septic tank began to clog and the chamber housing F-1 was possibly flooded on those days.

Looking closer at the drinking water data in Figure 2, one can observe a weekly cycle in which the DW usage is higher later in the week especially on Fridays and Sundays. A seasonal cycle is also demonstrated by the DW usage. The DW flow peaks during the summer months at around 7,500 gal/day (28.4 m³/day) on average. The low occurs during the winter months at around 4,000 gal/day (15.1 m³/day). These cycles are expected to correspond to the fluctuations in traffic volume on I-70.

Rainfall and Evapotranspiration. The effect of rain on the wetland system can be seen in Figure 3. The response of the outflow to a rain event is quick but with tailing. The tailing effect is mainly due to the recirculation after the parallel cells, which delays the response at the outlet. Infiltration also adds to such an effect. The estimated surface area of the three wetland cells is 12,600 ft² (1,170 m²). For 1 mm of rainfall depth, an equivalent of 300 gal (1.14 m³) of water is added to the system. Therefore,
rainfall can add a considerable volume of water into the system. If a treatment system is designed for subsurface disposal, rainfall must be taken into account for sizing of the drain field.

The weather station (Campbell Scientific ET106) installed onsite provides estimates of the potential evapotranspiration \( (\text{ET}_o) \) based on the Penman-Monteith equation using various parameters (radiation, temperature, wind speed, and humidity) measured real-time. The actual evapotranspiration \( (\text{ET}) \) from the system however is influenced by numerous factors such as type of vegetation, the developmental stage of the vegetation, and type of soil (substrates) and its cover (FAO UN, 1998). Typically for wetland vegetation, the actual ET rate is only a small fraction (less than 30%) of \( \text{ET}_o \) during non-growing season; during the full-grown period (~3 months), the actual ET rate is slightly higher (~120%). Since an accurate water balance has not been computed for the system, the ET estimates cannot be verified or computed as yet. Based on preliminary data, we do not expect a substantial amount of water loss from the system due to ET even during the summer season as ET can easily be offset by rainfall received.

**Recirculation and Hydraulic Retention Time.** Given the system is operating in an over-flow mode with full water level in the two parallel wetland cells, the HRT can be calculated by

\[
\text{HRT} = \frac{V_{\text{sys}} \eta}{Q}
\]

where \( V_{\text{sys}} \) is the nominal volume of the system, \( \eta \) the porosity of the substrates, and \( Q \) the flow rate. Table 1 shows the HRT computed using different flow rates, assuming a porosity of 0.4 within the wetland cells. With the design flow rate of 10,000 gpd (37.85 m³/day), the HRT in W-1 and W-2 is about 6.8 days. The HRT of the system increases during winter months due to lower flow rate. It should be noted that the porosity of the wetland cells will change overtime due to solid accumulation and plant root growth.

**Table 1: Estimated HRT of the wetland system.**

<table>
<thead>
<tr>
<th>Flow rate (gpd)/(m³/day)</th>
<th>HRT (days)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W-1 &amp; W-2</td>
<td>W-3</td>
<td>Septic tanks</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td><strong>Over-flow mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>10,000 / 37.9</td>
<td>6.8</td>
<td>0.6</td>
<td>2</td>
<td>9.4</td>
</tr>
<tr>
<td>Summer</td>
<td>7,500 / 28.4</td>
<td>9.1</td>
<td>0.8</td>
<td>2.7</td>
<td>12.6</td>
</tr>
<tr>
<td>Winter</td>
<td>4,000 / 15.1</td>
<td>17</td>
<td>1.5</td>
<td>5</td>
<td>23.5</td>
</tr>
<tr>
<td><strong>Draw-and-fill mode</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/20–22</td>
<td>5,280 / 20.0</td>
<td>8.7 (12.9)*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10/16–17</td>
<td>6,150 / 23.3</td>
<td>8.8 (11.1)*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*The value in parenthesis is the estimated HRT as if in the over-flow mode.

Under the cyclic draw-and-fill mode, the HRT cannot be calculated easily because water levels within the two parallel wetlands are constantly changing during the fill and drain cycle. Unfortunately, we did not install any instrument to measure the water level in the wetland cells. We can only infer from the flow data given by
F-2 to determine whether a particular wetland cell is full by looking for indication of overflow. Figures 3a and 3b show the flow data collected from F-2 from two different periods. In July, only wastewater from the north building is feeding the system, effectively cutting the inflow by half. There is no sign of overflow (see Figure 3a). The spikes in flow rates occurred after the drain–fill switch took place (indicated by dotted line). It is apparent that one cell is draining at a much faster rate than the other. This discrepancy in drain rates was not intended and the manual valves in ACT-2 will be adjusted for equal flow rates in the future. The fast draining cell usually emptied itself entirely (as flow being zero) before the fill cycle. It is not known however whether the water level in the cell reached the full level during each fill cycle. With full load feeding the system, overflow usually occurred at the filling cell near the end of its fill cycle (see Figure 3b). The difference in drain rates between the two cells is not obvious here as it is masked by the overflow.

**Dynamic Modeling of the Draw-and-Fill Hydraulic Scheme**

The hydraulics of the Greenfield wetland system is rather complex since it involves a pair of alternating draw-and-fill wetland cells plus recirculation. As mentioned earlier, the estimation of the HRT of the system under the draw-and-fill mode can be difficult because the volume of water present for each cell in the system changes over time due to water level fluctuations in the wetland cells. Due to the lack of water level monitoring within the cells, we have to estimate water volume by modeling of the wetland system and simulation of such model using measured input data. A simplified model of the paired wetlands with flow recirculation is built using a system approach, and we have taken advantage of the user-friendly environment of Simulink® in MATLAB® (Mathworks, Natick, MA) to handle the tasks of model creation and simulation.

**Model Description.** Each wetland cell is modeled as a giant bucket and the discharge, $Q_{out}$, during the drain cycle is given by

$$Q_{out} = C_d A_d \sqrt{2g(h - h_{min})}$$

for $h_{min} \leq h \leq h_{max}$

where $C_d$ is the discharge coefficient, $A_d$ the outlet pipe area, $g$ the gravitational constant, and $h$ the water depth in the wetland. The discharge coefficient accounts for
all energy losses including minor losses as well as friction losses in piping and within the wetland cell. Since the inflow, \( Q_{in} \), to a wetland during the fill cycle is controlled by a time-based actuator valve, overflow is possible once the wetland is full in capacity. In the model, we make a simplifying assumption that the response of the overflow is instantaneous and neglect the actual water flow through the substrate in the cell. As a result, for \( h > h_{max} \), \( Q_{out} = Q_{in} \). The inflow to the wetland cell during the fill cycle therefore also includes recycled flow from the draining cell and possible overflow from the filling cell. Rain directly contributes to the inflow to each wetland cell regardless of whether the cell is filling or draining. Lastly, each wetland cell has a trapezoidal cross-section; therefore, the change of water level within the cell is described by

\[
\frac{dh}{dt} = \frac{Q(t)}{(W + 6h)(L + 6h)\eta}, \quad Q(t) = Q_{in} - Q_{out}
\]

where \( W \) and \( L \) are the basal width and length of the cell, respectively. Note that the current model does not include the whole wetland treatment system but only the two alternating draw-and-fill cells and flow recirculation.

**Simulation Results.** There are two sources of inflow in the model: drinking water data and rainfall. Data from October 16 to October 23, 2004 were used in the simulation (see Figure 4a). Drinking water data was used because data measured by F-1 were deemed not reliable. The porosity of the wetland substrate is assumed to be 0.4. The discharge coefficient, \( C_d \), is the only parameter that needs to be calibrated. The calibration is done by matching the system outflow to the flow data measured by F-2. It was found that \( C_d = 0.04 \) for the flow data used in this simulation. The value of \( C_d \) is small mainly because the drain valves in ACT-2 were only partially opened to allow the wetland cells to drain slowly.

Figure 4b shows the simulated system outflow comparing to the observed F-2 flow data. As a result of the calibration, the simulated outflow matches the observed data very well when there is no overflow. The measured overflows, shown as spikes, were reproduced by the models; however, the timing of the onset and the magnitude were quite different. The simulated overflows were higher in magnitude than the observed ones, owing to the unrealistic assumption that the response of the overflow is instantaneous. Overflow begins when water level in the filling cell exceeds the top of the riser pipe in ACT-2. The water level in the cell should continue to rise and the rate of the overflow is governed by the head developed as a result. A more realistic overflow model, perhaps a weir equation, should be used in the continuing study. The discrepancy in the onset time of the overflows was probably because the maximum water level, \( h_{max} \), set by the riser pipe is perhaps lower in the actual system.

Figure 4c shows the water level changes within the two cells. The twice-a-day drain–fill switch causes smaller water level fluctuations with the cell. The drain rate is small enough that, even during once-a-day switch, the cell is not entirely drained. The HRT of the alternating cells can be estimated from the Figure 4d where the volume of water occupying the system is plotted against time. For days without the influence of rain, the HRT is approximately 8.7 days given an average inflow of 5,280 gpd (20.0 m³/day) (see Table 1). The twice-a-day switch does not alter the HRT much due to higher inflow on the weekend. The draw-and-fill mode cuts the overall HRT by 2
to 4 days at the daily flow rates simulated, comparing to the overflow mode. Rainfall may decrease the HRT of the system under draw-and-fill mode. However, such effect is considerably smaller than in the overflow mode because the drained headspace in the wetland cells act as storage for the rain water.

One interesting observation that can be made from the simulation and the observed data is that the overflow period on Tuesday, October 19, was particular long. It corresponds to the transition between the twice-a-day to once-a-day cycle. It turns out that this happened on every Tuesday and that it led to high outflows of the wetland system on those days (see Figure 2).

**Treatment Performance**

Wastewater samples from four locations (see Figure 1) within the treatment system were collected on a monthly basis. Samples were analyzed for BOD$_5$, TSS, and NH$_3$-N. Recent analysis results from July to December 2004 are presented in Table 2. These samples were collected after the commencement of the draw-and-fill mode. We observe that BOD removal rate has increased from 50% to 70% during this period. The system has also achieved a TSS removal rate on average of 80%. The ammonia removal was quite small (~30%) in the beginning; however, the removal efficiency has increased dramatically in November (46%) and December (73%). Although such increase can partly be explained by decrease in wastewater inflow and dilution by rainwater, we believe the alternating draw-and-fill scheme also helped by increasing oxygen transfer for nitrification to take place.

**Table 2: Wastewater sample analysis results.**

<table>
<thead>
<tr>
<th>Date</th>
<th>AS-1 (mg/L)</th>
<th>AS-2</th>
<th>AS-3</th>
<th>AS-4</th>
<th>%*</th>
<th>AS-1 (mg/L)</th>
<th>AS-2</th>
<th>AS-3</th>
<th>AS-4</th>
<th>%</th>
<th>AS-1 (mg/L)</th>
<th>AS-2</th>
<th>AS-3</th>
<th>AS-4</th>
<th>%</th>
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<td>07/30</td>
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<td>209</td>
<td>259</td>
<td>202</td>
<td>49</td>
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<td>24</td>
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<td>223</td>
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<td>177</td>
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<td>23</td>
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<tr>
<td>08/17</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>96</td>
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<td>89</td>
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<td>188</td>
<td>-</td>
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<tr>
<td>10/21</td>
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<td>-</td>
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<td>154</td>
<td>46</td>
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<td>73</td>
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</table>

*Percent removal

A number of factors and problems might have adversely impacted the treatment efficacy of wetland system. Firstly, water was ponded over the peat moss layer in one of the wetland cell (W-2) during the fill cycle when the cell was overflowing. The lack of an air-filled layer between the water table and the peat moss layer limits oxygen transfer (Wallace et al., 2001; Whitney et al., 2003). Secondly, plants tended to limit their root growth in the peat moss layer without further extension into the gravel layer. We have also a growing number of invasive plant species competing with the wetland plants. The diversity of original planted wetland species has decreased over time as a result. Lastly, overflows during the fill cycle may have caused “short circuiting,” shortening the travel time of wastewater through the system during this period.
Figure 4: (a) Drinking water and rainfall; (b) simulated outflow and observed data at F-2; (c) simulated water levels in W-1 and W-2; and (d) estimated volume of wastewater presence in the system.

Conclusions

A SFCW treatment system was designed with various features that enhance oxygen transfer and promote nitrification. This particular system was applied to treat high-strength wastewater generated at a highway rest area facility. Early monitoring results suggest that the alternating draw-and-fill scheme coupled with flow recirculation has improved the removal rates of BOD and ammonium nitrogen. Continued monitoring is required to establish the efficacy of the treatment system.

A dynamic model of the wetland system was built and the simulation results were used to determine the HRT of the system under the draw-and-fill hydraulic scheme. The model will be used to devise a control strategy that would maximize the HRT of the system and eliminate overflows in the current configuration. A flow-based schedule is being considered to replace the current time-based switch. An on-going effort is being spent on expanding the current model to describe the entire wetland system and also incorporating a treatment component to model effluent quality.
References


