Evaluation of the performance of horizontal subsurface constructed wetlands for treatment of combined sewer overflow

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Abstract

Constructed wetlands (CW) are regarded as an attractive alternative for combined sewer overflows (CSO) treatment and their high purification efficiency has been proven in several studies. However, in Portugal, there is no knowledge of any practical application of this type of technology.

The purpose of this research is to evaluate the application of “natural” solutions, such as CW, for CSO treatment in Portugal, a Mediterranean country with a long dry period. Besides, this study intends to gather the information and know-how required for the design of this type of infrastructures.

Four CW for CSO treatment were installed and evaluated “in situ”, close to an existing large wastewater treatment plant (WWTP), namely in terms of organic matter, total suspended solids and microorganism removal. The obtained results are considered very promising, even during start up.

Keywords: Combined sewer overflows; constructed wetlands; pollution control; sustainable approaches.

Introduction

The use of constructed wetlands (CW) is, when compared with traditional physical-chemical or biological plants, widely recognized as adequate for the treatment of wastewater and also considered a more natural and environment friendly solution. CW have been used for decades mostly for the treatment of domestic or municipal wastewater. Nevertheless, they have been recently applied to industrial and agricultural wastewater, landfill leachate and stormwater runoff (Vymazal, 2005).

During storm events, the flow in combined or partially separate sewer systems often exceeds the capacity of the wastewater treatment plants (WWTP) resulting in combined sewer overflows (CSO). Recently, studies have shown that the traditional approach to CSO management (including rainwater storage tanks, transport infrastructures and centralized wastewater treatment plants) is no longer sustainable (Balbo et al., 2010). Therefore, to reduce the detrimental impacts of CSO on receiving waters, enhanced treatment of these overflows may be required. CW are regarded as an attractive alternative and their high purification efficiency for CSO treatment has been proven in several studies (Uhl and Dittmer, 2005; Henrichs et al., 2007 and Van de Moortel et al., 2009).

For example, in Germany CSO treatment based on CW is already recognized as an appropriate technology and several systems have started operation in the last two decades (Uhl and
Dittmer, 2005). In Italy, the first examples began to emerge recently (Balbo et al., 2010) while in Portugal, a Mediterranean country with a long dry period, there is no knowledge of any practical application of this type of technology. This has motivated the present research for gathering information and know-how required for the design of this type of infrastructures, namely aiming at the upgrade of overflow discharges in the Frielas Drainage Basin, close to Lisbon, Portugal. The Frielas WWTP is one of the major tertiary treatment installations operating in Portugal, serving 700 000 p.e. (population equivalent). Nevertheless, during storm events, diluted effluents are directly discharged to the Trancão River. The use of “natural” treatment systems, such as CW, was considered to be a sustainable option for coping with such overflows. As such, four base alternative CW installations were evaluated “in situ”, namely in terms of organic matter, total suspended solids and microorganism removal.

Materials and Methods

A pilot scale experimental setup, including four horizontal subsurface flow CW, was implemented at the Frielas WWTP, in Lisbon, to simulate CSO treatment. Each bed measures 555x361x400 mm and is exposed to the local weather conditions.

Beds were organized into two groups (group 1 – CW1, CW2 – and group 2 – CW3, CW4) with each group being composed by two beds: one without vegetation (CW1 and CW3) and the other colonized with *Phragmites australis* (CW2 and CW4) (see Figure 1). The beds without vegetation acted as control. The formation of two identical groups intended to evaluate the effect of applying different affluent volumes (group 1 was fed with half the volume applied in group 2).

![Figure 1 - Pilot scale experimental installation (July 4, 2011).](image)

Gravel with diameters 4-8 mm was used as filling media, with a porosity of 30%. Feeding was conducted through a perforated pipe installed inside the bed. A throttle structure at the opposite end of the bed was installed at the bottom to allow the complete emptying of the filter and to set the maximum level allowed in the beds (about 5 cm below the surface).

Macrophytes were planted in the end of March 2011 to provide favourable weather conditions for establishment and growth. The beds were then inoculated for a period of two weeks,
involving irrigation with wastewater twice a week. Adaptation growth was solid and quickly. *Phragmites* were about 20 cm when planted and two months later reached an average length of 60 cm. Figure 2 shows the evolution of the growth of macrophytes between April and June.

It should be noted the significant contribution of the evapotranspiration effect in the volume reduction in beds with vegetation. In the last two events analysed, it wasn’t possible to collect samples after 7 days of retention in CW2.

The study of the start up phase was carried out from April to June 2011.

The system was batch fed with the effluent from the grid chamber of the WWTP to simulate the pre-treatment in a full scale CW, thus contributing to prevent clogging problems. To assess the evaluation of the performance during start up phase, feeding was performed once a week. When there were no rain events prior to the feeding, CSO was simulated by a dilution with potable water (about 1/3 of sewage and 2/3 of water). The water used was previously stored for some days in order to assure the absence of free chlorine.

The method of operation was as follows:

- At the beginning of each event effluent samples of each bed were collected from the discharge for analysis.
- The beds were then completely emptied, measuring the volume discharged by each one.
- A reservoir continuously stirred was filled with CSO and a sample was collected for analysis.
- All beds were fed from the reservoir with group 1 receiving 10 L and group 2 receiving 20 L.
- After 1, 3 and 7 days, effluent samples were collected at the discharge of each bed and analysed to assess the effect of hydraulic retention time.
Each sample was analysed regarding Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Coliforms (TC) and Enterococcus (Ent.). Experimental conditions such as temperature, redox potential, pH, conductivity and dissolved oxygen were also measured “in situ”.

**Results and Discussion**

The start up of CW for CSO treatment was analysed for a period of eight weeks.

Figures 3 to 6 present the precipitation that occurred from April 19 to June 14, 2011, as well as the pollutant concentrations measured in each bed, namely regarding COD, TSS, TC and Enterococcus.

![Figure 3](image1.png)  
Figure 3 - COD concentrations (CW1 to CW4) (April 19 to June 14, 2011).

![Figure 4](image2.png)  
Figure 4 - TSS concentrations (CW1 to CW4) (April 19 to June 14, 2011).
Globally, the experimental results show that the concentrations of these parameters usually decrease during the hydraulic retention time in the beds. The main COD and TSS removal occurred within the first 24 hours after each CSO event. This is probably due to the removal of particulate material by filtration in the filling media, promoting their subsequent degradation by the microorganism’s action and assimilation by the planted vegetation. During the remaining retention time a slower removal was observed. Similar results in terms of COD removal were reported in the study realized by Van de Moortel et al. (2009).

Microorganism removal efficiency, in terms of log decrease, showed a more steady decay through the seven days of each event.

Figure 7 presents the evolution of removal efficiencies after 7 days of retention in terms of COD, TSS, TC and Enterococcus, in each bed.
Figure 7 - COD, TSS, TC and Enterococcus removal efficiencies after 7 days.
During the first five weeks of operation COD removal efficiencies after 7 days increased 10 to 20% and seemed to stabilise after week six. Vegetated beds were the most unstable.

Regarding TSS removal, this effect was softened. There was a slight initial growth, reaching efficiencies near to 100% in recent events. The two lowest obtained values refer to beds with vegetation.

In terms of microbiological removal efficiencies, there was a gradual increase over time, reaching nearly 3 log and 4 log, respectively in terms of TC and enterococcus.

Table 1 presents the global average removal efficiencies after 7 days of retention for all CW. These efficiencies were calculated with the results from the last three weeks, when the performance of CW was more stable.

### Table 1 - COD and TC average removal efficiencies after 7 days.

<table>
<thead>
<tr>
<th>Retention time</th>
<th>Parameter</th>
<th>CW1</th>
<th>CW2</th>
<th>CW3</th>
<th>CW4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day</td>
<td>COD (%)</td>
<td>88</td>
<td>88</td>
<td>83</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>TSS (%)</td>
<td>95</td>
<td>94</td>
<td>94</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>TC (log)</td>
<td>1.8</td>
<td>2.9</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Ent. (log)</td>
<td>2.3</td>
<td>2.7</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>3 days</td>
<td>COD (%)</td>
<td>93</td>
<td>91</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>TSS (%)</td>
<td>99</td>
<td>96</td>
<td>99</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>TC (log)</td>
<td>3.4</td>
<td>3.8</td>
<td>3.8</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Ent. (log)</td>
<td>4.0</td>
<td>4.1</td>
<td>3.8</td>
<td>4.2</td>
</tr>
<tr>
<td>7 days</td>
<td>COD (%)</td>
<td>97</td>
<td>96</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>TSS (%)</td>
<td>99</td>
<td>96</td>
<td>99</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>TC (log)</td>
<td>4.8</td>
<td>5.1</td>
<td>4.6</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Ent. (log)</td>
<td>5.0</td>
<td>5.0</td>
<td>4.8</td>
<td>5.7</td>
</tr>
</tbody>
</table>

During start up phase, after 1 day of bed retention, average efficiencies of 82-88% and 86-95% were reached, in terms of COD and TSS respectively. These average values increased with the hydraulic retention time, and after 7 days achieved 93-97% for COD and 94-99% for TSS.

The variation of concentrations for microbiological indicators was more linear, presenting, on average and after one day, reductions of 1.5-2.9 log and 2.1-2.7 log for total coliforms and enterococcus respectively. For a retention time of 7 days, these reductions reached 4.6-5.2 log and 4.8-5.7 log.

Differences between groups 1 and 2 in terms of COD efficiency removal were not relevant, thus different affluent volumes did not seem to influence significantly the CW performance during start up. When comparing vegetated with non-vegetated beds, differences were also not relevant, which may be due to the fact that plants were not completely established and mature. During the analysed period, macrophytes had more influence on the removal efficiencies of TC and enterococcus.

In terms of COD and TSS removal, the results are similar to those referred in other studies (Van de Moortel et al., 2009; Uhl e Dittmer, 2005). Regarding microbiological parameters, higher efficiencies than expected were achieved, when compared with those generally obtained in wastewater treatment.
Conclusions

In recent decades, the technology of constructed wetlands has gained importance since it is simple to operate and maintain and given its low resources utilization. The application of constructed wetlands for treatment of combined sewer overflows is considered a sustainable approach with relevant potential and it can be interesting namely in an urban context, especially when it is important to promote the environmental and visual integration of the system.

In the start up phase, after 1 day of bed retention, average efficiencies of 82-88% and 86-95% were reached, in terms of COD and TSS, respectively. These average values increased with the hydraulic retention time, and after 7 days achieved to 94-97% for COD and 93-99% for TSS. The variation of concentrations for microbiological indicators was more linear, presenting, on average and after one day, reductions of 1.5-2.9 log and 2.1-2.7 log for total coliforms and enterococcus, respectively. For a retention time of 7 days, these reductions reached 4.6-5.2 log and 4.8-5.7 log, which is higher than expected.

The obtained results are considered very promising, in terms of removal of organic matter, TSS and pathogens, even during start up.

During the first five weeks of operation, COD removal efficiencies after 7 days increased 10 to 20% and seemed to stabilise after week six. Vegetated beds were the most unstable. Differences between groups 1 and 2 in terms of COD efficiency removal were not very relevant, thus different affluent volumes did not seem to influence significantly the CW performance during start up. When comparing vegetated with non-vegetated beds, differences were also not relevant, which may be due to the fact that plants were not completely established and mature.

During the analysed period, macrophytes had more influence on the removal efficiencies of TC and enterococcus.

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