Impact of operational maintenance on the asset life of storm reed beds

D.P.L. Rousseau*, D. Horton, P. Griffin**, P.A. Vanrolleghem*** and N. De Pauw***

*Department of Environmental Toxicology and Aquatic Ecology, Ghent University, Jozef Plateaustraat 22, 9000 Gent, Belgium (E-mail: *diederik.rousseau@ugent.be; niels.depauw@ugent.be*)

**Technology and Development, Severn Trent Water Ltd, Avon House, St Martin's Road, Coventry, CV3 6PR, UK (E-mail: *debbie.horton@severntrent.co.uk; paul.griffin@severntrent.co.uk*)

***BIOMATH, Ghent University, Coupure Links 653, 9000 Gent, Belgium (E-mail: *peter.vanrolleghem@ugent.be*)

Abstract This paper reviews the operation of storm reed beds to determine whether the current system of operational maintenance is contributing to premature process failures and if not, to identify other factors of importance. Twelve storm reed beds of the horizontal subsurface flow type, at seven locations in the South Warwickshire area of the United Kingdom, were surveyed. Each survey consisted of a site visit, an interview with the operators in charge and an assessment of the treatment performance based on routine monitoring data. Although some sites suffered from varying degrees of sludge accumulation, surface blinding and/or weed growth, all effluent concentrations remained far below the consent levels. Thorough operational maintenance on a reed bed is proven to be important for the asset life. However, there are other factors or features of a reed bed that play a more pivotal role in premature process failure such as the lack of pre-treatment and a premature operation of the storm overflow.

Keywords Combined sewer overflow; design life; *Phragmites australis*; sludge accumulation

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Introduction

Combined sewer overflows (CSOs) are becoming increasingly undesirable for river water quality considerations (Mulliss *et al.*, 1997) and multiple approaches have been adopted to reduce their impact (Zabel *et al.*, 2001). Storm water detention tanks are a common preventive measure but at small-scale wastewater treatment plants they are unpopular with the water companies because they require additional site visits and attendance time. As a consequence, operating costs can increase considerably. Another drawback of detention tanks is the virtual absence of pollutant removal processes. This concept is therefore increasingly being abandoned in favour of storm water treatment facilities (Griffin and Pamplin, 1998). Whilst CSO treatment options are multiple (Geiger, 1998), this paper focuses on constructed treatment wetlands as they present an eco-friendly and cost-effective solution in rural areas to minimize CSO effects on the receiving water course (Scholes *et al.*, 1999; Carleton *et al.*, 2001).

Severn Trent Water is the world's fourth largest privately-owned water company, serving over 8 million customers across the heart of the UK, stretching from the Bristol Channel to the Humber river, and from mid-Wales to the East Midlands. The company has more than 700 facilities serving populations of less than 2000. About 200 of these facilities rely on rotating biological contactors (RBCs) for wastewater treatment. A policy decision has been taken to provide capacity in the RBCs for 6 times the dry weather flow (DWF). Higher flows are firstly routed through a Copasac™ chamber fitted with bags made of woven polypropylene with a 2 to 10 mm mesh that are most effective in capturing plastic and other floatables. Further treatment occurs through storm reed beds of the horizontal subsurface flow (SSF) type where a surface of about $0.5\,m^2\,PE^{-1}$ is provided (Green and Martin, 1996). This process flow sheet is visualized in Figure 1.

Whilst design and performance of storm reed bed systems have formerly been positively evaluated (Green and Upton, 1995; Green and Martin, 1996), little is known about their optimal management and most importantly about their design life expectancy. Operational problems and premature failure are therefore not uncommon. Vymazal (1998) separates operational problems into two categories: those resulting from poor maintenance and those associated with parts of the system that were not properly designed or built. Billeter *et al.* (1998) add that problems can also result from faulty instructions by the owners, their forgetfulness or the erroneous view that low technology wastewater treatment plants do not need maintenance.

Maintenance and operation of constructed treatment wetlands are fairly easy due to the virtual absence of mechanical and/or electrical parts (Vymazal, 1998). It is nevertheless recommended to check smaller systems on a weekly basis and larger ones (>500 PE) on a daily basis. During this routine maintenance, attention should be focused on pre-treatment units as well as inlet and outlet structures of the reed beds. In practice however, insufficient maintenance is often observed, resulting in uneven flow distribution and consequently local overloading and partial surface-flow. Initially, treatment efficiency seems to be unaffected, but progressive deterioration of the system can irreversibly reduce the performance in the long term. Kadlec and Knight (1996) more or less concur and indicate that monitoring and adjustment of flows, water levels, water quality and biological parameters are the only day-to-day activities required to achieve successful performance in treatment wetlands. Other operations and maintenance activities in treatment wetlands such as repair of pumps, dikes and control structures; vegetation management; and removal of accumulated mineral solids must be carried out at much less frequent intervals. Kadlec *et al.* (2000) also recommend including cover estimates and observations concerning plant health as a routine part of operational monitoring. Because plants grow slowly and are important for maintaining the performance of wetland treatment systems, problems must be anticipated or prevented before they have caused irreversible damage.

The life expectancy of constructed wetlands is defined by Bavor *et al.* (1995) as the period of time over which sustained pollutant removal can be achieved at the mean loading rate. For horizontal SSF systems it seems to be mainly limited by accumulation of mineral solids in the pore space, mainly near the bottom of the gravel bed. Hydraulic conductivity is therefore less impacted than in the case of uniform pore blockage (Kadlec *et al.*, 2000).

Aim of the study

The storm reed beds that were surveyed during this study date from the early 1990s and there are already some indications that they will not last their expected asset life of 20 years. Consequently there is a need to investigate the factors influencing the design life

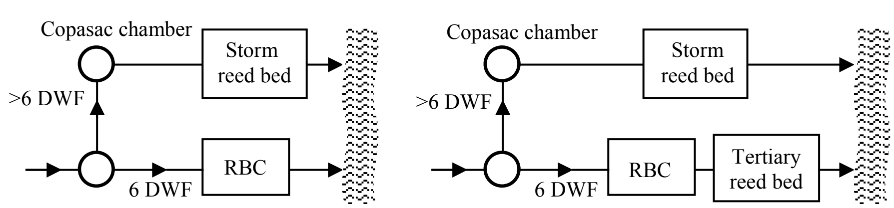

Figure 1 Process flow sheets indicating deployment of storm reed beds (after Griffin and Pamplin, 1998)

of storm reed beds and especially the rate of solids accumulation and degradation. The working life of the reed bed should match the physical life of the assets, otherwise there is a danger of early write-off of these treatment wetlands.

Materials and methods

Twelve storm reed beds at 7 locations in the South Warwickshire area of the United Kingdom were surveyed. All reed beds are of the horizontal subsurface flow type. They have been filled with pre-washed 5–10 mm gravel and planted with *Phragmites australis*. The inlet distribution system consists of a number of equidistant vertical riser pipes. Other basic design features are summarized in Table 1. All reed beds are operated by Severn Trent Water Ltd.

Each survey consisted of a site visit, an interview with the operators in charge and an assessment of the treatment performance through time using routine monitoring data.

Site surveys

For each site surveyed a data collection form (DCF) was devised in order to gather data from the field. The parameters investigated were:

- *General data*: data concerning age, dimensions, capacity (as PE) and type were collected from the Severn Trent Water reed bed data spreadsheet and checked on site.
- *Reed growth*: reed heights were roughly estimated at 15 different spots in each reed bed according to the following grid: 0, 50 and 100% of the bed width and 0, 25, 50, 75 and 100% of the bed length. The outlet of the bed corresponds to 100% width, 100% length.
- *Reed density*: reed density was assessed as low, medium or high, based on the surveyor's experience and *inter*-site comparison.
- *Reed condition*: reed condition was subjectively assessed as poor, good or excellent, based on the two previous indicators as well as on signs of chlorosis; and *inter*-site comparison.
- *Sludge depth*: sludge layer thickness on top of the gravel bed was measured by dipping a rule into the ground until it hit the gravel surface. This depth of sludge and leaf litter was then recorded. Measurements were carried out at 15 different spots in each reed bed according to the above-described grid.
- *Weed growth*: In order to measure the percentage weed cover, general observations were made by walking around and through the reed bed taking note of the position(s) of the weeds in pictorial form and estimating how much of the total reed bed was actually covered by weeds.

Table 1 Basic design features and consent levels of the investigated storm reed beds. Consents are expressed in the following order: mg BOD L^{-1} / mg SS L^{-1} / mg NH_4-N L^{-1}

Location	Design size (PE)	Number of reed beds	Total reed bed area (m^2)	Year of construction	Summer effluent consents
Napton	947	1	595	1992	15/25/10
Snitterfield	1,172	2	2,368	1994	15/25/5
Lighthorne Heath	1,154	2	700	1992	10/20/5
Fenny Compton	599	1	500	1993	10/15/5
Ettington	822	2	750	1993	15/25/5
Ilmington	701	2	780	1992	15/25/5
Bearly	709	2	1,408	1993	25/45/10

- *Site-specific issues*: issues like high infiltration of groundwater into the sewerage, flow split problems, rag/solids problems or remediation were assessed on site or obtained from the operators.
- *Depth of water*: in normal conditions, the wastewater level should be some 6 cm under the gravel surface. This level might be raised from time to time for weed control purposes. The water depth was measured by means of a rule in case of surface water or by digging a small pit and measuring the depth of the water table. This was again carried out at 15 different locations according to the above-described grid. If no water was encountered at 6 cm below the gravel surface, no further digging was carried out and the water depth was noted as >6 cm.
- *Flow distribution*: the type and number of inlet structures was indicated on the DCF schematically: vertical riser pipes, horizontal slotted pipes or troughs/channels. Finally, the flow distribution was assessed based on factors such as clogged pipes, unequal flows out of different pipes and a visual inspection of moist patches in the inlet zone.
- *Primary treatment*: presence of screening and pre-settlement units was indicated on the DCF.

Interview with the operators

The operators were asked closed questions with a limited number of answering options for ease of evaluation and analysis. The questions asked were: How often are the reed beds inspected? How often is the flow distribution inspected? Have the reeds ever been cut down or removed? How often is the inlet and outlet cleaned and how? Is there any weed control and, if so, what type and when was sludge last removed from the bed?

Data treatment

BOD, SS and NH_4-N effluent concentrations collected over the last couple of years, obtained from the Severn Trent Water performance database, were checked against the consents and were also graphically interpreted using MS Excel™ to determine whether or not there were any clearly visible trends to be seen. Other data were graphically interpreted using MS Excel™. Spearman's Rank Correlation Coefficient Test was used to identify correlations between the averages of two variables.

Results and discussion

Surface area. Surface areas range from 0.6 $m^2\,PE^{-1}$ at Lighthorne Heath and Napton to 1.99 $m^2\,PE^{-1}$ at Bearley. Therefore all storm beds surveyed have a larger surface area than the optimum of 0.5 $m^2\,PE^{-1}$ recommended by Green and Martin (1996). The advantage of these storm beds having a larger than recommended surface area is that they provide increased retention time. Thus in theory, they may produce better effluent quality. They also have increased treatment capacity which may be useful in the future if further development occurs in the catchment area.

Pre-settlement. Most studies advise pre-settlement of wastewater before it enters the reed bed system in order to reduce the sewage strength which, if too high, may cause problems with plant growth and also to reduce solids which may dramatically shorten the system life by clogging the pores. None of the studied storm reed bed influents is, however, subjected to pre-settlement, although they would greatly benefit from it. If settlement tanks were to be constructed they would require considerably more maintenance than the reed beds. The storm tanks would need to be emptied and cleaned out in order to prevent septic conditions which could lead to odour problems on site. This type of maintenance is very labour intensive and time consuming, which would negate the benefits offered by reed beds (Griffin and Pamplin, 1998).

Plant height (Figure 2). Reeds are strongly inhibited at Napton and Ilmington I and II, with an estimated 30 to 60% of the bed surface now covered by weeds. Lighthorne Heath I also shows significant reed growth inhibition but weed coverage is still low (approximately 5% of the bed surface) which suggests that the decline of the reed stand only started recently. Small patches of weeds near the inlet zone of Lighthorne Heath II seem to have outcompeted reed plants. The most abundant plant growth was observed at Ettington I. Another important observation is that reed plants tend to be shorter near the outlet side. Kadlec and Knight (1996) indeed suggest that macronutrient limitations might occur in the downstream areas of a wetland.

Sludge accumulation (Figure 3). A mixture of sludge and leaf litter has accumulated on all parts of the Ettington I and II beds and is of particular concern since it has penetrated into the outlet zone. This implies a chance of sludge washout during storm events and a possible breaching of the effluent consents. Ilmington I and II, in contrast, only have considerable sludge accumulation in the inlet zone and sludge washout is thus not likely

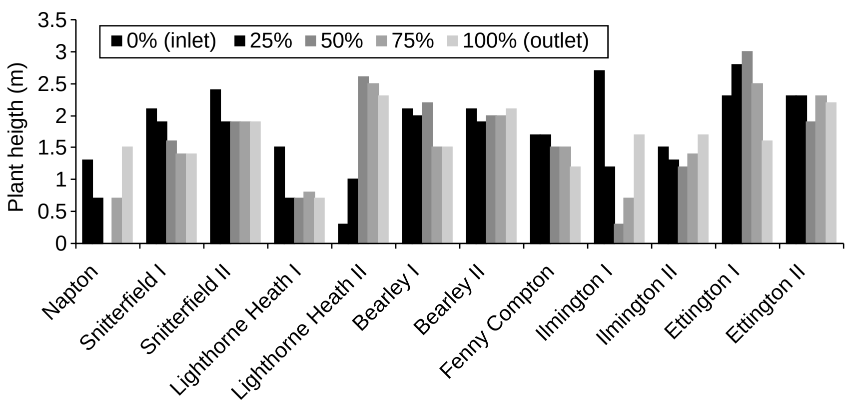

Figure 2 Reed heights at different locations between inlet and outlet of storm reed beds. Bars represent averages of 3 reed height measurements at 0%, 50% and 100% of the bed width

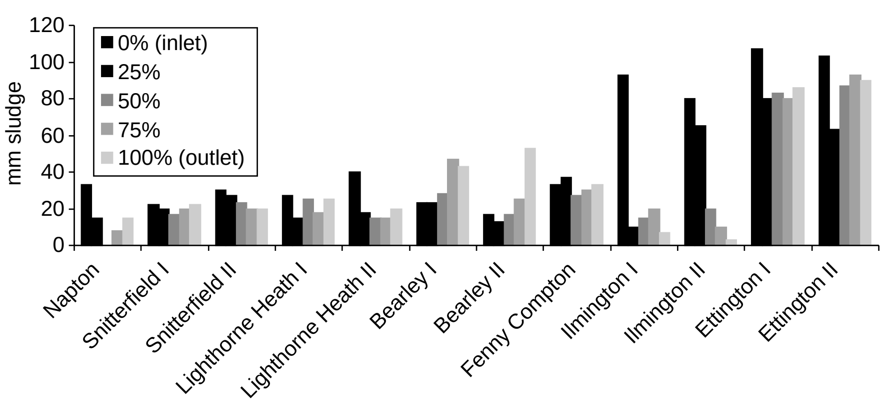

Figure 3 Sludge depths at different locations between inlet and outlet of storm reed beds. Bars represent averages of 3 sludge measurements at 0%, 50% and 100% of the bed width

to occur in the near future. It nevertheless hinders a good influent distribution over the entire bed width. There does not seem to be a design-related explanation for both cases since the provided area is more than sufficient ($0.91\,m^2\,PE^{-1}$ at Ettington and $1.11\,m^2\,PE^{-1}$ at Ilmington) and their length/width ratio also corresponds to commonly accepted design guidelines (0.4 for both systems). Influent loads might thus be higher than expected and/or the storm overflow operates prematurely. All other beds seem to be relatively unaffected by sludge accumulation.

Water level (Figure 4). At Napton, Snitterfield I and II, Lighthorne Heath I and II, Bearly II and Fenny Compton, the water level remains at least 60 mm below the gravel bed surface. At Bearly I, water levels are closer to the gravel surface but remain underground. Surface water occurs at Ilmington I and II, but only in the inlet zone, due to sludge accumulation. Only Ettington I and II are struck by serious surface blinding.

Correlations. Averaged variables were compared using the Spearman's Rank Correlation Coefficient. Since all reed beds were put into operation shortly after each other, age was proven to be no factor in this study for reed growth, sludge accumulation nor water level. No significant correlations were furthermore found between reed growth and sludge accumulation or water level. Only the water level proved to be highly correlated with the sludge accumulation ($P < 0.01$). Indeed, water surfaces in the inlet zones of Ilmington I and II, which coincides with significant sludge accumulation in these zones. Surface blinding at Ettington I and II correlates with pore blockages due to excessive sludge quantities.

Operation, maintenance and management (Figure 5). Most storm reed beds are inspected monthly or biweekly. This frequency is lower than the one recommended by Vymazal (1998) but is probably adequate since storm reed beds operate discontinuously. Confusingly, at 6 out of the 12 reed beds, inspection of the flow distribution is claimed to be carried out only occasionally, whereas at 11 out of the 12 reed beds, cleaning of the inlet is claimed to be done at least once per month.

This can however be explained by a different perception of the concept 'cleaning' between operators and surveyors. Some surveys indeed revealed that nearly half of the vertical riser pipes in the inlet zone were blocked by plant debris and sludge, which was

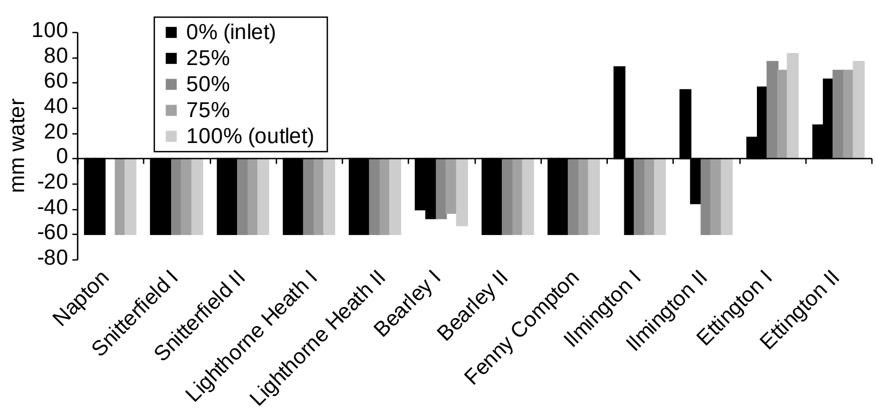

Figure 4 Water depths or water heights at different locations between inlet and outlet of storm reed beds. Bars represent averages of 3 measurements at 0%, 50% and 100% of the bed width. Water levels lower than 60 mm under the gravel surface are represented as -60 mm

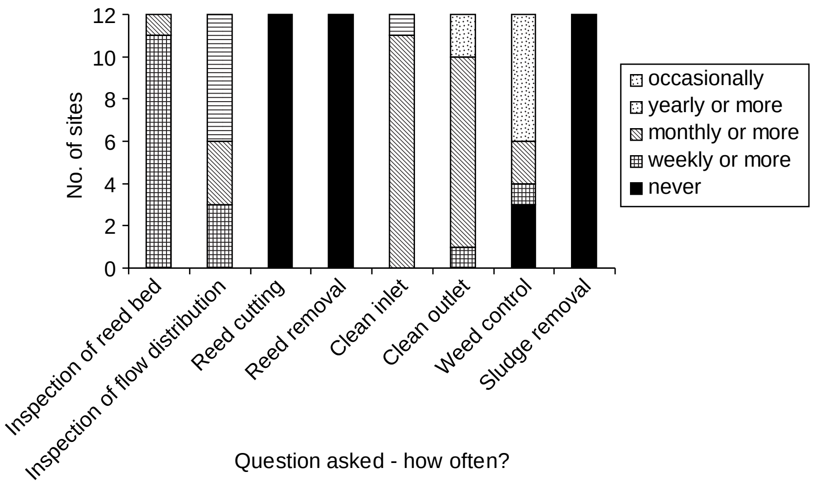

Figure 5 Frequency of inspection and maintenance of 12 storm reed beds

clearly not the result of one-month's accumulation. Reed cutting and removal as well as sludge removal are not a standard policy of Severn Trent Water Ltd. and have therefore never been done until now. However, considerable sludge accumulation at the storm reed beds of Ilmington and Ettington will probably need to be counteracted by desludging and consequent replanting of the beds.

Treatment performance. All storm reed beds were proven to perform exceptionally well. Data gathered from 2000 till 2002 (at least 30 effluent samples per location) clearly demonstrate that all effluent concentrations are far below the consent levels (cf. Table 1). Varying degrees of sludge accumulation, weed growth, surface blinding and unequal flow distribution therefore seemed to have only minor effects on the treatment performance of the selected storm reed beds.

Conclusions

Quick surveys with simple methods, as in this study, have been proven to provide valuable information on a range of factors that can influence the design life of storm reed beds. Measuring sludge layer thicknesses provides an assessment of solids accumulation and can act as an early warning sign for clogging. Plant heights and weed proliferation are a good visual sign of otherwise hidden water level problems.

Operational maintenance is an important factor in ensuring the longevity of a reed bed. However, observations from the on-site surveys indicate that it is not the frequency with which the maintenance activities are being undertaken that is having an effect on the performance of reed beds but the thoroughness with which these tasks are being carried out. This concurs with the conclusions of Cooper *et al.* (1996), Billeter *et al.* (1998) and others, that natural treatment systems are frequently considered to be a 'build-and-forget' solution and thus do not need any attention.

All of the sites surveyed would no doubt benefit from pre-settlement, especially those sites that suffer from very high sludge accumulations in the inlet zone of the bed. However, if settlement tanks were to be constructed they would require considerably more maintenance than the reed beds. This type of maintenance is very labour intensive and time consuming which would negate the benefits offered by reed beds.

Other factors or features of a reed bed also play a role in premature process failure and are thus important to the asset life. It is apparent that at some sites the storm overflow operates prematurely. This not only causes strong sewage to be applied to the bed, deteriorating the effluent quality but the life of the bed may be dramatically shortened due to excessive sludge accumulation.

Weed control, sufficient screening of the influent, a thorough maintenance of the inlet distribution system and a correct setting of the outlet level were identified as crucial factors contributing to the performance and the longevity of the beds.

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