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Constructed Wetlands for Combined Sewer Overflow Treatment—Comparison of German, French and Italian Approaches

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Abstract: Combined sewer systems are designed to transport stormwater surface run off in addition to the dry weather flows up to defined limits. In most European countries, hydraulic loads greater than the design flow are discharged directly into receiving water bodies, with minimal treatment (screening, sedimentation), or with no treatment at all. One feasible solution to prevent receiving waters from strong negative impacts seems to be the application of vertical flow constructed wetlands. In Germany, first attempts to use this ecological technology were recognized in early 1990s. Since then, further development continued until a high level of treatment performance was reached. During recent years the national "state-of-the-art" (defined in 2005) was adapted in other European countries, including France and Italy. Against the background of differing national requirements in combined sewer system design, substantial developmental steps were taken. The use of

coarser filter media in combination with alternating loadings of separated filter beds allows direct feedings with untreated combined runoff. Permanent water storage in deep layers of the wetland improves the system's robustness against extended dry periods, but contains operational risks. Besides similar functions (but different designs and layouts), correct dimensioning of all approaches suffers from uncertainties in long-term rainfall predictions as well as inside sewer system simulation tools.

Keywords: combined sewer overflow; constructed wetlands; design; layout; international comparison; simulation

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1. Introduction and Review

Wastewater treatment plants (WWTPs) maintain high standards in most member states of the European Community. Various end-of-pipe treatment techniques are designed to receive a specified dry-weather flow (DWF), which increases due to stormwater surface runoff conveyed in combined sewer systems (CSSs). CSS design underlies national regulations; however it is common that the WWTP design capacity gives limits for maximum inlet flow during stormflow periods. CSS accommodate high flow volumes and have integral combined sewer overflow (CSO) mechanisms to prevent flooding of surface water drains caused by the sewers backing up, should the stormflow volume exceed the sewer capacity. CSOs are designed to regulate flow volumes into the WWTP, either with or without water storage for subsequent treatment.

Annual CSO pollutant loads can exceed WWTPs effluents due to the enormous discharge volumes. This kind of "diffuse" pollution can lead to a high impact on the receiving water body over differing periods of time (e.g., short-term: acute oxygen demand, release of fish toxic NH_3-N, re-suspension of solids/long-term: sludge accumulation, eutrophication). To reach the requirements of the EC Water Framework Directive [1], CSOs need not only to be managed, but also require the effluent to be treated in many locations. One of the most (economically and ecologically) feasible solutions seems to be vertical flow constructed wetlands (VFCWs), specified as constructed wetlands for CSO treatment (CSO-CWs) in general and "retention soil filters" (RSFs) in Germany.

Compared to dry weather flows, flows from CSOs are usually diluted in terms of classical parameters like COD or NH_4-N. This correlation results in lower inlet concentrations for treatment facilities compared to WWTPs, but the hydraulic loads of single overflow discharges can exceed the typical loading of a VFCW due to enormous volumes of water.

Compared to surface runoffs in separated sewer systems, CSOs are highly polluted with carbon, nitrogen and phosphorus. Therefore, process interactions in CSO-CWs differ from CWs for surface water (stormwater) treatment in these separated systems. These stormwater-only treatment facilities, often called biofilters [2], are used to treat pollutants like heavy metals and polycyclic aromatic hydrocarbons (PAHs), which can be introduced from highly frequented street surface runoffs. Even if similar sources are connected to CSS, treatment of heavy metals or trace pollutants [3] in CWs for CSO treatment is considered only as a side issue so far.

In a short historic review of retention soil filter systems (RSFs), the design has evolved over time from pragmatic rules to a better understanding of the internal processes. The first CSO treatment filter was built in 1989 [4]. As this system was equipped with filtration layers consisting of natural soil, the (directly translated) terminology "retention soil filter" became established [5,6]. After early experiences, the filter media was changed to technically mixed sands with a maximum particle size of 2 mm in order to prevent clogging (see [7] which was described in [8]).

RSF systems consist of CSO tanks with sand filter beds in series (Figure 1A). CSO tanks (designed to hold a specific volume of 5–35 m^3/ha paved area, which is the equivalent to 1.5–3.5 mm rainfall) are widely used in Germany with more than 17,000 sites [9]. About 30%–60% of the total annual rainfall volume is discharged into water bodies as stormtank overflows (20–40 events per year [10]). Compared to CSO facilities without storage, they are designed with low outlet flow rates, leading to low runoff to sewer ratios and therefore meet the limits for subsequent treatment in WWTPs.

Figure 1. Simplified system sketch for in (**A**) retention soil filters in Germany; and (**B**) combined sewer overflow constructed wetlands in France; and (**C**) Italy.
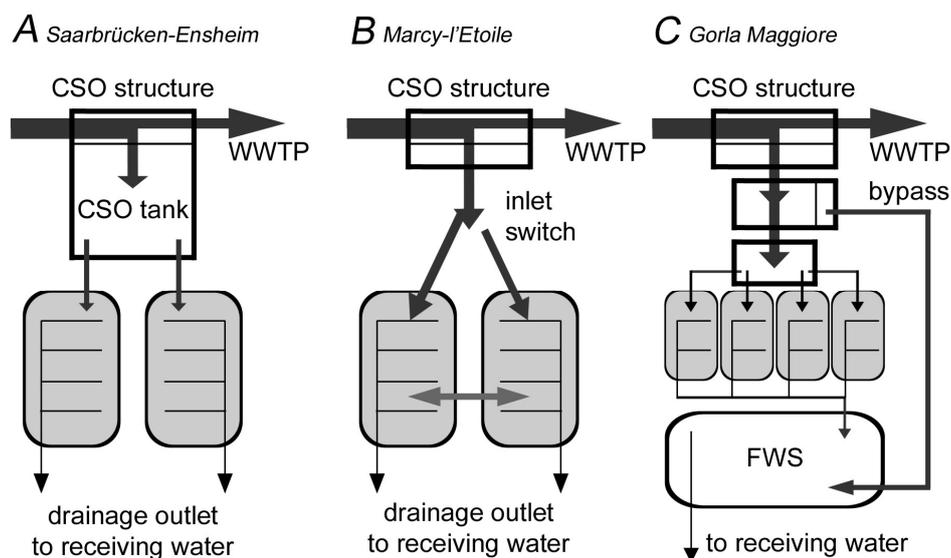
Filter beds could be added if enhanced treatment of the storage overflow was needed. The sand filter consists of a retention basin on top of the filter media layer (Figure 2A); however, it is not permissible to replace the stormtank completely with a natural treatment system [7]. The main reason can be found in possible RSF overloads during spring, which could exceed hydraulic or pollution consent limits. Relatively low outlet flow rates are chosen in order to slow down the rate of infiltration during ponding, and thereby reduce the risk of physical clogging. To consider RSFs as "wetlands" seems to be partly incorrect due to the complete drainage of the system after each loading event, resulting in the possibilities of prolonged dry periods of several months afterwards.

Challenges in fitting RSF design and dimensioning can be found according to limits of correctly simulated CSO predictions. Especially in Germany, the described overestimations of surface runoff led and still lead to many oversized CSO tanks, leading to increased return periods of storage overflows resulting in water stress in wetland plants due to the usual total drainage of RSFs.

Figure 2. Simplified cross-sections of CSO-CWs in (**A**) Germany, (**B**) France; and (**C**) Italy.
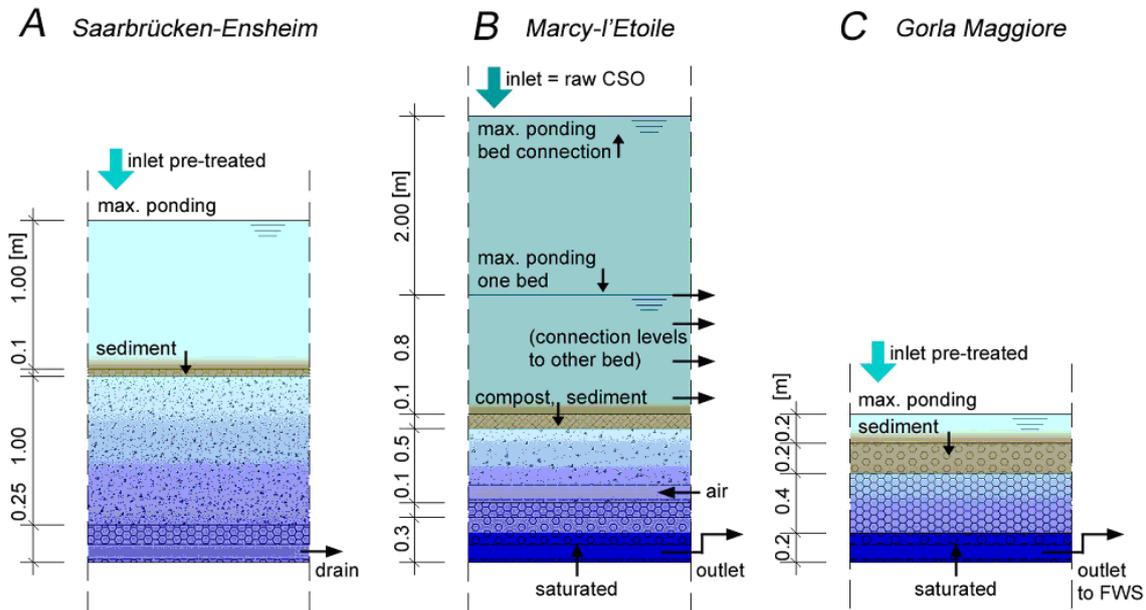
Development of CSO treatment filters in France and Italy started in the late 2000s. Fundamental differences can be found in the upstream CSO facilities: Direct discharges (without storage tanks) lead to shorter return periods of feeding events and increased particulate inlet concentrations by trend. Both new designs can be considered as wetlands, because they provide permanent water layers. The first CSO-CW in Italy (Gorla Maggiore) started operation in the summer of 2012. In France, different systems have been constructed during the last decade, but the new design has only been put in operation in 2012 at the experimental full-scale plant in Marcy-l'Etoile (France). Monitoring programs on both sites will show performances over the upcoming years. Beside the three given system examples, more approaches of using CWs for CSO treatment can be found in Europe, e.g., reed beds for tertiary treatment loaded with CSO occasionally (United Kingdom [11]).

Sewer system hydraulics simulation is a fundamental tool in all given countries to predict CSOs for a long-term view as well as for maximum peak single events. Compared to dry weather flow calculations, the implementation of surface runoffs drastically increases the complexity as well as uncertainties [12,13]. CSS models need to be fed with correct data of sealed surfaces (squares, slopes and grades of sealing), which can only be estimated. Common practice in Germany leads to overestimations by trend [14]. In addition to known influences, unknown parasitic sources (like runoff from permeable surfaces or illegal connections of drainage systems) can have a major impact. This is particularly true if—like in CSO predictions—the system limits are of highest interest, which are much more sensitive than annual balance estimations.

Pollution load simulation tools suffer even more from the described influences, because estimations for pollutant appearances on surfaces as well as remobilization of sludge inside the pipe systems are generally rawly estimated. Nevertheless it seems to be more reasonable to consider pollutant loads as design criteria in addition to hydraulic dimensioning [6]. An integrated approach of CSSs, WWTPs and CSO-CWs (RSFs) could be highly effective in efficiency and cost analysis.

Approaches to the use of models in order to improve design and operation of CSO-CWs can either focus on single events or long-term behavior [6]. Simulation studies with the detailed biokinetic

reaction model CW2D inside the Hydrus-2D software [15] were conducted to investigate fundamental treatment processes in RSFs [16–18]. The results achieved from this were used in addition to full-scale field studies (RSF "Ensheim" [10], RSF "Oberelsungen" [5]) to build up a simplified design and dimensioning tool. The main aim of this new model called RSF_Sim can be found in estimations of RSF performances in a long-term perspective [6,19]. The original approach is currently under verification by simulating the first results from France (project "ADEPTE") and Italy, but the necessary database needs to be realized first.

2. System Descriptions

In preparation to the CSO-CW comparison each national approach will first be described separately. Whereas for the German system, a given guideline will be summarized and supplemented with latest developments, basic ideas and design criteria will be described for the French and Italian approaches.

2.1. Retention Sand Filters in Germany

The German guideline ([7], described in [8]) criteria for the layout and design of RSFs in 2005. Since then, regional guidelines added new aspects according to results of numerous research projects (e.g., [5]). Currently, the advanced national guideline DWA-A 178 is in revision, focusing particularly on RSF robustness in order to handle occurring feedings characteristics diverging from predictions—and to improve the predictions themselves. Design criteria for RSFs according to [7] can be summarized as follows:

- RSFs and CSO tanks are considered as one treatment unit.
- The high number of existing CSO tanks is used to retain those fractions of surface runoffs, which need to be treated by legislation. In addition, these concrete basins provide physical storage overflow treatment (=RSF inlet) by sedimentation.
- The filtration layer below the retention layer needs to consist of three sub-layers, from top to bottom: (1) 0.05 m gravel (2/8 mm) or crushed stone (2/5 mm) to prevent surface erosion; (2) min. 0.75 m sand (0/2 mm), carbonate content min. 10%, min. hydraulic conductivity 10^{-4} m/s; (3) min. 0.25 m gravel (2/8 mm) as drainage (Figure 2A).
- Outflow rates are limited to 0.02 L/(m²·s), respectively 0.01–0.03 L/(m²·s) due to especially defined treatment requirements.
- To prove the designs of the retention layer and the filter surface in addition to the storage tanks, it is mandatory to use long-term hydraulic runoff simulations. As main criteria for filter surface dimensioning, the maximum hydraulic loads are given as 40 m/y (=40 m³/(m²·y)) in a long-term annual average, respectively 60 m/y for exceptionally rainy years.

In contrast to these "old" national standards, later regional guidelines are allowing the substitution of the CSO tank volume partly with the retention volume of the RSF. Substitution limits are currently being discussed. Average annual hydraulic loads and limited outflow rates could also be increased. In order to allow higher hydraulic or pollutant loads, new recommendations will suggest alternating loadings of two filter beds.

2.2. CSO-CWs in France

In France applications of CSO tanks are less common, storage capacities are given inside the pipe system. Overflow facilities usually do not provide a physical treatment. Thus, discharges contain higher particulate concentrations. The idea of CSO-CWs started from linking recommendations from [7] with well established experiences of more than 15 years from the "French design" two-stage VFCWs [20]; essentially allowing raw untreated CSO effluent loaded onto a coarse media. Required treatment performances will depend on the receiving water body quality. Actual treatment objectives aim to maintain outlet concentrations below 90 mg COD/L, 25 mg BOD_5/L and 35 mg TSS/L. For TKN, the outlet level will be below 5 mg TKN/L when using a mix of sand and zeolite as filtration layer and 10 mg TKN/L when using sand with a d10 of 0.4 mm [21].

Design is generally still in validation step: It is based on German experience with 50 $m^3/(m^2{\cdot}y)$ of cumulative water on the filter surface with an outflow limitation calibrated between 0.01 and 0.02 $L/(m^2{\cdot}s)$. At the experimental full-scale site, an adjustable CSO facility was installed in the sewer system to partly provide inflow control. Operation started with an overflow split at 30 L/s (equivalent to 5–6 times DWF). Another variable in the design is given by connections between the two filter beds at different levels above the surface. If one filter bed was flood, the connection level would determine if overflow to the other bed occurs earlier or later and therefore more adaptable to smaller or bigger rain events. In this way each filter bed can get resting periods, but the system is still able to cope with maximum events in both parts. The size of the filter and the water storage height (max. 0.8 m for each bed, 2.0 m for both beds connected) depend on the daily runoff volume to be treated. A precise design based on rain event volumes and frequencies linked to treatment performances is currently under development. In each case the filter will be fed with raw CSO and will implement some specific configurations such as:

- The filter body consists of sub-layers, from top to bottom: 0.1 m of compost (as an option to favor reed growth), 0.6 m filtration layer (sand or sand/zeolite mix), 0.1 m transition layer (coarse sand/fine gravel 2–6 mm) and 0.2–0.3 m of drainage layer (gravel 10/20 or 15/25 mm) (Figure 2B).
- To avoid reed suffering from water stress during extended dry weather periods a saturated layer at the bottom (min. 0.2–0.3 m) needs to be installed.
- To favor aeration inside the filter during drained periods an aeration pipe just above the saturated layer is mandatory.

2.3. CSO-CWs in Italy

In Italy, there are no guidelines available for CSO treatment dimensioning. In the northern part of the country, a high need for CSO treatment was declared by the Po River Basin Authority in 2007/08, and the same need is valid for the rest of the country where most of the rivers are not reaching the EC WFD [1] requirements for "good quality status", and also due to thousands of CSOs not working effectively. The study (in collaboration with Region Lombardy) was focused on a specific river basin (Lambro-Seveso-Olona). Recent studies show that the traditional approach to CSO management (tanks

for storage and centralized treatment) is not longer sustainable due to the insufficient capacity of WWTPs [22].

The main difference in CSO treatment can be found in the first flush concept. It is required by law to treat the overflow of the first 5 mm of rain, whereas no indications are provided on the flow rate, even if generally a return period of at least two years is considered in the design. Therefore a volume of 50 m^3/ha has to be considered for water quality purposes (regional law of Lombardy on CSO, R.R. 3/2006). Additional needs can be given in water storage before discharge to natural water bodies for flood protection. These requirements can result in differing concepts, because the retention function is disconnected from pollution treatment. Hence, a combined approach of a filter for first flush treatment and a free water surface wetland (FWS) for exceeding volume and secondary treatment was chosen. Basic design ideas for the filter beds are given as follows:

- The filtration layer below the retention layer consists of three sub-layers, from top to bottom: (1) 0.2 m gravel (10 mm); (2) 0.4 m siliceous pea gravel (2/6 mm); (3) 0.2 m gravel (40/80 mm) as protection for the drainage pipes (Figure 2C).
- Outflow rates are limited to 0.004 L/(m^2·s) to permit a HRT of 24 h in various feeding conditions, but could be changed by a valve in the outflow manhole.
- Maximum hydraulic loads are given as 0.6 m/day per rainfall event, with a predicted value of 35–40 m/y in a long-term annual average, respectively 50 m/y for exceptional rainy years.

A special emphasis is given on the wetland integration into the urban landscape, with the creation of an ecosystem service in a green riverine area previously used for fast growth biomasses, *i.e.*, Poplar trees: the VF and FWS are planted with native species to recreate a natural aquatic environment. Another aim of the project is to create a multifunctional park with cycling, didactic trails and buffer strips—giving the CSO-CW a multifunctional role not limited to water pollution control, but also in environmental restoration and for recreational use [22].

2.4. Comparison Methods

Methods of CSO-CW system comparison can be found in first-order due to design and dimensioning criteria. Uncertainties in using sewer system models will be discussed according to the use of CSO tanks. Since monitoring in Italy and France has just started, a data based comparison is not yet possible, but experiences from RSFs and "French design" VFCWs will be used for predictions.

3. System Comparison

The use of tanks, filter beds and FWS varies for each national approach. Whereas until now in Germany, one or more filter beds operated in parallel could be placed in a series with CSO tanks (Figure 1A), new recommendations will suggest the alternating feed of two filters such as those in France (Figure 1B).

The French solution avoids the need for concrete basins (Figure 1B) if a treatment demand was noticed by sewer simulations showing overflows on a regular basis. This direct discharge results in a stronger particulate load. In order to reduce clogging risks for small and concentrated as well as regular events, an alternating loading of two filter beds is necessary. In the "French design" VFCWs (treating

domestic wastewater), one bed is operated for about 3–4 days, while two other beds can regenerate sludge load abilities via mineralization [20]. This kind of process control cannot be transferred to CSO-CWs directly, because system feedings are only corresponding to rain fall events. Experiences from the currently running research projects "SEGTEUP" (pilot-scale [21]) and "ADEPT" (full-scale Marcy-l'Etoile) will indicate adapted operation strategies for switching the feedings between the two beds.

In Italy, the first flush concept separates the needs of treatment from that of hydraulic retention. The prototype located in Gorla Maggiore consists of two inlet splitters, four filter beds in parallel as well as an extended retention basin for the second flush flow (Figure 1C). The first splitter separates CSOs from sewer of more than 20 L/s (equivalent to 3.75 times DWF) directed to the WWTP. The second splitter protects the filter beds from hydraulic overloading: Up to 640 L/s can be taken as maximum first flush generated by a rainfall event of 10 mm/h, volumes exceeding this are bypassed into to the additional FWS. The filter inlet has to pass through an automatic screen and a grit separation tank (volume 110 m^3) as a rough mechanical pre-treatment. Flow from the filter bed outlets are also fed into the FWS for secondary treatment. The FWS water level can be raised (from usually 0.4 m) inside its artificial basin in order to release a maximum flow of 700 L/s to the River Olona. The water flow values given represent a system in which almost all CSO will be treated by passing through the filter beds. Only peaks of maximum events with a return period of 10 years will pass by.

Not only do the system layouts show variation, but also the layer structures of the filter beds. Figure 2A displays a typical vertical cross-section of a RSF in Germany according to [7]. The French and Italian approaches (Figure 2B,C) are based on the same ideas, but in comparison it can be seen that they are adapted to specific needs (Table 1).

In France the filter media is coarser in order to avoid clogging. "French design" VFCWs are equipped with similar particle size distributions in their first stages for wastewater treatment. Experiences show that the sludge deposit on the surfaces slows down the infiltration speed, but development of a stable matrix via loading and resting periods does not cause impermeabilities. Future experiences will show if the same behavior could be found in the experimental full-scale CSO-CW. One possible reason for differing results could be the use of a mixture of zeolite and gravel (one bed) and pozzolana (other bed), which—compared to gravel—is the more reactive media.

The Italian approach consists of saturated and unsaturated layers with similar ratios. The main part of the coarse filter media is unsaturated during dry periods; a permanent water level of 0.2 m is maintained in the beds. The top layer of 0.4 m gives additional volumes to the comparatively low depth of the retention basin. Deeper basins are not required due to the flood protection function of the FWS, but could be implemented in future. In combination with the comparatively low outlet flow rate, the small retention volume controls a relatively high hydraulic retention time of 24 h. It also results in a rapid ponding and thereby water distribution over the filters surfaces.

The French and the Italian CSO-CWs both provide permanent water layers. This is not particularly correlated to treatment processes—the design provides water for the reeds during extended dry periods, especially during hot and dry summers. In order to improve re-aeration after feedings, an additional set of pipes was implemented (in RSFs the two functions of drainage and aeration are given by the same pipe system). Earlier German experiences with permanent saturation showed negative effects: Treatment efficiencies were decreased, low pH-values led to a release of carbonates, and anaerobic conditions caused odors.

Table 1. Comparison of characteristic design criteria.

Criterion	RSF Germany (DWA-M 178, 2005)	CSO-CW France (full-scale Marcy-l'Etoile)	CSO-CW Italy (full-scale Gorla Maggiore)
Inlet water	CSO tank overflow	raw CSO	raw CSO (pre-treated before infiltrated)
Filter beds	1 or more in parallel	2 alternated loaded, in parallel for extreme events	4 alternated loaded, in parallel for extreme events
Retention layer depth	not defined (usually ~1.0 m)	flexible (0.1, 0.35, 0.6 or 0.8 m each bed), 2.0 m for connected beds	minimum 0.2 m
Filtration layer	0.75 m minimum (sand 0/2 mm, carbonate content > 10%)	minimum 0.5 m (one bed sand + zeolite, one bed pozzolana)	0.2 m (gravel 10 mm) + 0.4 m (gravel 2/6 mm)
Saturated layer	none (drainage layer unsaturated) (0.25 m gravel 2/8 mm)	flexible, minimum 0.2 m (0.3m gravel 10/20 mm, 0.1m gravel 3/8 mm)	0.2 m (gravel 40/80 mm)
Outflow limitation	0.02 L/(m²·s)	0.02 L/(m²·s)	0.004 L/(m²·s)
Max. hydraulic loads	40 m³/m² in annual average (maximum 60 m³/m² per year)	~40 to 80 m³/m² per year	35–40 m³/m² in annual average (maximum 50 m³/m² per year)
Design tool	long-term hydraulic sewer simulation	long-term hydraulic sewer simulation	long-term hydraulic sewer simulation

Full-scale RSF treatment performances were investigated on numerous German studies [5,17,23], but minimal data has been published internationally. Results from monitoring the RSF system Saarbrücken-Ensheim were summarized in [10], where detection of systematic limits was focussed: Treatments of COD and NH_4-N were considered as main functions of pollutant reduction. COD became reduced in different ways: the particulate fraction was filtrated down to hardly detectable background concentrations at the outlet. Dissolved COD was reduced by immediate degradation after aeration as well as by adsorption down to approximately 42% of inlet concentration over a long-term average without major variations. NH_4-N treatment performances seemed to result from a two-step-process: During the loading (ponding) period NH_4-N is adsorbed on surfaces of the filtrated sludge layer and on the filter media surface covered with biofilm. After system drainage, re-aeration enables nitrification. Resulting NO_3-N loads are washed out during the subsequent feeding.

Due to the recent launch of research projects in France and Italy, treatment performances cannot yet be directly compared, but a comparison to similar VFCW allows predictions by trend. The French CSO-CW approach shows similarities to the German system in terms of hydraulic operation inside the filter beds (loading, outlet limitation rate). Inlet characteristics will differ due to the avoidance of storage tanks. This means in first-order higher concentrations, especially for particulate pollutants. It can be expected, that suspended solids will be removed similarly to the first stage of "French design" VFCW (86% [20]) and CSO-CW pilots (>90% [21]). Dissolved COD might be degraded in a slightly lower percentage than in RSFs (42% [10]) due to higher concentrations and loads, but similar oxygen availability [24]. Ammonium retention efficiency could be high from the very beginning of system operation, because the abiotic adsorption onto reactive media, like zeolite and pozzolana (rich in zeolite) does not need to be established. Maximum retention capacities cannot be predicted yet, but might be higher than in Germany (6–12 g/m³ sand [10]) as a sum of biotic and abiotic sorption processes.

In Italy, the inlet characteristics will be similar to Germany. The Italian approach contains risks of lower filtration performances until a sediment layer becomes established due to the coarse filter media and high flow speeds until ponding occurs. On the other hand this could be balanced by pre-treatment

and by secondary treatment in the FWS. Dissolved COD removal will depend mostly on the inlet distribution and aeration of the filter's surface. Ammonium retention might be low at the beginning of operation and stay lower than the comparative systems. The coarser filter media provides a smaller specific surface area for biofilm attachment. Also the height of the unsaturated, regenerated gravel layer is comparatively low. Adsorption capacities might increase over time due to the rising sediment layer, and additional nitrification can be expected in the FWS.

The required use of CSS simulation tools contains differing levels of uncertainty. In Germany the runoff overestimations often led to oversized RSFs. This low accuracy in sealed surface estimations causes high insecurity levels for filter feeding occurrence, because a high number of storage fillings might be considered as tank overflows in simulation studies, but will be buffered in real systems. Due to higher durations and shorter return periods of critical dry periods many RSF suffer from water stress. In CSS without CSO tanks, similar systematic errors in runoff prediction can lead to similar miscalculations of annual overloads, but this contains lower risks for CSO-CW operation: The real total annual load might differ from simulations, but the feeding occurrence (whether it happens or not within certain time spans) will be barely affected.

Besides the technical aspects, social aspects can be compared. Experiences from all experimental sites reveal that riparian residents are skeptical of CSO filters in their neighborhood, although most of them like the basic idea of environmentally friendly wastewater treatment solutions. Over time, skepticism turns into acceptance as long as the filters operate correctly. Anaerobic operating conditions result in odor issues, which will reduce the acceptance of these systems drastically. CSO-CW design should consider emergency drainages in case of persistent pondings to prevent the system becoming a statutory nuisance.

4. Conclusions

The dimensions and designs of CWs for CSO treatment need to be adapted to meet national legislations as well as to handle specific CSO characteristics. The given approaches from three European countries show how different solutions for similar purposes can achieve this. In Germany RSFs were developed to treat overflows from existing CSO tanks. This well established approach shows high treatment performances in general, but in several systems a good balance between feeding and dry periods could not be maintained. Latest improvement discussions are headed in a similar direction such as the latest technical solutions found in France and Italy.

The French system targets raw CSO treatment with a high number of feedings and high particulate loads. Pilot systems show good performances, but long-term operation needs to prove successful avoidance of clogging by the use of coarse media. The Italian approach is based on the first flush treatment and maximum flush storage. In both Mediterranean countries, a permanently saturated water layer was installed for reed growth during extended periods without feedings. Upcoming experiences need to show if negative side effects from anaerobic microbial activities lead to problems in operation or social acceptance.

Main challenges in determining the dimensions are common for all CSO-CWs: mandatory CSS models are loaded with uncertainties which can be neglected or equalized at the end-of-pipe in a long-term view, but accumulate for overflow predictions. In addition, the stochastic nature of rain

events can result in unexpected high or low single or seasonal loadings. Therefore wetland systems with buffer capacities against critical operational conditions should be preferred against sensitive high-end fittings. Robustness can be improved, e.g. by a permanent water layer against water stress, by a decreased filter surface for enhanced sediment distribution and by at least two filter beds alternating loading (to ensure rest periods/avoid clogging). Current research programs on filter performances will allow the comparison of treatment efficiency and the accuracy of the simplified simulation tool.

Acknowledgments

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