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# PERFORMANCE OF CONSTRUCTED TREATMENT WETLANDS: MODEL-BASED EVALUATION AND IMPACT OF OPERATION AND MAINTENANCE

# WERKING VAN AANGELEGDE ZUIVERINGSMOERASSEN: MODELGEBASEERDE EVALUATIE EN IMPACT VAN BEDRIJFSVOERING EN ONDERHOUD


door:

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## SUMMARY

Under certain circumstances, wastewater treatment by activated sludge units and clarifiers appears to be an unfit technology. Mainly in developing countries where know-how, funding and assets are limited, one often recurs to inexpensive, low-technological but nevertheless efficient methods such as waste stabilisation ponds and/or constructed wetlands (CWs). Even in economically stronger countries, sustainable alternatives are often needed for these discharge points that cannot be connected to a conventional wastewater treatment plant due to technical, economical or ecological constraints. *In situ* treatment by means of CWs offers a potential alternative in certain cases.

How this green technology evolved and which types currently are in operation around the world, is being described in Chapter 1. Purification processes are then summarised and the role of some important internal and external influencing parameters such as pH and temperature is discussed. A brief economical analysis of costs and benefits concludes this introductory chapter.

For Chapter 2, a database on 107 CWs in Flanders (Belgium) has been assembled and analysed to summarise the available experience. For each type of CW, an overview is given of treatment performance and its seasonal variations. Free-water-surface CWs exhibited the lowest treatment performance whereas vertical subsurface-flow CWs seemed most efficient, with the exception of nitrogen removal. Indeed, adding a horizontal subsurface-flow CW as polishing step was clearly beneficial because of enhanced denitrification. Season c.q. temperature mainly influenced nutrient removal with lower removal efficiencies during cold periods. Investment costs proved to be highly variable and strongly dependent on the type of CW and on the design capacity. Finally, from practical experience, it appears that the specific legislation on CWs and certainly its enforcement fail and that many owners/operators have a wrong perception of the required maintenance of such a treatment system. Non-stringent effluent standards, the lack of compliance monitoring and the often-noted misconception that natural systems are able to manage themselves, cause neglection of many CWs.

Since treatment efficiency of both horizontal and vertical subsurface-flow CWs was positively evaluated in Chapter 2, Chapters 3 and 4 further exploit these technologies. Firstly, detailed mass balances for water, solids, organic material, nitrogen and phosphorus demonstrate that purification in CWs is accomplished by a complex array of interacting physical, chemical and biological processes. Influencing factors such as temperature, pH, C/N ratio etc. are also being discussed in detail. This theoretical framework is then applied on three data sets from a pilot-scale two-stage reed bed (Aquafin Ltd, Aartselaar, Belgium). Short and long-term dynamics are being compared and the influence of influent load and temperature on treatment performance is assessed. Higher loads mainly caused a transient effect on the effluent concentrations shortly after the load increment, but the concentrations then quickly leveled off at the earlier level. Ammonium was the only exception as the oxygen demand at higher loads exceeded the oxygen transfer capacity of the vertical subsurface-flow CW. Seasonal performance variations were not detected for COD and suspended solids but were obvious for nitrogen removal as denitrification seemed inhibited by cold temperatures. Phosphorus removal also fluctuated substantially and seemed to be correlated to the plant growth and decay processes.

Having demonstrated the obvious qualities of CWs, the following chapters of the thesis are devoted to two crucial topics, i.e. design and maintenance of CWs. Only horizontal subsurface-flow CWs (HSSF CWs) are further discussed, as these are the most widespread type of CW within a European context.

Chapter 5 elaborates on model-based design of HSSF CWs, starting with simple rules of thumb, continuing with the state-of-the-art k-C* model and ending with dynamic, mechanistic models. A simple case study has been used to prove that the performance of black box models is not satisfactory. Indeed, different models and within-model parameter variations caused the predicted required surface area for a 10 PE case to vary between 0.1 and 950 $m^2$. Dynamic models are still in a premature stage but offer interesting perspectives.

Chapter 6 therefore presents a model study with such a mechanistic model, applied on data of a two-stage HSSF CW at Saxby (UK). As a starting point, the model of Wynn and Liehr

(2001) was chosen as it gives a quantitative description of carbon and nitrogen transformations. After a number of changes to the model structure and after parameter estimation, this model seemed able to predict general trends in effluent quality, but missed some of the short-term dynamics. Due to a number of non-closed mass balances, the lack of an adequate description of particulate processes and the absence of anaerobic processes, it was decided to develop a new conceptual model that was able to describe and explain the interactions between the C, N and S cycli.

Chapter 7 presents this new mechanistic model of a HSSF CW in which 8 different microbial communities, together with the reed plants and a number of physical processes, interact and clean up the wastewater. The model equations are among others based on the widely spread and commonly accepted ‘Activated Sludge Models’. One advantage of this approach is that it enhances communication between wetland scientists as it introduces a sort of ‘common language’. Another advantage is that literature provides lots of parameter values as these models already have been applied in many case studies.

Calibration of such a complex model proves to be a very difficult task and would require many more data then are available up till now. It was therefore decided to use the default parameter values from each validated submodel. The model was then used to simulate an experimental HSSF CW of 0.55 $m^2$ and a pilot-scale HSSF CW of 55 $m^2$. Despite the many uncertainties, the model did a good job in predicting the effluent quality and most importantly it allowed to better explain the data.

Although a sound design forms the basis to a good performance, adequate operation and maintenance throughout the lifespan of a CW are of equal importance. Chapters 9 and 10 attempt to refute the widespread ‘reed beds are a build-and-forget solution’ mentality. Firstly, Chapter 9 reviews maintenance tasks, monitoring requirements and the frequency with which they should be carried out. Frequently occuring operational problems are described and troubleshooting guidelines are supplied. These rather theoretical recommendations are then being tested in a case study in Chapter 10. Twelve stormwater treatment CWs were examined by means of a site visit, an interview with the operators and by reviewing available effluent data. These investigations revealed that several CWs suffered from sludge accumulation, surface blinding and weed growth, but not to such an extent that the effluent quality was unsatisfactory. It has nevertheless been proved that adequate maintenance positively contributes to a longer lifespan of CWs.

Chapter 11 finaly summarises the most important findings of each chapter and lists some suggestions for future research.