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► **To cite this version:**

T. Dou, S. Troesch, A. Petitjean, T.G. Palfy, D. Esser. Wastewater and Rainwater Management in Urban Areas: A Role for Constructed Wetlands. *Procedia Environmental Sciences*, 2017, 37, pp.535-541. <10.1016/j.proenv.2017.03.036>. <hal-01778994>

HAL Id: hal-01778994

<https://hal.science/hal-01778994v1>

Submitted on 26 Apr 2018

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International Conference – Green Urbanism, GU 2016

Wastewater and Rainwater Management in Urban Areas: A Role for Constructed Wetlands

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Abstract

Lower space requirement, simple operation and economical aspects as well as landscape integration make decentralized natural sanitation systems necessary in eco-city construction. This paper focuses on water management through natural and alternative solutions in urban and peri-urban areas. Results and efficiency of raw wastewater by decentralized natural systems, intelligent storm water management and reuse of treated water in urban irrigation are discussed. Several full scale examples are presented regarding to their removal efficiency and environmental benefits. Their contribution in climate change mitigation is presented as a necessity in today's eco-city conception.

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Peer-review under responsibility of the organizing committee of GU 2016

Keywords: wastewater, storm water, constructed wetland, decentralized sanitation system, water reuse, urban area, eco-city.

1. Introduction

Urban water and wastewater management generally use centralized systems inheriting from concepts created in

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the early twentieth century¹. With the expansion of cities, sewer systems have been developed up to thousands of kilometres using the “end of pipe” concept. The large quantity of collected wastewater is then conveyed and treated in centralized industrial plants. In the 21st century, limited space, high human population density, noise and pollution become common issues in the modern urban areas. Urbanization is the trend of economic development but it also brings us serious environmental issues such as waste and water pollution, decreased biodiversity and urban heat islands effect (UHI), which are definitely not what we are looking forward to. With the expansion of urbanization, the “Eco-city” paradigm was introduced as an environmental-friendly city in which water and energy are valorised, wastes are managed and recycled. In most cities, wastewater is collected and conveyed far to a central treatment plant. This kind of approach requires long sewer systems and underground pipe layout construction which are expensive to build and maintain, and not necessarily environmental-friendly.

Constructed wetlands for domestic raw wastewater treatment are extensive systems that have demonstrated their high pollutants removal efficiency for over 20 years². Recent developments make them more intensive while enhancing their treatment efficiency. The potential of these systems for decentralized sanitation in urban areas is described in this paper.

Constructed wetlands are also adapted to rainwater management and will be presented in this paper. The modified two-stage vertical flow constructed wetland system is able to deal with combined sewer effluent, while a properly engineered single-stage constructed wetland can handle with combined sewer overflows.

Treated wastewater and harvested rainwater can be reused into agricultural irrigation, gardening and public utilizations. Constructed wetlands can be designed to produce water reaching standards for reuse purposes.

This publication will concentrate on these three main roles of constructed wetlands for decentralized wastewater treatment in urban areas, with respect to eco-city construction.

2. Constructed wetlands for wastewater treatment

Constructed wetlands (CW) for domestic wastewater treatment, developed by Epur Nature (Syntea Group) over 15 years as Phragmifilter[®] (more than 900 CW plants), can achieve high pollutant removal efficiency². They have been widely adopted by small communities in France over the last 20 years (>3 000 plants). They ensure good landscape integration and low operational costs compared to conventional treatment plants. They are usually considered as extensive systems which are not suitable for urban areas. However, a recently developed technology by the Syntea group in collaboration with Scott Wallace³ and Dion van Oirshot, “Rhizosph’air[®]” led to an intensification of these systems in which a better treatment efficiency is achieved, infiltration surface is decreased from 2 m² p.e⁻¹ (square meters per person equivalent) to 0.8 m² p.e⁻¹. The birth of CW with forced aeration technology marked the turning point of natural sanitation systems and made decentralized wastewater treatment by constructed wetlands possible in urban areas. Experiences showed classic constructed wetland systems generally refer to large space requirement while conventional wastewater treatment plants, which are largely adopted in cities, generally require a high level of exploitation and maintenance, as well as a high energy demand.

2.1. Technology description

“Rhizosph’Air[®]” is a combination of classic CWs with forced aeration system at the bottom of the basin (as shown in figure 1). This technology allows an increase in oxygen transfer by a factor of 3, meaning plant surface can be divided by 2 to 3. Nitrification (bacterial reaction that transforms ammonium to nitrate) is complete as well as denitrification (bacterial reaction that transforms nitrate to gaseous N₂), which is difficult to be managed in natural sanitation systems. This innovation can also deal with inflow coming from industry and agro-food industry.

“Rhizosph’Air[®]” technology solves the space requirement problem of traditional constructed wetlands, making urban wastewater treatment plant decentralized and improving treatment efficiency at the same time.

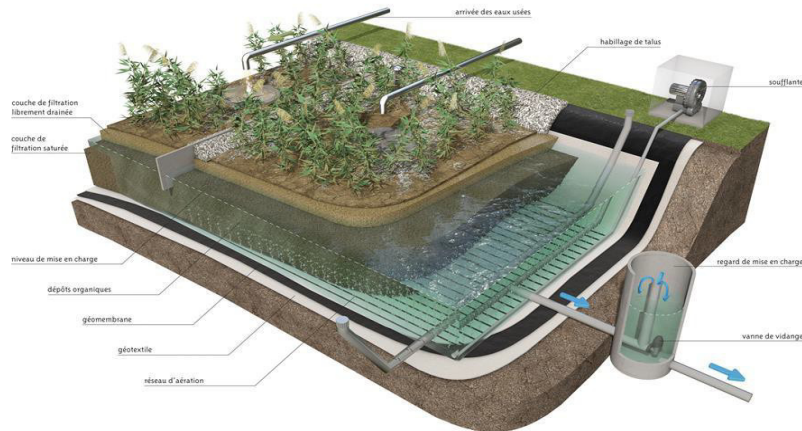


Fig.1. Constructed with FBA system design model;

2.2. Worldwide applications

Aerated Constructed wetland systems were implemented in various projects in the United Kingdom, North America and Europe. The airplane de-icing fluid treatment by aerated wetlands systems has demonstrated its efficiency in BOD₅ degradation (Biological oxygen demand during 5 days, it can be used as the gauge of effectiveness of wastewater treatment plants) at the Heathrow Airport in London⁴ and at the international Buffalo Niagara Airport⁴. The Aerated wetland systems have been used at Casper, Wyoming, America⁵ to treat effluent polluted by BTEX and hydrocarbons. The Badboot (Dutch for swimming pool boat) project by Rietland⁶ adopted aerated constructed wetlands system to treat all wastewater from on-boat activities with the limited space available on-board of ships. The result has been proven satisfying as the biological degradation of nitrogen is almost complete. These examples demonstrate the treatment efficiency of aerated wetland systems in domestic and industrial settings and the possibilities in space limited areas.

3. Constructed wetlands in rainwater treatment and management

More and more attention is paid on rainwater management due to increased water shortages, extreme rain events and flooding (issue of the impervious surfaces) in urban areas. Different methods have been developed for rainwater management, including storage systems such as storm water tanks, detention and settling tanks, and more recently flux reduction at the source (valleys, porous roadway and vegetable roofs and walls) as well as extensive systems like lagooning, infiltration tanks and traditional constructed wetlands.

A good management of rainwater is very important for the design of sanitation systems and for the environment. In urban areas, centralized wastewater treatment plants have common problems in dealing with excessive rainwater flows, and in most of the cases, the extra flows are not treated but spilled directly over to the natural water body. Decentralized constructed wetlands may solve the problem of overflow while accomplishing the treatment job. What's more, they create natural green spaces in the city, which improves the biodiversity, micro-climate and reduces the urban heat island effects (UHI)⁸. Two approaches of rainwater management by CWs are presented below.

3.1. Strict rainwater management by constructed wetlands

A system that receives only rainwater is called a strict rainwater system. Rainwater is harvested through a separate sewer system. This system may cause problems to urban areas due to the limited capacity of sewers and the

expansion of impermeable surfaces in urban areas. Thus, alternative systems are developed in order to create more vegetated and permeable areas such as green roofs, green walls, small retention parks and wetlands retaining runoff and excessive rainwater. Constructed wetlands collecting rainwater can encourage maximum urban biodiversity⁷ and mitigate urban heat island (UHI) effects⁸. The famous low-impact development (LID) practices⁹ aim to preserve, restore and create green spaces using soils, vegetation, and the rainwater harvest techniques, in which the processes of the natural water cycle are mimicked.

Constructed wetlands designed strictly for rainwater harvesting purpose are more and more demanded in France. Rainwater retained inside the basin moderates the surrounding land climate because of higher heat capacity of water than soil ground and cooling effect of evapotranspiration¹⁰. The Ouagadougou Park of Grenoble in France opened in 2008¹¹. The park can be considered as a good example of effective strict rainwater management in urban areas. The project covers a total surface of one hectare in which different rainwater management methods are involved: surface water drainage, runoff water treatment by reed bed filters, water storage, garden irrigation and creation of an urban wetland area with flood storage functions. What's more, water circulates throughout the park that enhances certain areas and makes it more attractive and entertaining.

Same principles of rainwater management by creation of more infiltration surfaces can be achieved by green infrastructures. For example, green roofs¹² may have several application domains including landscaping, ecosystems development, and urban heat island (UHI) effects reduction and also capacities to reduce runoff volumes and peaks for rainwater events. More applications have been carried out through different green infrastructures all over the world, as part of them, constructed wetlands offer great potential of rainwater management in the city of tomorrow.

3.2. Constructed wetlands for combined sewage overflow treatment(CSOs)

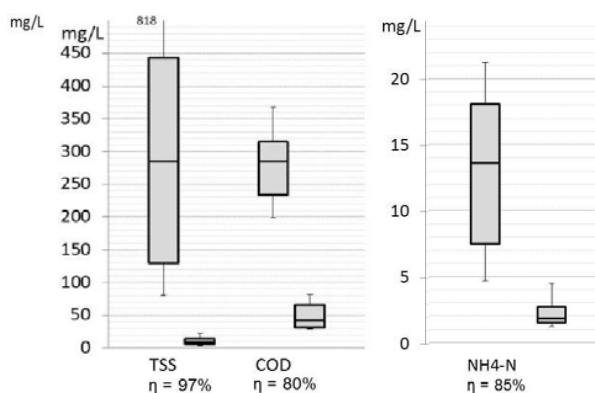
As mentioned earlier, rainwater overflows are an issue to conventional centralized treatment plants. During extreme rain events, excess flows are diverted as overflows into the receiving water body without treatment. If stormwater was considered during the conception of WWTP's, a larger WWTP would need to be designed as well as oversized or more pipelines need to be built which will require more investment and maintenance.

Thus, overflows not only need to be managed, but also require to be treated before diverting into the nature¹³. One of the most economical, ecological and feasible solutions are vertical flow constructed wetlands (VFCWs), specified as constructed wetlands for CSO treatment (CSO-CWs) in general.¹³

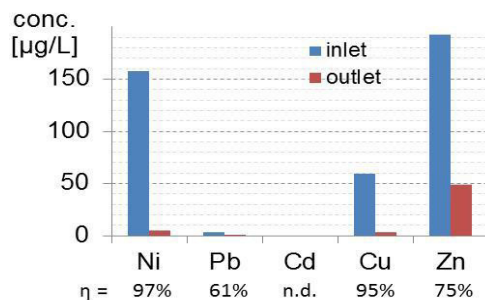
CSOs are usually less concentrated with carbon and nitrogen compared to dry weather flows because they are diluted by stormwater, but they are highly polluted compared to surface runoffs in separated sewer systems and natural waters as well. CSO-CWs can regulate inflow rates at the inlet of the constructed wetlands¹³. In France, the newest design of CSO-CW plants was built in 2012 by Epur Nature (Syntea Group) as an experimental full-scale site (Marcy l'Etoile treatment plant, France). The plant was designed according to the annual rain extremities and to raw waters without any pre-treatment. After 4 years' operation, the plant shows excellent removal efficiencies¹⁴. Figure 2 shows a general view of the site. Removal efficiencies of the targeted pollutants are shown by figure 3.



Figure 2: Station of Marcy l'Etoile (69), France (photo: Daniel Meyer)

Figure 3: Removal of target pollutants at Marcy l'Etoile (based on Pálffy et al. 2017)¹⁴.

The site at Marcy l'Etoile has indicated that the technology is effective in the removal of several micropollutants as well, both from the group of metals and PAHs. Priority substances are listed in the EU Water Framework Directive (2000/60/EC) based on their toxicity for humans and aquatic environment. These are cadmium (Cd), nickel (Ni) and lead (Pb) from the metal group. Removal of the most typical metal pollutants at the CSO CW of Marcy l'Etoile is shown by figure 4. Furthermore, eleven PAHs were found in the sludge withheld on the top of the filter, thanks to the feeding with raw wastewater. On the other hand, three common solved compounds were removed with high efficiency (Benzo (a) Pyrene, Naphtalene and Phenanthreneat with 90-95%removal).

Figure 4: Removal of common metals and priority contaminants in the CSO at Marcy l'Etoile (based on Pálffy et al. 2017)¹⁴

4. Constructed wetlands in water reuse

The combination of climate change and anthropic activities increases the threat on receiving water bodies in terms of quality and quantity. Diversified uses of treated wastewaters have been developed and studied over the last decades making reuse a central theme in modern urban water management¹⁵. Agricultural irrigation generally represents the biggest water demand, especially in the summer season when natural water levels are at their lowest. Then, treated wastewater reuse can be an efficient alternative to conventional irrigation methods. This has already been successfully implemented in Clermont-Ferrand (France), Milan (Italia), Ouagadougou (Burkina Faso) and Amman (Jordan). Rotbardt (2011)¹⁵ also mentions the possibility to reuse treated wastewater in order to recharge groundwater as in Nabeul and Korba (Tunisia) and Tel Aviv (Israel).

Treated wastewater reuse requires a water quality dependent on the expected application. Regulations on quality standards are generally imposed by countries in order to avoid risks of human contamination. In this context, a wide range of technologies have been developed to meet regulations¹⁶. They involve filtration technologies (sand filters, microfiltration, ultrafiltration, nanofiltration, and reverse osmosis) and/or disinfection technologies (ultraviolet irradiation, ozonation or chlorination). Sometimes both technology types are combined. As an alternative to these conventional techniques, the following constructed wetlands are suitable to treat wastewater up to the highest standards for reuse: (1) constructed wetlands with forced aeration and (2) soil infiltration systems.

Rhizosph'air[®] (see paragraph 2.1) is an engineered constructed wetland including forced aeration. Forced aeration is able to reach high yields in disinfection, provided a proper operation¹⁷. Thus Rhizosph'air[®] can be used as a tertiary treatment system providing water qualified for reuse purposes.

Natural soils are media allowing high pollutant and pathogen removal rates¹⁸. They are widely chosen within extensive systems for on-site sanitation. They also can be applied in the peri-urban context using buried wastewater irrigation and a drainage system. This design has been recently developed and optimized by Syntea Group. The large area needed to treat the wastewater can be utilized as recreational urban area (gardens, parks). The treated wastewater can be also used for municipal needs.

5. Conclusions

Decentralized wastewater management is complementary and can be as effective as centralized wastewater treatment plants, especially when facing the rapid population expansion and property development in urban areas.

Decentralized sanitation scan be performed by constructed wetlands with forced aeration which offer greater advantages than classic constructed wetlands, like less space requirement and better treatment efficiency. CWs can also provide eco-systemic services with enhanced biodiversity and can reduce urban heat island (UHI) effects.

Constructed wetlands for combined sewer overflow treatment prevent untreated overflows from polluting natural waters and with limited investment costs. Constructed wetlands serving as retention tanks during the rainy season can harvest and treat rainwater due to the natural purification. Tertiary treatment through constructed wetlands with aeration system and soils infiltration systems can produce high quality water for reuse purposes.

Newly engineered constructed wetlands can be considered as a driving force towards a change in paradigm regarding water management in the urban context.

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