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# Are constructed treatment wetlands sustainable sanitation solutions?

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**Abstract**
The main objective of sanitation systems is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable a sanitation system has to be not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. 'Resources-oriented sanitation' describes the approach in which human excreta and water from households are recognized as resource made available for re-use. Nowadays 'resources-oriented sanitation' is understood in the same way as 'ecological sanitation'. For resources-oriented sanitation systems to be truly sustainable they have to comply with the definition of sustainable sanitation as given by the Sustainable Sanitation Alliance (SuSanA, www.susana.org). Constructed treatment wetlands meet the basic criteria of sustainable sanitation systems by preventing diseases, protecting the environment, being an affordable, acceptable, and simple technology. Additionally, constructed treatment wetlands produce treated wastewater with high quality which is fostering reuse which makes them applicable in resources-oriented sanitation systems. The paper discusses the features that make constructed treatment wetlands a suitable solution in sustainable resources-oriented sanitation systems, the importance of system thinking for sustainability as well as key factors for sustainable implementation of constructed wetland systems.

**Keywords**
Constructed treatment wetlands, sanitation system, sustainable sanitation.

## INTRODUCTION

Constructed wetlands (CWs) are engineered water treatment systems that optimize the treatment processes found in natural environments. CWs are popular systems which efficiently treat different kinds of polluted water and are therefore sustainable environmentally friendly solutions (e.g. Kadlec and Wallace, 2009). Compared to technical solutions to treat wastewater, CWs are simple to operate and maintain, very robust, and they can buffer high fluctuations of flow and concentrations. Therefore they are very suitable for small communities and settlements for which there is a big demand for proper wastewater treatment (e.g. Haberl et al., 2003).

The main objective of sanitation systems is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable a sanitation system has to be not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources (SuSanA, 2008). 'Resources-oriented sanitation' describes the approach in which human excreta and water from households are recognized as resource made available for re-use (Langergraber and Müllegger, 2005; Werner et al., 2009). These systems are based on the closure of material flow cycles. To optimise the potential for reuse different wastewater flows are collected and treated separately. Nowadays ‘resources-oriented sanitation’ is often used in the same way as ‘ecological sanitation’. For resources-oriented sanitation systems to be truly sustainable they have to comply with the definition of sustainable sanitation as given by the Sustainable Sanitation Alliance (SuSanA, 2008), the following aspects needs to be considered:

- Health and hygiene
- Environment and natural resources
- Technology and operation
- Financial and economic issues
- Socio-cultural and institutional aspects

For sustainable implementation of sanitation systems the whole system has to be kept in mind. A sanitation system – contrary to a sanitation technology – considers all components required for the adequate management of human wastes (Zurbrügg and Tilley, 2009). In the "*Compendium of Sanitation Systems and Technologies*" (Tilley et al., 2008) the following five functional groups that form sanitation systems are defined: 1) User Interface, 2) Collection and Storage, 3) Conveyance, 4) Treatment and 5) Use and/or Disposal. Depending on the configuration of technologies that carry out different processes on specific products (wastes) different systems are defined. Two main criteria for subdividing the systems are "wet" and "dry", and the degree of waste separation, whereby the terms "wet" and "dry" indicate the presence of flushing water for the transport of excreta.

This paper reviews CWs against the SuSanA sustainability criteria and discusses key factors for sustainable implementation of CW systems.

## CONSTRUCTED WETLANDS AND THE SUSANA SUSTAINABILITY CRITERIA

### Health and hygiene

According to SuSanA (2008) this criteria includes the risk of exposure to pathogens and hazardous substances that could affect public health at all points of the sanitation system from the toilet via the collection and treatment system to the point of reuse or disposal and downstream populations as well as aspects such as hygiene, nutrition and improvement of livelihood achieved by the application of a certain sanitation system, and downstream effects.

CWs have been found to reduce pathogens with varying but significant degrees of effectiveness. The elimination efficiency is increasing with the retention time of the wetland (e.g. García et al., 2003; Kadlec and Wallace, 2009). For vertical flow CWs with intermittent loading pathogen elimination of at least 2 logs can be expected for each filter bed (e.g. Sleytr et al., 2007). In surface flow systems solar disinfection due to UV radiation plays a main role for removing pathogens (e.g. Gearheart, 1999; Greenway, 2005; Kadlec and Wallace, 2009).

### Environment and natural resources

This criterion involves the required energy, water and other natural resources for construction, operation and maintenance of the system, as well as the potential emissions to the environment resulting from use (SuSanA, 2008). It also includes the degree of recycling and reuse practiced and the effects of these (e.g. reusing wastewater), and the protecting of other non-renewable resources, for example through the production of renewable energies (e.g. biogas).

Using CWs the pollution load can be reduced significantly due to the high removal efficiencies (e.g. Kadlec and Wallace, 2009; García et al., 2010). Due to their high buffer capacity CW systems show a very robust treatment performance (e.g. Langergraber et al., 2010; Galvão and Matos, 2012; Mulling et al., 2012). CWs are also very sustainable options for treating diffuse pollution such as agricultural runoffs (e.g. Raisin et al., 1997; Ockenden et al., 2012). The very low energy requirement of CWs (e.g. Brix, 1999) saves energy resources. CWs perform quite favourable with other treatment technologies according their sustainability when using life-cycle assessment tools (Dixon et al., 2003; Steer et al., 2003; Fuchs et al., 2011). Besides water quality improvement and energy savings CWs have other features related to the environmental protection such as biodiversity, habitat for wetland organisms, climatic functions (e.g. less green-house gas emission, Dixon et al., 2003; Pan et al., 2011), water saving (e.g. Masi, 2009) and hydrological functions (e.g. Brix, 1999).

**Technology and operation**

The functionality and the ease with which the entire system including the collection, transport, treatment and reuse and/or final disposal can be constructed, operated and monitored by the local community and/or the technical teams of the local utilities are incorporated within the 3rd SuSanA sustainability criterion. Furthermore, the robustness of the system, its vulnerability towards power cuts, water shortages, floods, etc. and the flexibility and adaptability of its technical elements to the existing infrastructure and to demographic and socio-economic developments are important aspects (SuSanA, 2008).

Typical treatment wetlands are simple in design, construction and operation (e.g. Geller and Hörner, 2003; Kadlec and Wallace, 2009). However, specific treatment wetland designs such as intensified wetlands with aeration (e.g. Wallace and Knight, 2006; Fonder and Headley, 2013) are more complex and require more efforts and skills for operation and maintenance (O&M). It has to be distinguished whether or not a CW has been designed and constructed properly. CWs that have not been properly constructed suffer from various problems, like clogging, surface run-off, short-circuiting, bad plant development. As a consequence they show bad performance. In opposition to that, properly built CWs usually perform well. Only unpredictable problems which are common also with conventional systems occur, like failures of installation devices (i.e. pumps or valves). In addition to that a severe problem is low temperature, which does not influence the performance of the CW itself but - as an example - may affect the inflow distribution device of a vertical flow bed which is situated above bed-surface. In temperate climates this fact has to be taken into account (Haberl et al., 2003; Mitterer-Reichmann, 2012). When CWs are implemented in hot and dry climates and treated wastewater should be reused water losses have to be avoided. This can be achieved by i) selection of more efficient plants to minimise evapotranspiration losses, and/or ii) smaller footprints of the treatment system to avoid evaporation (Masi, 2013).

**Financial and economic issues**

SuSanA (2008) includes in this criterion the capacity of households and communities to pay for sanitation, including the construction, operation, maintenance and necessary reinvestements in the system. Besides the evaluation of these direct costs also direct benefits e.g. from recycled products and external costs and benefits should be taken into account.

In Europe the construction costs for CWs are in the same range compared to conventional technical treatment plants, taking the area requirement not into account (Haberl et al., 2003; Geller and Hörner, 2003). However, operation and maintenance (O&M) costs are lower for CWs due to less energy demand and technical devices used (e.g. Brix, 1999; Dixon et al., 2003). Usually the O/M-costs increase with the decreasing size of a plant. For Austria the O/M-costs are estimated to be about 300, 200 and 150 EUR.PE$^{-1}$.a$^{-1}$ for 5, 10, and 20 PE respectively (Haberl et al., 2003).

### Socio-cultural and institutional aspects

The socio-cultural and institutional aspects include evaluating the socio-cultural acceptance and appropriateness of the system, convenience, system perceptions, gender issues and impacts on human dignity, the contribution to food security, compliance with the legal framework and stable and efficient institutional settings (SuSanA, 2008).

Being a natural treatment system the appearance of CWs is more aesthetical compared to conventional technical treatment options. Additionally CWs also provide public use functions such as the possibility to create recreation areas or to produce fibres (e.g. Knight, 1997; Brix, 1999; Kadlec and Wallace, 2009). These additional benefits might increase the public acceptability of a CW treatment system.

## KEY FACTORS FOR SUSTAINABLE IMPLEMENTATION OF CW SYSTEMS

### Better overall performance compared to other treatment technologies

The local government of Salzburg in Austria carried out a survey regarding the performance of small wastewater treatment plants (WWTPs). 1771 small WWTPs have been in operation in 2009 whereby 1144 plants have a size of < 10 PE treating wastewater of about 7'500 PE, 554 plants of 11 < PE < 50 for 11'400 PE and 73 plants of 51 < PE < 500 for 10'400 PE (Schaber and Reif, 2009). The main technologies applied are conventional activated sludge (AS) plants (16 %), sequencing batch reactor (SBR) plants (9 %), trickling filters (22 %) and CWs (12 %), respectively. The remaining 41 % are mainly old 3-chamber mechanical treatment facilities which are no longer state-of-the-art and needs to be upgraded in due time. In their study Schaber and Reif (2009) selected randomly 10 plants from each of the 4 main technologies. During visits of the plants effluent samples have been taken and analysed for compliance with the Austrian affluent standards (Table 1). It can be seen that CWs are the only technology for which all tested plants have been in compliance with the Austrian effluent standards. Second best are SBR plants mainly due to the fact that the installed systems are rather new compared to trickling filters and activated sludge plants thus failures of the system are less likely. The study of Schaber and Reif (2009) confirmed that CW treatment systems are very robust in terms of treatment technology.

Table 1: Number plants fulfilling the required Austrian effluent standards for different parameters (adapted from Schaber and Reif, 2009)

| Type of WWTP | COD | $BOD_5$ | $NH_4$-N [1)] | $NH_4$-N [2)] | TSS | Meet all requirements |
|---|---|---|---|---|---|---|
| **Legal requirement (mg/L)** | 90 | 25 | 10 (> 12°C) | | 30 | |
| **Activated sludge** | 4 | 5 | 8 | 3 | 5 | **2** |
| **SBR** | 10 | 10 | 9 | 9 | 8 | **8** |
| **Trickling filter** | 6 | 5 | 7 | 6 | 5 | **2** |
| **Constructed wetland** | 10 | 10 | 10 | 9 | 10 | **10** |

[1] considering only measured data for effluent water temperatures > 12°C
[2] considering all measured data.

Weissenbacher et al. (2008) investigated wastewater treatment systems at mountain refuges in the Alpine region. Based on interviews carried out with about 100 huts with lessees regarding their evaluation of the wastewater treatment system in place, the energy demand and the overall costs of wastewater treatment constructed wetlands have been ranked to be the preferable technology for mountain refuges (Steinbacher and Weissenbacher, 2009).

Kalbar et al. (2012) compared different wastewater treatment technologies (a conventional AS process, a SBR, an upflow anaerobic sludge blanket reactor followed by a facultative aerated lagoon, and a CW system) for 7 scenarios ranging from rural areas with no land constraints to urban areas with high land constraints. The technologies have been compared using the following criteria: global warming, eutrophication, life cycle costs, land requirement, manpower requirement for operation, robustness of the system and sustainability. It was found that the CW system was ranked first in all scenarios in which no land constraints have been assumed. Not surprisingly, in urban scenarios with land constraints technical solutions (AS and SBR) were ranked first.

**Operation and maintenance requirements to ensure long-term operation of CWs**

It is commonly known and agreed that CW systems require only little O&M efforts. If O&M is carried out by professionals it is more likely to detect problems before they become visible in a reduction of treatment efficiency (Mitterer-Reichmann, 2012). It is a characteristic of CWs that mistakes in operation are buffered over a long time. In the case of long term these malfunctions might lead to soil clogging.

In Austria plant owners are instructed about the necessary maintenance works and obliged to keep a “maintenance book” documenting weekly or monthly controls of nitrification with a test kit. They also should check the condition of the three chamber septic tank, the intermittent feeding system and the even distribution through the pipe system in regular intervals.

Based on experiences from service contracts with more than 800 CW systems in Austria Mitterer-Reichmann (2012) concludes that the main O&M problems for the different part of VF CWs are:

- *Pre-treatment*: The sludge of the pre-treatment has to be emptied in time in order to prevent sludge drift into the reed beds. The emptying intervals depend on the size of the pre-treatment system and vary between one year and several years. The sludge can be stabilized in a separate sludge drying reed bed on the spot. Alternatively it can be transported to a central sewer plant for further treatment.
- *Intermittent feeding system*: The functioning of the intermittent feeding by the valve can be checked by measuring the difference in height in the well before and after the feeding process. After some years the rubber part of the flexible pipe can be porous which is why the wastewater seeps continuously only into the front part of the filter bed. If this is not detected the filter will be clogged after some time. This is why the device should be controlled once a month.
- *Distribution system*: An uneven distribution of wastewater above the filter is the most common problem of malfunctioning of constructed wetlands. It can be measured by collecting the water flowing out the pipes at the 4 corner points of the filter bed. The distribution system can be best adjusted and cleaned after the cutting of the plants.
- *Wetland plants*: During the first year attention should be paid to the growing of the plants. Weeds should be removed until the reed is established. The cutting of the plants can be made in spring. Some operators prefer to cut the reed in autumn, lay the dry straw on the filter surface and remove it in spring because then there are less small leave parts on the filter surface. The water level in the filter bed should be as low as possible.

Similar conclusions for operation and maintenance requirements of treatment wetlands to ensure long term operation have been drawn based on experiences from e.g. the UK (Cooper et al., 2005; Cooper, 2007), the Czech Republic (Vymazal, 2011), Slovenia (Bulc, 2006), Denmark (Nielsen, 2012) and the USA (Wallace and Knight, 2006).

## DISCUSSION

As described above CW technology fulfils the basic SuSanA sustainability criteria. This makes CWs a technology suitable for sustainable implementation of sanitation systems as well as for being used in resources-oriented systems (e.g. Langergraber and Haberl, 2004). CWs are used in sanitation systems for treating greywater, storm water and/or the total wastewater flow. Especially concepts with greywater separation have considerable benefits in terms of costs and re-use potential compared to concepts where the total wastewater flow has to be treated (Lechner and Langergraber, 2004; Masi, 2009; Paulo et al., 2012).

Compared to other wastewater treatment technologies CWs have very robust treatment performance and low operation and maintenance requirements (Mitterer-Reichmann, 2012). Several studies showed that CWs are the preferable technology when applied in situations where land for extensive treatment is available, e.g. in rural areas (e.g. Kalbar et al., 2012), and/or for small WWTPs for which O&M is often neglected (e.g. Schaber and Reif, 2009; Steinbacher and Weissenbacher, 2009).

Several authors proposed CW technology as very suitable for the application in developing countries as CW technology is affordable and adaptable to local conditions (e.g. Haberl, 1999; Kivaisi, 2001). Nowadays, CWs are used to treat wastewater in many developing countries in different continents including Nepal (Shrestha et al., 2001; Singh et al., 2010), Nicaragua (Platzer et al., 2004) and Tanzania (Mashauri et al., 2000). Applications of CWs in resources-oriented sanitation systems in developing countries have been reported e.g. by Kenge et al. (2009) for treating faecal sludge, Mandal et al. (2011) for treating greywater, and Platzer et al. (2004) for reusing treated wastewater from CWs. A crucial step for the implementation of CWs in developing countries is proper technology transfer (e.g. Haberl, 1999).

For sustainable implementation of a sanitation system the whole sanitation chain has to be considered. Although CWs as a technology compares quite favourable to the SuSanA sustainability criteria, a sustainable implementation can only be reached when the whole system is considered. This includes e.g. the consideration of O&M requirements (e.g. Müllegger et al, 2010) and the treatment of residues from the CW treatment systems (e.g. sludge).

CW systems for treating raw sewage, i.e. integrated treatment of sludge and wastewater, have been developed in France during the last 20 years (Liénard, 2010; Troesch and Esser, 2012). Using this systems sludge and wastewater are treated in one type of reactor (planted filter beds) and thus making construction cheaper (no mechanical pre-treatment unit required and simpler design of inlet distribution pipes), operation and maintenance simpler, and avoiding the necessity management and disposal or treatment of primary sludge. These systems comprise two vertical flow CWs operated in series. In the first stage sludge treatment and partly organic matter removal takes place, in the second stage final organic matter removal and nitrification. The treated sludge from the first stage has to be removed every 10-15 years (Molle et al., 2005). The integrated sludge and wastewater treatment wetlands are nowadays becoming more popular and have been already applied in several other countries including Spain (Burkard and Esser, 2006), Morocco (El Hamouri et al., 2010) and the Mayotte island (Esser et al., 2010) thus showing high potential.

Up to now treatment wetland design is either based on empirical rules of thumb (e.g. using specific surface area requirements) or simple first-order decay models (Kadlec and Wallace, 2009). The drawback of these design rules is that the parameters have been drawn from experiments and experiences and therefore are only valid for systems operating under similar boundary conditions (climatic conditions, wastewater composition, porous filter material, plant species, etc.). For applying CWs in resources-oriented systems and/or other countries these boundary conditions might vary significantly (e.g. for CWs treating wastewater streams such as greywater and/or CWs applied in developing countries, respectively). To improve the design of treatment wetlands for these applications new design tools that are based on process-based numerical models are needed (Langergraber, 2011).

## CONCLUSIONS

The following conclusions can be drawn:

- Sustainable implementation of sanitation systems can only be achieved when the whole sanitation service chain is considered.
- Constructed wetlands compare quite favourable against the SuSanA sustainability criteria, i.e.
  - the high treatment efficiency of CWs contributes to health and hygiene, and
  - protects environment and safes natural resources,
  - CWs are a simple technological solution which is easy to operate and maintain,
  - CWs can be implemented at reasonable costs and especially have low O&M costs, and
  - being a natural treatment technology CWs have high socio-cultural acceptance and can be an appropriate technological solution.
- CWs have a high potential for being implemented in sustainable sanitation solutions.

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