Chapter 3

Design approach for treatment wetlands

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3.1 DEFINE THE TREATMENT OBJECTIVES

Treatment wetlands have one main objective, i.e., treating water to make it suitable for a certain purpose. Other objectives, besides treating water can be:

- Retaining water to store it to later evapotranspire it or attenuate flood waves;
- Evapotranspirating water, which is key for sludge treatment wetlands, but also for cooling and reducing urban heat island effects;
- Producing biomass;
- Harvesting nutrients;
- Creating a nice landscape, including for recreational purposes;
- Enhancing ecosystem services (mainly for FWS wetlands);
- Fostering biodiversity, directly or by creating habitats.

This list is not exhaustive but shows some of the additional benefits. TWs can be designed for a single objective, which then would be just to treat water, or with multiple objectives, whereby treating water is always included. Engineers should seek multi-objective solutions.

The purpose for which treated water should be utilised defines the treatment objective. For example, if treated water is to be used for irrigation purposes, it makes less sense to remove nutrients that are beneficial for crop fertigation.

However, restrictive regulations in various countries often obstruct the producing of effluent with a desired quality for a particular purpose. The full potential of circular management of water and substances will therefore only be possible after a revision of the respective guidelines. Such a revision should aim at protecting water users and the consumers of products that have come into contact with the "reused" water, but also eliminating unnecessary obstacles. A zero-risk approach, as applied e.g. in Italy for treated wastewater for irrigation, leads to difficulties in spreading this practice. A different view of the same concern is offered by the World Health Organization, which proposed a pragmatic approach based on microbial risk assessment, evaluating case by case the pathogen reduction for treated wastewater to be used in agriculture, and how to achieve this (Licciardello *et al.*, 2018).

3.2 WHICH PROCESSES DO WE NEED TO REACH THE DESIGN OBJECTIVES?

Once the design objectives are defined, the designer needs to identify the processes that are required to deliver them. Table 3.1 summarises the most significant processes required to reach typical treatment objectives. As the main treatment objective is improving water quality, most processes are related to this aspect.

3.3 WHICH TW TYPE CAN BE USED TO REACH THE SPECIFIED OBJECTIVES?

Table 3.2 summarises the processes occurring in the main TW types. A '++' indicates that this process is a primary process in this TW type, meaning that the TW type is primarily designed in a way that this process occurs. For instance, if nitrification is required, only TW types with vertical flow (VF) and intermittent loading can be used, i.e. classical VF wetlands and French VF wetlands. A '+' or 'o' indicates that the process occurs to some extent, but that the TW type is not primarily designed for this process.

3.4 OTHER IMPORTANT DESIGN ASPECTS

During the design of TWs additional important aspects have to be taken into account. These are:

- *Considering malfunctioning*. Designers have to consider situations in which the system is not working in the way it was designed, e.g. when pumps break or when filter beds become clogged. A major challenge that has to be considered is that inflow water still needs to pass through the system without causing severe damage. Two typical strategies are bypasses and redundant structures: overflows within pump sumps or wetland beds could be one way, or planning several treatment lines in parallel so that if one is offline, the wastewater can still be treated by the other lines. Risk considerations must be given particular attention when there is not only a treatment but also a supply commitment, either in terms of quantity or quality or both, that must be complied with.

Table 3.1 Processes required to reach specific design objectives.

Objective	Processes
Improve water quality	
Removal of solids	Filtration Sedimentation
Removal of dissolved organic matter	Aerobic degradation Anaerobic degradation
Removal of ammonia	Nitrification Adsorption
Removal of nitrogen	Denitrification after nitrification Plant uptake
Removal of phosphorus	Adsorption Precipitation Plant uptake
Removal of microbial contamination	Filtration Disinfection
Removal of organic micropollutants	Biological degradation Adsorption
Removal of metals	Sorption Plant uptake Precipitation
Remove water/reduce water content	Evaporation Evapotranspiration
Recover energy from biomass	Biomass production
Enhance biodiversity	Creation of habitats

Table 3.2 Processes in TW main types.

TW Type/Processes	Sedimentation	Filtration	Aerobic Degradation	Anaerobic Degradation	Nitrification	Denitrification	Adsorption	Sorption	Precipitation	Plant Uptake	Evaporation	Biomass Production	Creation of Habitats
VF wetland		++	++		++		+	+				+	+
French VF wetland	+	++	++		++		+					+	+
HF wetland		++	o	++		o	+	+	o		+	+	+
FWS wetland	++	+	+	+	+	+			o	+	o	+	++
Sludge treatment wetland	+	++	++								++		+
Aerated wetlands		++	++		++		+		o			o	o

- *Operation and maintenance*. Operation and maintenance of the system must be considered during the planning phase. These considerations include:
  - Requirements for removing the sludge from the primary treatment unit (e.g. frequency, method for sludge or solid waste transport, treatment and reuse/disposal);
  - The required maintenance for the wetland plants (e.g. frequency and timing of harvesting/cutting of vegetation, further use);
  - General responsibilities and tasks for routine operation, monitoring and maintaining of the wetland system, including the preparation of a user-friendly operation manual and operational materials including (but not limited to) checklists and logbooks;
  - The expected running time before major intervention will be required (e.g., removal of accumulated sludge from wetland surface) and the type of intervention it will require (e.g., digging and cleaning media, surface scrapping, replanting); as well as
  - Access to the facility for major maintenance and repair work if required.
- *Monitoring of treatment wetlands*. Considerations for future monitoring of the TW should ensure that:
  - Sampling locations must be present and easy to access;
  - Sampling and analysis required for routine monitoring to ensure the proper operation of the system is clearly defined (frequency, location and parameters); and
  - External requirements for sampling and analysis to fulfil legal obligations are met.
- *Construction phase*. Considerations important for the construction phase include, e.g.,
  - The shape of the terrain and possible constraints such as the presence of power lines, gas pipes, railways, roads, riverine buffer zones, etc.;
  - The local availability of sand/gravel required for the filter bed in the physical and chemical quality and granulometry required,
  - The capacity of local workers available for welding plastic polymer liners,
  - The availability of wetland plants (amount, species, etc.),
  - The proper planning of the time schedule so that all materials are available on site when needed.
- *Health, Safety and Environment (HSE)*. HSE means a systematic process of identifying the impact of wetland technology projects related to health, safety and the environmental conditions that may occur during the construction and operational phases, along with recommendations for their management. Potential risks occur in different phases of the project:
  - *The construction phase*. The Construction Design and Management Regulations 2015 (CDM, 2015) offer guidelines that broadly prescribe the general duties for employers, employees and the self-employed, and is useful for wetland technology construction sites. The fundamental principles that have been adopted in many countries around the world include (Aboagye-Nimo *et al*., 2018; CDM, 2015):
    - Proper planning and coordination need to be undertaken from the beginning of the project
    - Safety and health must be considered throughout the project
    - All persons who contribute to the health and safety of a wetland technology project need to be included
    - Those in charge of the provision of health and safety need to be professionally competent
    - Communication and sharing of information between all parties must be undertaken
    - A record of safety information for future use must be made.

    Early implementation of HSE principles is essential to the success of a construction project and can prevent negative consequences. All stakeholders, including the owners, have a duty to ensure works and activities are carried out under safe conditions (Aboagye-Nimo *et al*., 2018)

- *The operational phase*. Operation, maintenance and water reuse require planned strategies that incorporate multiple measures to minimise risks to public health and the environment. The WHO *Sanitation Safety Planning Manual* (WHO, 2015) can be used as a reference to identify potential hazards and define measures to prevent these.
- *Workers' safety*. Workers at TWs are exposed to hazardous chemical constituents and biological agents contained within the wastewater and in the biofilm during their work. Appropriate design of facilities, training of workers, proper use of personal protective equipment, and careful attention to personal hygiene can all greatly reduce the likelihood of exposure to hazardous chemicals, biological agents, wastewater and injury (Brown, 1997; NIOSH, 2002). These include:
  - Avoiding direct contact with wastewater – carefully wash the hands and face with soap and water after contact with wastewater and before eating, drinking or smoking
  - Avoiding touching face, mouth, eyes, nose, genitalia, or open sores and cuts, or nail-biting with dirty hands while working
  - Use of appropriate protective clothing (coveralls) and personal protective equipment (e.g. boots, gloves) and wearing respiratory protective equipment
  - Thoroughly cleansing all exposed injuries with soap and water and keeping them covered with a bandage (preferably waterproof) while at work, and seeking medical attention immediately after suffering cuts or penetrating injuries
  - Removing personal protective clothing and footwear at the end of shift, changing out of work clothes and taking a shower before leaving work and contact with other people.

- *Decommissioning of the TW system*. Each treatment system has a specific lifetime. Considerations on what to do once the lifetime is reached or the treatment system is no longer needed and is to be taken out of operation should be included.