Project funded by the EUROPEAN UNION

WASTEnet - A Black Sea network promoting integrated natural WAStewater Treatment systEms

EDUCATIONAL MATERIAL

Black Sea Basin 2007-2013
Joint Operational Programme

CONTENTS

1. WASTEWATER: COMPOSITION, LEGISLATION AND TREATMENT TECHNOLOGIES

1.1 WASTEWATER COMPOSITION

Wastewater is the liquid end-product, or by-product, of municipal, agricultural, and industrial activity. As such, the chemical composition of wastewater naturally reflects its origin. The term 'wastewater', however, implies that it is a waste product to be discarded in an environmentally sound manner. On the average, the overall wastewater generation rate varies significantly from country to country; for example, it is approximately 265 liters per capita and per day in the U.S. but it is less in European countries (e.g., in Greece it is about 180 liters per capita per day). The typical composition of municipal wastewater is given in Table 1.

Table 1. Typical composition of untreated domestic wastewater

		Concentration		
Contaminants	**Unit**	**Weak**	**Medium**	**Strong**
Solids, total (TS)	mg L^{-1}	350	720	1200
Dissolved, total (TDS)	mg L^{-1}	250	500	850
Fixed	mg L^{-1}	145	300	525
Volatile	mg L^{-1}	105	200	325
Suspended solids (SS)	mg L^{-1}	100	220	350
Fixed	mg L^{-1}	20	55	75
Volatile	mg L^{-1}	80	165	275
Settleable solids	mg L^{-1}	5	10	20
BOD_5 at 20° C	mg L^{-1}	110	220	400
Total organic carbon (TOC)	mg L^{-1}	80	160	290
Chemical oxygen demand (COD)	mg L^{-1}	250	500	1000
Nitrogen (total as N)	mg L^{-1}	20	40	85
Organic	mg L^{-1}	8	15	35
Free ammonia	mg L^{-1}	12	25	50
Nitrites	mg L^{-1}	0	0	0
Nitrates	mg L^{-1}	0	0	0
Phosphorus (total as P)	mg L^{-1}	4	8	15
Organic	mg L^{-1}	1	3	5
Inorganic	mg L^{-1}	3	5	10
Chlorides	mg L^{-1}	30	50	100
Sulfate	mg L^{-1}	20	30	50
Alkalinity (as $CaC0_3$)	mg L^{-1}	50	100	200
Grease	mg L^{-1}	50	100	150
Total coliform	CFU 100 mL^{-1}	106-107	107-108	108-109
Volatile organic compounds (VOCs)	mg L^{-1}	<100	100-400	>400

Adapted from Metcalf and Eddy (1991) Wastewater Engineering Treatment Disposal Reuse, G. Tchobanoglous and F.L. Burton (Eds.), 1820 pp. New York: McGraw-Hill.

1.2 EUROPEAN LEGISLATION

The Council Directive 91/271/EEC concerning municipal wastewater treatment was adopted on 21 May 1991. Its objective is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industries, and concerns the collection, treatment and discharge of:

- Domestic wastewater
- Mixture of wastewater
- Wastewater from certain industrial sectors

Four main **principles** are laid down in the Directive:

- Planning
- Regulation
- Monitoring
- Information and reporting

Specifically the Directive requires:

- The Collection and treatment of wastewater in all agglomerations of > 2,000 population equivalents (p.e.);
- Secondary treatment of all discharges from agglomerations of > 2,000 p.e., and more advanced treatment for agglomerations >10,000 population equivalents in designated sensitive areas and their catchments;
- A requirement for pre-authorisation of all discharges of urban wastewater, discharges from the food-processing industry and industrial discharges into the urban wastewater collection systems;
- Monitoring of the performance of treatment plants and receiving waters; and
- Controls of sewage sludge disposal and re-use, and treated wastewater re-use whenever it is appropriate.

1.3 TREATMENT TECHNOLOGIES

A host of new technologies and techniques for wastewater management are being developed around the world, in response to environmental, economic and societal limitations increasingly posed by conventional wastewater treatment systems. New approaches incorporate natural processes and are designed with sustainability in mind, in contrast to energy-intensive and chemical-dependent systems in current use (Table 2).

Table 2. Urban and rural wastewater treatment

URBAN/LARGE SCALE	RURAL/ONSITE
Constructed Wetlands	*Individual dwellings*
Membrane Bio-reactors	Advanced Treatment Systems
Small Diameter Collection Systems	Composting Toilets
Wastewater land application and groundwater recharge	*Shared and Cluster Systems*
Sludge and Septage Treatment Options	

2. NATURAL TREATMENT SYSTEMS

2.1 NATURAL VS. CONVENTIONAL WASTEWATER TREATMENT

What is the ideal wastewater treatment system? An ideal one would produce high-quality discharge, be aesthetically appealing, having the minimal environmental impacts. Conventional Treatment Systems (CTS) for wastewater offer a combination of physical, chemical, and biological processes and operations taking place within an artificial environment, in order to remove solids, organic matter and even nutrients from wastewater. The Natural Treatment Systems (NTS) attempt to simulate the naturally occurring processes of wastewater degradation and contribute to the removal of pollutants. When natural systems are incorporated into a natural landscape or a building design, they can provide added benefits compared to a conventional treatment system.
The main parameters to compare natural and conventional wastewater treatment systems are shown in Table 3.

Table 3. Natural vs conventional wastewater treatment systems

	Wastewater treatment	
	Conventional	**Natural**
Objectives	Single one	Multiple
Benefits for the environment	Low priority	High priority (habitat creation, aesthetic appeal, education, etc.)
Construction	Mechanical devices required, human origin materials	No mechanical devices requirements, use of natural materials
Energy requirements	Large quantities of conventional energy sources, electricity etc.	Renewable energy sources, use of plants etc.
Mass transfer mechanisms	Pumps, air-blowers	Gravity, natural microbial processes
Processes	Man-controlled	Natural
Installation location	Irrelevant, not important	Crucial, depending on scale and country
Life expectancy	Relatively low	High
Efficiency	Controlled but insufficient when it experiences an occasional process upset (unexpectedly high loads)	Susceptible to climate, adaptability-flexibility and tolerance on fluctuations in flow and pollutant concentrations
Labor and maintenance cost	High, frequent monitoring and specialized staff	Low
Land requirement	Low	High (limiting factors are the availability and cost of land to place the treatment plants)
Lifetime costs	High total lifetime and often capital costs	Low total lifetime costs and often lower capital costs

Overall, natural systems have proven to be well-suited, cost-effective, and environmentally friendly treatment alternative to conventional systems. They are ideal for treating wastewater originating from small, isolated or peri-urban communities where land cost is low and availability is high.

2.2 TYPES OF NATURAL TREATMENT SYSTEMS

In general, Natural Treatment Systems are divided in four broad types:

2.2.1 TERRESTRIAL TREATMENT METHODS

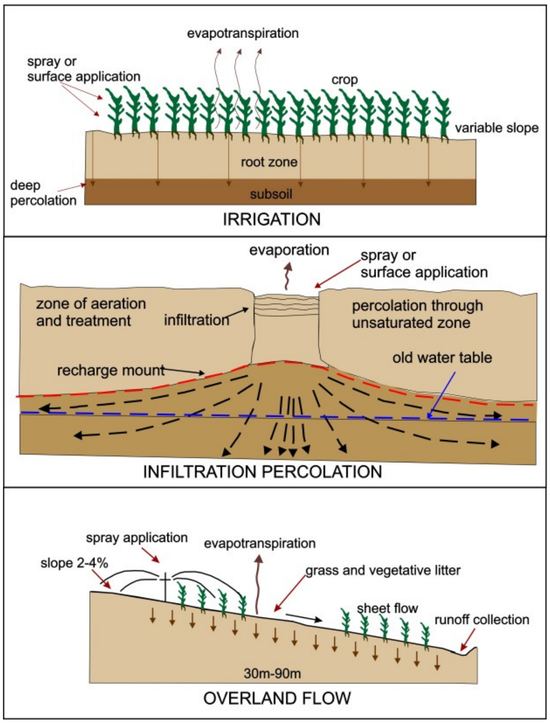

Figure 1. Methods of land application

These methods depend on the physical, chemical and biological reactions on and within the soil matrix. The wastewater after a preliminary treatment step is disposed on the soil (vegetated or not). Technologies comprise of slow rate, rapid infiltration and overland flow systems, as well as combinations of these types. In slow rate (SR) and overland flow (OF) methods, vegetation constitutes a significant treatment component while in rapid infiltration, vegetation is not necessary.

2.2.2 WASTEWATER STABILIZATION PONDS

They are open ponds, whose treatment function depends on sun light, the microbial life and the lower forms of plants and animals. Organic matter is decomposed naturally, i.e., biologically. With the contribution of bacteria and algae, wastewater is stabilized and its pathogens are reduced. Generally organic content of the effluent is converted to more stable forms. Stabilization ponds include various types, as: sewage lagoons, and oxidation, redox, maturation, facultative, anaerobic, aerobic and aerated ponds. They can be used in a wide range of weather conditions alone, in series of various pond types (the common series is anaerobic, facultative and maturation ponds), or in combination with other wastewater treatment systems.

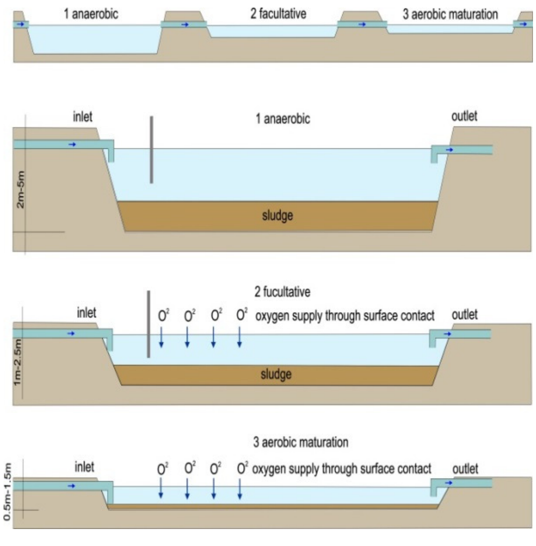

Figure 2. Types of stabilization ponds.

2.2.3 AQUATIC PLANT SYSTEMS

They are similar to stabilization ponds but they also treat wastewater through their content of higher plants and animals. Such systems may be divided in those with floating plants and those with submerged plants. Their extensive root system generates a substrate for micro-organism growth, which contributes to the removal of pollutants, thus achieving the best possible treatment.

2.2.4 CONSTRUCTED WETLANDS

CWs are man-made, engineered systems designed to simulate the function of natural wetlands in pollutant removal. To achieve wastewater treatment, a series of physical, chemical and biological processes take place in CWs, based on water, soil, atmosphere (i.e. sun and wind) and micro-organism interactions. Wetland plants play a vital role in the removal and retention of organic matter, nutrients, heavy metals and various toxic substances. The common reed (*Phragmites australis*) and the cattail (*Typha latifolia*, *T. angustifolia*) are good examples of marsh species that can effectively uptake pollutants, and therefore, are commonly used in CWs.

2.3 TYPES OF CONSTRUCTED WETLAND TREATMENT SYSTEMS

Three are the most common CW types: Free Water Surface (FWS) systems, Horizontal Subsurface Flow (HSF) systems and Vertical Flow (VF) systems.

2.3.1 FREE-WATER SURFACE CWS

They consist of one or more vegetated shallow impermeable basins or channels (40 to 60 cm deep) filled with soil, planted native vegetation (e.g., cattails, reeds and/or rushes), and equipped with appropriate inlet and outlet structures. The wastewater flows at depths 10 to 30 cm or even 45 cm, and is exposed to the atmosphere, the wind and direct sunlight.

An anoxic/anaerobic zone prevails at the bottom of the wetland, while an aerobic zone exists near the surface oxygenated through atmospheric re-aeration aided by the plant movement by the wind. As the wastewater flows through the wetland, simultaneous physical, chemical and biological processes remove the pollutants. Although the soil layer below the water is anaerobic, the plant roots release oxygen into the area creating an environment of complex biological and chemical activity.

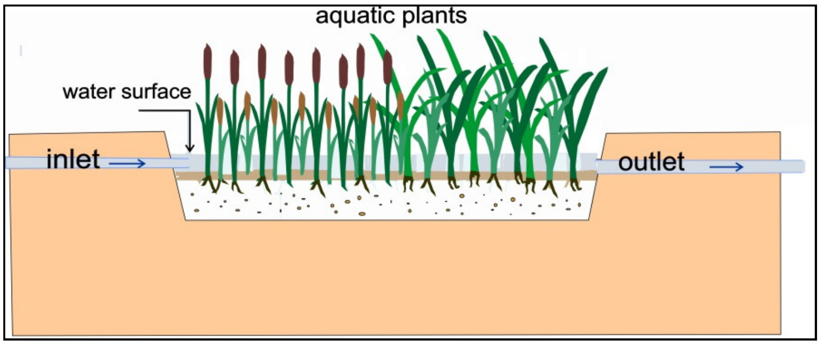

Figure 3. Schematic of a free-surface wetland.

2.3.2 HORIZONTAL SUBSURFACE FLOW CWS

They are large gravel and sand-filled channels, planted with aquatic vegetation. The bed is 0.5 to 1 m deep (3–32 mm in grain size diameter) and is lined over an impermeable liner (clay or impermeable geomembrane) in order to prevent leaching. Wastewater is intended to stay beneath the surface of the porous media flowing within the pores and around the roots and the rhizomes of the plants. The bed should be wide and shallow so that the flow path of the water is maximized. A wide inlet zone is used to evenly distribute the flow. The bottom slope is normally 1%. Regarding wetland vegetation any plant with deep, wide roots that can grow in the wet, nutrient-rich environment may be considered as appropriate for such systems. Wastewater is purified as it comes in contact with the filter media and plant roots.

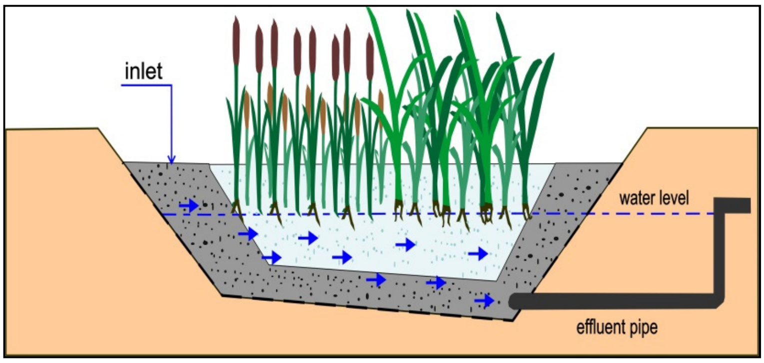

Figure 4. Schematic of a horizontal subsurface flow CW.

2.3.3 VERTICAL FLOW CWS

They are filter beds planted with aquatic plants. Wastewater is introduced to the wetland surface through a network of perforated pipes in order to achieve uniform flooding. The water percolates by gravity downwards through the filter matrix. It reaches then the drainage layer (bottom), which contains a network of perforated collection and aeration tubes. The bed contains various layers of different gradation. The first layer near the bed comprises of gravel used for drainage (at minimum 20 cm thick), followed on top by layers of gravel and sand (surface layer 10-30 cm thick). The top layer is planted and the vegetation is allowed to develop deep, wide roots which permeate the filter media. The total depth varies from 0.90 m to 1.20 m. A bed slope of 1% is needed for drainage.

Vertical flow CWs can operate with: Intermittent flow, unsaturated downflow, saturated up or downflow and tidal flow. Two phases appear on these systems: the flush and the drying phase. Depending on the climate, *Phragmites australis*, *Typha latifolia* or *Echinochloa Pyramidalis* are common options. The important difference between a vertical flow and the horizontal subsurface flow CWs is not simply the direction of the flow path, but rather the fill and dry cycles and the enhanced aerobic conditions in the VF case, factors leading to reduced area requirements.

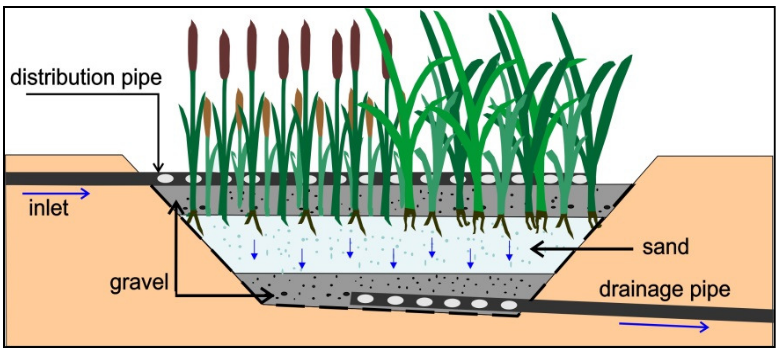

Figure 5. Schematic of a vertical flow CW.

3. CONSTRUCTED WETLAND TREATMENT MECHANISMS

Constructed wetlands utilize the natural processes (wetland vegetation, soil, microbial activity) within a more controlled environment in order to remove pollutants. The main removal mechanisms can be divided in abiotic (physical and chemical) and biotic (biological) processes. The abiotic processes that are responsible for removing pollutants in a constructed wetland are:

- Settling and sedimentation, which contribute to particulate matter and suspended solids removal
- Adsorption and absorption, which take place on the surfaces of plants, substrate, sediments, and litter and result in short-term retention or long-term immobilization of contaminants
- Chemical oxidation/reduction/precipitation, where influent metals convert to an insoluble solid form and are immobilized when water comes in contact with the substrate and litter
- Photodegradation, oxidation and degradation of compounds in the presence of sunlight
- Volatilization - which occurs when volatile compounds partition to the gaseous state

Respectively, the biotic processes are:

- Aerobic/anaerobic biodegradation by microorganism metabolic activities
- Phyto-accumulation of inorganic elements
- Phyto-stabilization - the ability to sequester inorganic compounds in plant roots
- Phyto-degradation of organic and inorganic contaminants that enter into the plant during transpiration by enzymes that plants produce
- Rhizo-degradation by exudates that plants produce which lead to microbial degradation of organic compounds
- Phyto-volatilization/evapotranspiration achieved by plant leaves

Table 4. Removal mechanisms of certain contaminants

Pollutant removal	***Process***
Organic matter	Biological degradation, sedimentation, microbial consumption
Suspended solids	Sedimentation, filtration
Nitrogen	Sedimentation, nitrification/denitrification, microbial consumption, plant uptake, gasification
Phosphorus	Sedimentation, filtration, adsorption, plant and microbial consumption
Pathogens	Natural death, sedimentation, filtration, UV degradation, adsorption
Heavy metals	Sedimentation, adsorption, plant uptake
Organic compounds (pesticides, etc)	Adsorption, gasification, photolysis, biotic/abiotic degradation

4. COSTS ESTIMATES OF CWS

Key components of the total CW cost include the: (a) capital cost, i.e., the cost of land, the construction costs (common earth moving, excavating, backfilling, and grading, influent and effluent structures, distribution piping, liners, planting, and roads), and the engineer's and contractor's fees; and (b) the operation and maintenance costs.

Constructed wetlands have a relatively large land area requirement which is related to the hydraulic retention time and the design flow rate. Factors that affect the costs of wastewater treatment wetlands include treatment goals, wetlands size, site conditions, and the need for liners. Construction costs of a 200 – 1,000 People Equivalent (p.e.) CWs in Greece can be estimated between 310 and 570 Euros per p.e., while operating costs range 7 to 14 Euros per p.e. per year for SSF systems. This is less than 1/10th of the cost for conventional wastewater treatment plants. For rough calculation it can be assumed, that operation costs may amount up to 50% of the total costs for conventional wastewater treatment. In average, for conventional wastewater treatment plants in Europe with more than 10,000 p.e., the specific operation costs will amount up to 25–35 € per p.e. per year. Smaller installations can achieve more than twice of that number.

4.1 CONSTRUCTION COSTS

Elements of the construction costs for FWS constructed wetlands include excavation for basin and berm construction, placement of liners, inlet and outlet structures and pipes, media filling, vegetation planting, and peripheral works such as roads and fencing.

However, the proportions of individual costs vary widely in different parts of the world. Also, larger systems demonstrate greater economies of scale. In general, the capital costs for subsurface flow constructed wetlands are about the same or slightly less than for conventional treatment systems. The capital costs for FWS CWs are usually less than for subsurface flow systems mainly because of the cost of the porous media.

4.2 OPERATION AND MAINTENANCE (O&M) COSTS

Constructed wetlands have very low operation and maintenance costs, including energy for pumping (if necessary), monitoring, maintenance of access roads and berms, pretreatment maintenance (including regular cleaning of screens and emptying septic or Imhoff tank and grit chambers), vegetation harvesting (if applicable), repair of berms and liners, and equipment repairs and replacement . The basic costs are much lower than those for competing concrete and steel technologies, by a factor of 10. In addition, as wetlands have a higher rate of biological activity than most ecosystems, they can transform many of the common pollutants that occur in conventional wastewaters into harmless byproducts or essential nutrients that can be used for additional biological productivity. These transformations are accomplished with the inherent natural environmental energies of sun, wind, soil, plants, and animals. Because of the natural environmental energies at work in constructed treatment wetlands, minimal fossil fuel energy and chemicals are typically needed to meet treatment objectives.

5. CONCLUSIONS

Constructed wetlands (CWs) have been used in ecological engineering for more than three decades, since 1980. CWs have been recognized as a reliable wastewater treatment technology and, at present, they represent a suitable solution for treatment of many types of wastewater. Furthermore, constructed wetlands have received increasing attention and popularity from international scientists and engineers due to the economic and ecological benefits of these wetlands. First, compared to conventional energy-intensive treatment technologies (physical–chemical–biological treatments), constructed wetlands have been shown an attractive and stable alternative due to low costs, and energy savings (Zhang et al., 2009). Second, constructed wetlands provide potentially valuable wildlife habitat in urban and suburban areas (Rousseau et al., 2008), as well as esthetic value within the local natural environment. Finally, constructed wetlands can be beneficial in small to medium sized towns due to easy operation and maintenance, providing a useful complement to traditional sewage systems, which are used predominantly in large cities.

In the future, constructed wetland technology could be focused on the following (Vymazal 2011):

- combination of various types of constructed wetlands in hybrid systems to achieve better treatment performance, especially for nitrogen;
- treatment of specific compounds present in wastewaters;
- search for suitable media with high capacity for phosphorus removal in subsurface flow constructed wetlands;
- identification of bacteria which assist in treatment processes;
- modeling of hydraulics and pollution removal in various types of constructed wetlands.

6. PROPOSED FURTHER READING

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Partnership

Applicant	Water and Sewage Municipal Enterprise of Kavala, Greece
ENPI Partner 1	Democritus University of Thrace, Greece
ENPI Partner 2	American University of Armenia, Armenia
ENPI Partner 3	Ilia State University, Georgia
ENPI Partner 4	Eco-TIRAS International Environmental Association of River Keepers, Moldova
ENPI Partner 5	Danube Delta National Institute for Research and Development, Romania
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