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Ecosystem Technologies and Ecoremediation for Water Protection, Treatment and Reuse

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1. Introduction

Despite the access to safe drinking and sanitary water, which is a precondition for human health and well-being, water quality is still seriously threatened by point and non-point sources of pollution, originating mostly from urban and rural areas. Due to rapid development, the problems associated with urbanization do not delay to appear: water scarcity, food insecurity and pollution (Esrey, 2000). Most people in Europe do have access to drinking water of good quality, but on the other hand there are one billion people worldwide with limited or no access to uncontaminated water (Jenssen et al., 2004). Conventional sewer systems use considerable amounts of valuable drinking water for flushing and transporting toilet waste. In the processes, huge amounts of fresh water, up to 50,000 liters per year per person, are contaminated and deemed unfit for other purposes. A massive flow of nutrients, drained from rural and urban areas, mixes with fresh waters. These nutrients take the form of excreta and are usually disposed into deep lakes or pits, rivers, and coastal waters. The excreta are toxic for many forms of aquatic life (*e.g.* fish and coral reefs), they cause eutrophication, reduce biodiversity, affect human health and soil quality (Esrey, 2000). Accretion of excreta also causes accumulation and release of toxic substances like heavy metals and micro-pollutants. On the other hand, research findings show that the world's reserves of commercial phosphate will exhaust in fifty to hundred years and, as predicted, the production of phosphorus will reach its peak around 2030 (Cordell et al., 2009). It is obvious that wrong flow of nutrients causes the loss of soil fertility and unnecessary water pollution at the same time.

However, agriculture is beside sewage still recognized as one of the major sources of nutrient loading and a significant factor in terms of ecological quality (Iital et al., 2008). According to OECD (2006) pollution from agriculture have been declining in recent years , diffuse pollution of ground and surface waters with excess nitrogen and phosphorus remains the most severe environmental problem of intensive agriculture (Herzog et al., 2008). Soluble reactive phosphorus originates from point sources (*e.g.* overflow from slurry tanks, farmyard cleaning) (Neal et al., 2008), meanwhile non-point sources of phosphorus are caused by soil erosion, agricultural runoff, and drainage where phosphorus is mainly

attached to soil particles (Simon & Makarewicz, 2009). In addition to nutrients, pesticides and heavy metals are also frequent pollutants originating from agriculture. It is reported that only 0.1% of pesticides applied to fields actually reaches the target out of 500 different used pesticides, while the rest enters the environment and contaminate soil, water and air (Arias-Estevez et al., 2008). The reason for inefficient application of pesticides and the resulting high emissions to the environment is inappropriate use of pesticides, including the use of unsuitable equipment for pesticide application, preventive use of the pesticide instead of obeying application programmes according to the crop growth, and application before the rainfall (Appleyard & Schmoll, 2006). Pollution of water bodies with pesticides usually coincides with nitrate and bacteria pollution. Further on, there is little information available about the fate, the behaviour, and the potential effects of xenobiotics in the environment (Žegura et al., 2009). Nevertheless, both water and soil pollution has to be considered holistically, including the synergistic effects of pollutants; namely, in most cases of pollution with non-degradable or slowly degradable pollutants, such as heavy metals and xenobiotics, sediments are the final recipient of these substances that consequently accumulate there. A problem arises when toxic substances re-enter the biological mass flows and integrate into food chains, which may represent hazard to numerous organisms.

The human perception of non-limited water and soil resources and the assumption that the environment can assimilate the wastes that we produce from using these resources, leads to a linear flow of resources and waste that are not reconnected. The linear attitude that regards resources and wastes must be therefore changed towards a circular one, advancing towards to a recycling society. The concept of ecological sanitation therefore provides a "recycle" philosophy of dealing with what in the past has been regarded as waste and wastewater (Werner et al., 2000). The incentives for wastewater reuse/recycling are becoming ever stronger with increasing pressures on drinking water supplies. As a reaction, water reclamation, recycling and reuse are now recognized worldwide as the key constituent of the efficient management of water resources. An increasing number of novel systems integrating decentralized treatment approaches, source separation and nutrient recycling have evolved in recent years (Jenssen et al., 2009). With such an approach we can minimize water pollution while ensuring rational water consumption and its reuse for irrigation, groundwater recharge or even direct reuse to the benefit of agriculture (Werner et al., 2000,). Recycling by the recovery of phosphorous from waste products and the efficient use of phosphatic mineral fertiliser and manure in agriculture are the major opportunities of increasing its life expectancy. As Vinnerås (2002) said, 80-90% of plant nutrients (nitrogen, phosphorus and potassium) in wastewater are present in the toilet waste and if these nutrients are reclaimed by safe methods, they can be applied locally as fertilizer in sustainable agriculture.

An important aspect in water consumption and reuse as well as in pollution of natural water bodies is also management of stormwater. Stormwater runoff generates as a result of precipitation on impervious surfaces, from where it flushes different pollutants. It also presents a hydraulic load for the receiving water body causing erosion and floods. Stormwater is characterized by containing relatively low, but not insignificant pollutant concentrations. This characteristic of stormwater creates difficulties in treatment of runoff water because rather low pollutant levels in large volumes of water need to be reduced to yet lower concentrations. However, in the short period of first flush event high concentrations of pollutants can occur. In order to protect natural water bodies against pollution and

physical damage caused by stormwater runoff, the water has to be retained and treated. Due to the dispersed origin and the big quantities of runoff water that have to be controlled, the strategy of nowadays stormwater treatment systems is towards a large number of low-cost decentralized facilities. A proper retention and treatment of stormwater enables reuse of treated water for different purposes including toilet flushing, watering gardens and parks, carwash etc. which can significantly reduce the consumption of drinking water. Stormwater systems are frequently located in parks and recreational zones, and thus need to be planned in consideration of urban and landscape architecture. They often represent a pleasant wetland or pond element in urban parks and residential areas and as such give an added value to the area. Many systems for stormwater retention and treatment enable percolation of stormwater to the underground and thus recharge of the aquifers, which are otherwise disconnected from the recharge by precipitation due to impervious surfaces.

2. Approaches to water and pollution management

Sources of data for this chapter are EC official web page (www.ec.europa.eu) and European Environment Agency web page (www.eea.europa.eu).

The EU legislation and international agreements have extensively addressed the pollution of aquatic ecosystems in the last three decades, to mention in particular the Urban Wastewater Treatment Directive (91/271/EEC), the Nitrates Directive (Directive 91/676/EEC) and IPPC Directive (96/61/EC), the Bathing Waters Directive (76/160/EEC & 2006/7/EC) and the Water Framework Directive (WFD; 2000/60/EC). Data for this chapter are taken from the EC official web page (ec.uropa.eu).

The main requirements of the Water Framework Directive are to reach good ecological and chemical status of all inland, transitional and coastal waters by 2015. All pollutants and their associated anthropogenic activities must be addressed on river basin scale to ensure that good status is attained and maintained. Moreover, the WFD requires the removal or substantial reductions in the discharge of hazardous substances to water bodies. The adoption of the WFD has renewed debate on how the European Union's Common Agricultural Policy can contribute to achieving the goal of "good status" for all water bodies. Since 2000, a shift of the policy from a strictly production-oriented system towards a tool to support sustainable development has occurred (Agenda 2000).

Agri-environmental measures (AEM) have been a significant move towards achieving a good status for all water bodies, in particular with regard to nutrient losses. In the context of ecosystem technologies (ET) and ecoremediations (ERM), the AEM are the most effective legislative tool, which was first introduced into EU agricultural policy during the late 1980s. Since 1992, the application of agri-environment programmes has been compulsory for Member States in the framework of their rural development plans, whereas they remain optional for farmers.

The commitments included in national/regional agri-environmental schemes are:

- environmentally favourable extensification of farming;
- management of low-intensity pasture systems;
- integrated farm management and organic agriculture;
- preservation of landscape and historical features such as hedgerows, ditches and woods;
- conservation of high-value habitats and their associated biodiversity.

The AEM are implemented at the national, regional or local levels so that they can be adapted to particular farming systems and specific environmental conditions. Therefore, the agri-environment measures are a targeted tool for achieving environmental goals. The AEM are co-financed by Member States. For the period 2007-2013, the EU expenditure on AEM amounts to nearly 20 billion EUR or 22 % of the expenditure for rural development.

In Slovenia agricultural policy started to apply the first measures to support the environment-friendly ways of production in 1999 and after the adoption of the Slovenian agri-environmental programme in 2001. After joining the EU in 2004, the support under agri-environmental programme became part of the Rural Development Programme of the Republic of Slovenia. The area included in the implementation of AEM has been strongly increased after 1999 and in 2008 covered 323,043 ha (gross), or 247,420 ha (net). The share of area with one or several AEM (net) in the period 1999-2008 has increased from 0.6 % to 50.2 % of all utilised agricultural area.

However, only with adequate water monitoring can the potential impact of mitigation measures under the Water Framework Directive, Nitrate Directive, and AEM is assessed (Iital et al., 2008). Although some national studies regarding the impact of policy on pollutants concentration in waters already exist (Erisman et al., 2001) and some of them has been performed recently (Herzog et al., 2008), there is no international data base that compares the dynamic of implementation of national legislations concerning water quality and the level of water pollution deriving from agriculture in different countries.

In 2009, the European Commission introduced the White Paper on adapting to climate change, presenting the framework for measures and policies to reduce the European Union's vulnerability to the impacts of climate change. The White Paper underlines the need "to promote strategies which increase the resilience to climate change of health, property and the productive functions of land, inter alia by improving the management of water resources and ecosystems." Within this framework, Water Directors of EU Member States adopted in December 2009 a guidance document on adaptation to climate change in water management to ensure that the River Basin Management Plans (RBMP) are climate-proofed.

In spite of all these endeavours, the European Environment Agency indicated in its Environment State and Outlook Report 2010 that the attainment of EU water policy objectives is far from certain due to a number of old and emerging challenges. Therefore, the EU policy response to these challenges will be the Blueprint to Safeguard Europe's Water, aiming to ensure good quality water in sufficient quantities for all legitimate uses. The time horizon of the Blueprint is 2020 since it is closely related to the EU 2020 Strategy and, in particular, to planned Resource Efficiency Roadmap. The Blueprint will be the water milestone on the Roadmap. However, the groundwork supporting the Blueprint will take longer and will drive the EU policy until at least 2050.

3. Development of ecosystem technologies (ET) in sustainable water management

In its long history, nature has developed intense self-cleaning and buffering capacities. In the context of ecological sanitation and sustainable water management, the application of technologies that mimic healthy natural ecosystems became vital. These technologies aim to close the loop and return resources back to the source. Their basic characteristics, which can

be utilised and further improved, are their high buffer and self-protective capacity as well as the provision of habitat diversity. Moreover, these systems have the remediation ability, provide for a high level of biodiversity and higher stability of ecosystems.

Ecosystem technologies or ecoremediations by definition comprise methods of protection and restoration of the environment through natural ecosystem processes. The establishment of ET provides sustainable solutions that contribute to the preservation of biodiversity, pollution reduction, enable nutrient recycling and reuse of material and can be applied in protected and sensitive areas. The functions of ET are based on aquatic, waterside, wetland as well as terrestrial ecosystems' characteristics, such as high water retention capacity, flood prevention, biodiversity as well as specific physical, chemical and biological processes for the reduction of diverse pollutants.

Most ET designs have its origin in the treatment wetlands (TW), ponds, and river restoration where, along with hydraulic, physical, chemical and microbiological processes, phytoremedation also plays an important role. The possibility of applying phytoremediation has become well recognized and integrated in ET development. Yet, the decision on a particular phytoremediation method depends not only on the type of pollutant and the polluted medium, but also on the objectives to be achieved, i.e. reduction, stabilization, sequestration, assimilation, detoxification, mineralization and decomposition.

By applying the ET, a local community or even a small society can play a significant role. Namely, the application of ecological sanitation has shown for the importance of a design of sustainable wastewater treatment systems as a "household-centred approach" that seeks to resolve environmental sanitation problems at the minimum practicable size (Schertenleib, 2001). In the context of our contemporary environment, it is important to bring sustainability to local communities or to a household level. The life style of local communities is an important factor in pollution quantity and quality and is aggravated by trans-boundary air, water and soil pollution. Pollution originating from local communities should be treated with the use of ET. ET should be seen as prophylactic and therapeutic measures to overcome local environmental problems. They include alleviation and adaptation of local communities at a time when climate change system and global changes affect common life in local communities. They could represent an innovative approach towards nature, space and environment protection based upon system thinking or, in other words, a holistic approach involving technologies aimed at regional and local community levels. Macro remediation includes region-specific complex problem solving as exemplified by integrated river basin management, coastal region management, management of water resources but encompassing also techniques for specific remediation of damaged local habitats, remediation of pollution hot spots, such as landfill sites, polluted waters, soils, etc., which strictly speaking should be regarded as micro remediation measures or local problem solving techniques. As said, from a spatial perspective one can distinguish between macro and micro remediation, while in the context of complex problem solving, one can also distinguish between social, natural and technical measures differentiating from integrated management to single techniques aimed, for instance, at wastewater treatment by means of TW, river restoration or co-natural reclamation of landfills, etc.

Although some concern still exists regarding the "technical" completeness of ET, its application is consistently enforced in practice as well as among the environmentally aware society. The ecosystem technologies are most useful in the remediation of persistent

environmental contamination, impacts of point pollution as well as seasonal pollution due to tourism and non-point pollution caused by agriculture. They are also appropriate for protecting sensitive areas and for rational water management in dry areas (Griessler Bulc & Šajn-Slak, 2009).

3.1 Why ET?

Multi-functionality is an intrinsic feature of ET, which can be considered a flagship application of good ecological engineering/biotechnology.

- Water treatment: ET effectively treat a large variety of wastewater (sewage, gray water, agricultural, highway runoff, landfill leachate, wastewater from food processing and textile industry, composting facility runoff, etc.) and increase the self-cleaning capacity of natural or revitalized ecosystems.
- Water retention in the landscape: ET reduce hydraulic peaks by retaining water in the system and therefore prevent and mitigate floods and droughts. They can contribute to an improved water management, mitigate water abstractions and recharge groundwater.
- Saving energy: ET can provide their services with very little or no energy input if designed accordingly.
- Enhanced biodiversity: ET create a new habitat for wildlife and can contribute to an increased biodiversity in a barren landscape (e.g. spawning ground for frogs and toads, breeding sites for birds etc.).
- Biomass production and nutrient recycling; if designed for this purpose, ET can recycle nutrients from runoff to a large degree and convert them to biomass which can be used as energy or raw material source (*e.g.* thermal insulation).
- Recreation: ET can be designed with elements of landscape architecture and can create an attractive place for the population.
- Education: ET are a good and tangible example of a measure aimed to achieve sustainable development. They can be used to present the problems of pollution and its remediation in a natural way to different target groups (e.g. how a waste product can be transformed into something valuable).

4. Overview of pollutant pathways and the efficiency of ecosystem technologies

Nutrients and pollutants in natural systems as well as in ET are subdued to numerous processes that enable pollutant and nutrient transformations, degradation or stabilization. The pathways of pollutants in natural ecosystems and ET depend on the characteristics of the system, namely dissolved oxygen concentration, pH, Eh, mineral composition of the media, bacterial, plant and animal communities; besides this, also external influences like climatic conditions and input loads are of significant importance.

4.1 Nitrogen and phosphorous

Regarding the nutrients, nitrogen and phosphorous compounds are of major concern. Increased ammonia concentrations in natural water bodies mainly indicate pollution from wastewater discharge, agricultural runoff or organic waste disposal. The presence of

ammonia can significantly reduce the oxygen level in water body. Due to rapid oxidation to nitrate, nitrite is usually present in negligible concentrations in natural water bodies. In contrast to nitrite, the concentrations of nitrate in water surface and groundwater bodies are elevated in many parts of the world. The areas with intense agriculture are the most vulnerable due to nitrate pollution of drinking water.

Nitrogen and phosphorous are also of big interest because they are needed for the production of human food and have an important role in plant growth which further stimulates the wildlife production. Phosphorus in nature does not appear in elementary form but always in different compounds together with other elements. The extraction of P is a damaging process (strip-mining is most common method) having as result toxic by-products (arsenic, cadmium, etc.). Phosphorus is highly bondable and is adsorbed to soil molecules and as such it is not available for the plant use. Plants can uptake phosphorous when the soil is saturated and there is free phosphorous available. The result of this fact is high demand on artificial fertilizers to increase nutrient content in less fertile soil.

Nitrogen and phosphorous removal is required in most European countries in order to reduce the input to water bodies or the sea (eutrophication). Removal of nitrogen compounds is also important in order to prevent oxygen depletion and the toxicity on invertebrate and invertebrate species, including humans.

The processes of volatilization, plant uptake, nitrification and denitrification enable efficient removal of nitrogen from wastewaters in ET (Brix, 1993; Šajn-Slak et al., 2005). However also numerous other processes affect nitrogen elimination and retention in ET, i.e. ammonia volatilization, anaerobic ammonia oxidation (ANAMOX), fixation of nitrogen from the atmosphere, incorporation into plant and microbial biomass, fragmentation, burial, degradation of organic nitrogen compounds (mineralization), reduction of nitrate to ammonia, sorption and desorption from different media, filtration and leaching. Only certain pathways enable N elimination, whereas other processes only transform N from one form to another (Vymazal, 2007). A crucial condition for N elimination in an ET is an exchange of oxic and anoxic areas in micro level, which enable a co-existence of nitrifying and denitrifying bacteria. First step in N elimination is degradation of organic N compounds (ammonification) where ammonia is generated. NH_4-N is then oxidized to nitrite and further to nitrate, but in contrast to organic material, NH_4-N is more demanding for oxidation in TW as nitrifying microbes are autotrophic bacteria which have slow respiration and need a significant amount of oxygen to function. Besides oxygen conditions plants can also be an important factor in nitrogen elimination. Plants preferably take up the reduced form of nitrogen (ammonia), but can also take up nitrate. Nitrogen is integrated in plant tissues and can be eliminated from the ET by mowing and removing the plant biomass. This can present a significant nutrient removal in systems that receive low nutrient loads (Langergraber, 2005); according to Vymazal (2006) plant harvesting can significantly contribute to nitrogen removal in wetlands that receive less than 100-200 g N m^{-2} year^{-1}. However, in other free water ET denitrification is usually the main mechanism for nitrate removal), which enables reduction of nitrite and nitrate to gas nitrogen. N_2 is released to the atmosphere and thus presents ultimate elimination of N from the ET. Unlike nitrogen removal, the capacity of ET to eliminate phosphorus is of a concern and has not been reasonably resolved. Phosphorous in TW systems is mainly accumulated in the sediment/media and/or accumulated in the plant biomass. Elimination of P from a wetland

treatment system is possible only by harvesting of the plant biomass and removing the saturated sediment.

The investigations on TW show that wetlands have a limited capacity to remove phosphorus and are greatly dependent on the characteristics of the media integrated into TW, namely as the media gets saturated with phosphorus, phosphorus removal efficiency decreases. Phosphorous removal mechanisms can be affected also by other factors, such as biofilm growth on the media, which limits the contact between the media and the treated water. In open water ET P is mainly accumulated in the bottom sediment. A crucial condition for trapping P in the sediment is a consistent and high redox potential in the surface sediment layer. P is leached from the sediments during anoxic conditions, however also microbial activity can cause its release. In neutral and acid conditions, microorganisms can use Fe^{3+} as electron acceptor thus releasing bound P. In basic conditions, microorganisms can dissolve insoluble P by increasing the ion exchange of OH^- and PO_4^{3-}, which arise from Fe-P or Al-P (Huang et al., 2008).

As for nitrogen also for elimination of P with plant harvesting is efficient only in the systems with low P loads. Inflow P concentrations depend on the type of water treated, while P content in the plant tissues remains in the same range, i.e. 1-5 g P m^{-2}. Primary treated municipal wastewater usually presents between 100 in 200 (800) g P m^{-2} $year^{-1}$, which means low P elimination with plant harvesting. However when treating secondary treated wastewater with less than 20 g P m^{-2} $year^{-1}$, harvesting plant biomass can contribute to P elimination from the system for more than 20 % yearly. Despite this, plant harvesting demands specific attention in terms of timing the harvest, as plant harvesting in growth season can severely damage the canopy. Removal of plant biomass can also present a problem in temperate and cold climates due to dead plant material acts as an isolation layer during winter months. In tropical climates with long vegetation period plant harvesting can significantly contribute to nutrient elimination due to several harvests per year are feasible (Vymazal, 2004).

To improve the removal of P in ET numerous solutions have been proposed and examined: e.g. a use of chemically enhanced material with high sorption capacity for P (e.g. Filtralite) for construction of the ET system; an integration of a pre-treatment step for chemical precipitation of P; an elimination of P in separate filters with specific media, etc. The tests of finding appropriate media for P elimination suggest the selection of materials, which must at the same time have good hydraulic features and consistent and continual elimination of P from treated waters.

4.2 Heavy metals

Unlike nutrients, metals in natural ecosystems and ET are not subdued to degradation, but can only change the ionic form. During water treatment with an ET metals cannot be eliminated but are accumulated in the systems' sediment, soil or plant tissues. Many heavy metals are micronutrients for animals and plants and are essential in low concentrations (e.g. Zn and Cu). Other heavy metals (e.g. Cd) as well as high concentrations of micronutrients can be toxic to biota. In water, metals take forms of free metal ions or can be bound to or adsorbed onto organic and inorganic particulate matter and complexes. The most bioavailable form is the soluble form, especially when the metal is present as a free ion or is weakly complexed, and can cause bioaccumulation in the food chain.

The removal of metals from water in wetlands can result in accumulation in the sediment, which might be harmful for the organisms that live or feed on these sediments. To avoid this problem pretreatment to reduce inflow metal concentrations, installation of deep water systems or subsurface wetlands can be considered. In deep water systems with free-floating plants the sediment is deposited at great depths and is thus not available to the top feeders and subsurface wetlands minimize the opportunity for ingestion of metals (Kadlec & Wallace, 2009). Depositing sediments have the ability to adsorb significant quantities of trace metals. Especially organic matter, iron and manganese oxyhydroxides act as metal adsorbents in aerated systems. Under anaerobic conditions iron and manganese oxyhydrohydes dissolves and thus release metals into the aqueous phase. This may lead to a repartitioning of metals into the sulphide or carbonate precipitates. In the conditions where metal's concentrations are in excess of sulphides, metals may complex with organic matter. Organic matter can appear as surface coatings or as particulates and significantly affects metal speciation and bioavailability (Kadlec & Wallace, 2009). Besides, at oxic conditions, co-precipitation of heavy metals with iron, manganese, and aluminum hydroxides also relies on considerable supplies of secondary metals in the system, which might not be present. According to this retention of metals in the sediment can be modified by changes in substrate chemistry and redox potential, which is affected by wetland water depth and biological processes. Besides redox potential, also pH affects sorption/desorption of heavy metals at/from the sediment.

Metals are also accumulated in plant tissues. Most of the metals found in plants are stored in the roots and rhizomes, only small amounts may find their way to stems and leaves as plant physiological mechanisms prevent the transport of heavy metals from the underground tissues to the aboveground tissues, where the toxic heavy metals could damage the photosynthetic tissues. Consequently, harvesting aboveground parts does not enable effective removal of metals from the wetland. However, with the root's death some fraction of the metal may be permanently buried (Kadlec & Wallace, 2009).

4.3 Organic micropollutants

Numerous studies investigate the elimination of organic micropollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), phthalates, linear alkylbenzene sulphonates (LAS), nonylphenols etc. Besides listed, there is also a long list of emerging pollutants which are gaining lot of attention from the scientist in recent years. Mainly they focus on personal care products and pharmaceuticals (Hijosa-Valsero et al., 2010a, 2010b).

The pathways of micro and emerging pollutants in ET systems are not clearly known and are still under research. As aromatic compounds, PAHs have low water solubility/high hydrophobicity and thus they tend to absorb to solid particles and are thus removed by sedimentation and filtration. Higher organic carbon content in soils and sediments increases sorption of PAHs. It is known that PAHs are decomposed relatively rapidly in many vertebrates, but more slowly and in a different way in certain other life forms; nevertheless, the degradation products of PAHs can be more harmful than the original compound. The PAHs with four or less aromatic rings are subdued to biodegradation by microbes or are metabolized by multicellular organisms. The heavier PAHs (four, five and six rings) are more insistent compared to the lighter (two and three rings) and tend to have greater carcinogenic and other chronic impacts (Mangas et al., 1998). Also many emerging

pollutants are rather lipophilic in character, and are consequently likely to bind with the particulate matter. For this reason mechanical treatment can present an important step in elimination of these substances, but nevertheless, the absence of any biological step may have substantial effect on the total removal of more biodegradable compounds (Vogelsang et al., 2006).

Many treatment processes in ET (e.g. nitrification, aerobic degradation of organic matter and P trapping) are oxygen-limited. Studies have shown that the amount of oxygen transferred through the plants is very small compared to the oxygen demand utilized by the wastewater under usual loading rates. Consequently, many recent studies entirely neglect oxygen transfer by plants and include plants mostly as a microorganism carrier and biodiversity factor. The inadequate oxygen transfer of typical subsurface flow wetlands resulted in the progress of improved treatment systems, which are able to assure adequate oxygen levels for nitrification, degradation of organic matter, and prevention of P leaching. The systems include introduction of oxygen to the wetland by means of regular water level oscillations, passive air pumps or powered mechanical aeration of the reed bed (Nivala et al., 2007). Yet, the elimination of nitrogen in ET has been enhanced by the different flows, cascades, open areas, and with the application of recirculation of the treated outflow back to the inflow (Griessler Bulc & Šajn-Slak, 2009; Griessler Bulc et al., 2011).

4.4 Role of plants and algae

Removal processes of pollutants in ET can be controlled by hydraulic load, ET design as well as with macrophytes and algae. They directly and indirectly influence the physical and chemical environment in ET and play an important role in removal processes. Macrophytes e.g. enhanced sedimentation and sorption on biofilm and therefore accelerate removal of suspended solids, settleable solids, organic N, total N, COD and BOD_5. Floating macrophytes shade the water surface and reduce temperature oscillations, algal development and gas exchange with the atmosphere. Wooden plants can play an important role in phytoremediation processes and evapotranspiration. Algae with photosynthetic activity cause a higher pH (and consequently ammonia volatilisation and ortho-P precipitation), P accumulation and a higher DO concentration in water (consequently higher ortho-phosphate retention and more intensive nitrification). On the other hand, algae in the effluent cause a lower treatment efficiency of suspended solids and BOD_5 (Šajn-Slak et. al., 2005).

5. ET types

ET for water management merges vegetated drainage ditches (VDD), waste stabilization ponds (WSP) and stormwater detention ponds (SDP), TW, buffer zones, phytoremediation with dense woodland establishment, river revitalization, and in stream and bank side river techniques. One of the main aims of ET concept is to integrate exchange, combine and use multi-functionality of different kind of "green technologies" to obtain innovative and sustainable solutions for environmental protection and restoration.

5.1 Vegetated drainage ditches (VDD)

Drainage networks of surface and subsurface drains mainly serve to remove and accumulate excess water associated with irrigation and storm events. In agricultural areas

they help to reduce surface water retention and low water tables for optimum plant production and therefore representing integral components for sustaining the economic development. Nonetheless, drainage networks affect several hundred thousand hectares of land in Western and Eastern Europe, leading to reduced water's self purification and retention capacity and the loss of biodiversity. Although the amount of new drainage networks declined significantly in Europe during the 90's, the existing drainage systems continue to pose negative impacts on the environment. Therefore, management of VDD to optimize sorption, complexation and sedimentation processes of pollutants is an important issue in drainage pollution control, which complies with AEM at the point of conservation of habitats and their associated biodiversity.

5.2 Waste stabilization ponds (WSP)

WSP are simple man-made basins for primary, secondary and tertiary treatment of variety of wastewaters. They are used worldwide, alone or in combination with other treatment processes. Anaerobic, facultative and maturation ponds are constructed in one or several series. Anaerobic ponds are designed for primary treatment. They remove suspended solids and some of the soluble element of organic matter (BOD). Most of the remaining BOD is removed in facultative pond (secondary stage) by algae and heterotrophic bacteria. Tertiary treatment takes place in maturation pond where pathogens and nutrients (especially nitrogen) are removed. WSP are low cost treatment technology with simple operation and maintenance (Ramadan & Ponce, n.d.).

5.3 Stormwater detention ponds (SDP)

Detention ponds are open water bodies for the retention of stormwater runoff from urban, agricultural and other areas. The stormwater treatment facility must be flexible to manage high flow rates of the runoff followed by dry periods, and high pollutant concentrations in the first flush followed by diluted concentrations in the main flow. Stormwater detention ponds are diverse biological system with a high buffering capacity that enable water detention, minimize the hydraulic peaks and reduce the pollutant input in downstream facilities and/or receiving waters (Hvitved-Jacobsen et al., 1994). Detained and treated water can be used for different purposes or discharged to the environment. Different plant species can appear in detention ponds (usually colonized by natural way): at the shallower marginal areas emergent and in deeper parts floating and submerged species. The treatment processes in wet detention ponds are similar to those occurring in natural smaller lakes and pools: e.g. contaminant accretion in the bottom deposits via sedimentation, adsorption to colloidal and particulate matter, conversions and degradation of biodegradable compounds by microorganisms and uptake of contaminants by plants. Among those, the key mechanism for pollutants removal in detention ponds is sedimentation. Since the main removal mechanism in wet detention ponds is sedimentation, the wet detention ponds generally have high efficiency in particulate matter removal (Terzakis et al., 2008). Organic matter is subdued to microbial and macroinvertebrate decomposition and final transformation to inorganic matter in the sediment, where it is stored. Sediment accretion at the bottom of wet ponds might vary greatly according to inflow and catchment characteristics. Hvitved-Jacobsen et al. (1994) estimated that excavation and removal of the sediments from wet ponds would be needed every 25 years of the operational period.

5.4 Treatment wetlands (TW)

TW are technically and economically feasible solutions for the treatment of different wastewater types. The technology is widespread around the world. Already ten years ago, more than 5,000 TW were operational in Europe (Vymazal et al., 1998). The performance is thoroughly documented and the systems are capable of reducing the concentration of target pollutants by different bacteriological, physical and chemical processes to acceptable levels before discharging to the environment and therefore mitigating the harmful effect that the disposal of untreated wastewater may have (Vymazal, 2007). TW imitate natural wetlands by using an array of natural processes to transform and remove the contaminants and as such they represent important part of ET. Compared to their natural counterpart, these processes are intensified. This is achieved with appropriate design, filling material, planting, and incorporation of technical equipment (pumps, aeration, pre-treatment) which ensures optimal utilization of the TW area and volume. As TW typically require less or no supplemental energy, their operational costs can be approximately two orders of magnitude lower than those of a standard three-stage waste water treatment plants (WWTP) (Grönlund et al., 2004). The TW removal efficiency usually assessed by the decrease in biochemical and chemical oxygen demand (BOD, COD), total suspended solids (TSS) and nutrient (N, P) load, has already been studied widely (Kadlec & Wallace, 2009). TW can also effectively remove a wide array of persistent pollutants such as pathogens, trace organic contaminants and heavy metals, which all have a negative influence if released into the environment. TW have been used as a treatment step before wastewater is reused in agriculture, but with very variable success. Although wetlands are effective for the treatment of wastewaters, the ever-changing reality of more stringent discharge regulations by the local governments imply that the wastewater treatment systems have to meet high water quality standards before discharge.
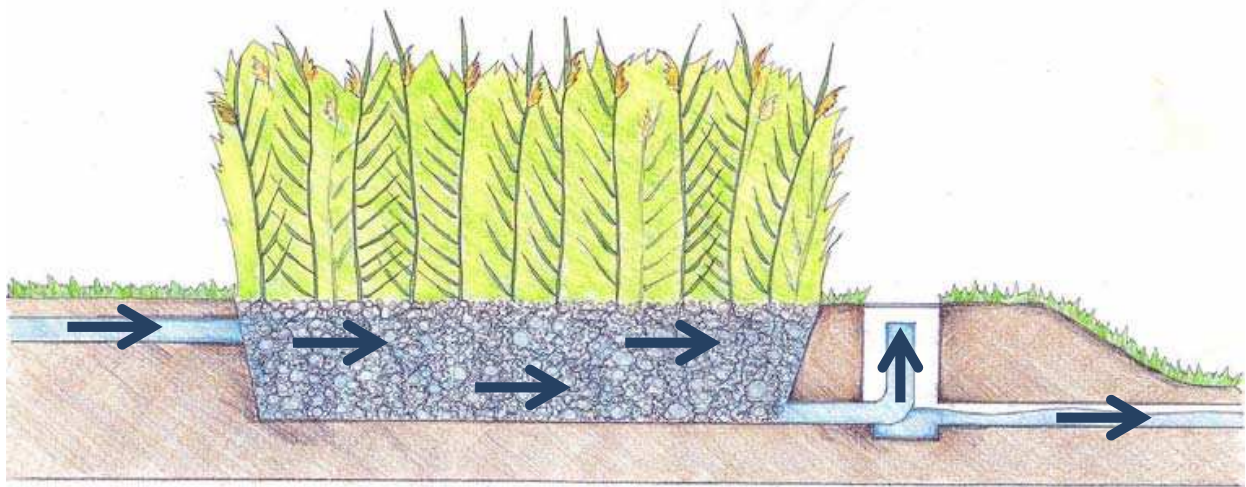

Fig. 1. A simple sketch of horizontal subsurface flow treatment wetland (source: LIMNOS Ltd.)

5.5 Phytoremediation of landfill sites

This ET involves the treatment and recycling of leachate on a vegetative landfill cover in order to avoid additional pollution by treated leachate discharges into the environment, to achieve landfill stabilization and easier public recognition of a reclaimed site. The final aim

is to reduce the wastes' impacts on the environment through a closed hydrological and pollution cycle within a landfill site and the utilisation of leachate as a nutrient source. Leachate recycling belongs to a phytoremediation method where the assimilation of plant nutrients from leachate into biomass and faster waste decomposition by enabling leachate infiltration into the landfill body take place. Discharge of treated leachate to vegetation caps can provide an opportunity for closing the nutrient cycling loop and producing an effluent of a suitable quality. A controlled input of leachate results in a better provision of soil with nutrients and organic substances, improved growth of vegetation and intensified microbiological activity in soil. Today, the phytotechnology employing ligneous plants is used for the treatment of various forms of pollution. With a large water uptake from soil pores, plants take up also water pollutants and create a new capacity for water accumulation in soil. Poplars and willows are capable of taking up diverse pollutants and nutrients (nitrate, ammonium, phosphorus), metals, metalloids and petrochemical compounds (fuels, solvents), pesticides and soluble radionuclides (Zupančič et al., 2005). The methods applied for the treatment of leachate are vegetation barriers, filters, vegetation caps and short rotation coppices (SRC) with fast growing woody species. In addition to landfill sites, the planting of trees is used for the remediation of watercourse banks, abandoned and polluted industrial areas, at the margins of intensive agricultural areas and other polluted areas, as well as for the treatment of wastewater and sludge (Griessler Bulc & Zupančič Justin, 2007).

5.6 Watercourse revitalization

Natural watercourses have a great ability of water retention, a great diversity of habitats and biodiversity and high self-cleaning capacity. Regulations or canalizations of watercourses were common in the past but in some places sill appearing in the present with the main goal of flood protection and gaining space for agriculture and urbanization. Canalizations of watercourses do decreased flooding in a local scale but downstream floods were even more severe. Canalized watercourse has trapezium profile; river bed is straightened and often covered with stones or concrete. Habitats for different animal and plant species are destroyed, self-cleaning capacity is scarce and there is no water retention in the riverbed, banks and floodplains. In a canalized watercourse pollutants from surroundings can freely flow into the water. With revitalization of a watercourse ecological balance is restored using appropriate water management interventions. Revitalization of a watercourse enables restoration of habitats for aquatic plants and animals, increases water retention and self-cleaning capacity of a water body. The type of revitalization is chosen according to the scope of revitalization and space abilities in the environment. Where the space around watercourse is limited revitalizations can be implemented inside existing canal. With revitalization measures like stabilization of river banks with vegetation, construction of weirs, pools, rapids, water deflectors, buffer strips along the watercourse, purification beds, creation of meanders and floodplains, backwater etc. habitat and biotic diversity is improved, self-purification capability and water retention are increased (Vrhovšek et al., 2008).

5.7 Additional technologies for integration in ET systems

Additional technologies can be integrated in ET systems in order to enhance the removal of target pollutants. Those technologies mainly target at different soluble pollutants like phosphorous, nitrogen, soluble heavy metals and specific micropollutants. Enhanced

removal of dissolved and colloidal pollutants is especially important in case of a discharge into a sensitive recipient and in case of further production of drinking water. Different treatment units can be combined, e.g. coagulation, flocculation and subsequent sedimentation, plant uptake, sorption of dissolved and colloid matter to surfaces, etc. In contrast to sedimentation, the mentioned processes enable higher removal of dissolved and colloidal pollutants. Dissolved and colloidal pollutants are known for its mobile nature in water systems and therefore have the highest risk of causing harmful effects.
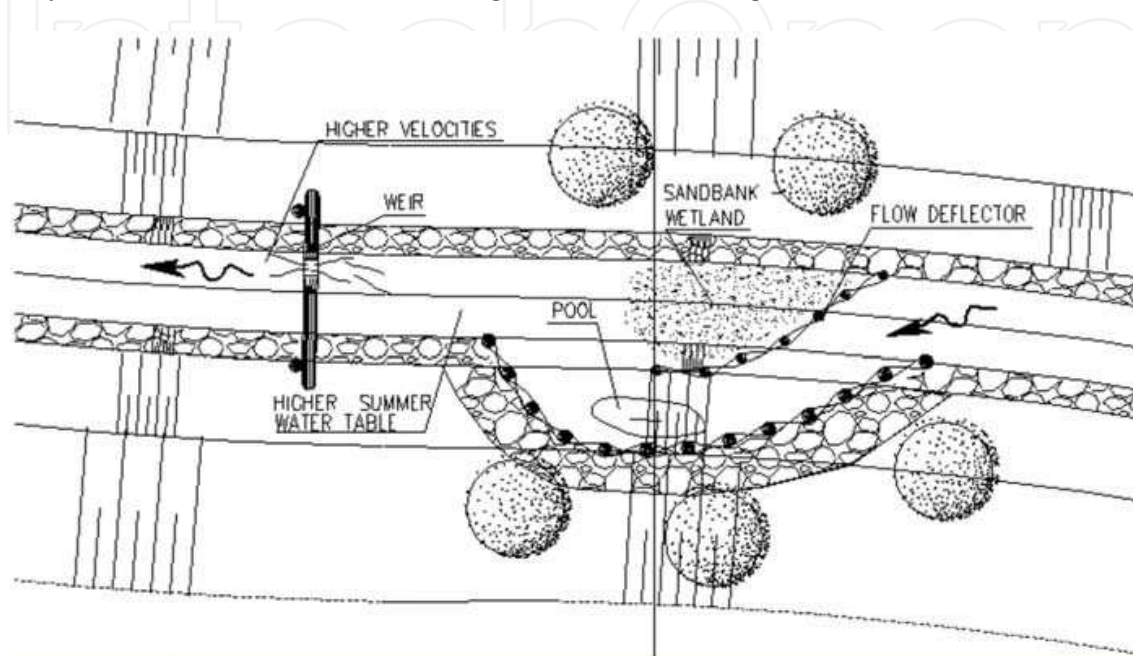
Fig. 2. An example of revitalization measures in a short segment of a watercourse (source: LIMNOS Ltd.)

Flocculation: Aluminum salts form insoluble aluminium hydroxide flocks $Al(OH)_3$ in bulk water. The flocks have good settling properties and high sorption capacity for phosphate, heavy metals, organic micropollutants and algae (El Samrani et al., 2008). Accordingly, these pollutants are removed by sorption to the flocks in bulk water and subsequent sedimentation in the pond. Besides aluminum also lime and iron salts are used, and calcium and iron, which have similar characteristics.

Sediment and media enrichment: Sediment and media in ET can be enriched with minerals that have high sorption capacity for target pollutants. E.g. Ferric iron $(Fe(OH)_3)$ binds phosphate and several heavy metals under aerobic conditions (Kadlec & Wallace, 2009). In an aqueous environment, $Fe(OH)_3$ is least soluble at pH between 7 and 10 and provides sorption sites for a number of pollutants. Besides adsorption of pollutants to $Fe(OH)_3$, also insoluble precipitates with iron can be formed, e.g. $FePO_4$ and complexes with metals. Using Fe to adsorb pollutants, it is essential that the redox potential of the media is sufficiently high to prevent reduction of ferric iron to ferrous iron.

Sorption filters: One of the possible technologies for upgrading existing ET is an installation of sorption filters after the system. Dissolved and colloidal pollutants as heavy metals and phosphorous are thus removed by sorption to the filter media. However filter clogging and saturation of the media may be of a concern. Elimination of dissolved pollutants like

phosphorous and heavy metals is enabled by the characteristics of the filter materials. Filter materials that comprise a lot of dolomite ($CaMg(CO_3)_2$) or calcite ($CaCO_3$) minerals are effective in P adsorption (Brix et al., 2001) and materials containing iron or alumina are shown to have good sorption capacities for heavy metals (Genc-Fuhrman et al., 2007).

Ultrasound: Sonication is mainly used for algae control and disinfection of water in different systems. Ultrasound breaks up large suspended particles in treated water. The effect of ultrasound to algal cells is not clearly known; however, it is known that ultrasound suppresses algae growth and causes their sedimentation in the open water (Griessler Bulc et al., 2010; Krivograd Klemenčič & Griessler Bulc, 2010).

UV: UV is commonly used for disinfection of treated water, where it usually presents a final stage of the treatment train. The UV lamps produce ultraviolet light that enters cells and damages proteins and genetic material. An ideal wavelength for efficient disinfection is believed to be of approximately 254 nm (Modak, 2008).

6. ET systems in Slovenia

The use of ET, as a new, wider concept of understanding of natural treatment systems has started in Slovenia in the late eighties. The idea of ET was introduced in Slovenia first by floating macrophytes and later by subsurface flow TW for water treatment. An experimental period of treating wastewater with plants, mostly as different types of TW followed. During this period experiences were based on certain European researchers such us Kickuth (1984) and Clayton (1988). The basic design was developed in a project started in 1991 in Austria (Perfler & Haberl, 1992) which was modified to select, apply, and compare various options in situ. After 1995, innovative ET were developed for different applications (*e.g.* protection of lakes and watercourses from non-point pollution) based on design and experiences of TW, primarily regarding geographical, demographical and water management characteristics of Slovenia. The introduction of ET was not systematic, since this alternative way of wastewater treatment was not accepted by the government as a state of the art before the nineties. Most installed systems were pilot-systems, destined above all for experimental work. Nevertheless, from 1989 to 2011, several ET systems were installed in Slovenia; 73 TW, 12 sections of river revitalization, 2 VDD, 2 ET for landfill restoration and 1 WSP were constructed in the Karst, coastal, mountain and agricultural lowland regions of Slovenia. The Karst region, covering about 44 % of the surface, is marked by expressive shortage of surface water and soil, and by scattered communities. All this is reflecting in pollution, which is a serious threat for the extremely sensible underground sources of drinking water, based on the complex underground systems with numerous caves (under UNESCO protection). Similar difficulties are recognized also in the coastal region at the Adriatic Sea, where treated wastewaters are discharged into the sea or in its catchment area in the mountain region, which is conserved because of its ecological and scenic values, and in agricultural lowlands characterized by a high contamination with pesticides and other agricultural contaminants. The majority of inhabitants (60 %) live in the settlements with less than 5,000, most of them even 200 to 500 inhabitants, so usually the only way of treatment is the septic tank. Particular problems are tourist centres with large quantities of wastewater in the high seasons. Nowadays, the ET development in Slovenia is mainly focused on the reduction of dispersed pollution, protection of drinking water sources, revitalization of watercourses, and wastewater separation and reuse.

6.1 Design and performance of different ET types

6.1.1 Vegetated drainage ditches

Design: Two pilot VDD (Figure 3) were constructed in agricultural area to reduce watercourse pollution, draught threat, to mitigate agricultural contaminants, and to develop new wetland habitats in order to improve biodiversity. Ditches approx. 20 m long, 5 m top width, 1.40 m bottom width and 1.5 m deep were filled with selected substrata of 0.4 m in height and planted with macrophytes (*Phragmites australis*) (Griessler Bulc & Šajn-Slak, 2007; Griessler Bulc et al., 2011). In one of the VDD, the treated water flows into a meandering stream of an overall length of 70 m where the revitalization principle was followed to further increase the water quality and biodiversity.

Monitoring: From April 2008 until March 2009, physical and chemical parameters and pesticides in water were sampled and analyzed according to Standard Methods (APHA, 2005). The treatment performance was also monitored by localization of the principal denitrification processes within the VDD. The location and relative abundance of denitrifying microorganisms was determined by real time PCR (rtPCR) of the narG gene.

Results and Discussion: With the exception of SS, pollutant concentrations met the outflow permitted levels (OG RS 47/2005). The comparison of our results with the results of monitoring of the same system in previous years showed that the VDD's efficiency for nitrite and ammonia increased due the maturity of the system. The analyses showed also 91 % removal efficiency for metholaclor pesticide. A relatively even distribution of the narG gene showed the flexibility of the VDD system. The results indicate that the facultative anaerobic denitrifiers were present throughout the system, and when the conditions were suitable, denitrification was performed. The research showed that the regularly maintained VDD efficiently decreased pollutants and is an adequate and promising technology that can be further developed. Start-up period with non-consistent treatment performance could be significantly decreased with bioaugmentation with a proliferous and well adapted microbial community.
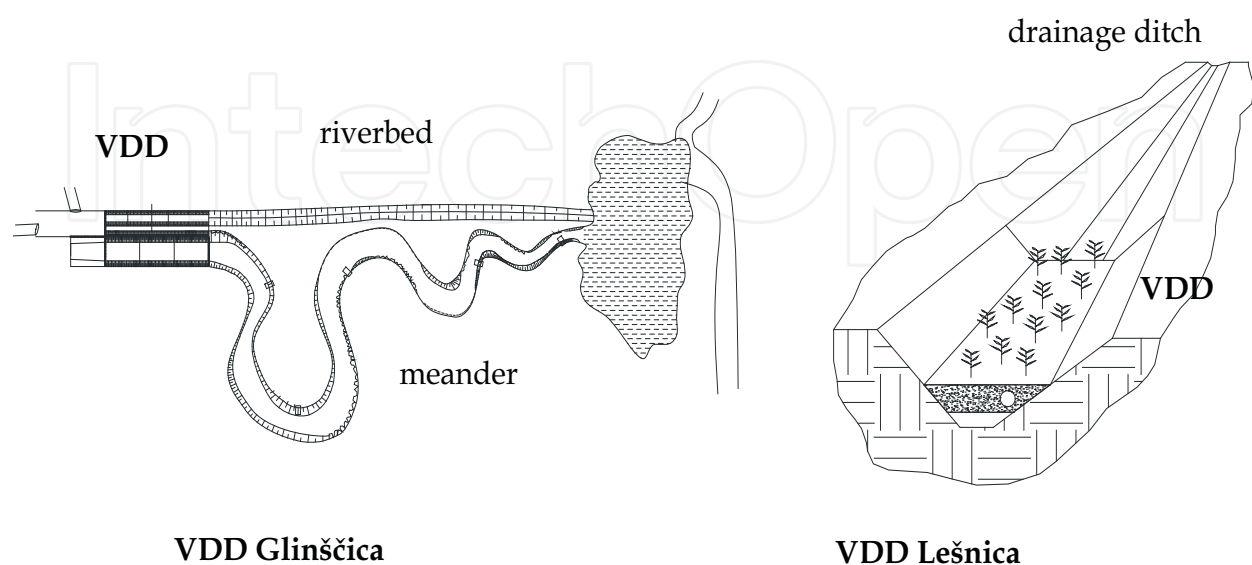

Fig. 3. Design of the two VDD Glinščica and Lešnica (source: LIMNOS Ltd., CGS plus Ltd.)

6.1.2 Waste stabilization ponds (WSP) / surface flow wetlands (SFW)

Design: In the period between 2000 and 2003, a pilot SFW and a pilot WSP were constructed at the outlet of wastewater treatment plant (WWTP). The SFW was planted with *Phragmites australis* and *Eichhornia crassipes*, while in the WSP development of algae was spontaneous.

Monitoring: The systems were monitored under the same operating conditions. The efficiency was evaluated by means of physical and chemical parameters in the inflow and outflow water, by plant productivity and by the analysis of N and P contents in biomass.

Results and Discussion: The SFW proved more efficient in the elimination of suspended solids (64.6 %), settleable solids (91.8 %), organic N (59.3 %), total N (38 %), COD (67.2 %) and BOD5 (72.1 %) than the WSP. The WSP was more efficient in the treatment of ammonia nitrogen (48.9 %) and orthophosphate (43.9 %). The difference in treatment efficiency between the systems most probably originates from different primary producers (macrophytes vs. algae) and consequent food webs established. The results of this study provide data of help in optimising combinations of SFW and WSP (Šajn-Slak et. al., 2005).

6.1.3 Treatment wetlands (TW)

Design: From 1989 to 2011, over 73 TW were constructed in different regions of Slovenia. Most TW are horizontal or/and vertical systems (VF, HSF), operating in combination or integrated in zero foot print unite. Most of them consist of several interconnected beds. Most TW were installed to treat sewage, industrial wastewater, highway run-off, gray water for toilet flushing, drinking water, water from fish farms and landfill leachate. Pre-treatment mostly comprised septic tanks or sedimentation basins. Excavations were sealed with PVC or HDPE membranes, clay or the combination of both. The medium was mostly a mixture of different material (peat, soil, sand, gravel, expended clay), varying in grain size and proportion. The depths of the TW varied from 0.5 to 0.8 m, and the bottom slope from 0 to 3 %. Most systems were between 20 and 1500 m² in area (Table 1). Theoretical hydraulic loading of media was in each case at least 10^{-3} m/s. The TW for sewage vary in size with 2-2.5 m² per people equivalent on average. Wide adaptability to different environmental conditions, tolerance to stress, high productivity is evident characteristic of *P. australis* that favoured the use of this species in TW. Different parts of reed were used for planting, most frequently clumps. In shallow beds of integrated systems, where the depth was 0.4 m, other species, such as *Juncus effusus, J. inflexus, Carex gracilis, Schoenoplectus lacustris*, and *Thyphoides arundinacea*, were successfully tested. Systems were planted generally in spring or autumn when the environmental conditions were optimal.

Monitoring: The efficiency of TW was monitored by sampling at the inlets and outlets in different periods between 1989 and 2011. TW for landfill leachate were monitored regularly on a long-term basis, from 1992 till 2003, while other systems were monitored monthly for one year or occasionally for one up to 5 years. The efficiency of TWs was evaluated by analyzing suspended and settlements solids, COD, BOD5, total phosphorus and ammonia nitrogen. Grab samples were taken mostly according to the measured retention time and analyzed by independent laboratories. Analyses were done according to Standard Methods (APHA, 2005). At sampling sites, flow, temperature, pH, dissolved oxygen and electric conductivity were measured. More extensive chemical and microbiological analyses were done occasionally.

Results and Discussion: Most TW were satisfactory efficient in BOD_5 and COD removal, and only partly efficient in N and P removal. The TW for industry were constructed for the treatment of food processing wastewater, characterized by high COD, BOD_5, and ammonia nitrogen and for dye-rich textile wastewater. The results indicated that TW can be an appropriate technology for the treatment of wastewaters from those industries because the outflow parameters reached the prescribed legislation standards (Griessler Bulc & Ojsteršek, 2008; Zupančič Justin et al., 2009). Two pilot TW were constructed at the end of 2005 for the treatment of water from drinking water wells, polluted with pesticides (atrazine, metholaclor), and pathogens. The results showed the removal efficiency of *E.coli* from 130 to 500 bacteria/100 mL at the inflow to 0 to 3 bacteria/100 mL at the outflow from TW (Istenič et al., 2009). Regarding the pesticides removal, bentazon was reduced from 1.8 µg/L at the inflow to 0.06 µg/L at the outflow, metholaclor from 0.73 µg/L to <0.05 µg/L, and terbutylazine from 0.53 µg/L to <0.03 µg/L (LIMNOS Ltd., results not published). TW for highway run-off treatment showed 69 % removal efficiency for suspended solids, 97 % for settleable solids, 51 % for COD, 11 % for BOD5 and 80 % for Fe. Heavy metals (Cu, Zn, Cd, Ni and Pb) were below the legislation limits at the inflow with the reduction efficiency in the system of over 90 % while the concentrations of N and P showed a low level of nutrients for biological processes (Bulc and Sajn Slak, 2003). The TW for gray water was constructed in 2011. Preliminary data showed that gray water was mostly lost due to evapotranspiration. The TW for landfill leachate were constructed for the landfill sites that cover approximately 0.5 to 2 ha. With regard to the studied parameters, the performance of TW was not influenced by annual seasons, but primarily by precipitation. The reduction efficiency reached on average 50 % for NH_4-N, BOD_5 and COD (Griessler Bulc, 2006; Griessler Bulc & Zupančič Justin, 2007). The results proved that a TW can be considered a method appropriate for the leachate treatments of old waste dumps (Zupančič Justin et al., 2005).

6.1.4 Restorations of landfill sites

Case 1; Design: The ET approach for the reclamation of a 1.5 ha landfill in south-eastern part of Slovenia consists of a landfill soil cover, which is densely planted with grasses and fast growing trees (poplars, willows) as a phytoremediation layer, a TW of 1,000 m² with an average hydraulic load of 12 m³/d and an irrigation system. Landfill leachate is treated in the TW from where it is recycled on the landfill cover without outflow into the environment. Closed loop leachate circulation enables additional leachate treatment by assimilation of nutrients into the plant biomass and by mineralization processes of microbes in the soil layer. Fast growing trees allow the evapotranspiration of a considerable amount of leachate, while the excess percolates back into the landfill body and enables further biodegradation of deposited wastes. The results provided an environmentally and economically-viable solution, with large buffering capacity and simple in concept. The presented methods won international awards (2001 Lillehammer Award; 2008 Global Energy Award, Griessler Bulc & Zupančič Justin, 2007).

Monitoring: To evaluate plant response on leachate irrigation, a remote sensing of the canopy reflectance was performed by ground-based monitoring of vegetation indices of the phytoremediation system with a multispectral camera (Tetracam, USA). Images were taken in regular monthly intervals during one vegetation season, from April to October, after two years of leachate irrigation.

Results and Discussion: The obtained results confirmed the findings that leachate can be a good fertilizer for short rotation coppice produced elsewhere for energy crops. The macronutrient requirements of willow, in relation to nitrogen set to 100, were found to be for N:P:K in the relation of 100:14:72. The N:P:K ratio usually found in leachate ranges from 100:0:54, respectively (Duggan, 2005) to 100:1.5:103 (Dimitriou et al., 2006). The N:P:K ratio calculated from the average concentration of nitrogen, phosphorous and potassium in leachate analyzed during 18-month period was 100:0.5:246, respectively. The potassium concentration was found in excess and phosphorous concentration was low as it is common for leachate. The lack of phosphorous for plant growth is usually expressed in a long-term period (>10 years) and its deficiency could therefore not have been expressed during our observation.

Case 2; Design: A phytoremediation method for the treatment of tannery substrate on the industrial waste dump in Slovenia was used in 2006 to research the potential of various plant species to reduce Cr pollution. Several herbaceous and woody species were planted in the tannery substrate in a greenhouse and on the four testing polygons on the waste dump.

Monitoring: Prior to planting, hardly degradable and toxic substances in the substrate and leachate were analyzed. Moreover, the substrate was examined for its inhibition and chronic toxicity to higher plants according to the ISO standard (ISO/DIS 22030). Several growth parameters were measured in the glasshouse and on the polygons. The growth parameters were measured on a monthly basis in the growing season. Prompt fluorescence, i.e. potential photochemical efficiency (parameter Fv/Fm), was measured on the plants in the glasshouse and on polygons.

Results and Discussion: The preliminary substrate analyses had shown that the most crucial pollutant in the tannery landfill site was Cr (III). The biological accessibility of Cr in roots and shoots of herbaceous and woody plant species showed that beet and sunflower were the most suitable species for phytoremediation, although Cr bioavailability was low. The results revealed that the growth of plants was inhibited and, their health worsened. The results also showed that phytoremediation could be a very delicate method that needs a careful insight into the processes of specific pollutants removal.

6.1.5 River revitalization

Design: The majority of watercourse revitalizations in Slovenia were carried out in the north-east part of the country. Revitalizations of short stretches of rivers and streams were designed in order to increase self-cleaning capacities of the streams in an intensive agricultural landscape and also in order to protect the natural population of otter. According to the data, the most continuous and viable population of *Eurasian otter* in Slovenia lives in the north-east of the country. Threats for otter in this area are degraded habitats due to the agro-operational works, including ameliorations and canalization of watercourses which took place in last decades. The results of non-sustainable management were among others the opening of corridors by removing tree canopies as well as riparian vegetation on watercourse banks (the shelter for otters disappeared, the living conditions for pray species worsened and consequently the food supply was reduced), the permeability of corridors had lowered and the risk for population fragmentation was higher. In order to protect and restore the otter population, ETs were implemented in

Goričko on short sections of watercourses and lakes of eight local communities. Different in-stream and stream bank features were implemented to attain a successful revitalization. Weirs with small pools were constructed in the channels to improve streambed substrate, slow down the flow velocity, retain water and provide proper fish passages. Artificial indentations as well as restored and protected indentations contribute to better water habitats diversity. The passages for otters under the bridges were implemented which enabled otters to pass the roads safely. New vegetation zones (riparian wetlands and constructed wetlands) prevent erosion, provide buffer and better connectivity between terrestrial and aquatic ecosystems (Griessler Bulc & Šajn-Slak, 2009). The revitalization measures were also widely accepted by the local population, satisfied by the re-gained natural appearance of the streams and water murmur.
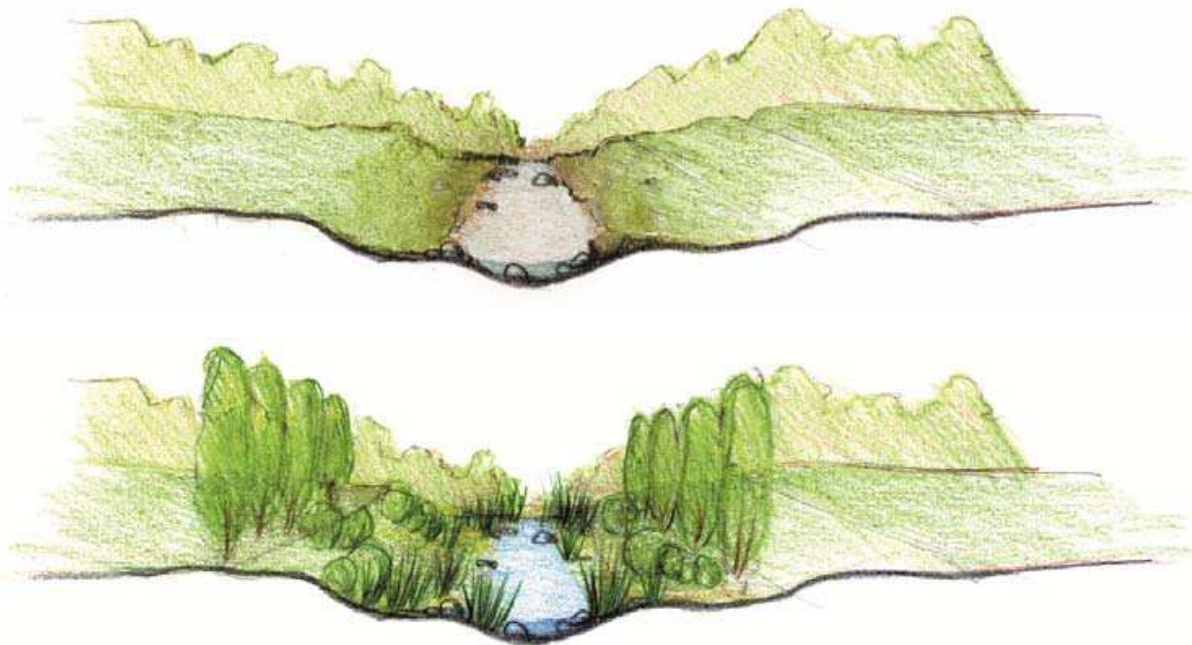

Fig. 4. Schematic evolution of river revitalization (source: LIMNOS Ltd.)

7. Conclusions

Despite numerous measures to improve the quality of the environment in the last decades, water quality is still seriously threatened by point and non-point sources of pollution. The application and development of ET for water protection, treatment and reuse in Slovenia have shown that they are appropriate measures for reaching EU regulations in terms of good water quality; moreover, they consider also the recycling of nutrients, reuse of water and potentially the production of biomass.

ET or ecoremediations mimic healthy natural ecosystems, have high buffer and self-cleaning capacity and contribute to habitat diversity. Moreover, these systems have the remediation ability, ensure high biodiversity and contribute to the stability of ecosystems. Nutrients and pollutants in ET are subdued to numerous processes that enable pollutant and nutrient transformations, degradation or stabilization. Through these processes, ET enable the reuse or recycling of nutrients as phosphorous and nitrogen, which nowadays have one way flow

from consumption to waste, which will result in a shortage of plant fertilizers in a near future. Closing the loops of wastewater treatment is therefore crucial.

In Slovenia ET are in a rise since 1989. Different ET have been applied, namely treatment wetlands, watercourse revitalization, vegetated drainage ditches, waste stabilization ponds, phytoremediation of landfill sites. Most common ET in Slovenia are treatment wetlands for municipal sewage followed by watercourses revitalization. A high number of treatment wetlands indicate the priority of local communities and the authorities to solve deficient wastewater treatment systems in the country. An important part of the research and development of ET in Slovenia was focused also on the restoration of landfill sites, where a closed water and pollutant loop was investigated and successfully implemented; however, the system is not yet successful in the market because the local governance and environmental managers are still focused on wastewater treatment. Due to gradual acceptance and implementation of ET in local environments there is still a long way to walk in order to achieve sustainable society in terms of closing the loops of water and nutrient usage.

Nr.	Type	Area m2	Year of construction	Operation period	Treated water	Average inflow concentration	Efficiency	Reference
55*	Treatment wetland	7.5-1500	1989-2011	1989-2011	Municipal sewage	COD: 239 NH4-N: 496 TP: 8.9	50 51 53	Urbanc-Bercic et al., 1998, Sajn-Slak et al., 2005
9	Treatment wetland	125-750	1991-2008		Industrial	-	-	Vrhovsek et al., 1996, Griessler-Bulc and Ojstersek, 2008; Zupancic-Justin et al., 2009)
8	Treatment wetland	311-1000	1995-2004	1995-2004	Landfill leachate	COD:979 NH4-N:281 TP:2.5	54 51 58	Griessler-Bulc, 2006; Griessler-Bulc and Zupancic-Justin, 2007
1	Treatment wetland	85	2001	2001	Highway runoff	COD:29 NH4-N:- TP: 0.4	51 - 79	Griessler-Bulc and Sajn-Slak, 2003
1	Treatment wetland	20	2011	2011	Grey water	COD: 411 NH4-N: 128 TP: 56	-	Griessler-Bulc et al., 2010
2	Treatment wetland	0.5-1	2009	2009-2011	Drinking water	-	-	Data not published
2	Vegetated drainage ditch	20-90	2006	2006-2011	Surface water, agricultural run off	COD: 25 NH4-N: 0.3 TP: 0.3	neg 7 3	Griessler-Bulc and Sajn-Slak, 2007; Bulc et al., 2011, Griessler-Bulc and Krivograd-Klemenčič, 2011
12*	Watercourse revitalization	10-100*	2006-2008	2006-	Surface water	-	-	Vrhovsek et al., 2007; Griessler-Bulc and Sajn-Slak, 2009
	Waste stabilization pond	36	2000-2003	2001	Sewage	COD:391 NH4-N: 3.3 TP:2.07	67.2 neg-49 33	Sajn-Slak et al., 2005
2	Phytoremediation	15000	2003-2005	2003-2011	Leachate, soil	COD: 1257 NH4-N: 217 TP: 2.5	35 37 49	Griessler-Bulc and Zupancic-Justin, 2007

*estimated numbers

Table 1. Data about ET in Slovenia

8. Acknowledgment

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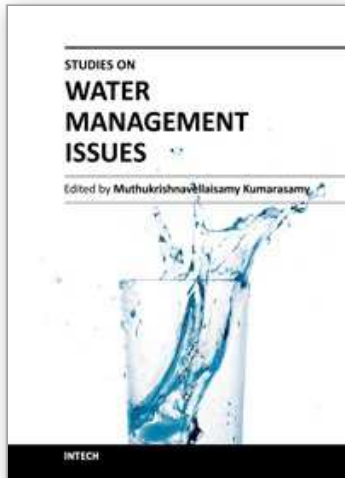
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