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Chapter 14

ECOLOGICAL ENGINEERING FOR CONTROLLING SURFACE RUNOFF POLLUTION

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ABSTRACT

Ecological engineering involve the design, construction, operation, and management of aquatic and terrestrial ecosystems to mitigate environmental pollution, this benefit both humanity and nature. The field has its roots in ecology and is practiced within an engineering context. Ecological engineering differs from environmental engineering because the latter focuses on solving problems of pollution using advanced technologies, which are heavily dependent on fossil fuels while the first relays on ecosystems and renewable energy sources. Currently, ecological engineering is used widely to solve different environmental problems such as controlling non point source pollution. Surface runoff is a term used to describe the flow of water, from rain, snowmelt, or other sources over the land and is a major component of the water cycle . When runoff flows along the ground, it can pick up soil contaminants such as petroleum, pesticides, or fertilizers that reach the water bodies. If a nonpoint source contains man-made contaminants, the runoff is called nonpoint source pollution. Bioswales and created or constructed wetlands are ecological engineered systems for controlling non point source pollution. This chapter presents a review of the state of art on the principles and applications of ecological engineering to control water contamination from different types of surface run off. The first part defines and describes the principles that govern ecological engineering. The second part presents a broad and update review about the design principles and applications ecological engineered systems to control different types of non point source pollution.

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INTRODUCCION

Pollution of rivers, lakes and marine waters by chemical compounds has become one of the most crucial environmental problems of the past and present centuries. Water pollution occurs when a water body is adversely affected by the addition of large amounts of materials to the water. There are two types of water pollution: a) point source and b) nonpoint source, the first occurs when harmful substances are emitted directly into a body of water; a nonpoint source delivers pollutants indirectly to water bodies; an example of this type of water pollution is when fertilizers from a field are carried into a stream by rain, in the form of runoff (Chen, et al., 2007).

Humanity is inseparable from natural systems; however the growing worldwide population and consequent natural resource consumption have damaged global ecosystems (Urbanska et al., 1997). The emerging discipline of ecological engineering is a response to the growing need for engineering practice to provide welfare for human while at the same time protecting the natural environment from which goods and services are drawn. A sustainable human society requires engineering design practices that protect and enhance the ability of ecosystems to perpetuate themselves while continuing to support humanity (Bergan, et al, 2001).

The practice of ecological engineering emerged in early 1970s from a number of experimental trials, and today is a growing industry (Kangas, 2004). Applications of ecological engineering include ecological restoration of streams, wetlands, lakes and forest; the design of ecosystems to control water pollution, and practices of sustainable agriculture (Jorgensen and Nilsen, 1996). Ecological engineered ecosystems to control run off pollution include, constructed and created wetlands, and bioswales. This chapter presents a broad and updated review about the concepts and principles of ecological engineering, and its applications for controlling surface runoff pollution.

2. CONCEPT AND PRINCIPLES OF ECOLOGICAL ENGINEERING

Ecological Engineering combines the disciplines of ecology and engineering in order to solve environmental problems. As a relatively new field, effort continues to define its scope and purpose. Several authors have put forward definitions for ecological engineering. The term itself is attributed to H.T. Odum, who defined ecological engineering as ''environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources'' (Odum et al., 1963).

A more recent definition of ecological engineering is "the design of human society with its natural environment for the benefit of both", provided by Mitsch and Jørgensen (1989). This definition was slightly refined as ''the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both'' (Mitsch and Jørgensen, 2003, 2004).

Teal (1997) defined ecological engineering as "the use of ecological process within natural or constructed imitations of natural systems to achieve engineering goals". In other words, the ecosystems are designed, constructed and operated to solve environmental problems otherwise addressed by conventional technology.

Barrett (1999) provides a straightforward definition of ecological engineering: "the design, construction, operation, and management (that is, engineering) of landscape/aquatic structures and associated plant and animal communities (that is, ecosystems) to benefit humanity and, often, nature".

Ecological engineering is a new approach to both ecology and engineering which justified a new name. In the past, ecologist and engineers not always shared the common view of nature, because of this situation an adverse relationship between them has evolved. The challenge for ecologist and engineers is to break down the stereotypes of ecology and engineering and to combine the strengths of both disciplines, by using a design with nature philosophy and by taking the best of the both worlds.

Although there are some similarities, ecological engineering should not be confused with environmental engineering, wherein the focus is on solving problems of pollution using advanced technologies heavily dependent on fossil resources. Traditional engineering relies mainly on human control processes occurring in human-created, "hard" structures, and it is reliant upon fossil resources, including both energy and materials. In contrast, ecological engineering attempts to utilize natural processes occurring in natural land- and waterscapes (i.e., "soft" structures), which are driven primarily by natural energy (solar and gravity). Ecological engineering differs from environmental management because the latter, often means humans making the environment to suit their wishes. Contrasting, ecological engineering involves light management that joins human design and environmental self-design so that they are mutually symbiotic (Odum, 1996, Mitsch, 1997, Kells and Webner, 2000, Allen et al, 2003, Mitsch and Jorgensen, 2004).

Mitsch and Jorgensen, 2004 described the following basic concepts that collectively distinguish the approach of ecological engineering to solve environmental problems from conventional technologies:

1) It is based on self-designing capacity of ecosystems: Self-design and self-regulation comprises the basic premise behind ecologically engineered systems. There are natural adjustments in food chains and shifts in species within populations and communities. In fact, a considerable degree of resiliency is inherent in self-organization, which allows ecosystems to adapt to both natural and human-induced changes. Within this framework, engineers participate as a choice generator and as a facilitator of matching environment with ecosystem, but nature does the rest of the engineering. In this way, nature is a collaborator.
2) It can be the acid test of ecological theories: Ecological theories developed over the past 100 years serve as bases for practicing ecosystem restoration and ecological engineering. However, just as there is the possibility of these theories helps the engineering design of ecosystems, there is also a possibility of finding that some of these ecological theories are wrong. Thus, ecological engineering is an important tool for fundamental and applied ecological research.
3) It relies on system approaches: Ecological engineering planning, design and monitoring should be founded within the framework of natural systems. In essence, it involves using nature as our guide and moves us toward a symbiotic relationship between human society and the natural environment. Ecological engineering has been dubbed "green technology" because it relies on photosynthetic plants and natural biological systems, which are useful and environmentally friendly. Moreover,

systems with living plants are often both aesthetically and economically appealing. Property values may increase because of the cost-effectiveness and fuel savings, aesthetics and novelty of an ecologically designed project.

4) It conserves non renewable energy sources: Ecological engineering is based on a solar energy philosophy. It does not depend on fossil fuels and other potentially damaging energy sources. Furthermore, greenhouse gas emissions are minimized by the possible sequestration of carbon in the biomass of the organisms comprising the ecosystem. Once a system is designed and put in place, it sustains itself indefinitely with only a modest amount of human intervention. Moreover, most projects have direct and indirect, expected and unexpected, spin-off benefits.
5) It supports ecosystem conservation: A consequence of an ecologically engineered system is preservation of ecosystems. In part, this effect occurs in response to increased recognition of the value of ecosystems. For example, when the abiotic values of wetlands were recognized for flood control and water quality enhancement in addition to the provision of habitat for fish and wildlife, then the protection of natural wetlands and construction of wetlands have increased dramatically.

3. Characteristics of Surface Runoff Pollution

Surface runoff is water from rain, snowmelt, or other sources that flows over the land surface, and is a major component of the water cycle (Hottenroth et al., 1999). Urbanization increases surface runoff, by creating more impervious surfaces such as pavement and buildings that do not allow percolation of the water down through the soil to the aquifer. When runoff flows along the ground, it can pick up soil contaminants such as petroleum, pesticides, or fertilizers that become discharge or overland flow. If surface run off contains man-made contaminants, the runoff is called nonpoint source pollution (NPS), which unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution moves over and through the ground, as the runoff moves, it picks up and carries away natural and human-made compounds, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water (Chen et al., 2007). These pollutants include:

- Excess of fertilizers, herbicides, and insecticides from agricultural lands and residential areas.
- Oil, grease, and toxic chemicals from urban runoff and energy production.
- Sediments from improperly managed construction sites, crop and forest lands, and eroding streambanks.
- Salt from irrigation practices and acid drainage from abandoned mines.
- Bacteria and nutrients from livestock, pet wastes, and faulty septic systems.

Impacts from stormwater can be physical, chemical and/or biological. The natural flow regime of a stream is altered by increasing peaks. Another physical change is the modification in the amount of sediments. There are also chemical changes from stormwater, which include temperature, pH and dissolved solids. Stormwater impacts can affect an individual, population, or an entire species. Specific changes to aquatic species can include: impaired feeding, damaged gills, reduced photosynthesis, destruction of spawning habitat, metals ingested and increased nutrients that lead to oxygen depletion (Hottenroth et al., 1999, Chen et al., 2007).

4. ECOLOGICAL ENGINEERED SYSYTEMS FOR SURFACE RUN OFF POLLUTION CONTROL

Ecological engineering approaches for treating contaminated water using natural processes emphasis on combining ecology and engineering knowledge to understand the fundamental processes that govern the effectiveness of complex natural treatment systems. Created and constructed wetlands, and bioswales are ecological engineered systems useful for improving water quality from non point source pollution. In the following section details of these systems are described.

4.1. Constructed and Created Wetlands

The idea to use an ecosystem type (wetlands) to address a specific human need that ordinary requires a great deal of engineering (wastewater treatment) is probably the best example of ecological engineering because the mix of ecology and engineering is nearly even.

Constructed wetlands are those wetlands intentionally created from no wetland sites for the unique purpose of treat wastewater or stormwater. These systems must be managed and monitored continuously (Hammer, 1992). Constructed wetlands are shallow ponds or channels which have been planted with aquatic plants. They relay upon natural microbial, biological, physical and chemical process to treat wastewater. Wetlands have a higher rate of biological activity than most ecosystems; therefore they can transform many of the common pollutants that occur in a conventional wastewater into harmless byproducts or essential nutrients than can be used for additional biological productivity (Kaldec and Knight, 1996).

Created wetlands are those wetlands intentionally created from non-wetland sites to produce or replace functions of natural wetlands. The characteristic of the site should be carefully studied before wetland creation, particularly hydrology and soils. Created wetlands might be designed to provide habitat and improve water quality (Hammer, 1992).

Wetlands include a complex assemblage of water, substrate, plants, algae, litter (primarily fallen plant material), invertebrates (mostly insect larvae and worms) and an array of microorganisms (most importantly bacteria). The mechanisms that are available to improve water quality are therefore numerous and often interrelated (Kaldec and Knight, 1996). These mechanisms include:

a) Settling of suspended particulate matter
b) Filtration and chemical precipitation through contact of the water with the substrate and litter
c) Chemical transformations
d) Adsorption and ion exchange on the surfaces of plants, substrate, sediment, and litter

e) Breakdown and transformation of pollutants by microorganisms and plants
f) Uptake and transformation of nutrients by microorganisms and plants
g) Predation and natural die-off of pathogens.

Constructed wetlands can be subdivided into three main categories: surface flow wetlands (SF), subsurface flow wetlands (SSF) and hybrid systems that incorporate surface and subsurface flow wetlands. Created wetlands are designed only as SF wetlands, since they try to be similar to the natural ones.

A surface flow (SF) wetland consists of a shallow basin, soil or other medium to support the roots of vegetation, and a water control structure that maintains a shallow depth of water (Figure 1). The water surface is above the substrate. SF wetlands look much like natural marshes and can provide wildlife habitat and aesthetic benefits as well as water treatment. In SF wetlands, the near surface layer is aerobic, while the deeper waters and substrate are usually anaerobic (Kaldec and Knight, 1996). Stormwater wetlands, is the term used to dscribe wetlands built to treat mine drainage, urban and agricultural runoff. Usually they are SF wetlands, sometimes called free water surface wetlands. The advantages of SF wetlands are that their contruction and operating costs are low, they have high wildlife habitat values, and that their construction, operation, and maintenance are straightforward. The main disadvantage of SF systems is that they generally require a larger land area than other systems.

A subsurface flow (SSF) wetland consists of a sealed basin with a porous substrate of rock or gravel. The water level is designed to remain below the top of the substrate. In most of the systems in the United States, the flow path is horizontal (Figure 2a), although some European systems use vertical flow paths (Figure 2b). SSF systems are called by several names, including vegetated submerged bed; root zone method, microbial rock reed filter, and plant-rock filter systems (Kaldec and Knight, 1996).

The advantages cited for SSF wetlands are greater cold tolerance, minimization of pest and odor problems and, possibly of greater assimilation potential per unit of land area than in SF systems.

The disadvantages of SSF wetlands are that they are more expensive to construct, on a unit basis than SF wetlands. Because of cost, SSF wetlands are often used for small flows. SSF wetlands may be more difficult to regulate than SF wetlands and maintenance and repair costs are generally higher than for SF wetlands (Knight et al., 2003). A number of systems have had problems with clogging and unintended surface flows.

Subsurface-flow wetlands, however, tend to be more effective at filtering out solids and removing BOD per unit land area. Because the wastewater remains below the surface in these systems, there is less possibility for human or wildlife contact with wastewaters and less potential for insect infestation. These types of wetlands are recommended to treat point source pollution with high organic and nutrient loading.

The use of hybrid designs incorporating both surface and subsurface-flow sections is now becoming more common.

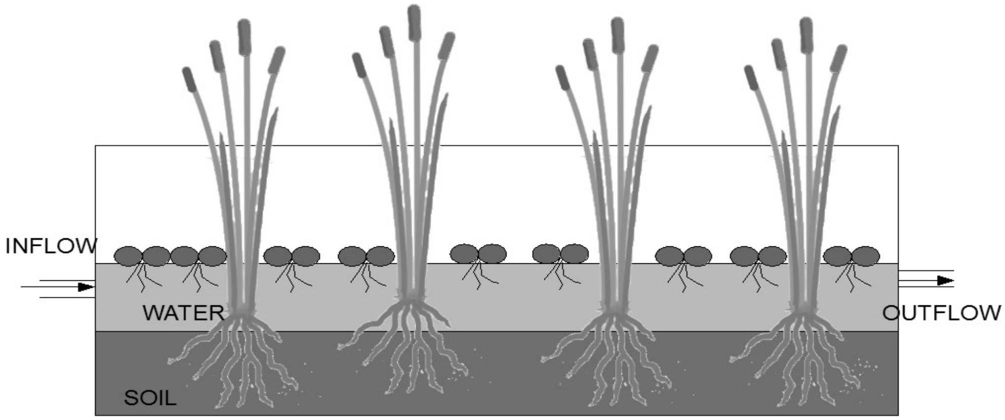

Figure 1. Free surface water flow wetland

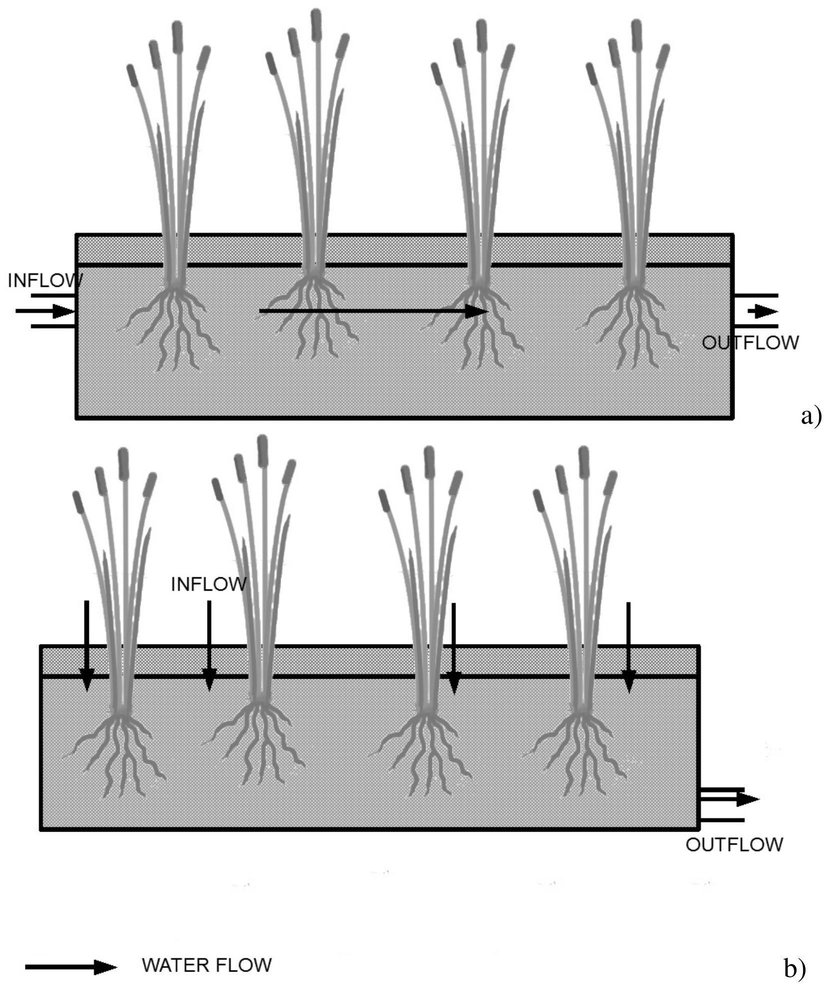

Figure 2. Subsurface flow (SSF) constructed wetlands, a) horizontal flow and b) vertical flow.

4.1.1. Design criteria for wetlands to control surface runoff pollution

There are some differences between the design of wetland wastewater treatment systems and wetland NPS pollution control systems. For example, the hydraulic loading rates of wastewater treatment systems are related to wastewater characteristics. A retention time of 6-7 days has been reported as optimal for primary and secondary treatment of wastewater in wetlands (Wood, 1995). Residence time is considered an important variable when designing wetlands and wastewater treatment systems (Hammer, 1993). The hydraulic loading rates for NPS wetland systems vary with the characteristics of the stormwater to be treated. Retention time for stormwater calculations depends on the precipitation event, and the volume of water generated from the watershed. Therefore, for any given wetland, the retention time will be greater for smaller storm events than for larger storm events. Due to the variable nature of runoff, the sizing of NPS wetland systems is based on a ratio of wetland size to watershed area. In the mid-Atlantic region, a wetland to watershed ratio of 2.0% has been recommended for shallow marsh wetlands and 1.0% for wetlands with a pond incorporated into the design (Schueler, 1992).

Similarly, Hammer (1993) reports that the wetland to watershed ratio for nutrient and sediment removal from agricultural runoff should be 0.6% for marsh systems.

Regarding with vegetation, investigators have studied the relative effectiveness of various wetland species to remove pollutants (Iamchaturapart et al., 2007). The NPS wetland systems seem to be less dependent on maintaining a monoculture of plant species and in some cases they are designed to increase species diversity (Schueler, 1992). The filtering effectiveness of the vegetation depends on its roughness coefficient, the degree of slope present, and the length of the buffer strip (Brix, 1997). Emergent vegetation has been used much more extensively than forested systems because of the difficulty in establishing mature forested systems.

Key design factors to be incorporated into an NPS wetland system include surface area/volume ratio, the nature and length of flow path, and deep water pools. Surface area may be increased by planting dense emergent vegetation or increasing the topographic diversity in a wetland. The flow path length should be maximized within the available wetland area. Deep water pools at the inlet are important in reducing inlet velocity, trapping coarse sediment and increasing habitat diversity. Length to width ratio of between 4 -7 to 1 have been utilized (Hammer, 1992)

Constructed wetlands provide storage capacity for runoff water within their basins. In addition, organic soils found in mature wetland systems act like a sponge to retain water and allow infiltration into the groundwater. This decreases not only total runoff volume but also peak discharges which may otherwise cause flooding or erosion downstream. As channelized flow enters a wetland, the velocity is reduced as the water spreads out over the wetland. Velocity is further reduced by the frictional resistance of aquatic vegetation. This reduction in velocity is responsible for sediment and nutrient retention in constructed wetlands. As the velocity of flowing water slows, it loses the energy needed to keep particles in suspension, and these particles and associated nutrients then settle out. Wetlands should not be expected, however, to control all the influx of sediments and nutrients from a watershed, nor should the creation of one small wetland be expected to result in significant improvements in downstream water quality.

According to Mitsch, 1992, created and constructed wetlands to control non point source pollution should be located in the landscape considering the following designs criteria:

a) *Instream wetlands*: Wetlands can be design as in stream systems by adding control structures to the streams themselves or by impounding a distributary of the stream (Figure 3). Blocking an entire stream is a reasonable alternative only for low-order streams but is not generally cost-effective. This design is particularly vulnerable during flooding and might be very unpredictable in its ultimate stability, but it has the advantage potentially treating a significant portion of the water that passes that point of stream. Maintenance to the control structure and the distributaries might mean significant management commitments of this design.
b) *Riparian wetlands:* The natural design for riparian wetlands primary fed by flooding stream (Figure 4) allows for flood events of a river to deposit sediments and chemicals on seasonal basis. These types of wetlands are often possible to create with minimal construction. They can be designed to capture flooding water and sediments and slowly release water back to the river after flood passes such as the natural the riparian wetlands in a bottomland hardwood forest areas or they can be design to receive water from the flooding a retain in through the use of flap-gates.

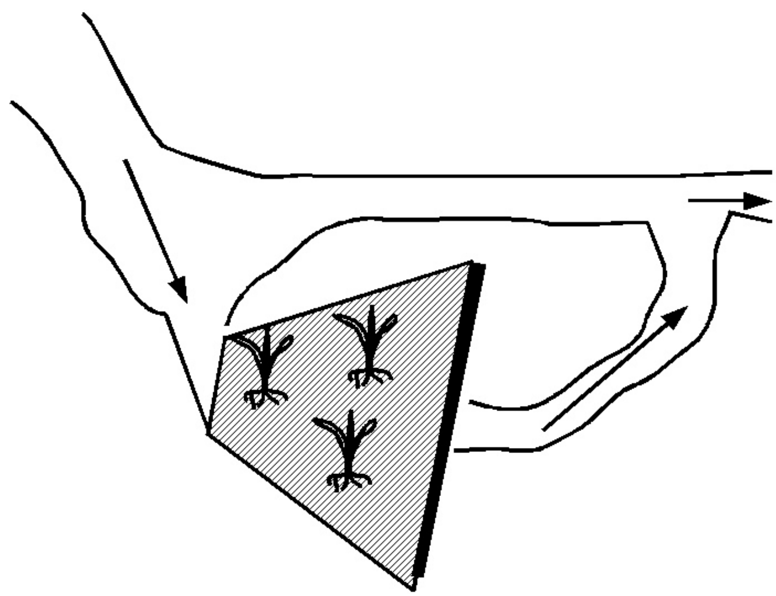

Figure 3. Constructed in stream wetland with part of the flow bypassing the wetland during high flow conditions

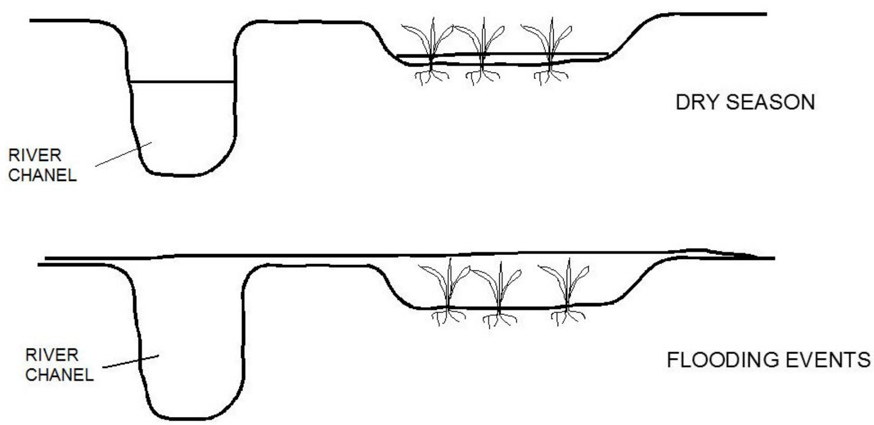

Figure 4. Natural or created riparian wetland fed during flooding seasons

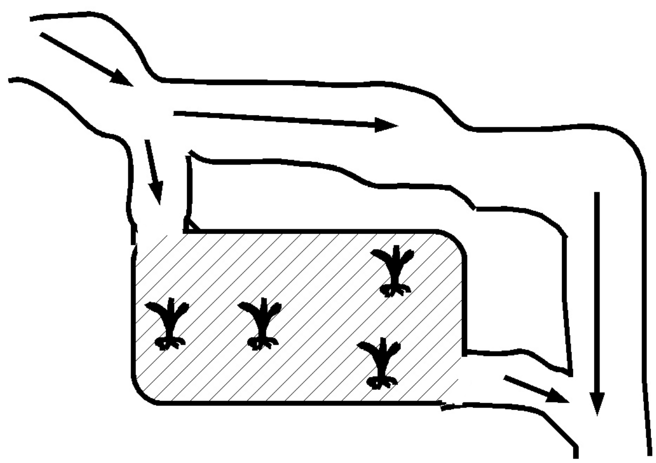

Figure 5. Riparian created wetland fed by gravity from upstream

A sustainable created riparian wetland could be constructed by diversion of the stream at such distance upstream that could be fed by gravity (Figure 5). In such design, natural energies rather than pumps could be used, and natural levees rather than impoundments would effectively hold the water on the floodplain.

Constructed and created wetlands to control non-point source pollution have been utilized successfully in a large scale in some European countries and United States. However, there is not available information of their use in developing countries.

4.1.2 Experiences of using wetlands for non point source pollution control

In Ireland, the Irish National Parks and Wildlife Service has promoted the free surface flow Integrated Constructed Wetlands (ICW) concept, which is based upon the use of the land-water interface to enhance environmental and nature conservation management (Harrington et al., 2005). The ICW concept was developed in 1990 to improve the management of natural resources for the rural community in the catchment of the Dunhill-Annestown stream in south County Waterford with an area of 25 km^2. ICW concept explicitly combines the objectives of cleansing and managing water flow from farmyards with that of integrating the wetland infrastructure into the landscape and enhancing its biological diversity (Miklas et al., 2007). Approximately 75% of farmyard runoff in the watershed was intercepted in the constructed wetlands, leading to improvements in the receiving surface waters of the catchment. Most of the recorded phosphate concentrations after ICW treatment agreed with the 2001 Irish Urban Wastewater Treatment Regulation (Miklas et al., 2007).

In Denmark, one of the measures taken to reduce nitrogen load to aquatic systems is to re-establish wetlands by bringing streams back to their old meandering courses, restore waterholes and lakes as well as the wetlands connected to them. These wetlands include riparian systems such as wet meadows and fens. The Danish Action Plan on the Aquatic Environment II (DAPAE-II) from 1998 has set a national target of increasing the wetland area with 16,000 ha and the long-term objective is to restore 60,000–100,000 ha wetlands within the next two decades (Grant and Mathiesen, 2004). The target of the DAPAE-II was to reduce the annual nitrogen load to the sea with 5600 tonnes. This figure equals a nitrogen removal rate of 350 kgNha^{-1} year^{-1} (Hoffmann and Baattrup-Pedersen, 2006). The wetland restoration program was meant to take place during the years 1998–2003, but the program has been prolonged so that funding of projects continued until the end of 2006, and construction works may continue for several years after 2006. Total costs are set at DKK 500 million. In August 2005, 3060 ha of land was restored and 3769 ha of land approved for restoration. A monitoring program for surveying the effects of the restoration of the wetlands has been set up. The program included basic data on land use and surveys of environmental effects and natural values. The mean nitrogen removal for all projects was estimated to 259 kg N ha^{-1} year^{-1}, while results from the monitoring program have shown that wetlands removed between 39 and 372 kg N ha^{-1} year^{-1}(Braskerud, 2002; Hoffmann and Baattrup-Pedersen, 2006)

In United States , agricultural runoff is the main source of nitrogen loading in the Mississippi River and increase of nitrate loading is cited as the major cause of the extensive hypoxia in the Gulf of Mexico (Goolsby and Battaglin, 2001; Dagg and Breed, 2003). To mitigate this problem, the creation and restoration of wetlands has been recommended in the Mississippi–Ohio–Missouri (MOM) river basin (Mitsch et al., 2001, 2005; Mitsch and Day, 2006). Two types of wetlands have been recommended by Mitsch and Day (2006):

1. Farm runoff wetlands—creation and restoration of wetlands and riparian buffers between farms and adjacent streams and rivers; and
2. River diversion wetlands—diversion of river water into adjacent constructed and restored wetlands along the main river channels and in the Mississippi delta during flood periods.

Farm runoff wetlands

Four surface-flow wetlands were constructed in 1994 on the Embarras River floodplain in east-central Illinois, USA, to intercept field drainage tiles that drained corn and soybean fields (Kovicic et al., 2000; Larson et al., 2000; Hoagland et al., 2001). These wetlands decreased nitrate-nitrogen flux from 32 to 66%, with an average retention of 44% and 23 g-N m^{-2} yr^{-1}.

A multi-celled, 1.2 ha agricultural runoff wetland in Logan County, Ohio, USA, receives drainage from a 17-ha watershed, 14.2 ha of which was used for intensive row-crop agriculture. Surface inflow and groundwater discharge were about equal at multiple locations within the site amounted to almost the same amount. Overall, the wetlands retained 40% of nitrate-nitrite and retained a mass of 39 g-N m^{-2} yr^{-1} (Fink and Mitsch, 2004).

River diversion wetlands

A series of experimental diversion wetlands, 1.8 to 3.8 ha, were constructed at the Des Plaines River Wetlands in northeastern Illinois (Sanville and Mitsch, 1994). All of the wetlands were sinks for nitrate-nitrogen, removing 78 – 84% of the inflowing nitrate, by mass (Phipps and Crumption 1994). Over a 3-year period, retention by concentration ranged from 46 to 95% and detention rates ranged from 2 to 43 g-N m^{-2} yr^{-1}.

Created wetlands in the Olentangy River Wetland Research Park at Ohio State University, have shown an average of 34% of nitrate-nitrogen retention by concentration and 33% by mass (Mitsch et al., 2005)

In Louisiana, nutrient uptake has been studied at a Mississippi River diversion where river water is being reintroduced into a coastal estuarine system to restore deteriorating wetlands (Day et al. 1997). The diversion structure delivers up to about 250 m^3 sec^{-1} to a 500 km^2 area of fresh and brackish wetlands. The Caernarvon wetland retained 39 to 72% of nitrate by concentration (Mitsch et al., 2005)

4.2. Bioswales

Bioswale is the term generally given to any vegetated swale, ditch, or depression that conveys storm water. Bioswales are landscape elements designed to remove silt and pollution from surface runoff water (Mazer et al., 2001). They consist of a swaled drainage course with gently sloped sides (less than six percent) and filled with vegetation, compost and/or riprap. The water's flow path along with the wide and shallow ditch, they are designed to maximize the time water spends in the swale, which aids the trapping of pollutants and silt. Depending upon the geometry of land available, a bioswale may have a meandering or almost straight channel alignment. Bioswales can remove and immobilize or break down a large portion of pollutants found in stormwater runoff. Bioswales have achieved high levels of removal of suspended solids (TSS), turbidity, and oil and grease. They can also remove a moderate percentage of metals and nutrients in runoff (Davis et al., 2003). A common application of bioswales is around parking lots, where substantial automotive pollution is collected by the paving and then flushed by rain. The bioswale located around the parking lot treats the runoff before releasing it to the watershed or storm-sewer. Pollutant removal rates increase when bioswales are well maintained, and as the residence time of water in a swale increases. Besides removing pollutants from storm water runoff, bioswales provide storm water detention and thus can reduce the increased peak flow rate that is the result of increased impervious surfaces from site development

4.2.1. Design criteria for bioswales

There are the two basic types of vegetated swales based upon the degree of vegetation:

a) The fully vegetated bioswale
b) The open channel bioswale (used in roadsides).

Some subtypes of bioswale are based upon their general cross-sectional shape, i.e. "U", "V", and "trapezoid". Generally, the "U" and "V" shaped swales are just ditches that have become naturally vegetated and they are usually open channeled. The Trapezoidal fully vegetated bioswale is the most effective bioswale for removing pollutants (Figure 6). Open channels do not add much more than infiltration to the process of removing pollutants.

Vegetation must meet certain criteria to be planted along a swale since plants maintain channel stability and improve the bioswale's ability to filter pollutants from stormwater. In Table 1, are listed some plant species commonly used in bioswales in the United States. The vegetation must have the following characteristics:

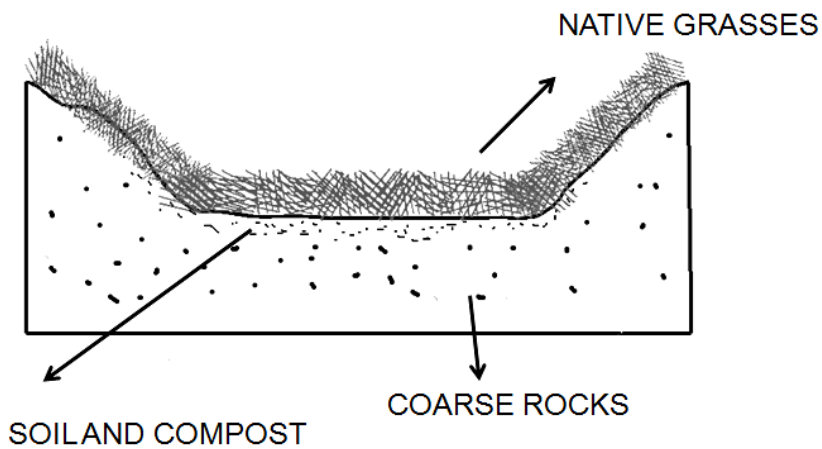

Figure 6. A cross-sectional view of a trapezoidal fully vegetated bioswale

- Produce a dense cover and a root or rhizome structure that holds the soil in place in order to resist erosion.
- It must stand upright (during high water flows) in order to provide maximum residence time and pollutant removal.
- Tolerate a bioswale's soil conditions (pH, compaction, composition); and
- Tolerate periodic flooding and drought. It must not be dormant during the period of the year that the pollutants are to be treated.

4.2.2. Experience of using bioswales to control surface runoff pollution

Urban stormwater is a result of land development in a watershed that creates impervious surfaces such as roads, parking lots and buildings, where precipitation moves across the surfaces, intercepting and altering the natural hydrological cycle. Increased urban sprawl and construction accelerates the rate of loss of naturally pervious surfaces.

In United States, in 1987 the Clean Water Act (CWA) was amended to address non-point sources through the National Pollutant Discharge Elimination System (NPDES) program.

In order to mitigate the effects of urbanization has on the natural balance between stormwater runoff and the ecosystem of wetlands and streams, Best Management Practices (BMP) have been developed to improve water quality and flow control. Bioswales provide good treatment of stormwater runoff without the extensive maintenance. Oregon and Washington states in the east coast, have implemented bioswales to treat urban stormwater around parking lots and roads (Mazer, 2001, Weber, 2007).

The treatment goal for bioswales in King County, in Washington State was 80% removal of total suspended solids (TSS). Treatment efficiencies documented for bioswales and sections of grassed waterways (including roadside swales) have been described to be 60–99% removal of TSS, 21– 91% removal of metals, and 7.5 to more than 80% removal of total phosphorus (Yousef et al., 1985). Treatment efficiency greatly depends upon inflow rate and pollutant concentration, both of which tend to vary considerably in storm-water runoff (Tarutis et al., 1999).

Table 1. Plant species commonly planted in bioswales in United States

Position in the bioswale			
Bottom ground-layer	Sides slopes Ground-layer	Sides slopes understory	Sides slopes overstory
Agrostis tenuis	*Bromus carinatus*	*Cornus stolonifera*	*Cornus stolonifera*
Carex densa	*Deschampsia cespitosa*	*Crataegus douglasii*	*Crataegus douglasii*
Carex obnupta	*Elymus glaucus*	*Lonicera involcrata*	*Lonicera involcr*
Deschampsia cespitosa	*Festuca occidentalis*	*Oemlaria cerasiformis*	*Lonicera involcrata*
Eleocharis palustris		*Physocarpus capitatus*	*Oemlaria cerasiformis*
Epilobium densiflorum		*Rosa nutkana*	*Physocarpus capitatu*
Hypericum anagalloides		*Rosa pisocarpa*	*Rosa nutkana*
Juncus acuminatus		*Salix scouleriana*	*Rosa pisocarpa*
Juncus effusus		*Salix sitchensis*	*Salix scouleriana*
Juncus tenuis		*Sambucus racemosa*	*Salix sitchensis*
Mimulus guttatus		*Spiraea douglasii*	*Sambucus racemosa*
Potentilla gracilis		*Symphoricarpos albus*	*Spiraea douglasii*
Ranunculus alismifolius			
Ranunculus occidentalis			

Davis et *al.*, 2003, investigated the effectiveness for removing low levels of lead, copper, and zinc from synthetic stormwater runoff using pilot-plant laboratory bioretention systems and two existing bioretention facilities in Maryland US. They found removal rates close to 100% for all metals under most conditions, with effluent copper and lead levels mostly less than 5 µg/L and zinc less than 25 µg/L. Runoff pH, duration, intensity, and pollutant concentrations were varied, and all had minimal effect on removal. The two field investigations generally supported the laboratory studies. Overall, excellent removal of dissolved heavy metals can be expected through bioretention infiltration.

CONCLUSION

Ecological engineered systems such as constructed wetlands and bioswales are a sustainable option to control surface runoff. These systems use natural process to improve water quality in surface runoff, they are cheap to construct and require low maintenance, and relay in renewable energy sources. Construction and creation of wetlands are an important practice of ecological engineering and the effectiveness of these systems to remove nutrient and pollutants from surface run off has been proved manly in developed European countries and United States, but information about their use in developing countries is scare. Construction of bioswales has been practiced in the US and Canada to control urban runoff, however there are few peer review papers about the evaluation of their treatment efficiency, also little information is available about the using of bioswales in other parts of the world.

6. REFERENCES

Allen, T. F. H., Giampietro, M. & Little, A. M. (2003). Distinguishing ecological engineering from environmental engineering. *Ecological Engineering*, *20*, *5*, 389-407.

Barrett, K. R. (1999). Ecological engineering in water resources: The benefit of collaborating with nature. *Water International*, *2*, *3*, 182-188.

Bergen, S. D., Bolton S. M. & Fridley, J. L. (2001). Design principles for ecological engineering. *Ecological Engineering*, *18*, 201-210.

Braskerud, B. C. (2002). Factors affecting nitrogen retention in small constructed wetlands treating agricultural non-point pollution. *Ecological Engineering*, *18*, 351-370.

Brattebo, B. O. & Booth, D. B. (2003). Long-term stormwater quantity and quality performance of permeable pavement systems, *Water Research*, *37*, 4369-4376.

Brix, H. (1996). Do macrophytes play a role in constructed treatment wetlands? *Water Science and Technolohy*, *35*, *5*, 11-17

Chen, Y. S., Lin, L. S., Viadero, R. C, & Gang D. C. (2007). Nonpoint source pollution. *Water Environmental Research*, *79*, *10,* 2032-2048.

Davis, A. P., Shokouhian, M., Sharma, H., Minami, C. & Winogradoff, D. (2003). Water quality improvement through bioretention: Lead, copper, and zinc removal. *Water Environment Research*, *75*, *1,* 73-82.

Day, J. W. Jr., Martin, J. F., Cardoch, L. & Templet, P. H. (1997). System functioning as a basis for sustainable management of deltaic ecosystems *Coastal Management*, *25*, 115-153.

Fink, D. & Mitsch, W. J. (2004). Seasonal and storm event nutrient removal by a created wetland in an agricultural watershed. *Ecological Engineering*, *23*, 315-325.

Grant, R. & Mathiesen, G. B. (2004). Danish policy measures to reduce diffuse nitrogen emissions from agriculture to the aquatic environment. *Water Science and Technology*, *14*, *49*, 91-100.

Goolsby, D. A., W. A. & Battaglin, W. A. (2001). Long-term changes in concentrations and flux of nitrogen in the Mississippi River Basin, USA. *Hydrological Processes*, *15*, 1209-1226.

Harrington, R., Dunne, E. J., Carroll, P., Keohane, J. & Ryder, C. (2005). The concept, design and performance of integrated constructed wetlands for the treatment of farmyard dirty water. In E. J., Dunne, K. R. Reddy, & O. T. Carton, (Eds*). Nutrient Management in Agricultural Watersheds: A Wetlands Solution* (first edition, p. 179–88). Wageningen, the Netherlands: Wageningen Academic Publishers.

Hammer, D. A. (1992). *Creating freshwater wetlands*. (First edition) Chelsea MI: Lewis Publishers , Inc.

Hoagland, C., Gentry, L., David, M. & Kovacic, D. (2001). Plant nutrient uptake and biomass accumulation in a constructed wetland. *Journal of Freshwater Ecology*, *16*, 527-540.

Hoffmann, C. C. & Baattrup-Pedersen, A. (2006). Re-establishing freshwater wetlands in Denmark. *Ecological Engineering*, *20*, *2*, 157-166.

Hottenroth, D., Harper, C. & Turner, J. (1999). Effectiveness of integrated stormwater management in a Portland Oregon Watershed. *Journal of the American Recourses Association*, *35*, *3*, 633-641.

Iamchaturapart, J., Yi, S. W. & Rhee, J. S. (2007). Nutrient removals by 21 aquatic plants for vertical free surface-flow (VFS) constructed wetland. *Ecological Engineering*, *29*, 287-293.

Jorgensen, S. K. & Nielsen, S. N. (1996). Application of ecological engineering principles in agriculture. *Ecological Engineering*, *7*, *4*, 373-381.

Kadlec Robert, H. & Robert, L. Knight. (1996). *Treatment Wetlands*. (First edition). Ann Arbor, MI: Lewis Publishers Inc.

Kangas, P. (2004). *Ecological engineering: Principles and Practice*. (First edition). Boca Raton FL:CRC Press.

Kellls, J. A. & Warner, B. G. (2000). The emergence of Ecological Engineering and green technology. *The Canadian Civil Engineer*, *17*, 11-13.

Kovacic, D. A., David, M. B., Gentry, L. E., Starks, K. M. & Cooke, R. A. (2000). Effectiveness of constructed wetlands in reducing nitrogen and phosphorus export from agricultural tile drainage. *Journal of Environmental Quality*, *29*, 1262-1274.

Knight, R. L., Walton, W. E., O´Meara, G. F., Reisen, W. K. & Wass, R. (2003). Strategies for effective mosquito control in constructed treatment wetlands. *Ecological Engineering*, *21*, 211-232.

Larson, A. L., Gentry, M., David, R., Cooke, L. & Kovacic, D. (2000). The role of seepage in constructed wetlands receiving agricultural tile drainage. *Ecological Engineering, 15*, 91-104.

Mazer*, G.*, Booth, D. & Ewing, E. (2001). Limitations to vegetation establishment and growth in biofiltrationn swales. *Ecological Engineering*, 17, 429-443.

Miklas, S., Harrington, R., Carroll, P. & Mustafa, A. (2007). The integrated constructed wetlands (ICW) concept. *Wetlands*, *27*, 337-354.

Mitsch, W. J. & Jørgensen, S. E. (1989). Introduction to ecological engineering. In: W. J. Mitsch, & S. E. Jørgensen, (Eds.), *Ecological Engineering: An Introduction to Ecotechnology*. (First edition, 3-12) New York , NY: John Wiley & Sons.

Mitsch, W. J. (1992). Landscape desing and the role of created, restored and riparian wetlands controlling non point source pollution. *Ecological Engineering*, *1*, 27-47.

Mitsch, W. J. (1997).Ecological Engineering: The roots and rationale of a new Ecological Paradigm. In: Etnier, C. and Guterstam, B. (Eds). *Ecological engineering for wastewater treatment* (First edition, 1-20). Boca Raton FL:CRC Press/Lewis Publishers.

Mitsch, W. J., John, W. Day, Jr., Gilliam, W. J., Groffman, P. M., Hey, D. L., Gyles. C., Randall, W. & Wang, N. (2001). Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent ecological problem. *BioScience*, *51*, 373-388.

Mitsch, W. J. & Jorgensen, S. E. (2003). Ecological engineering: a field whose time has come. *Ecological Engineering*, *20*, 363-377.

Mitsch, W. J. & Jorgensen, S. E. (2004). *Ecological Engineering and Ecosystem Restoration*. (First edition). New York, NY: John Wiley & Sons.

Mitsch, W. J. & Day, J. W. Jr. (2006). Restoration of wetlands in the Mississippi-Ohio-Missouri (MOM) River Basin: Experience and needed research. *Ecological Engineering*, *26*, 55-69.

Mitsch, W. J., Day, J. W. Jr., Zhang, L. & Lane, R. (2005). Nitrate-nitrogen retention by wetlands in the Mississippi River Basin. *Ecological Engineering*, *24*, 267-278.

Odum, H. T., Silver, W. L., Beyers, R. J. & Amstrong, N. (1963). Experiments with engineering of marine ecosystems.*Publ. Inst. Mar. Sci. Univ Texas*, *9*, 374-403.

Odum, H. T., (1996). Scales of ecological engineering. *Ecological Engineering*, *6*, 7-19.

Phipps, R. G. & W. G. Crumpton. (1994). Factors affecting nitrogen loss in experimental wetlands with different hydrologic loads. *Ecological Engineering*, *3*, 399-408.

Sanville, W. & Mitsch W. J. (eds.). 1994. Creating Freshwater Marshes in a Riparian Landscape: Research at the Des Plaines River Wetland Demonstration Project. Special Issue of *Ecological Engineering*, *3*, *4*, 315-521.

Schueler, Thomas. (1992). Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetland Systems in the Mid-Atlantic Region. Metropolitan Washington Council of Governments (WASHCOG), *Department of Environmental Programs*.

Tarutis, W. J., Stark, L. R. & Williams, F. M. (1999). Sizing and performance estimation of coal mine drainage wetlands. *Ecological Engineering*, *12*, 353-372.

Teal, J. M. (1997). Contributions of marshes and salt marshes to ecological engineering.

In: Etnier, C. and Guterstam, B. (Eds). *Ecological engineering for wastewater treatment* (First edition, pp. 175-182) Boca raton FL:CRC Press/Lewis Publishers.

Urbanska, K. M., Wedd, N. R. & Edwards, P. J. (1997). Why restoration? In: K. M., Urbanska, N. R. Wedd, & P. J. Edwards, (Eds). *Restoration Ecology and Sustainable Development*. (First edition, pp. 3-8) Cambridge UK: Cambridge University Press.

Weber, S. L. (2007). Evaluation of two Washington State Department of Transportation stormwater Facilities along State Rout18 Highway. Professional Project Report. *Master Degree University of New Mexico*.

Wood, A. (1995). Constructed wetlands in water pollution control: Fundamentals to their understanding. *Water Science Technology*, *32*, *3*, 21-29.

Yousef, Y. A., Wanielista, M. P. & Harper, H. H. (1985). Removal of highway contaminants by roadside swales. *Transportation Research Record*, *10*, *17*, 62-68.