Applications of Constructed Wetlands for Wastewater Treatment

Xi Jiang
CE 521
Term Paper
11/27/2005

Application of Constructed Wetlands for Wastewater Treatment

Xi Jiang

ABSTRACT

During the past decades, the high cost of conventional treatment processes has produced much economic pressure and they are not as natural methods as we expected. Thus, engineers begin to search for some creative, cost effective, and environmentally sound ways to treat wastewaters. Constructed wetland is a man made system which provides us many benefits and it is a very attractive way for many wastewaters treatment applications. Its mechanism of treatment is useing physical, chemical and biological processes separately or corporately. High efficiency of removal can be achieved for many kinds of contaminants, such as suspended solids, organic carbon, nitrogen, phosphorus, metals, and toxic organic compounds. And this kind of system could be used by a large range of users including governmental departments and agro-based industries in treating wastewaters before it is discharge into natural waterways. Except above virtues, constructed wetlands also serve as a wildlife sanctuary and provide habitat for wildlife, which satisfy us on the ecology aspect. This wastewater treatment system also can recreate publics, and can be an attractive destination for tourists or be a basic education center about natural ecosystem for researchers to study as well. However, constructed wetlands still have some limitations, for example, they cannot treat wastewaters with very high concentrations of contaminants and its treatment efficiency is considerably affected by climate or environmental conditions. What is more, compared with other traditional processes, it always takes longer time during the treatment process. Nevertheless, constructed wetlands treatment is considered to be the best choice for many kinds of wastewater treatment or pretreatment of wastewaters because of the low build and maintenance costs, high removal efficiency of contaminations, and simplicity of operation.

KEYWORDS

Constructed wetlands, wastewater treatment, benefits, applications, developments

Introduction

Various wastewaters discharged from industry, municipal and agriculture sources pollute both surface and groundwater, and need to be treated to qualify the federal, state and local regulations. Thus, we have to think about some methods not only meet the effective treatment requirements, but economic requirements as well.

Constructed wetlands provide us a quite attractive solution for many kinds of wastewater treatment applications. Constructed wetlands are man-made systems designed, constructed and operated to remediate various kinds of polluted waters. And their functions to improve water quality through physical, chemical and biological processes separately or corporately accord to the different conditions. Moreover, constructed wetlands also offer us a low-cost, natural treatment for wastewaters from small towns and big cities' industry, municipal and agriculture sources. Typically, construction and operating costs range from 10% to 50% as costly as comparable traditional wastewater treatment systems. (Gearheart, 1999)

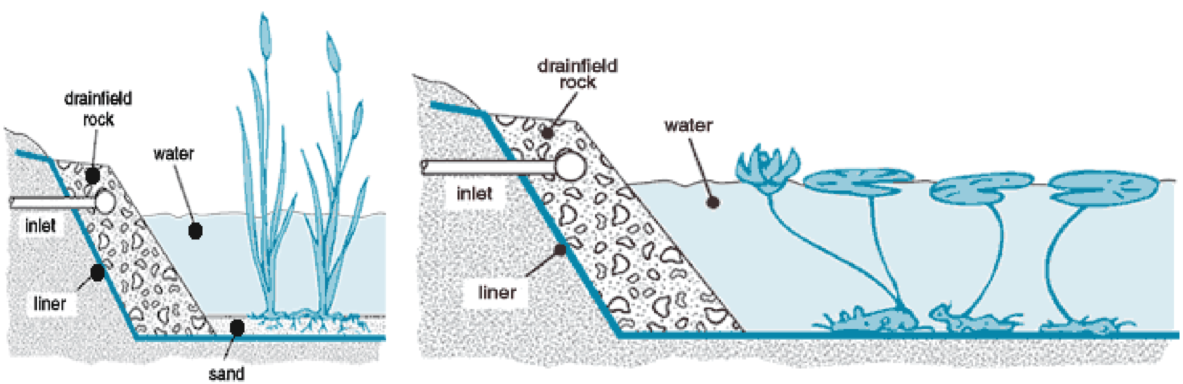
Why create a wetland to treat wastewater

Constructed wetlands provide us an attractive solution for wastewater treatments

Constructed wetlands are man-made wetlands designed to improve water quality. They are used for industrial, municipal and agricultural wastewater, specifically saying are storm water run-off, landfill leachate, acid mine drainage, surface and ground water contaminated by agriculture fertilizer.

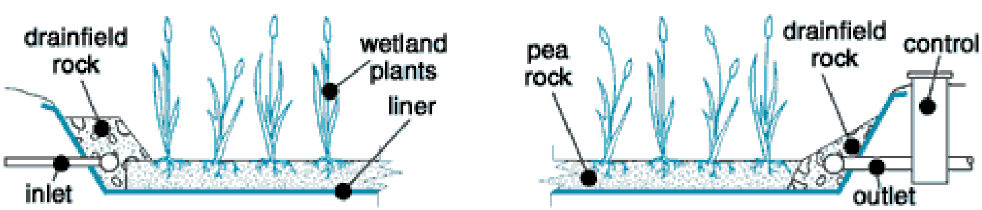
There are two basic types of Constructed wetlands: surface flow wetlands (also know as free water wetlands) and subsurface flow wetlands. (HYDRA Aquatic, 2004)

Figure 1



Surface flow wetlands (open water SF) Surface flow wetlands (hydroponics SF)

Figure 2



Subsurface flow constructed wetland (Anderson et al., 2002)

Wetlands are used in common and it seems to be the best choice for wastewater treatment not only for its effective function, but have lower operation and maintenance costs as well. Personally, I hold that except the previous virtues, its character as a pure natural system is another important advantage which complies with the new concept of protecting our ecosystem by the most natural way.

Benefits of constructed wetlands on various aspects

Economic benefit

First, let's comprehend the basic concept of value within economy area fully. The value concept related to economy area means exchange value and is a basic constituent of relationship marketing. Since money is the medium of exchange, the value of the benefit is generally determined by its price-is the quantity of money for which it will be exchanged. (Ravald and Grönroos, 1996) On the other hand, the value of a benefit is not simply the price showed in the open markets. It is, to some extent, the worth of that benefit to a potential buyer. This is measured in economic terms as willingness to pay. The ability to provide superior value to customers is a prerequisite when trying to establish and maintain long-term customer relationships. (Environment Canada, 2001)

Think about the concept of value from another angle out of markets area, it is easily find that we should add other economic benefits which wetlands can bring to us at the same time, such as social benefit, natural benefit and other related productions' benefit. For example, trends such as the growing demand for ecologically certified wood products, organic/green foods, non-toxic cleaners, and other goods and services with an environmental advantage, suggest that there is increasing market recognition of the economic value of preserving natural areas and processes. (Environment Canada, 2001)Thus, we should not measure the value of wetlands only focus on the markets concept, but the other economic benefits the constructed wetlands can provide us as well.

Ecological benefit

Compare to other wastewater treatment systems, constructed wetland can be regarded as the most natural system. Although there are not many accurate documents can certify constructed wetland are good for increasing wildlife, the potential benefits of ecology can not be ignored at least. The most exciting thing is they can offer us a perfect chance to get valuable information about how wetlands work generally and about how plant and animals species interact within a wetland environment. In other words, constructed wetlands can solve the limitations on available researches of ecosystems.

Both scientists and the general public can benefit from access to wetland environments, especially when constructed wetlands are well designed, for example, boardwalks are built. Constructed wetlands also bring us a lot of fun, such as hiking, biking, and depending on the water depth and quality, even boating and canoeing. (Smith and Moore, 1993)

Figure 3

Biological productivity (Black Tern) / John Mitchell

Other benefits

"There are bioeconomic linkages among wetland functions, services generated by those functions, and socially valued outcomes." (Wetlands and Agriculture, 1997)

According to the quality and characteristics of the constructed wetlands, byproduct or joint product will be produced during the wetlands function process. And these kinds of production can also provide us benefits in varying degrees. For example, sediments and nutrition elements appearing during the constructed wetland functional process can nourish fish and other aquatics, even some of them are traded in market. Moreover, many other byproducts which have a great of marketing potentials are not traded on the market now, but economists have already do some researches on these aspects and started to estimating the economic values of these non-market byproducts. Generally speaking, marketed goods and services provide mainly private benefits, while non-marketed goods and services provide mainly public (social) benefits.

<u>How constructed wetlands treat wastewater</u>

Mechanism of constructed wetlands treating wastewater

Constructed wetlands function through the combination of three basic processes: physical, biological, and chemical. All of these treatment process work simultaneously, thus, the most important factors which affect the efficiency of wastewater treatment are the characteristics of the wastewater and the amount of time spent in the constructed wetland system.

Here, I want to indicate the principles of the three processes separately as the following.

Physical treatment process --- this is a process mainly related to the water flow. When the wastewater flow slowly down to the constructed wetlands, it will spread across the whole surface of the wetlands, and then allows soil and sediment particles to filter or physically settle out. During this process, nutrients, such as phosphorous, nitrogen and other chemicals are attached to the sediments. Although it is just physically remove those of things, it shows a quite visible effect to us.

Biological treatment process --- this is a process functions depends on plants stems and roots surface areas. Plant stems and roots provide enough areas to support communities of microorganisms which use the nutrients and organic matter in the wastewater to survival. For example, microorganisms on the plant stems can convert organic nitrogen to the inorganic ammonium nitrogen form. And other biological treatments involve plant uptake of nutrients, such as nitrates and phosphates. (Smith and Moore, 1993)

Chemical treatment process --- occurs when incoming compounds react with oxygen or soil minerals in the wetland. The most important two factors affect this process's rate and extents are the constructed wetlands acidity and other related environmental conditions. For example, if the wetlands have high concentrations of ferrous iron, a chemical transformation can occur between the iron and incoming sulfides, forming insoluble ferrous sulfide, which settles to the bottom of the wetland. The characteristics of soil in wetlands system have partly responsible for the highly efficient way in which they treat water. Specifically speaking, it is the layer of an oxygen-containing soil (aerobic soil) above a layer without oxygen soil (anaerobic soil) that supports much of these degradation and transformation processes. This layer, a very large area indeed, is called the rhizosphere and is where much biological and chemical activity occurs. (Smith and Moore, 1993) It provides a circumstance for a wide specious of oxygen-using aquatic organisms, some of which directly or indirectly consume additional nutrients in the runoff water. Many complex reactions occurring because of interface arrangements of the aerobic and anaerobic layers.

Just because all of these three treatment processes function together and simultaneously, as the water flows out of the wetlands, the water's nitrate, phosphorus, sulfur, other organic compounds and bacterial content can be greatly removed. And many other kinds of water pollutants can be reduced in constructed wetlands through these three processes as well.

Incorporate physical, biological, and chemical processes

Suspended Solids Removal

Well designed constructed wetlands have a really high removal efficiency of suspended solids from the wastewater. Those suspended solids probably contain a number of contaminants, such as nutrients, organic compounds and even heavy metals. And the contaminants may originally in a particulate form or may be bound to the particular matter through physical or chemical way. Thus, when bulk of contaminants combined with particular matter, physical settling of suspended solids will occur, in other words, the contaminants will be efficient removal from the wastewater.

In environmental engineering area, we often use total suspended solids (TSS) to indicate the concentration of suspended solids in the wastewater, whose unit is milligram per liter. “To measure TSS, the water sample is filtered through a pre-weighed filter. The residue retained on the filter is dried in an oven at 103 to 105° C until the weight of the filter no longer changes. The increase in weight of the filter represents the total suspended solids. TSS can also be measured by analyzing for total solids and subtracting total dissolved solids.” (Murphy, 2002)

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the amount of material dissolved in the water and wastewater. Such as carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. Many of these materials may not be considered contaminants, contribute to the sum total of dissolved solids.

TDS measurement is usually used to estimate the quality of drinking water, because it can represent the amount of ions in the water. High TDS in water will cause a bad taste and high water hardness, and could result in a laxative effect to some extent. To measure TDS, the water sample is filtered, and then the filtrate (the water that passes through the filter) is evaporated in a pre-weighed dish and dried in an oven at 180° C, until the weight of the dish no longer changes. The increase in weight of the dish represents the total dissolved solids, and is reported in milligrams per liter (mg/l). (Murphy, 2002) TDS can also be determined by measuring individual ions and adding them up.

A certain level of ions in water is really necessary for aquatic life and they are biologically utilized or chemically reactive in wetlands. But, TDS often contains very high concentrations of unreactive dissolved compounds, which cannot be removed in wetlands. For example, wetlands have effect on the concentration of sodium and chloride ions, or more commonly, on salinity levels. Therefore, reduction of TDS concentrations in wetlands is usually not significant despite high removal rates of fixed contaminants. (DeBusk, 1997)

Organic Carbon (BOD) Removal

A wide array of microorganisms uses organic matter as a source of energy to survival. And there is approximately 45-50% carbon in those organic matters. During the process of growth, a great number of microorganisms need to consume oxygen to break down organic carbon to carbon dioxide, in order to provide energy. Thus, when release excessive amount of organic carbon to surface water, it can result in a significant consume of oxygen and the subsequent result is there are more fish or other aquatic depended on oxygen will die.

Wetlands contain a large number of organic carbon-utilizing microorganisms that adapted to the aerobic (O_2-rich) surface waters and anaerobic (O_2-depleted) soils. Thus, wetlands are capable of highly effective removal of organic compounds from a variety of wastewaters. In wetlands organic C is broken down to CO_2 and methane (CH_4), both of which are release to the atmosphere. Wetlands also store and recycle copious amounts of organic C, contained in plants and animals, dead plant material. Therefore, wetlands tend to be natural producers of organic carbon as a result of degradation of organic matter into fine particulate matter and dissolved compounds. (DeBusk, 1997)

Biological Oxygen Demand (BOD) is a measure of the oxygen used by microorganisms to decompose this waste. If there is a large quantity of organic waste in the water supply, there will also be a large amount of bacteria exist to decompose this organic matters in wastewater. Thus, the demand for oxygen will be high and the BOD level will be high as well. The BOD test is done by taking a water sample and keeping it cool and dark for five days so as not to stimulate algal growth. Then take a water sample from the same site after five days. Perform a dissolved oxygen test on both samples and subtract the two results so see how much oxygen was used during the time period. (Texas Environmental Center, 1995)

Nitrogen Removal

Nitrogen (N) can be found in most wastewater from various sources, such as municipal, industrial and agriculture wastewater. Although nitrogen-containing compounds act as nutrients in streams and rivers, high concentrations of nitrate in drinking water can cause many problems. One problem is that nitrate reactions (NO^{3-}) in fresh water can cause oxygen depletion, thus, aquatic organisms depending on the supply of oxygen in the stream will die. And nitrites can produce a serious condition in fish called "brown blood disease." as well. Another problem is that nitrites also can react directly with hemoglobin in human blood and other warm-blooded animals to produce methemoglobin. Methemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious in babies under three months of age. It causes a condition known as methemoglobinemia or "blue baby" disease.

Wetlands are commonly well-suited for N removal, though the natural background level of total N in wetland outflows is usually greater than 1 mg/L. “As with organic carbon in wetlands, it is common for organic N compounds to be exported as a consequence of naturally-occurring organic matter decomposition within the wetland.” (DeBusk, 1997) And N is usually removed through setting of N-containing particulate matter in the wetlands inflow. What is more, since N is an essential plant nutrient, it also can be removed through plant uptake of ammonium or nitrate, and stored in organic form in wetland vegetation. Then, large portion of those N can be released or recycled as plants die and decompose.

Nitrification and denitrification are the two important nitrogen transformation processes that require aerobic and anaerobic conditions respectively in order to get maximum transformation rates. Providing aerobic and anaerobic conditions alternatively would help maximize the nitrogen transformation and hence removal from wetlands. The condition of keeping the wetland system dries (primarily aerobic) and wet (primarily anaerobic) becomes a key point in maximizing nitrogen removal. (Fedler et al., 2002)

Phosphorus Removal

Same as nitrogen, Phosphorus (P) is another important plant nutrient, thus, excess P will cause eutrophication problem in lakes and coastal waters. In most cases, wetlands can not removal P efficiently as nitrogen removal, which is because lack of a metabolic pathway for P removal compared with denitrification for N removal. But, wetlands can still remove P from wastewater quite well through a combination of physical, chemical and biological processes.

Orthophosphate is the predominant inorganic form of P in surface waters and wastewaters, and it readily accumulates in wetland vegetation and soils, as a result of biological uptake and chemical bonding. Formation of iron and aluminum phosphate minerals (low-pH wetlands) and calcium phosphate minerals (high-pH wetlands) is the major pathway for P removal in some constructed wetlands. Particulate organic P may be removed by settling from the water column. Both dissolved and particulate organic P may be biologically broken down into inorganic P (mineralization), and subsequently removed through both biological and chemical processes. (DeBusk, 1997)

Trace Metals Removal

Although small amount of metals are required for plant or animal growth, but if those metals, such as copper, selenium and zinc are in high concentration, the waters or wastewater will be toxic. Other metals, such as cadmium, mercury and lead, which can be found in many types of wastewater, have no biological benefits, and they are toxic even in a quite low concentration. What's more, certain metals can lead to a biomagnification effect, which can cause serious health hazards to higher organisms and even humans.

Removal of metals in constructed wetlands may occur through a serious of processes, on physical and biological aspects:

1. Plant uptake
2. Soil adsorption (primarily to organic substances in the wetlands.)
3. Co-precipitation with iron oxyhydroxides
4. Precipitation (formation of solid compounds, like metal sulfides.)

Uptake rates and tolerance of metals are quite different among plant species. Some are known as having strong capable of high concentration of metals in roots and other tissues, like terrestrial plant. And metals may also tend to accumulate on the root surface of plants rather than being absorbed into the plant root or tissues.

Constructed wetlands' performances on metals removal vary a lot depend on different types and test time during the year. "Based on a limited data set for treatment wetlands, metals removal efficiency is potentially very high, but also highly variable among sites. For example, reported mass removal efficiencies were 75-99% for cadmium, 40-96% for copper, 0-86% for lead, 49-88% for nickel, and 33-96% for zinc." (DeBusk, 1997)

Toxic Organic Compounds Removal

Municipal, industrial and agriculture wastewaters contain variable concentrations of synthetic organic compounds. And a more disturbing observation is that persistent, toxic compounds are found to accumulate in food chains because of the tendency of the compounds to be fat soluble.

Organic compounds can be removed from solution in an aqueous system by serious mechanisms, they are: biological, chemical, photochemical alternatives, and physicochemical processes such as absorption, sedimentation, and evaporative stripping. Among these mechanisms, biological degradation of easily degraded organic compounds is considered the most important. Microbes are considered to be capable of degrading most classes of organic pollutants, but the rate of degradation varies considerably, mainly depending on chemical and structural properties of the organic compounds, and the physical environment of the wetlands.

Till now, studies have been reported that treatment of PCBs, lindane, pentachlorophenol and atrazine are successfully by constructed wetlands. In some cases, actual removal processes – like sediment retention or microbial degradation -- were not determined. However, there is substantial evidence that pentachlorophenol breaks down readily under the alternating aerobic and anaerobic conditions found in wetland soils. (DeBusk, 1997)

Limits and drawbacks of constructed wetlands treat wastewater

The main limits of constructed wetlands are as the flowing:

- Large area's land use
- Limitations on wastewater characteristics
- Limitations on climate conditions
- Local permitting authorities

Before construction of wetlands starts, we should think about the area's land use first, because not every city or town is fit for this kind of wastewater treatment system. We have to consider whether constructed wetlands will fit to the setting in this part of the community while still providing efficient treatment with low maintenance requirements. And wetlands always require large land areas.

A wetlands treatment system will fail if it is loaded with heavy solids or wastewater with high concentration of organics matter. When these conditions are appear, the wastewater cannot be treated directly by wetlands, in other words, it is usually pretreated at another facility.

Since the constructed wetlands always open to the air (especially, surface flow type), in other words, these kinds of systems are more or less affected by climate conditions. Thus, what we concern a lot is how we can make them function well in cold as well as warm climates.

In addition, local permitting authorities should be consulted prior to designing and maintaining constructed wetland systems in order to determine if any local regulations apply to their use or maintenance. Except technical problems, questions about nuisances as potential odors and mosquitoes also have to be considered.

The future applications and developments

Constructed wetlands have been used extensively and successfully to treat many types of wastewater and runoff. A number of contaminants, such as suspended solids, nutrients, metals and organic compounds can be removed efficiently. And wetlands treatment is always considered to be the best choice for various wastewaters because of the low maintenance costs and simplicity of operation.

The future applications and developments of constructed wetlands will focus on the aspects as the following:

Application of constructed wetlands to treat various wastewaters must be free of unreasonable risks to public health. Pathogenic organisms may be present in both wastewaters and sludges and their control is one of the fundamental reasons for waste management. Constructed developers have found how important role the public perceptions play in whether or not a wetland wastewater treatment system is ever built. With this mind, they have to dedicate their efforts to make the public informed of the many benefits a constructed wetland can have for a community. For example, they pay more attention to aesthetic and recreational opportunities so the publics can enjoy constructed wetlands. Such improvements on the public benefits are valuable assets that go a long way toward helping the proposed wetlands gain the necessary permits and municipal approval.

On the other hand, the designers are still trying to do some research to make constructed wetlands more efficient and can be functional with fewer limitations. For example, many efforts are made on recognize the relationship between hydrology and ecosystem characteristics, and try to decrease the limitations on geographic and environmental conditions, such as source of wastewaters, velocity, climates, and frequency of inundation.

Summary and Conclusion

Constructed wetlands have been used successfully and extensively to treat many types of wastewaters. High efficiency of removal can be achieved for many kinds of contaminants, such as, suspended solids, nutrients, metals and organic compounds. And this kind of system can tolerant to various pollutants and could be used by a large rang of users including governmental departments and agro-based industries in treating wastewaters before it is discharge into natural waterways, like river and lake. And except above virtues, constructed wetlands also serve as a wildlife sanctuary and provide habitat for wildlife. This wastewater treatment system can recreate publics, and can be an attractive destination for tourists or be a basic education center about natural ecosystem for researchers to study as well.

Although, constructed wetlands have many benefits and virtues, they still get some inherent limitations to treat all kinds of wastewaters. For example, they may not they cannot be used to treat the wastewater which has very high concentration of contaminations. And the effect and efficiency of treatment are quite unstable due to different climate and environmental conditions. What is more, compared with other traditional wastewater treatment methods, they usually take far more time to function. Nevertheless, constructed wetlands treatment are considered to be the best choice for many kinds of wastewater treatment or pretreatment of wastewaters because of the low build and maintenance costs and simplicity of operation.

References

J.A.Moore. (1993) Using constructed wetlands to improve water quality. *Water Quality*. **8**, 14

Ravald A. and Grönroos C., 1996. The value concept and relationship marketing. *European Journal of Marketing,* **30**, 19

C.B. Fedler, P.Sahu, and T.L. White, 2002. Improving Wastewater Nitrogen Removal in Wetlands. Written for presentation at the 2002 ASAE/CIGR International Meeting (Chicago, Illinois)Sponsored by THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Tanner, C.C., 2001. Plants as ecosystem engineers in subsurface-flow treatment wetlands. *Water Sci. Technol.* **44**, 9

Giraldo, E. and Zarate, E., 2001. Development of a conceptual model for vertical flow wetland metabolism. *Water Sci. Technol.* **44**, 273

Arthur F. M. Meuleman, Richard van Logtestijn, Gerard B. J. Rijs and Jos T. A. Verhoeven. (2002) Water and mass budgets of a vertical-flow constructed wetland used for wastewater treatment. *Ecological Engineering*. **20**, 31

Merlin, G., Pajean, J.L. and Lissolo, T., 2002. Performances of constructed wetlands for municipal wastewater treatment in rural mountainous area. *Hydrobiologia* **469**, 87

Brix, H., Arias, C.A. and del Bubba, M., 2001. Media selection for sustainable phosphorus removal in subsurface flow constructed wetlands. *Water Sci. Technol.* **44**, 47

Verhoeven, J.T.A. and Meuleman, A.F.M., 1999. Wetlands for wastewater treatment: opportunities and limitations. *Ecol. Eng.* **12**, 5

Gervin, L. and Brix, H., 2001. Removal of nutrients from combined sewer overflows and lake water in a vertical-flow constructed wetland system. *Water Sci. Technol.* **44**, 171

Demin, O.A., Dudeney, A.W.L. and Tarasova, I.I., 2002. Remediation of ammonia-rich minewater in constructed wetlands. *Environ. Technol.* **23**, 497

Knight, R.L., Ruble, R.W., Kadlec, R.H. and Reed, S., 1993. Wetlands for wastewater treatment: performance database. In: Moshiri, G.A., Editor, 1993. *Constructed Wetlands for Water Quality Improvement*, Lewis Publishers, Boca Raton, USA, 35

D. Smith and J.A. Moore. (1993) Understanding Natural Wetlands. *Water Quality*. **7**, 41

Graneli, W., Weisner, S.E.B. and Sytsma, M.D., 1992. Rhizome dynamics and resource storage in *Phragmites australis*. *Wetlands Ecol. Manag.* **1** 4, 239