The use of Constructed Wetlands

for Wastewater Treatment

Published by

WETLANDS INTERNATIONAL

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Website: www.wetlands.org

Financially supported by

Ford Motor Company

Conservation & Environmental Grants

First Edition 2003

ISBN 983-40960-2-X

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ISBN 983-40960-2-X

Compiled by Sim Cheng Hua

Designed by www.WirePortfolio.com

Colour separation by Central Graphic

Printed and bound by Polar Vista Sdn. Bhd.

Sim, C.H. 2003. The use of constructed wetlands for wastewater treatment.
Wetlands International - Malaysia Office. 24 pp.

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Foreword

Constructed wetlands have only recently been developed in Malaysia for stormwater and wastewater treatment. The largest and most widely publicised example is the constructed wetland system for stormwater treatment at Putrajaya. Not only is this a very impressive system which has enhanced the visual landscape of the new city, but it is complemented by an excellent Nature Interpretation Centre which raises public awareness of the value of both natural and constructed wetlands.

The climatic conditions and nutrient rich soil in Malaysia are ideal for plant growth and there is considerable potential for the development and use of constructed wetlands as a sustainable method of wastewater treatment. To achieve this objective there is a need for human capacity training in the design, operation, monitoring and maintenance of constructed wetlands. This booklet provides a valuable introduction to constructed wetlands and it will raise awareness of their value among environmental professionals. The next step is to develop staff training and guidance manuals to ensure that constructed wetlands achieve their optimum performance.

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Introduction to constructed wetland systems

Wetlands, either constructed or natural, offer a cheaper and low-cost alternative technology for wastewater treatment. A constructed wetland system that is specifically engineered for water quality improvement as a primary purpose is termed as a 'Constructed Wetland Treatment System' (CWTS). In the past, many such systems were constructed to treat low volumes of wastewater loaded with easily degradable organic matter for isolated populations in urban areas. However, widespread demand for improved receiving water quality, and water reclamation and reuse, is currently the driving force for the implementation of CWTS all over the world.

Recent concerns over wetland losses have generated a need for the creation of wetlands, which are intended to emulate the functions and values of natural wetlands that have been destroyed. Natural characteristics are applied to CWTS with emergent macrophyte stands that duplicate the physical, chemical and biological processes of natural wetland systems. The number of CWTS in use has very much increased in the past few years. The use of constructed wetlands in the United States, New Zealand and Australia is gaining rapid interest. Most of these systems cater for tertiary treatment from towns and cites. They are larger in size, usually using surface-flow system to remove low concentration of nutrient (N and P) and suspended solids. However, in European countries, these constructed wetland treatment systems are usually used to provide secondary treatment of domestic sewage for village populations. These constructed wetland systems have been seen as an economically attractive, energy-efficient way of providing high standards of wastewater treatment.

Typically, wetlands are constructed for one or more of four primary purposes: creation of habitat to compensate for natural wetlands converted for agriculture and urban development, water quality improvement, flood control, and production of food and fiber (constructed aquaculture wetlands). In this booklet, the uses of constructed wetlands for wastewater treatment or water quality improvement is discussed in detail.

Advantages of constructed wetland treatment systems

Constructed wetland treatment systems are a new technology for Malaysia. It is a cheaper alternative for wastewater treatment using local resources. Aesthetically, it is a more landscaped looking wetland site compared to the conventional wastewater treatment plants. This system promotes sustainable use of local resources, which is a more environment friendly biological wastewater treatment system.

Constructed wetlands can be created at lower costs than other treatment options, with low-technology methods where no new or complex technological tools are needed. The system relies on renewable energy sources such as solar and kinetic energy, and wetland plants and micro-organisms, which are the active agents in the treatment processes.

The system can tolerate both great and small volumes of water and varying contaminant levels. These include municipal and domestic wastewater, urban storm runoff, agricultural wastewater, industrial effluents and polluted surface waters in rivers and lakes. The system could be promoted to various potential users for water quality improvement and pollutant removal. These potential users include the tourism industry, governmental departments, private entrepreneurs, private residences, aquaculture industries and agro-industries.

Utilisation of local products and labour, helps to reduce the operation and maintenance costs of the applied industries. Less energy and raw materials are needed, with periodic on-site labour, rather than continuous full time attention. This system indirectly will contribute greatly in the reduction of use of natural resources in conventional treatment plants, and wastewater discharges to natural waterways are also reduced.

The constructed wetland system also could be used to clean polluted rivers and other water bodies. This derived technology can eventually be used to rehabilitate grossly polluted rivers in the country. The constructed wetland treatment system is widely applied for various functions. These functions include primary settled and secondary treated sewage treatment, tertiary effluent polishing and disinfecting, urban and rural runoff management, toxicant management, landfill and mining leachate treatment, sludge management, industrial effluent treatment, enhancement of instream nutrient assimilation, nutrient removal via biomass production and export, and groundwater recharge.

The primary purpose of constructed wetland treatment systems is to treat various kinds of wastewater (municipal, industrial, agricultural and stormwater). However the system usually serves other purposes as well. A wetland can serve as a wildlife sanctuary and provide a habitat for wetland animals. The wetland system can also be aesthetically pleasing and serve as an attractive destination for tourists and local urban dwellers. It can also serve as a public attraction sanctuary for visitors to explore its environmental and educational possibilities. It appeals to different groups varying from engineers to those involved in wastewater facilities as well as environmentalists and people concerned with recreation. This constructed wetland treatment system also provides a research and training ground for young scientists in this new research and education arena.


A natural wetland: Tasek Bera, a freshwater swamp system

Natural wetlands vs. constructed wetlands

Constructed wetlands, in contrast to natural wetlands, are man-made systems or engineered wetlands that are designed, built and operated to emulate functions of natural wetlands for human desires and needs. It is created from a non-wetland ecosystem or a former terrestrial environment, mainly for the purpose of contaminant or pollutant removal from wastewater (Hammer, 1994).

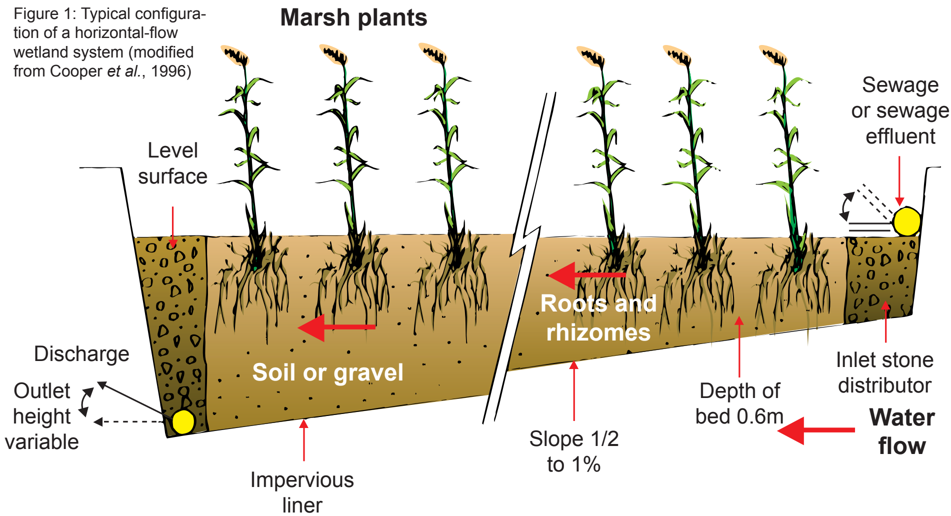
These constructed wastewater treatments may include swamps and marshes. Most of the constructed wetland systems are marshes. Marshes are shallow water regions dominated by emergent herbaceous vegetation including cattails, bulrushes, rushes and reeds.

Types and wise use of constructed wetland treatment systems

Constructed wetland systems are classified into two general types: the Horizontal Flow System (HFS) and the Vertical Flow System (VFS). HFS has two general types: Surface Flow (SF) and Sub-surface Flow (SSF) systems. It is called HFS because wastewater is fed at the inlet and flows horizontally through the bed to the outlet. VFS are fed intermittently and drains vertically through the bed via a network of drainage pipes.

A constructed wetland: Putrajaya Wetlands

Figure 1: Typical configuration of a horizontal-flow wetland system (modified from Cooper *et al.*, 1996)



Surface Flow (SF) - The use of SF systems is extensive in North America. These systems are used mainly for municipal wastewater treatment with large wastewater flows for nutrient polishing. The SF system tends to be rather large in size with only a few smaller systems in use.

The majority of constructed wetland treatment systems are Surface-Flow or Free-Water surface (SF) systems. These types utilise influent waters that flow across a basin or a channel that supports a variety of vegetation, and water is visible at a relatively shallow depth above the surface of the substrate materials. Substrates are generally native soils and clay or impervious geotechnical materials that prevent seepage (Reed, *et al.*, 1995). Inlet devices are installed to maximise sheetflow of wastewater through the wetland, to the outflow channel. Typically, bed depth is about 0.4 m.

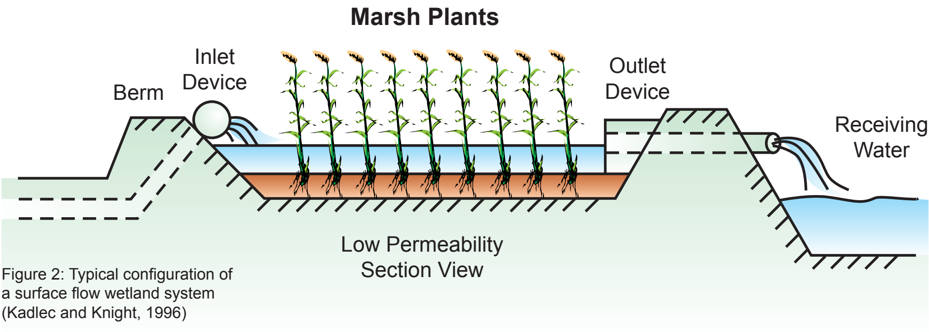


Figure 2: Typical configuration of a surface flow wetland system (Kadlec and Knight, 1996)

Sub-surface Flow (SSF) system - The SSF system includes soil based technology which is predominantly used in Northern Europe and the vegetated gravel beds are found in Europe, Australia, South Africa and almost all over the world.

In a vegetated Sub-surface Flow (SSF) system, water flows from one end to the other end through permeable substrates which is made of mixture of soil and gravel or crusher rock. The substrate will support the growth of rooted emergent vegetation. It is also called “Root-Zone Method” or “Rock-Reed-Filter” or “Emergent Vegetation Bed System”. The media depth is about 0.6 m deep and the bottom is a clay layer to prevent seepage. Media size for most gravel substrate ranged from 5 to 230 mm with 13 to 76 mm being typical. The bottom of the bed is sloped to minimise water that flows overland. Wastewater flows by gravity horizontally through the root zone of the vegetation about 100-150 mm below the gravel surface. Many macro and micro-organisms inhabit the substrates. Free water is not visible. The inlet zone has a buried perforated pipe to distribute maximum flow horizontally through the treatment zone. Treated water is collected at outlets at the base of the media, typically 0.3 to 0.6 m below bed surface.

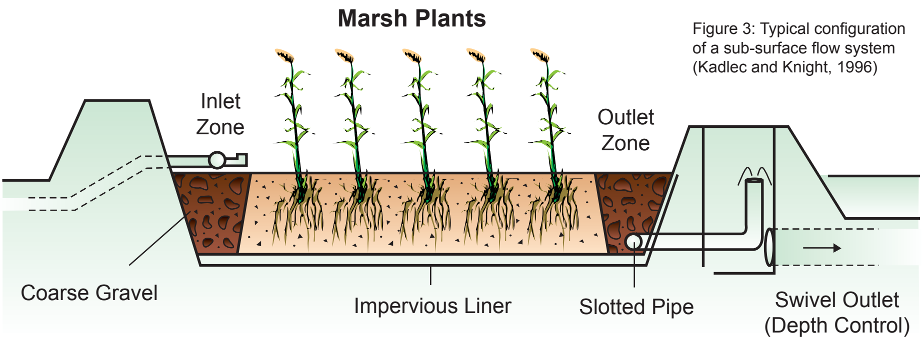


Figure 3: Typical configuration of a sub-surface flow system (Kadlec and Knight, 1996)

Establishment of constructed wetland treatment systems

The creation of a constructed wetland treatment system can be divided into a wetland construction and vegetation establishment stage. Wetland construction includes pre-construction activities such as land clearing and site preparation, followed by construction of a wetland landform and installation of water control structures. In the stage of site clearing and grubbing, the site is cleared and existing vegetation is removed to allow construction of wetland cells. All tree root stumps and rubble below ground should be removed. Some endemic species with conservation values should be transferred off site for ex-conservation or protected intact on the site. For landforming, tractors are used to remove and stockpile topsoils from the created wetland to be reused. General contours of the wetland are graded, followed by the construction of wetland cell berms by compacting soil and installing of liners. Deep zones and islands will be created. Final site grading consists of leveling the wetland cell bottom to optimise the spreading and sheetflow of wastewaters in the completed wetland. The wetland cells are flooded to a 'wet' condition for planting. Wetland plants are transferred to the site and planted manually. After plants are established, water levels are gradually increased to normal water levels, and wetlands are completely created.

Clearance of existing vegetation to construct a wetland landform

A complete constructed wetland cell

Transplanting of wetland plants to the wetland cells

Roles of wetlands plants in wastewater treatment

In general, the most significant functions of wetland plants (emergents) in relation to water purification are the physical effects brought by the presence of the plants. The plants provide a huge surface area for attachment and growth of microbes. The physical components of the plants stabilise the surface of the beds, slow down the water flow thus assist in sediment settling and trapping process and finally increasing water transparency.

Wetland plants play a vital role in the removal and retention of nutrients and help in preventing the eutrophication of wetlands. A range of wetland plants has shown their ability to assist in the breakdown of wastewater. The Common Reed *Phragmites karka* and Cattail *Typha angustifolia* are good examples of marsh species that can effectively uptake nutrients. These plants have a large biomass both above (leaves) and below (underground stem and roots) the surface of the substrate. The sub-surface plant tissues grow horizontally and vertically, and create an extensive matrix, which binds the soil particles and creates a large surface area for the uptake of nutrients and ions.

Hollow vessels in the plant tissues enable oxygen to be transported from the leaves to the root zone and to the surrounding soil (Armstrong *et al.*, 1990; Brix and Schierup, 1990). This enables the active microbial aerobic decomposition process and the uptake of pollutants from the water system to take place.

The roles of wetland plants in constructed wetland systems can be divided into 6 categories:

Physical - Macrophytes stablise the surface of plant beds, provide good conditions for physical filtration, and provide a huge surface area for attached microbial growth. Growth of macrophytes reduces current velocity, allowing for sedimentation and increase in contact time between effluent and plant surface area, thus, to an increase in the removal of Nitrogen.

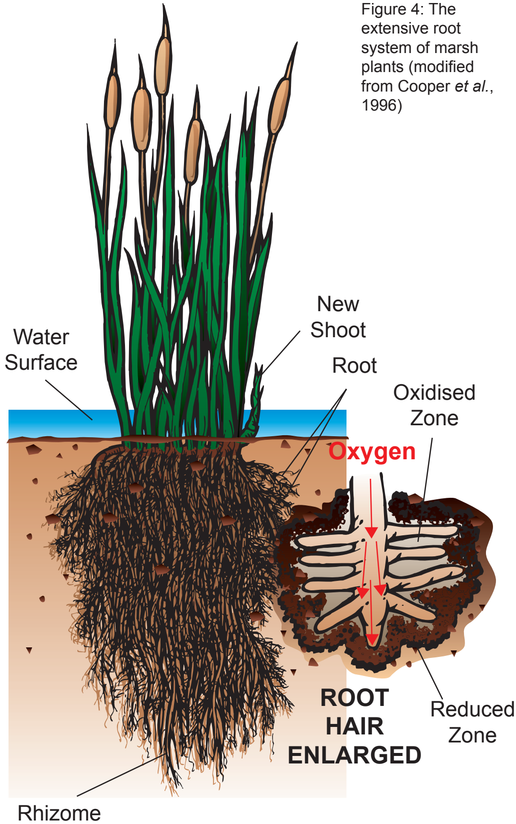


Figure 4: The extensive root system of marsh plants (modified from Cooper *et al.*, 1996)

Soil hydraulic conductivity - Soil hydraulic conductivity is improved in an emergent plant bed system. Turnover of root mass creates macropores in a constructed wetland soil system allowing for greater percolation of water, thus increasing effluent/plant interactions.

Organic compound release - Plants have been shown to release a wide variety of organic compounds through their root systems, at rates up to 25% of the total photosynthetically fixed carbon. This carbon release may act as a source of food for denitrifying microbes (Brix, 1997). Decomposing plant biomass also provides a durable, readily available carbon source for the microbial populations.

Microbial growth - Macrophytes have above and below ground biomass to provide a large surface area for growth of microbial biofilms. These biofilms are responsible for a majority of the microbial processes in a constructed wetland system, including Nitrogen reduction (Brix, 1997).

Plants create and maintain the litter/humus layer that may be likened to a thin biofilm. As plants grow and die, leaves and stems falling to the surface of the substrate create multiple layers of organic debris (the litter/humus component). This accumulation of partially decomposed biomass creates highly porous substrate layers that provide a substantial amount of attachment surface for microbial organisms. The water quality improvement function in constructed and natural wetlands is related to and dependent upon the high conductivity of this litter/humus layer and the large surface area for microbial attachment.

Creation of aerobic soils - Macrophytes mediate transfer of oxygen through the hollow plant tissue and leakage from root systems to the rhizosphere where aerobic degradation of organic matter and nitrification will take place. Wetland plants have adaptations with suberised and lignified layers in the hypodermis and outer cortex to minimise the rate of oxygen leakage.

The high Nitrogen removal of *Phragmites* is most likely attributable to the characteristics of its root growth. *Phragmites* allocates 50% of plant biomass to root and rhizome systems. Increased root biomass allows for greater oxygen transport into the substrate, creating a more aerobic environment favoring nitrification reactions. Nitrification requires a minimum of 2 mg O_2/l to proceed at a maximum rate. It is evident that the rate of nitrification is most likely the rate limiting factor for overall Nitrogen removal from a constructed wetland system (Sikora *et al.,* 1995).

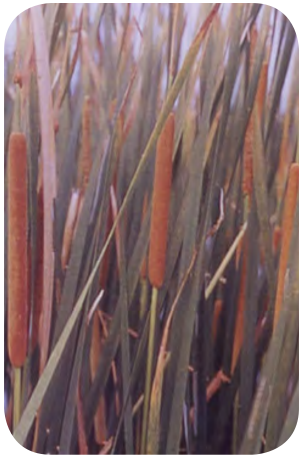
Aesthetic values - The macrophytes have additional site-specific values by providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing.

Selection of wetland plants

Floating and submerged plants are used in an aquatic plant treatment system. A range of aquatic plants have shown their ability to assist in the breakdown of wastewater. The Water Hyacinth (*Eichhornia crassipes*), and Duckweed (*Lemna*) are common floating aquatic plants which have shown their ability to reduce concentrations of BOD, TSS and Total Phosphorus and Total Nitrogen. However prolonged presence of *Eichhornia crassipes* and *Lemna* can lead to deterioration of the water quality unless these plants are manually removed on a regular basis. These floating plants will produce a massive mat that will obstruct light penetration to the lower layer of the water column that will affect the survival of living water organisms. This system is colonised rapidly with one or only a few initial individuals. The system needs to be closely monitored to prevent attack from these nuisance species. Loss of plant cover will impair the treatment effectiveness. Maintenance cost of a floating plant system is high. Plant biomass should be regularly harvested to ensure significant nutrient removal. Plant growth also needs to be maintained at an optimum rate to maintain treatment efficiency.

The Water Hyacinth *Eichhornia crassipes*

The Common Reed (*Phragmites* spp.) and Cattail (*Typha* spp.) are good examples of emergent species used in constructed wetland treatment systems. Plant selection is quite similar for SF and SSF constructed wetlands. Emergent wetland plants grow best in both systems. These emergent plants play a vital role in the removal and retention of nutrients in a constructed wetland. Although emergent macrophytes are less efficient at lowering Nitrogen and Phosphorus contents by direct uptake due to their lower growth rates (compared to floating and submerged plants), their ability to uptake Nitrogen and Phosphorus from sediment sources through rhizomes is higher than from the water.



The Cattail *Typha angustifolia*

The Common Reed *Phragmites karka*

Design and principles of constructed wetland systems

The principal design criteria for a constructed wetland system includes substrate types, pollutant loading rate and retention time. Some design criteria are discussed in detail as below.

Choice of wetland plant species - The selected wetland plants are preferred because they have a rapid and relatively constant growth rate. In a tropical system, wetland plants have a higher growth rate. These wetland plants are easily propagated by means of runners and by bits of mats breaking off and drifting to new areas. This will help in increasing the capacity of pollutant absorption by the plants. The plants should also be able to tolerate waterlogged-anoxic and hyper-eutrophic conditions.

The plant species should be local species and widely distributed in the country. Use of exotic plants in constructed wetland systems should be avoided as they are highly invasive and difficult to control. The plant should be a perennial with a life cycle of more than one year or two growing seasons to ensure the sustainability of the constructed wetland system. Wetland plants with aesthetic appeal will provide a landscape-pleasing environment.

Substrates - Substrates may remove wastewater constituents by ion exchange/non-specific adsorption, specific adsorption/precipitation and complexation.

The choice of substrate is determined in terms of their hydraulic permeability and their capacity to absorb nutrients and pollutants. The substrate must provide a suitable medium for successful plant growth and allow even infiltration and movement of wastewater. Poor hydraulic conductivity will result in surface flow and channeling of wastewater, severely reducing the effectiveness of the system.

A successful operation requires a hydraulic conductance of approximately 10^{-3} to 10^{-4} $m^{-1}\ s^{-1}$. The chemical composition of the substrate will also affect the efficiency of the system. Soils with low nutrient content will encourage direct uptake of nutrients from the wastewater by plants. Substrate with high Al or Fe content will be most effective at lowering Phosphate concentrations in the influent. Gravels are washed to reduce clogging (increase void spaces) for better filtration. The reed system on gravel reached better nitrification rates, while denitrification was higher in the soil-based reed system (Markantonatos *et al*., 1996).

A mixture of organic clay soils, sand, gravels and crushed stones could be used to provide support for plant growth. These substrates are ideal reactive surfaces for ion complexation and microbial attachment, also provide a sufficiently high hydraulic conductivity to avoid short-circuiting in the system.

Area of reed bed - Most wastewater treatment wetlands have been designed for minimum size and cost to provide the required level of pollutant removal. However, operation and maintenance costs may be high. The creation of a maximum effective treatment area will reduce the short-circuiting problem. Generally, horizontal flow wastewater treatment systems should have a 3-4: 1 length to width ratio and be rectangular in shape if minimal treatment area is available. A long length-width ratio is required to ensure plug flow hydraulics (Miller and Black, 1985).

The required surface area for a sub-surface flow system is calculated according to an empirical formula for the reduction of BOD_5 in sewage effluent.

$$A_h = KQ_d (\ln C_0 - \ln C_t)$$

Where A_h = surface area of bed, m^2

K = rate constant, $m\ d^{-1}$

Q_d = average daily flow rate of wastewater ($m^3\ d^{-1}$)

C_0 = average daily BOD_5 of the influent ($mg\ l^{-1}$)

C_t = required average daily BOD_5 of the effluent ($mg\ l^{-1}$)

The value of K = 5.2 was derived for a 0.6 m deep bed and operating at a minimum temperature of 8^0C. For less biodegradable wastewater, K values of up to 15 may be appropriate. Using this formula, a minimum area of 2.2 $m^2\ pe^{-1}$ is obtained for the treatment of domestic sewage. In practice, most design systems operate on the basis of 3-5 $m^2\ pe^{-1}$.

Nature, loading and distribution of effluent - The long-term efficiency of an emergent bed system is improved if the effluent is pre-treated prior to discharge to the active bed. Suspended particles are settled during storage in a settlement tank or a pond for 24 hours. The BOD of the primary effluent may be reduced by 40%. The removal of Nitrogen and Phosphorus for secondary wastewater is higher.

The flow of wastewater through the emergent bed system is slow, giving a long retention time, therefore the flow must be regulated so that retention times are sufficiently long for pollutant removal to be efficient. A higher reduction efficiency for mass balances of N and P could be achieved by *Phragmites* if water retention time is more than 5 days. Shorter retention times do not provide adequate time for pollutant degradation to occur. Longer retention times can lead to stagnant and anaerobic conditions. Evapotranspiration can significantly increase the retention time.

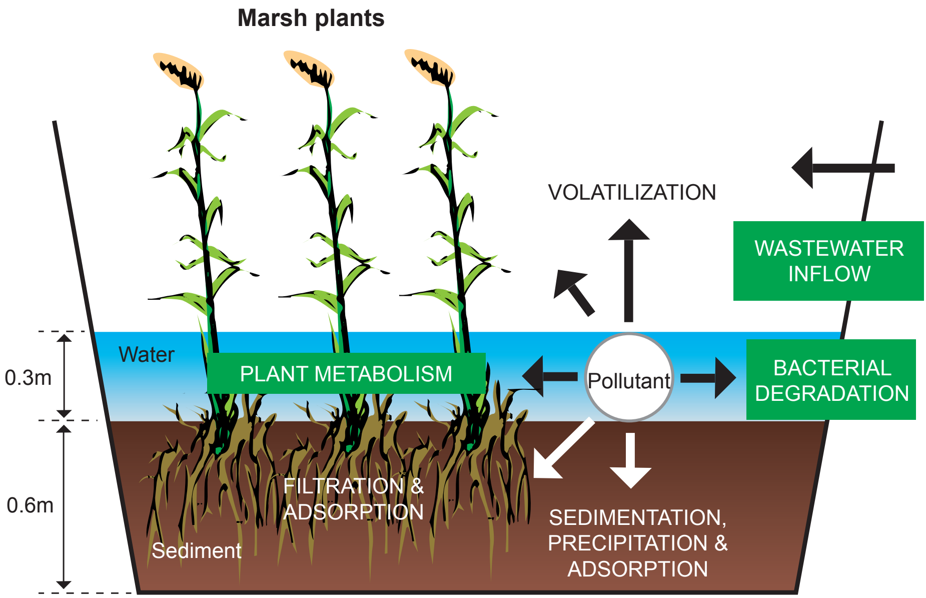


Figure 5: Pollutant removal processes in a constructed wetland system

Constructed wetland treatment mechanisms

Wetlands have been found to be effective in treating BOD, TSS, N and P as well as for reducing metals, organic pollutants and pathogens. The principal pollutant removal mechanisms in constructed wetlands include biological processes such as microbial metabolic activity and plant uptake as well as physico-chemical processes such as sedimentation, adsorption and precipitation at the water-sediment, root-sediment and plant-water interfaces (Reddy and DeBusk, 1987).

Microbial degradation plays a dominant role in the removal of soluble/colloidal biodegradable organic matter in wastewater. Biodegradation occurs when dissolved organic matter is carried into the biofilms that attached on submerged plant stems, root systems and surrounding soil or media by diffusion process. Suspended solids are removed by filtration and gravitational settlement.

A pollutant may be removed as a result of more than one process at work.

Nitrogen removal mechanisms - There are sufficient studies to indicate some roles being played by wetland plants in Nitrogen removal but the significance of plant uptake vis-à-vis nitrification/denitrification is still being questioned. Nitrogen (N) can exist in various forms, namely Ammoniacal Nitrogen (NH_3 and NH_4^+), organic Nitrogen and oxidised Nitrogen (NO_2^- and NO_3^-). The removal of Nitrogen is achieved through nitrification/denitrification, volatilisation of Ammonia (NH_3) storage in detritus and sediment, and uptake by wetland plants and storage in plant biomass (Brix, 1993). A majority of Nitrogen removal occurs through either plant uptake or denitrification. Nitrogen uptake is significant if plants are harvested and biomass is removed from the system.

At the root-soil interface, atmospheric oxygen diffuses into the rhizosphere through the leaves, stems, rhizomes and roots of the wetland plants thus creating an aerobic layer similar to those that exists in the media-water or media-air interface. Nitrogen transformation takes place in the oxidised and reduced layers of media, the root-media interface and the below ground portion of the emergent plants. Ammonification takes place where Organic N is mineralised to NH_4^+-N in both oxidised and reduced layers. The oxidised layer and the submerged portions of plants are important sites for nitrification in which Ammoniacal Nitrogen (AN) is converted to nitrite N (NO_2-N) by the *Nitrosomonas* bacteria and eventually to nitrate N (NO_3-N) by the *Nitrobacter* bacteria which is either taken up by the plants or diffuses into the reduced zone where it is converted to N_2 and N_2O by the denitrification process .

Denitrification is the permanent removal of Nitrogen from the system, however the process is limited by a number of factors, such as temperature, pH, redox potential, carbon availability and nitrate availability (Johnston, 1991). The annual denitrification rate of a surface-flow wetland could be determined using a Nitrogen mass-balance approach, accounting for measured influx and efflux of Nitrogen, measured uptake of Nitrogen by plants, and sediment, and estimated NH_3 volatilisation (Frankenbach and Meyer, 1999).

The extent of Nitrogen removal depends on the design of the system and the form and amount of Nitrogen present in the wastewater. If influent Nitrogen content is low, wetland plants will compete directly with nitrifying and denitrifying bacteria for NH_4^+ and NO_3^-, while in high Nitrogen content, particularly Ammonia, this will stimulate nitrifying and denitrifying activity (Good and Patrick, 1987).

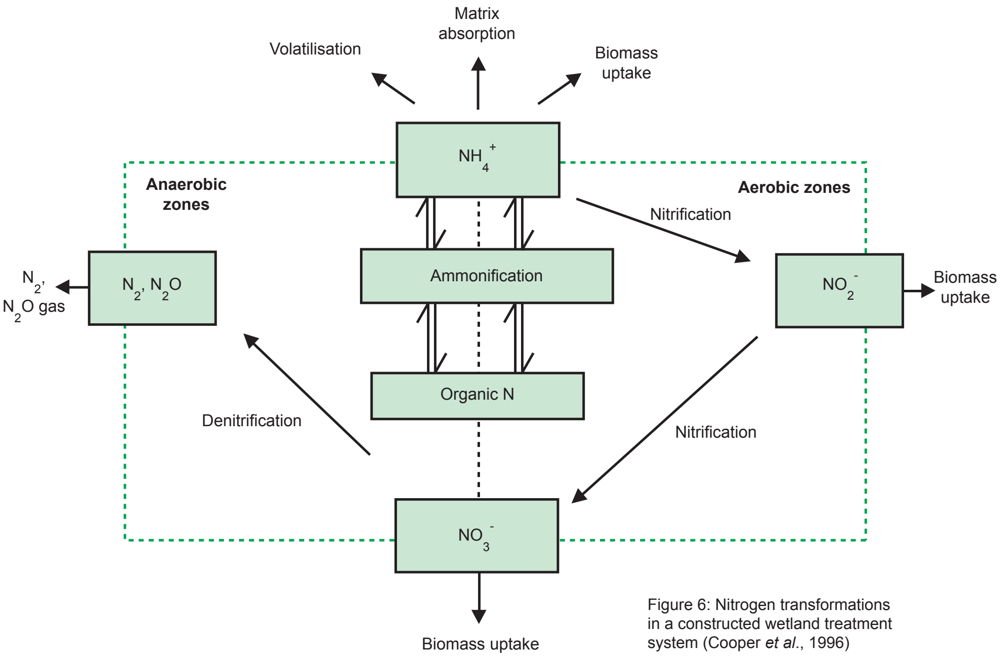


Figure 6: Nitrogen transformations in a constructed wetland treatment system (Cooper *et al*., 1996)

Phosphorus removal mechanisms - Phosphorus is present in wastewaters as Orthophosphate, Dehydrated Orthophosphate (Polyphosphate) and Organic Phosphorus. The conversion of most Phosphorus to the Orthophosphate forms ($H_2PO_4^-$, Po_4^{2-}, PO_4^{3-}) is caused by biological oxidation.

Most of the Phosphorus component may fix within the soil media. Phosphate removal is achieved by physical-chemical processes, by adsorption, complexation and precipitation reactions involving Calcium (Ca), Iron (Fe) and Aluminium (Al). The capacity of wetland systems to absorb Phosphorus is positively correlated with the sediment concentration of extractable Amorphous Aluminium and Iron (Fe).

Although plant uptake may be substantial, the sorption of Phosphorus (Orthophosphate P) by anaerobic reducing sediments appears to be the most important process. The removal of Phosphorus is more dependent on biomass uptake in constructed wetland systems with subsequent harvesting.

Plant uptake - Nitrogen will be taken up by macrophytes in a mineralised state and incorporated it into plant biomass. Accumulated Nitrogen is released into the system during a die-back period. Plant uptake is not a measure of net removal. This is because dead plant biomass will decompose to detritus and litter in the life cycle, and some of this Nitrogen will leach and be released into the sediment. Johnston (1991) shows only 26-55% of annual N and P uptake is retained in above-ground tissue, the balance is lost to leaching and litter fall.

Metals - Metals such as Zinc and Copper occur in soluble or particulate associated forms and the distribution in these forms are determined by physico-chemical processes such as adsorption, precipitation, complexation, sedimentation, erosion and diffusion. Metals accumulate in a bed matrix through adsorption and complexation with organic material. Metals are also reduced through direct uptake by wetland plants. However over-accumulation may kill the plants.

Pathogens - Pathogens are removed mainly by sedimentation, filtration and absorption by biomass and by natural die-off and predation.

Other pollutant removal mechanisms - Evapotranspiration is one of the mechanisms for pollutant removal. Atmospheric water losses from a wetland that occurs from the water and soil is termed as evaporation and from emergent portions of plants is termed as transpiration. The combination of both processes is termed as evapotranspiration.

Daily transpiration is positively related to mineral adsorption and daily transpiration could be used as an index of the water purification capability of plants.

Precipitation and evapotranspiration influence the water flow through a wetland system. Evapotranspiration slows water flow and increases contact times, whereas rainfall, which has the opposite effect, will cause dilution and increased flow.

Precipitation and evaporation are likely to have minimal effects on constructed wetlands in most areas. If the wetland type is primarily shallow open water, precipitation/evaporation ratios fairly approximate water balances. However, in large, dense stands of tall plants, transpiration losses from photosynthetically active plants become significant.

Wetland monitoring and maintenance

Monitoring and maintenance of the wetland areas is a key issue in maintaining wetland functioning. Wetland monitoring is required to obtain sufficient data to determine the wetland performance in fulfilling the objectives. Wetland maintenance is required to manage macrophytes and desirable species, to remove invading weeds, to remove sediment from the wetlands, and to remove litter from the wetlands (Beharrel *et al*., 2002).

Effective wetland performance depends on adequate pretreatment, conservative constituent and hydraulic loading rates, collection of monitoring information to assess system performance, and knowledge of successful operation strategies. The CWTS system could be rather easy to design and construct, however it needs to be closely monitored and maintained.

Sustaining a dense stand of desirable vegetation within the wetland is crucial to ensure treatment efficiency. Aggressive species will out-compete less competitive ones and cause gradual changes in wetland vegetation. Certain undesirable plant species or weeds may be introduced to the wetland from the catchment. Natural succession of wetland plants will take place. However, some aquatic weeds may require maintenance

Manual removal of noxious and undesirable weeds

by manually being removed. Weed invasion can dramatically reduce the ability of wetlands to meet its design objectives. For example, Pondweed (*Azolla*), Duckweed (*Lemna*), Water Fern (*Salvinia molesta*) and Water Hyacinth (*Eichhornia crassipes*) can form dense mats, exclude light and reduce dissolved oxygen in the water column, and increase the movement of nutrients through the system. Water level management is crucial to control weed growth.

Floods will cause plants to be scoured from the wetland and/or drowned. If a large area of plants is lost, re-establishment will need to be carried out. Small areas will generally recover naturally while larger areas above 5 m^2 may require replanting.

Plant viability is vital to water quality improvement in wetlands. Visible signs of plant distress or pest attack should be investigated promptly. Some common pest insects include Lepidopterrous Stem Borers on *Scirpus grossus*, aphids on *Phragmites karka* and Leaf Roller on *Phragmites karka*. Severe infestation could lead to severe stunting and death of plants. Biopesticides or narrow spectrum-pest specific insecticides could be used if pest population exceeds a certain threshold value. Other pests include the Golden Apple Snail *Pomacea sp*, which feeds actively on wetland plants.

Water levels are important in wetlands with effects on hydrology and hydraulics and impact on wetland biota. Water level should be monitored using water level control structures to ensure successful plant growth. A recirculation system should be in place to allow water from outlet points to be fed back to the wetlands to supplement catchment flows during dry periods. Suspended solids from effluents and litter fall from plants will accumulate in time and gradually reduce the pore space which has to be flushed to prevent short-circuiting.

Monitoring of mosquito populations should be undertaken to avoid diseases, which can result in a local health problem.

Water quality monitoring

Water quality data are a good indication of wetland performance. Water quality should be monitored through assessment of inflow and outflow water quality parameters.

Some important water quality parameters to be monitored include Dissolved Oxygen, redox potential, water temperature, pH value and turbidity, which are the in-situ parameters while laboratory analysis parameters include Total Suspended Solids (TSS), chemical conductivity, Ammoniacal Nitrogen (AN), Nitrate-Nitrogen, Phosphorus, Potassium, Magnesium, Soluble Fe, Mercury, Lead, Zinc, Iron, Cyanide, Arsenic, Phenols, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Faecal Coliforms, and Oil and Grease.

Examples of wetland plants

There is a variety of marsh vegetation that is suitable for planting in a CWTS (see Table 1). These marsh species could be divided into deep and shallow marshes.

Table 1: List of emergent wetland plants used in constructed wetland treatment systems (Lim *et al*., 1998).

Planting zones	Common name	Scientific name
Marsh and deep marsh (0.3-1.0 m)	Common Reed	*Phragmites karka*
	Spike Rush	*Eleocharis dulcis*
	Greater Club Rush	*Scirpus grossus*
	Bog Bulrush	*Scirpus mucronatus*
	Tube Sedge	*Lepironia articulata*
	Fan Grass	*Phylidrium lanuginosum*
	Cattail	*Typha angustifolia*
Shallow marsh (0-0.3 m)	Golden Beak Sedge	*Rhynchospora corymbosa*
	Spike Rush	*Eleocharis variegata*
	Sumatran Scleria	*Scleria sumatrana*
	Globular Fimbristylis	*Fimbristylis globulosa*
	Knot Grass	*Polygonum barbatum*
	Asiatic Pipewort	*Erioucaulon longifolium*

Phragmites karka - *Phragmites karka* is a tall, aquatic perennial in the family of Gramineae. It is commonly known as Common Reed Grass. It is a gregarious plant, and can grow erect up to 4 m tall, with creeping stolons up to 20 m long. The stems grow up to 1.5 cm wide, are hollow and many noded. The leaves are 20-60 cm long by 8-30 mm wide and alternate. The inflorescence is 20-70 cm long on drooping panicles, dense with many fine branches, brownish when young but turn silver upon maturity. *Phragmites* is a highly invasive plant. *Phragmites* can spread laterally throughout the year by producing new shoots from spreading rhizomes.

Phragmites karka also propagates through seeds and stem cuttings. However the seed germination rate is low. The plant grows abundantly in moist and water-logged areas, both freshwater and brackish, along rivers, ditches, lake shores and ponds. It is also common in abandoned mining areas. It is widespread throughout Malaysia.

There is no record of studies on pollutant removal by *Phragmites karka*. However, *Phragmites australis* is widely used for reed bed treatment systems in temperate countries.

Lepironia articulata - *Lepironia articulata* is a reed-like, perennial plant in the family of Cyperaceae. The plant can grow up to 2.3 m tall with tubular, hollow, septate bluish green stems of 2-3 cm in diameter. The stems arise from creeping, underground rhizomes in clumps. The leaves are reduced to basal sheathing scales. The single reddish brown ovoid to elliptical compact inflorescence or spikelet of 1-2 cm long is produced at the end of the stem, overtopped by a tubular tapering bract of 2.5 m to 7 cm long.

The Tube Sedge *Lepironia articulata*

Lepironia propagates with seeds and rhizomes. *Lepironia* seeds germinate well although the germination rate is slow initially. It grows in open wet areas, from littoral areas to deep water, in swamps, ex-mining ponds, lakes and ditches. It is typically grown in swamps with low pH (up to pH 3). It is common throughout the country, especially at Tasek Bera Ramsar Site of Malaysia.

The Spike Rush *Eleocharis dulcis*

Cattail *Typha angustifolia* - The Cattail is a perennial plant. It is a tufted, robust and erect plant, with a height of 1.5-3 m. It has short round stems which creep underground, from which new tufted plants emerge. Leaves are linear with a pointed tip and are up to 3.5 m long, arising from the base of the stems. The flowering stem is normally taller with cigar-like flower spikes towards the end. The female inflorescence is below the male one and it is a compact and thicker cylinder of

2.5-4 cm. The inflorescences are reddish brown in colour and covered with fluffy white hairs when mature. It is often found in open areas, ex-mining ponds, lakes and in fresh and brackish water.

Spike Rush *Eleocharis dulcis* - The Spike Rush is a perennial plant. It is a tufted plant with leafless slender stems. It has hollow stems with internal transverse partitions. The inflorescence is a single spikelet at the end of the stem, upright with glumes that spirally arranged. It is brownish in colour and 1.5-6.0 cm in length. It is normally found in open wet places, in brackish and freshwater swamps, rice fields, ponds and lakes.

Wetland design

The criteria for wetland design include site selection, hydrologic analysis, water source and quality, plant material selection, soil and geologic conditions, buffer zone placement and maintenance procedures (Kusler and Kentula, 1996). Hydrology is one of the primary factors in controlling wetland functions (Hammer, 1989). Flow rate should be regulated to achieve a satisfactory treatment. Sufficient water supply is crucial to establish a viable constructed wetland system.

The pilot tank system planted with Common Reed at University Malaysia

Wetlands are highly ephemeral and variable in their capabilities for sequestering and retention of nutrients and other pollutants. Initial retentive capacities may be high for certain pollutants in the short-term, but may change markedly over the long-term (Wetzel, 2000).

A pilot study on the efficiency of the constructed wetland treatment system is being carried out (Sim, 2002). Two aquatic plants *Lepironia articulata* and *Phragmites* *karka* are used in this study carried out by Wetlands International - Malaysia Office in collaboration with University Putra Malaysia. Mathematical models could be developed to simulate the treatment performance of wetlands under different circumstances (Ahmad *et al.*, 2002). Water budget models are often used in evaluating wetlands (Arnold *et al.,* 2001).

This pilot study imitates (with some modifications) the constructed wetland treatment system at Putrajaya Wetlands where emergents are used in this surface flow system for urban runoff treatment. A specific wetland site (UN 4-6) in Putrajaya Wetlands receiving nutrient based runoff from the upper catchment is used as a demonstration site.

The Putrajaya constructed wetland, wetland cell UN5

Conclusion

The use of constructed wetlands to treat wastewater is relatively new in Malaysia. However the impressive results achieved thus far have prompted great expectations about the technology and what it can achieve. The wetlands can be used in a sustainable manner, by defining a clear design objective for the wetland system to achieve its ultimate goal and close monitoring to assess the performance of the wetlands and to ensure all objectives are fulfilled.

Putrajaya Wetlands can be considered a pioneer venture in constructed wetland treatment system in Malaysia. Most of the constructed wetland design is derived from Putrajaya Wetlands. It is a good example of a water filtration system for water resource management with environmental enhancements. The system creates an aesthetic environment for both leisure and eco-tourism purposes, and serves as habitats for native flora and fauna. Wetland education and research opportunities are very promising in this field.

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Acknowledgements

We are very grateful to the following people or organisation for their kind contributions in the preparation of this booklet:

Financial assistance
Ford Motor Company Conservation and Environmental Grants

Text compilation
Sim Cheng Hua, Senior Technical Officer of Wetlands International - Malaysia Office (sim@wiap.nasionet.net)

Text editing
Mohala Santharamohana, Communications and Education Officer of Wetlands International - Malaysia Office

Technical assistance
Murugadas T. Loganathan, Senior Technical Officer of Wetlands International - Malaysia Office
Dr. Sundari Ramakrishna, Director of Wetlands International - Malaysia Office

Advisors / Sources
Putrajaya Corporation
Professor Brian Shutes, Middlesex University, United Kingdom
Associate Professor Mohd Kamil Yusoff, University Putra Malaysia
Professor Dick Ho Sinn Chye, University Science Malaysia
Professor Mashhor Mansor, University Science Malaysia

Drawings and illustrations
www.WirePortfolio.com

Abbreviation

COD - Chemical Oxygen Demand
CWTS - Constructed Wetland Treatment System
RBTS - Reed Bed Treatment System
NH_4-N - Ammoniacal Nitrogen
SSF - Sub-surface Flow
SF - Surface Flow
HF - Horizontal Flow
VF - Vertical Flow
Total-N - Total-Nitrogen
Total-P - Total-Phosphorus

Glossary

Ammonia volatilisation - It is a process by which Ammonium is converted to Ammonia gas and followed by volatilisation and occurs only when the pH value in the wastewater is higher than the pK_a value of Ammonium.

Ammonification - It is a process whereby Nitrogen-containing organics are mineralized to Ammoniacal Nitrogen.

Organic Nitrogen $\Leftrightarrow NH4^+$

Biological denitrification - This process involves the removal of Nitrate by conversion to Nitrogen gas under anoxic conditions. Several genera of heterotrophic bacteria which are capable of Nitrate reduction include *Achromobacter*, *Aerobacter*, *Alcaligenes*, *Bacillus*, *Brevibacterium*, *Flavobactrium*, *Lactobacillus*, *Micrococcus*, *Proteus*, *Pseudomonas* and *Spirillum.* Two steps are involved in this process. The first step is the conversion of Nitrate to Nitrite and will be followed by the production of Nitric Oxide, Nitrous Oxide and Nitrogen gas.

$$NO_3^- \Rightarrow NO_2^- \Rightarrow NO \Rightarrow N_2O \Rightarrow N_2$$

Biological nitrification - This is a chemoautotrophic process that involves two microbial genera, which are *Nitrosomonas* and *Nitrobacter.* In the first step, Ammoniacal Nitrogen is converted to Nitrite and followed by conversion of Nitrite to Nitrate in the second step. In the conversion process, a large amount of alkalinity is consumed, resulting in the increase of pH values.

$$NH_4^+ + CO_2 + O_2 \Rightarrow \text{Cells} + NO_2^-$$

Nitrosomonas

$$NO_2^- + CO_2 + O_2 \Rightarrow \text{Cells} + NO_3^-$$

Nitrobacter

Matrix adsorption - Ammoniacal-Nitrogen is adsorbed onto active sites of the bed matrix. However sorption of NH_4-N is reversible as the cation exchange site of matrix is saturated and AN will be released back into the water system.

Reduction - Phosphorus is reduced to gaseous Hydrogen Phosphides (Phosphine and Diphosphine) under anaerobic conditions by some strains of anaerobes and subsequently release to the atmosphere.

Sorption - Phosphorus sorption is controlled by the interaction of redox potential, pH, Fe, Al and Ca minerals. Inorganic P is retained by Fe and Al oxides and hydroxides, calcite and organometallic complexes where Phosphate displaces water or hydoxyls from the surface of Fe and Al hydrous oxides to form monodentate and binuclear complexes within the coordination sphere of the hydrous oxide. In acidic conditions, inorganic P is rapidly absorbed on hydrous oxides of Fe and Al and may precipitate as insoluble Fe Phosphates and Al Phosphates.