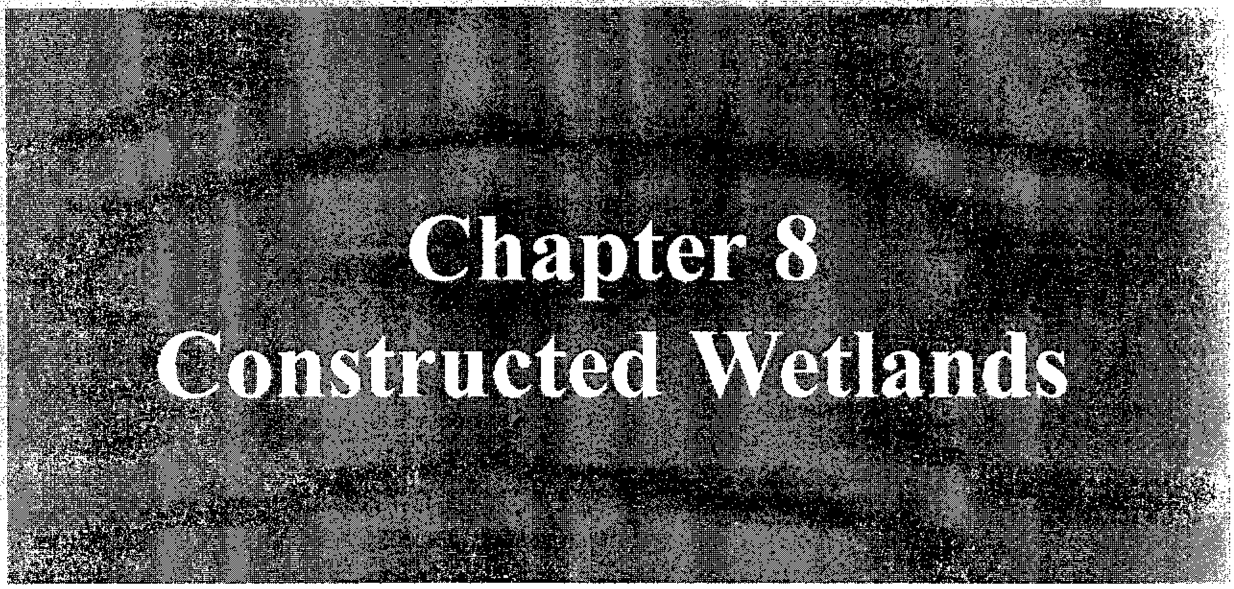

Chapter 8
Constructed Wetlands

8.1 Introduction

Wetlands are often referred to as nature's kidneys. Wetlands can cleanse contaminants from water in the same way that kidneys cleanse impurities from the bloodstream. Historically, wetlands were used as *de facto* wastewater treatment systems. Human communities dumped their waste into low-lying areas containing water. Wetland plants take up nutrients in the waste and in the runoff. The still water in a wetland facilitates the settling of particulate matter. These quantities are depicted in **table 8.1**. Microorganisms living on the roots of the wetland plants and in the soil degrade organic matter. The water in a

Table 8.1: Potential constructed wetland benefits.

Chapter Number	Chapter Name	Treatment Process	Reduce Nitrogen	Reduce Phosphorus	Reduce Biochemical Oxygen Demand	Stabilize Manure	Reduce Manure Volume	Reduce Pathogens	Reduce Manure Gases	Reduce Odor	Reduce Ammonia Volatilization	Operate at Low Temperatures	Minimal Footprint	Low Energy Requirement	Create Biogas	Create Value-Added Products
8	Constructed Wetlands	Open water	√		√			√	√					√		
		Subsurface flow	√		√			√	√	√	√			√		
		Floating aquatic	√		√			√	√							
		Reciprocating	√		√			√	√	√	√					

wetland travels through the system, and out to surface water or percolates to groundwater. **Figure 8.1** is a photograph of a naturally occurring wetland.

Figure 8.1: Naturally occurring wetland (T. Blagden, Jr., 2004).

Natural wetlands are now protected under federal, most state, and some local laws from pollution and are no longer appropriate for the treatment of waste. Instead, human-designed wetlands are constructed for the purpose of wastewater treatment. Today, constructed wetlands are used to treat agricultural, municipal, private, and industrial wastewater, as well as acid mine drainage. These constructed wetlands are engineered to mimic the processes that occur in natural wetlands. Both natural and constructed wetlands use biological, chemical, and physical processes to treat waste, as depicted in **figure 8.2. Table 8.2** lists a few of the mechanisms responsible for wastewater treatment in wetlands.

This chapter focuses on the design considerations, constructed wetland management, performance, and different kinds of wetland systems.

Constructed wetlands are best suited to treat relatively low-strength manure with a low solids content or as an addition to an existing solids separation system. Nitrogen can be

Pathogen: A disease-causing organism.

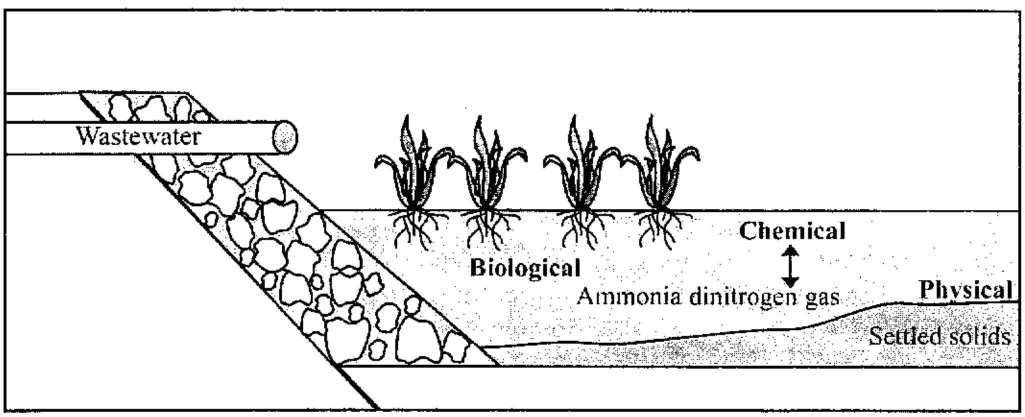

Figure 8.2: Treatment processes in wetlands (United States Geological Survey, 1998).

Table 8.2: Biological, chemical, and physical processes in naturally occurring and constructed wetlands (Miner et al., 2000).

Biological Processes	Chemical Processes	Physical Processes
Uptake of nutrients by microorganisms and plants	Chemical precipitation of particulate matter	Filtration of particulate matter through contact with litter
Transformation of nutrients by microorganisms and plants	Chemical transformation of pollutants	Settling of suspended particulate matter
Predation of **pathogens**	Adsorption and ion exchange on the surfaces of plants, sediment, and litter	
Natural die-off of pathogens		

effectively removed from manure, but phosphorus may not be consistently removed. Constructed wetlands are often used as a "finishing" or "polishing" treatment after a series of other unit processes.

8.2 Advantages and Disadvantages of Constructed Wetlands

It is important to note, as with any other treatment technology, that constructed wetlands are not the only answer for managing livestock waste. They require large tracts of relatively level land, and do not operate well in cool climates. Constructed wetlands are complicated systems and have a track record of finicky behavior, requiring an operator with a green thumb and a discerning eye. The manure may require pretreatment and post treatment to meet treatment objectives. As always, systems of treatment processes are more effective than the use of a single treatment technology.

8.2.1 Advantages

Constructed wetlands can provide a high level of animal waste treatment when properly designed, constructed, managed, and maintained. Ammonia, nitrite, nitrate, **biochemical oxygen demand (BOD)**, and suspended solids can be reduced to acceptable levels with some constructed wetland designs. Depending on the type of wetland and the topography of the area, constructed wetlands can be inexpensive to operate and require little if any energy and equipment. A well-designed constructed wetland transfers water throughout the system by gravity, but if restrictive topography exists, a pump may be required to circulate the wastewater. Constructed wetlands can handle variable wastewater nutrient loadings, which is helpful since varying production levels, changing weather conditions, and modifications to animal and manure management all impact nutrient loading rates. Constructed wetlands require a dedicated, though smaller, land base than traditional land application of manure. Depending on the type of wetland, odor reduction or elimination is possible. Healthy constructed wetlands have the added advantage of increasing animal habitat and **biodiversity**. The new plant and animal communities that form in and around wetlands can add an aesthetic quality to the farm and surrounding area.

8.2.2 Disadvantages

Constructed wetlands require a continuous supply of water. Supplemental water may be necessary during dry periods to counteract **evapotranspiration.** Constructed wetlands are costly if undesirable topographical features require expensive construction, such as cut and fill, to create a level surface. The different kinds of constructed wetlands also have varying costs.

Care must be taken to prevent solids overloading or high input concentrations of ammonia, which may damage the wetland ecosystem and cause treatment failure. Constructed wetlands are only able to treat wastewater, not solids. Manure solids must be removed prior to constructed wetland treatment.

Since treatment is largely driven by live plants and microorganisms, treatment performance can be affected by seasonal weather, which can influence plant vitality and bacteria viability. The design of constructed wetlands must account for periods of

Biochemical oxygen demand (BOD): A measure of the amount of oxygen needed by aerobic microorganisms to break down solids and organic matter present in wastewater. Although BOD is not a specific compound, it is defined as a conventional pollutant under the federal Clean Water Act. The BOD_5 test is a five-day laboratory test to determine the amount of oxygen available for biochemical oxidation in a sample.

Biodiversity: The diversity of plant and animal species in an ecosystem.

Evapotranspiration: The sum of the evaporation of water from the earth's surface and transpiration, the evaporation of water from plant leaves and other plant surfaces.

cold or drought when treatment will be incomplete. During these periods it is important that the wastewater is retained in the wetland or treated in some other manner.

Ammonia volatilization: A process in which gaseous nitrogen-ammonia is released to the atmosphere.

Biomass: The total dry mass of an individual or population.

Constructed wetlands transform and remove nitrogen through many pathways, including **ammonia volatilization.** Although volatilization is not the primary mechanism for nitrogen removal in all types of constructed wetlands, it may still occur, particularly with open and floating aquatic wetlands (see Sections 8.6.1 and 8.6.3). Additionally, the wetland plants take up nutrients which otherwise could have been captured and utilized by harvestable crops.

8.3 Constructed Wetland Design Considerations

There are many elements of well-designed constructed wetlands. Design considerations include the amount of waste, including seasonal variability; type of feed; amounts, timing, and intensity of rainfall; frequency of solids removal from feedlots and loafing lots; relationship of solids removal to rainfall; and solid waste and **biomass** removal schedule. Each component—water, solids, and nutrients—must be accounted for in order to have a successful treatment system. The type of plant used for the wetland and method of establishment are also considerations made during the design process.

8.3.1 Water Loading

The water budget—the amount of water going into, flowing through, infiltrating, evaporating, transpiring, and remaining in the wetland—should be carefully monitored and managed. Wetland water levels must remain relatively constant, with the exception of reciprocating wetlands, which are drained and filled at prescribed times. See Section 8.6.5 for more information on reciprocating wetlands. Flow control devices such as inflow and outflow valves can be used to regulate water levels. Storage ponds may also be used to temporarily hold wastewater for flow equalization.

Supplemental water can be added during dry times from a variety of sources including springs, creeks, and ponds. Too much water is also a problem. Runoff water from roofs and pavement should be diverted from the constructed wetland unless these volumes and their associated nutrient and contaminant contents have been specifically accounted for in the wetland design.

Wastewater treatment results are best when the flow is uniformly distributed across the wetland. Ideal plug flow, a condition where water moves as a whole plug or mass, is typically assumed in the design process. In reality, perfect plug flow rarely exists. Water always takes the path of least resistance, forming channels of preferential flow. Preferential flow can cause uneven wastewater treatment. The most successful treatment situations exist when the wastewater flows like natural wetland overland flow.

8.3.2 Solids Loading

Wetlands can only treat wastewater, not solids, so it is extremely important to keep the solids loading, the amount of solids entering the wetland system, to a minimum. Several pretreatment options are available. Mechanical solids separation systems can be used to remove solids from the wastestream prior to treatment in the constructed wetland. Storage ponds and settling basins can be used for solids separation as well as for storage and flow equalization. Treatment **lagoons** may be used to settle solids, to allow organic matter to degrade, and to reduce nutrient levels before the wastewater enters the wetland.

8.3.3 Nutrient Loading

The amount of nutrients a constructed wetland can treat depends on a number of variables including the local climatic conditions; the characteristics of incoming wastes, which depends on the animal and feed; and pretreatment processes. A constructed wetland overloaded with nutrients will not meet the nutrient treatment goals—the outflow will still have very high concentrations of nitrogen and phosphorus. High nutrient loads may even kill the wetland organisms, destroying the treatment system. The wastewater should be diluted so that nutrient concentrations are not excessive. Nutrient levels that are too low will not provide the wetland plants with the necessary nutrients for growth. Typical nitrogen loading rates are between two and ten kilograms per acre per day (four and 22 pounds per acre per day) (Miner et al., 2000). Constructed wetland vegetation will utilize phosphorus from wastewater, but constructed wetlands are not an adequate treatment process for significant phosphorus reductions. Typical organic matter loading rates are based on the BOD and can range from 16 to 81 kilograms per acre per day (36 to 178 pounds per acre per day) (Miner et al., 2000). Retention times in a mature wetland can range from four to 15 days to meet desired outflow nutrient reductions (Miner et al., 2000).

8.3.4 Wetland Vegetation

Rushes, reeds, cattails, sedges, and arrowheads are some plants suited for constructed wetlands. These plants thrive in **hydric soils** and standing water. The plants used in a constructed wetland should be chosen carefully, with treatment objectives and projected wetland conditions in mind. Some plants have specific temperature, salinity, and pH tolerances. **Table 8.3** depicts some typical plants used in constructed wetlands and the desired temperature, pH, and maximum salinity.

a. Plant Establishment

There are three methods used to establish plants in a wetland:

1. Mechanical seeding,
2. Transplantation, and
3. Natural establishment.

Lagoon: A shallow pond where sunlight, oxygen, and bacteria degrade and transform compounds in manure.

Hydric soils: Soils that are flooded or saturated long enough to develop anaerobic conditions that favor the growth of hydrophytic (water-loving) plants.

Table 8.3: Typical characteristics of emergent plants used in constructed wetlands (Stephenson et al., 1980).

Common Name	Latin Name	Temperature		pH	Maximum Salinity
		(°C)	(°F)		(ppt)
Bulrush	*Scirpus spp.*	16-27	61-81	4-9	20
Cattail	*Typha latifolia*	10-30	50-86	4-10	30
Common reed	*Phragmites australis*	12-23	54-73	2-8	45
Rush	*Juncus* spp.	16-26	61-79	5-7.5	20
Sedge	*Carex* spp.	14-32	57-90	5-7.5	NA

Rhizome: An underground horizontal stem that produces root systems and new shoots. New plants may be propagated from rhizomes.

Stolon: An aboveground horizontal stem that produces root systems and new shoots. New plants may be propagated from stolons.

Freeboard: The vertical space between the surface of a water body and the top of the surrounding embankment.

It takes six months to two years for vegetation in a constructed wetland to become fully established and to reach maximum treatment efficiency, regardless of establishment method. During the establishment period, manure should be treated in some other manner.

1. Mechanical Seeding

This method of establishment relies on machinery to plant the vegetation. The success of mechanical seeding depends mostly upon climatic conditions, water levels, and the density of seeding. Most plants will not establish from seed in standing water, but must be germinated in constantly wet soils.

2. Transplantation

Transplanting is the fastest and most reliable method of wetland propagation; however it is the most expensive method of plant propagation if the plants are purchased. By obtaining appropriate materials from local sources such as road ditches, pond edges, and natural seepage areas costs will be reduced. Local plants chosen within 80 kilometers (50 miles) tend to be more suited to the regional conditions and have higher survival rates (Simeral, 1998). It is important to note that it is often unlawful to remove plant materials from naturally occurring wetlands, and permitting requirements should be checked before removing plants. Natural wetlands are protected under law.

Transplantation of **rhizomes, stolons**, or entire plants is possible. For example, cattail rhizomes can simply be dug up and spread on saturated wetland substrate, soil, or porous materials and the plants will take root and grow.

3. Natural Establishment

Natural establishment is the cheapest of all the propagation methods. Wind and water will introduce seeds to the wetland area and these plants will grow on their own. Over a period of three or more years, a constructed wetland with naturally established vegetation will equal or surpass wetlands that were deliberately seeded or started from transplant. Naturally occurring plants are suited for the specific soils, water conditions, nutrient loadings, and climatic conditions for the particular area.

8.3.5 Wetland Cell Size and Shape

A constructed wetland unit is called a cell. A minimum of two parallel wetland cells should be part of the design. Having more than one cell allows for the shutdown and maintenance of one cell without compromising the entire wetland treatment system. Pumps and valves should be installed to permit an easy switch between wetland cells.

The cells can be shaped to meet the restrictions of the local terrain. Length to width ratios generally range from 1:1 to 10:1. The embankments surrounding the wetland cell should generally be 0.45 to 0.6 meters (1.5 to two feet) above the highest expected water level (Miner et al., 2000). This extra space, or **freeboard**, provides additional storage capacity to accommodate sediment accumulation and prevent flooding in the event of severe rainfall.

Another design consideration is the width of the embankments. The top surface should be wide enough to mow and maintain. Trees should not be permitted to grow on the embankment. The tree roots will penetrate the embankment, jeopardizing the integrity of the embankment, which can lead to a catastrophic spill. Wide embankments also prevent burrowing animals from creating channels between the cells, which can lead to **short-circuiting**. Three meters (ten feet) is a common top width recommendation (Miner et al., 2000). The suggested minimum slope from the top of the embankment to the bottom of the wetland cell is 2:1. This ratio ensures that the berm will not be compromised by the pressure and weight of the water within the wetland.

The bottom of constructed wetlands should consist of a compacted clay layer or a geosynthetic liner to prevent groundwater contamination. The liner should be covered by at least 0.3 meters (12 inches) of topsoil to serve as a rooting bed for plants in open water systems (Miner et al., 2000).

8.3.6 Wetland Discharge

While natural wetlands discharge water to surface systems like streams and lakes or percolate to groundwater systems, constructed wetlands are usually designed as an ideal closed system with no discharge. Ideal conditions are rarely achieved in real life, so even well-designed wetlands may produce some effluent. Operations and maintenance plans should account for effluent management and treatment.

There are several options for wetland discharge management. These options include direct discharge to surface water, infiltration through grass filter strips, land application, and the recycling of the discharge back through the wetland system.

Direct discharge from waste treatment systems to surface waters may be illegal in some areas or require additional permits, such as a National Pollution Discharge Elimination System (NPDES) permit.

Grass filter strips require additional land and maintenance. As with constructed wetlands, it is important to prevent preferential flow in grass filter strips to prevent ground and surface water contamination.

Land application of treated water also requires additional land and equipment and may require permits. Land application is also dependent upon climatic conditions, nutrient content of the effluent and the soil, and agronomic needs of the growing plants.

Recycling the effluent back through the wetland system is the preferred method of discharge management. Recycling is an efficient way to dilute wetland inflows to achieve the appropriate nutrient, solids, and organic matter concentrations, while decreasing the potential for odors, enhancing **nitrification-denitrification**, and maintaining adequate flow requirements during dry periods. Recycling does increase construction, operation, and management costs, but can decrease the cost of supplemental water for dilution and water level management.

8.4 Constructed Wetland Management

In addition to the monitoring of water, solids, and nutrient loading, the management of constructed wetlands involves several other issues such as insect control, wildlife considerations, and biomass harvesting.

Short-circuiting: Incomplete treatment due to the formation of channels of preferential flow bypassing a portion of the treatment system.

Nitrification: The conversion of ammonia to nitrite and then to nitrate by the autotrophic aerobic bacteria *Nitrosomonas* and *Nitrobacter*, respectively.

Denitrification: The conversion of nitrate to dinitrogen gas by heterotrophic facultative bacteria.

Aerobic: An oxygenated environment or requiring an oxygenated environment to survive.

Larvae: (*pl.* of larva) Insects that are in the immature, worm-like stage after hatching from the egg.

Nutria: A large semi-aquatic rodent native to South America but invasive in the United States.

Insect control is an important aspect of wetland management because mosquitoes lay their eggs in standing water and their proliferation can create public health issues. Other insects may destroy wetland vegetation, destroying the system. Mosquitoes can be kept in check using biological controls, including maintaining **aerobic** conditions and introducing natural predators. Mosquitofish will feast upon mosquito **larvae** and dragonflies love nothing better than mosquitoes. Cattail caterpillar populations, which can wipe out a cattail wetland, can be kept in check with a thriving population of red wing blackbirds (Baird et al., 2003).

Wetlands attract a number of animals such as ducks, shorebirds, raptors, field birds, deer, jackrabbits, and muskrats. Not all critters attracted to wetlands are welcomed, though. Burrowing animals, such as **nutria** and other rodents, may create leakage problems, so embankments should be monitored for leakage.

If wildlife enhancement is a goal, small raised islands above deeper water should be considered to support terrestrial vegetation and to provide nesting areas for birds. These islands should be part of the original design and may help provide a structured flow pattern through the wetland treatment system. Embankment and buffer area mowing is required to prevent roots from damaging the berm, but timed to prevent disturbing ground-nesting birds.

8.5 Constructed Wetland Performance

As is true of any treatment system, even a perfectly designed and constructed system may be ineffective if it is poorly implemented or managed. It is important to monitor the constructed wetlands to manage them for optimal performance and to quickly identify any problems that arise. There is no uniform standard for measuring the performance of all wetlands because performance is a function of so many variables—growing season, local climate, plant populations, waste characteristics, and bacterial populations. Nitrogen removal and odor reduction may indicate overall wetland performance. Phosphorus removal is also an issue; however, use of a constructed wetland to achieve significant phosphorus reductions is not appropriate.

8.5.1 Nitrogen Removal

Nitrogen entering wetlands is removed from the wastewater through several mechanisms, including ammonia volatilization, nitrification-denitrification, and plant uptake. Although volatilization is not the primary mechanism for nitrogen removal, volatilization may account for seven to 16 percent of the nitrogen reduction (Poach et al., 2002). Ammonia is an air pollutant and if volatilization becomes a problem, pretreatment of the incoming wastewater may be required. Pretreatment nitrification can curb ammonia volatilization from the wetland by converting ammonia to nitrate. Nitrification, as well as denitrification, the conversion of nitrate to harmless dinitrogen gas, occurs naturally within the wetland system. For more information please see Chapter 6, Nitrification-Denitrification. Plants remove nitrogen, a crucial nutrient for growth, from water and soil and incorporate it into plant biomass.

8.5.2 Phosphorus Removal

Compared to the nitrogen reduction achieved in constructed wetlands, the reduction of phosphorus is usually relatively low. If the reduction of phosphorus is the primary treatment objective then a constructed wetland may not be an appropriate treatment system.

Different studies reflect various levels of success in wetland reduction of phosphorus. Prantner et al. (2001) found that constructed wetlands reduce total phosphorus levels by about 81 percent. A study by Hunt et al. (2003), however, did not show effective removal of large quantities of phosphorus. In the Hunt study, continuous marsh and marsh-pond systems were designed to treat swine lagoon effluent. These bulrush and the cattail wetlands consistently removed less than 50 percent of phosphorus from the wastewater stream (Hunt et al., 2003). A study of subsurface-flow wetlands in Missouri conducted by Regmi et al. (2002) compared wetlands with established vegetated beds and wetlands with no vegetation to determine if the vegetal biomass or the hydric soils are responsible for phosphorus reductions. The researchers found that the dissolved phosphorus reductions were greater in the vegetated bed than in the unvegetated bed, with 81 and ten percent reductions respectively (Regmi et al., 2002). In short, phosphorous removal does occur, though likely not at levels consistently compelling enough to warrant a constructed wetland treatment system if phosphorous removal is a primary treatment goal. When phosphorus is removed, it is through four mechanisms: sediment accumulation and sorption to soil particles, precipitation, plant uptake, and **luxury microbial uptake.**

Luxury microbial uptake: A process where microorganisms digest and incorporate more phosphorus than they physiologically require. This remains a highly researched, yet poorly understood process.

8.5.3 Odor Reduction

While odor itself may not be considered an air pollutant in the Clean Air Act, individual odor-causing compounds may be pollutants. In any case, odor should be kept to a minimum whenever possible to facilitate good farm-neighbor relations, improve animal welfare, and increase worker health and morale. One study found that constructed subsurface-flow wetlands (see Section 8.6.2) removed about 80 percent of the odor-causing compounds from swine wastewater containing feces, urine and flushwater (Wood et al., 2000). These results are very promising for odor reduction, but as always, odor reduction is highly variable and can be influenced by the type of wetland, pretreatment of waste, and climatic conditions.

8.5.4 Performance Summary

It is important to remember that there is no standard for measuring the performance of constructed wetlands since performance is a function of so many variables. **Table 8.4** summarizes the findings of a single study that assessed the wastewater constituents of both the inflowing water and outflowing wastewater from 68 different constructed wetland systems. Each of these wetlands was designed to treat the wastewaters from confined animal feedlot operations.

Table 8.4: Average inflow and outflow concentrations for 68 different constructed wetland systems * (Miner et al., 2000).

Wastewater Constituent	Average Inflow Concentration	Average Outflow Concentration	Average Reduction
	(mg/L)	(mg/L)	(percent)
Biochemical oxygen demand (BOD)	263	93	65
Total suspended solids (TSS)	585	273	53
Ammonia nitrogen (NH_3)	122	64	48
Total nitrogen (TN)	254	148	42
Total phosphorus (TP)	24	14	42

*46 dairy and cattle operations, 19 swine operations, three poultry and aquaculture operations; dairy and cattle operation wastewater generally surface runoff or diluted flushwater; swine operation wastewater generally from anaerobic pretreatment lagoons; in all cases, wastewater effluent was generally dilute before introduction to the wetland system.

8.6 Types of Constructed Wetlands

There are four basic types of constructed wetlands:

1. Open wetlands,
2. Subsurface flow wetlands,
3. Floating aquatic plant wetlands, and
4. Reciprocating wetlands.

These wetland types may be used individually or combined into a system.

8.6.1 Open Wetland

An open wetland, also called a free-water surface wetland, is constructed as a fairly flat (slope of zero to three percent) channel or basin with an impermeable subsurface. The area is typically flooded with pretreated wastewater to a depth of 0.1 to 0.45 meters (four to 18 inches) (Crites and Tchobanoglous, 1998). **Figure 8.3** is a diagram of an open wetland. The standing water in an open wetland can be the source of odors and can create a favorable habitat for mosquitos.

Aquatic plants, such as cattails, reeds, rushes, sedges, and arrowheads grow with their root systems submerged in the wastewater. The plants play many roles in the wetland. The submerged parts of the plants, such as roots, stems, and leaf litter provide a surface for bacterial growth. Bacteria decompose organic matter and transform nutrients found in wastewater. The leaves above the water surface shade the water, reducing the potential for algal growth, helping to maintain a healthy wetland.

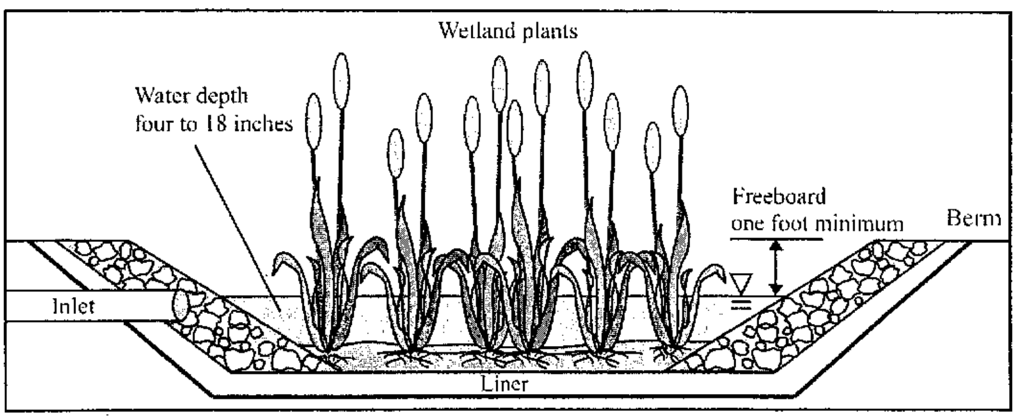

Figure 8.3: Diagram of open wetland (C. White, 2004).

Aquatic plants also transport oxygen from the leaves down to the roots, supporting plant growth and providing oxygen for microbes growing in the substrate. **Figure 8.4** is a photograph of an open wetland.

Figure 8.4: Photograph of open wetland (M. Grismer, 2004).

Wetland plants may be harvested periodically to improve water circulation. Heavy vegetative growth may inhibit water circulation, which is important for aeration and organic matter decomposition. Harvesting also promotes nutrient absorption by removing older plants—leaving room for the younger, thirstier plants to flourish. Harvesting also reduces mosquito production. However, harvesting reduces the capacity of the wetland to treat the wastewater, so after harvesting the wetland cell needs to rest for several weeks to allow plant populations to reestablish before introducing wastewater again. The harvested material may be chopped and composted, or chopped and used as mulch, or incinerated where lawful.

8.6.2 Subsurface Flow Wetland

Subsurface flow wetlands are known by many names, including submerged wetlands, rock-reed filters, vegetated submerged beds, marsh beds, tule beds, hydrobotanical systems, and the root zone method. Unlike open wetlands, subsurface flow wetlands do not have standing water. The area usually filled with water is instead filled with gravel or sand, which provides both ample pore space for water circulation and a structure for plant roots. Subsurface flow wetlands are constructed on relatively flat areas with slopes between zero to 0.5 percent (Crites and Tchobanoglous, 1998). They are also much deeper than open wetlands, ranging from 0.45 to one meter (1.5 to 3.3 feet) (Crites and Tchobanoglous, 1998). **Figure 8.5** is a diagram of a subsurface flow wetland.

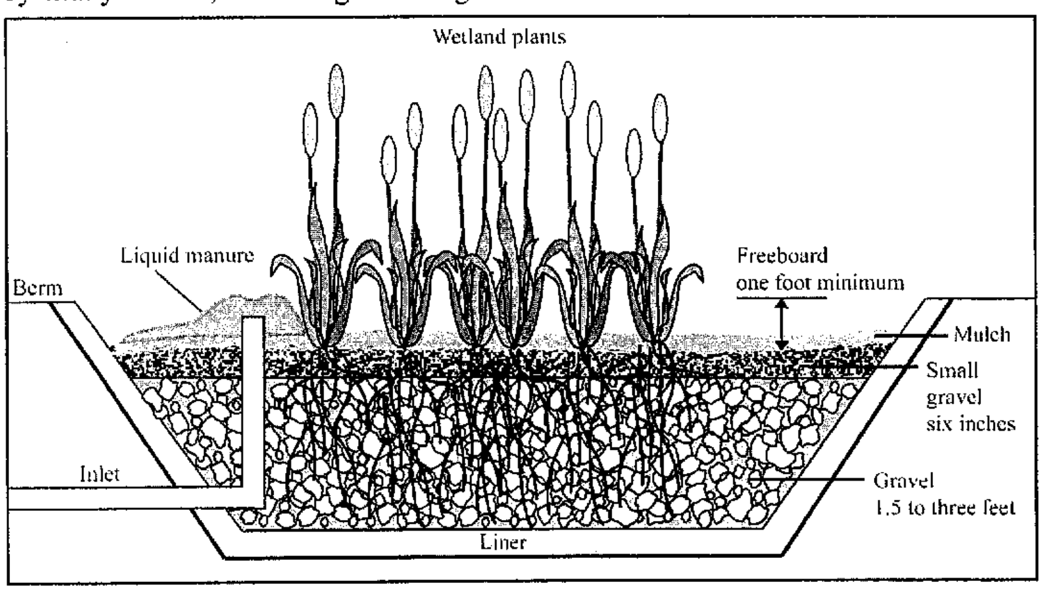

Figure 8.5: Diagram of subsurface flow wetland (C. White, 2004).

The vegetation in subsurface flow wetlands is similar to the vegetation found in open wetlands and performs the same roles, such as providing surface area for bacterial growth and conveying oxygen to the root zone. Subsurface flow wetlands are a better option than open wetlands in areas where mosquito and odor control are important; however, they may be more expensive to construct if gravel or sand is not readily available and must be purchased and transported to the site. **Figure 8.6** is a photograph of a subsurface flow wetland.

Figure 8.6: Photograph of subsurface flow wetland (M. Grismer, 2004).

8.6.3 Floating Aquatic Plant Wetlands

Floating aquatic plant wetlands are unique in that they generally use a single plant species in the design. These plants float or may be suspended in the water. The two main species of plants used in floating aquatic wetlands are water hyacinth (*Eichhornia crassipes*) and duckweed (*Lemna*).

a. Water Hyacinth

Water hyacinth wetlands are constructed on relatively level ground and are typically flooded to a depth of 0.6 to 1.2 meters (two to four feet) (Crites and Tchobanoglous, 1998). They can be designed as either aerobic nonaerated or aerobic aerated systems. Aerobic nonaerated systems are generally composed of shallow ponds or channels covered with water hyacinths. Aerobic aerated wetlands have floating or submerged aerators that provide oxygen. The supplemental oxygen allows for greater water depth and higher organic loading rates without expansion of the wetland land requirements.

Figure 8.7: Water hyacinth (Agricultural Research Service, 2004).

The water hyacinth is a perennial aquatic plant ranging from 0.5 to 1.2 meters in length (20 to 47 inches) from the top of the lavender flower to tips of the relatively long roots. **Figure 8.7** is a photograph of a water hyacinth. The root structure serves as a medium for