CHAPTER II

LITERATURE REVIEW

Wastewater Treatment in General

Constructed wetlands can be defined into two types which characterized by the flow path of the water in the systems (Reed, 1991). The first, called Free Water Surface wetlands (FWS) is that the surface of water is exposed to the atmosphere as it fllows through the bed. It contains appropriate emergent aquatic vegetation in a relatively shallow bed or channel. Its water flows slowly and has treatment system as plug flow. Crites *et al.*, (1995) proposed that the bed of this systems contain emergent aquatic vegetation, a layer of soil to serve as rooting media, a liner if necessary to protect the groundwater, and appropriate inlet and outlet structures. The water depth in this type of wetlands can be ranged from a few centimeters to 0.8 m or more, depending on the purpose of the wetland. A normal operating depth of 0.3 m (1 ft) is typical. In tropical countries, FWS constructed wetlands are generally favored because of their lower capital and operating costs.

The second type, called Vegetated Submerged Beds wetlands (VSB), that the water level in the bed is maintained below the top of the media, so that all flow is supported to the subsurface. It contains permeable media (rock, gravel, sand, and soil have all been used). This media supports the root system of the same types of emergent vegetation. A liner is also used to protect groundwater quality. The depth of the media is typically 0.3 - 0.6 m (1 - 2 ft).

Performance of constructed wetlands depend on many factors, including type of pretreatment, influent concentration, flow, wetland type, wetland size, and soil (Brown, 1994). The pollutants in constructed wetlands are

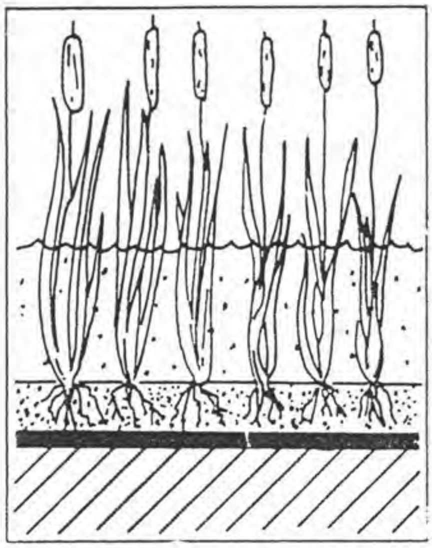

Figure 2.1 Free water surface wetland system (FWS) schematics. Water level is above the surface; vegetation is rooted and emergent above the water surface.

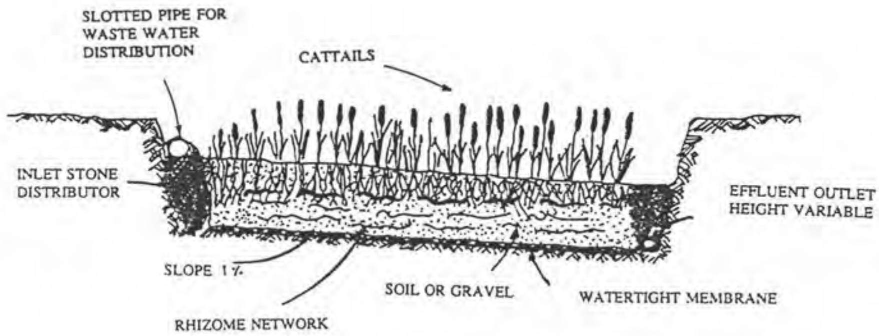

Figure 2.2 Vegetated submerged bed wetland (VSB).

removed through a combination of biological, physical, and chemical processes including assimilation by the plant tissue, microbial transformations, edge of the performance of artificial wetlands shows that suspended solids and readily biodegradable organic matter are generally removed effectively, effluents very nearly attaining advanced secondary treatment quality (Brix and Schierup, 1989)

Table2.1 Relative importance of the macrophytes in different design of constructed wetlands. Number of +'s increase with importance of the process; "-" designates no importance.

	Surface Flow	Subsurface Flow	Combined Systems
Stabilize bed surface	+++++	+++++	+++
Prevent clogging	-	-	+++++
Reduce current velocity	+++	-	-
Attenuate light	+++++	++	+++
Attached microbes	+++++	+++	+
Uptake of nutrients	+++++	+	+
Oxygen transfer & release	+	++	+
Habitat for wildlife	+++++	+++	+
Aesthetics	+++++	+++++	+++++

Source : Modify from Brix, 1994

Gillette (1992) stated that constructed wetlands work by funneling wastewater through aquatic plant systems. Organics in the wastewater are absorbed and biodegraded by plants and - the real workhorses in these natural systems - the microorganisms that thrive on plant roots and stems. Gearheart (1993) has revealed that the wetlands reduced the concentration of orthophosphate through plants uptake, suspended solids adsorption and settling, and sediment adsorption.

Breen (1990) has described, quantifying system performance, major nutrient storage components and nutrient removal mechanisms together with a mass balance method. They were capable of a high level of performance. Percentage load removals for chemical oxygen demand, total nitrogen and total phosphorus were 86, 95 and 99 %, respectively.

Removal efficiencies for nitrogen and phosphorus are variable, and dependent on loading rate, type of substrate, and type of wastewater (Gersberg, Elkins and Goldman, 1984).

Aquatic Plants

Emergent macrophytes have large internal air spaces for transportation of oxygen to roots and rhizomes (Brix, 1988). Farming cattails and other aquatic plants to purify wastewater have been a fast-growing new treatment technology (Gillette, 1992).

The plant rhizome provides surface for bacterial growth as well as for filtration of solids. More importantly, plants are known to translocate oxygen from the shoots to the roots (Gersberg, 1986). The root zone will offer an oxidized microenvironment in an otherwise anaerobic substrate, which stimulate both the decomposition of organic matter and the growth of nitrifying bacteria, the latter which can convert ammonia to nitrate.

Emergent aquatic macrophytes are the dominating life form in wetlands, growing within a water-table range 50 cm below the soil surface to a water depth 150 cm or more. In general they produce aerial stems and leaves and an extensive root and rhizome system. The plants are morphologically adapted to growing in a waterlogged or submerged substrate by virtue of large internal air spaces for transportation of oxygen to roots and rhizomes. Part of the oxygen may leak into the surrounding rhizosphere creating oxidized conditions in the otherwise anoxic environment and stimulating both decomposition of organic matter and growth of nitrifying bacterial (Brix and Schierup, 1989).

Guntenspergen, Stearns and Kadlec (1989) have pointed out that the vegetation in wastewater act as a temporary storage pool, with most pollutant transformations and sequestering processes occurring in the substrate. Emergent and floating leaved species have been preferentially used in pilot studies of constructed wetlands. Potentially useful emergent species include many members of the cattail, reed, rush, sedge and grass families. They have potentially high uptake and production rates. They are widespread, able to tolerate a range of environmental conditions, and can alter their environment in ways suitable for wastewater treatment. Submerged aquatic plants do not appear to have attributes that would be useful in wastewater treatment. They have low production rates and many species are intolerant of eutrophic conditions and have detrimental interactions with algae in the water column.

Three higher aquatic plant types, Scirpus validus (bulrus), Phragmites communis (common reed), and Typha latifola (cattail) were studied in the removal of nitrogen, BOD and TSS from primary municipal wastewaters. During the period of August 1983 - December 1984, The mean ammonia concentration of 24.7 mg/l in the primary wastewater inflow was reduced to mean effluent levels of 1.4 mg/l for the bulrush bed, 5.3 mg/l for the reed bed and 17.7 mg/l for the cattail bed, as compared to a mean value of 22.1 mg/l for the unvegetated (control) bed. BOD removal efficiencies were highest in the bulrush and reed beds, both with mean effluent BOD levels (5.3 and 22.2 mg/l, respectively) significantly below that for the unvegetated bed (36.4 mg/l) (Gersberg *et al.*, 1986).

A study by Gearheart, Klopp and Allen has shown that ten pilot eperimental wetlands, 6.1 m by 61 m and 1.22 m deep, could be operated at variable depth and variable hydraulic loading. Aquatic vegetation was principally bulrush (Scirpus validus). Design flow was maintained at 0.34 L/sec. Suspended solids were effectively removed to less than 10 mg /l at all hydraulic loading rates. Average SS effluent concentration was 5.3 mg/l, representing 85 % removal and their SS effluent values ranged from 4.0 to 9.4 mg/l. Average BOD_5 effluent values ranged from 9.0 to 15.3 mg/l and averaged 13.3 mg/l. The BOD_5 removal rate varied from 41 % to 65 % and averaged 56 %.

The plants in a FWS wetland serve several physical functions. The leaves and stems of the plants help to distribute flow, dampen influent flow velocity, filter wastewater solids, and function as support structures for microbs (Brown,1994).

Nutrient Uptake

Wetland plants take up nutrients with root systems. As wetland plants are very productive, considerable amounts of nutrients can be bound in the biomass (Brix, 1994). Their nutrient uptake rate plays an important role in the removal of nutrients (nitrogen, phosphorus) and other wastewater components (heavy metals, refractory organics, etc.). The uptake rate of a plant is limited by a net growth rate and the concentration of nutrients in the plant tissue. Nutrient concentration of emergent macrophytes is high (more than 25 g/kg of tissue) in young plants and decrease in mature ones (Reed and Debusk, 1987).

Plant uptake of phosphorus is rapid, and following plant death, phosphorus may be recycled to the water column or deposited in the sediments (WPCF, 1990).

<u>Nitrogen</u>

Treatment of wastewater nitrogen by constructed wetlands is influenced by system design, the chemistry of root-water-sediment environment, plant uptake, available carbon, ammonia volatilization as influenced by pH, and the type of substrate. The amount of treatment of nitrogen by constructed wetlands is also dependent on the amount of time the wastewater remains within the system.

A detention time of 5-7 days is usually sufficient to produce a discharge containing < 10 mg/l of TKN (Bavor, Roser and McKersie, 1987).

Phosphorus

Phosphorus levels are especially important in freshwater systems where it may be the limiting nutrient for algae and aquatic plant growth and, therefore, excess phosphorus added to these systems contributes to eutrophication (Dillon and Rigler, 1974). Reactions of phosphorus with formation of organic phosphates and uptake by aquatic plants and microorganisms can be manipulated through design variables with a constructed system. Though phosphorus adsorption can be maximized for a particular constructed wetland, aerobic terrestrial environments should be used if feasible. To maximize wetland removal of phosphorus, more actively growing woody species and persistent emergent species may be benificial. The nitrogen to phosphorus ratio of the wastewater should be manipulated to encourage more plant growth and more phosphorus uptake (Ulrick and Burton, 1985).

Oxygen Transfer

The emergent plants such as cattails, bulrushes and reeds can absorb oxygen from the atmosphere through the leaves and above-water stems to their roots. These oxygen molecules leak out into the root zone and create an aerobic layer. Therefore aerobic-anaerobic condition exists in the soil zone. Aerenchyma tissue plays an important role in oxygen movement within the plants (Good and Patrick, 1987). These plants can transfer between 5 and 45 g of oxygen per day per square meter of wetland surface area, depending on plants density and oxygen stress levels in the root zone (Reed, Crites, and Middlebrooks, 1995).

Exchange of gases between the gas spaces of buried plant tissue and the surrounding water may also lead to convective air flow inside the plant. This mechanism is based on the different solubilities of oxygen and carbon dioxide

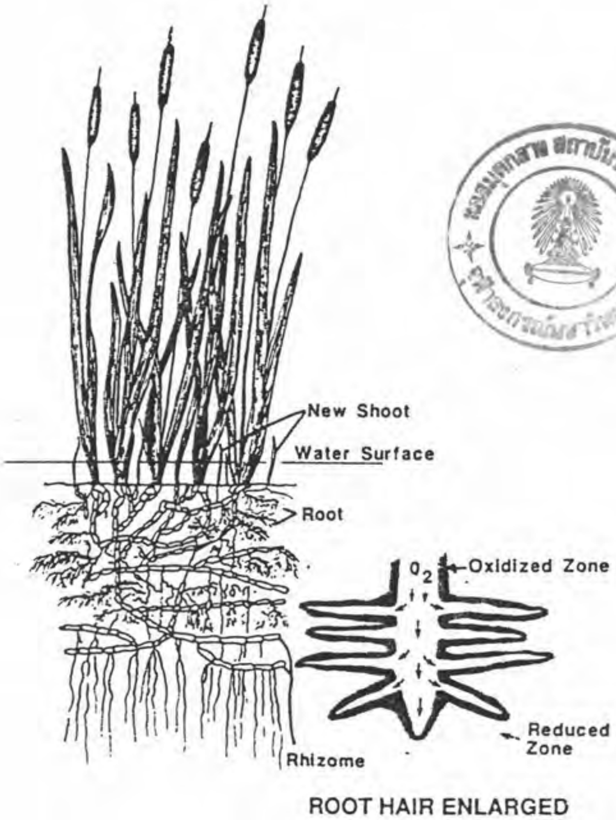

Figure 2.3 Treatment of oxygen by roots and rhizomes in anaerobic wetland substrate.(After Novotny and Olem, 1994).

Table 2.2 Summary of performance of selected pilot-scale of constructed wetland systems

System name	System type	Area m^2	HRT days	Water depth cm	BOD_5			Total suspended solid			Ammonia-nitrogen			Total phosphorus		
					In mg/L	Out mg/L	Rem. eff. %	In mg/L	Out mg/L	Rem. eff. %	In mg/L	Out mg/L	Rem . eff. %	In mg/L	Out mg/L	Rem. eff. %
Listowel 4	FWS	1320	23.3	30	56.3	9.6	82	111	8	93	8.6	3.3	23	3.2	0.6	79
Iselin	FWS	2200	-	-	140	7.4	95	380	19	95	30	3.8	89	13.0	2.6	80
Arcata High	FWS	361	1.9	47	26	12.8	51	37	5.4	85	12.8	6.1	23	-	-	-
Arcata low	FWS	361	7.8	47	26	10.7	59	37	6	84	12.8	9.8	25	-	-	-
Santee RE	VSB	65	16.3	-	118	22.3	81	37	5.4	86	24.7	11.6	78	-	-	-

Note: Based on WPCF, 1990

in water, carbon dioxide being approximately 30 times more soluble in water than oxygen. Solubilization of respiratory carbon dioxide has been shown to be able to produce some convective gas flow in wetland plants (Koncalova *et al.*, 1988).

General Design Procedures

Many studies have indicated that the wetlands were able to remove significant quantities of organic matter (BOD), suspended solid (SS), nutrients (N,P), heavy metals (Zn) trace organics and pathogen from various types of wastewater. The basic treatment mechanisms involve sedimentation, microbial activity, absorption, chemical decomposition, soil building (Reed, Middlebrooks and Crites, 1988). The treatment efficiencies of several pilot-scale wetland system are summarized in table 2.2.

The principal process design criteria for FWS constructed wetlands are detention time, organic loading rate, water depth and aspect ratio. Other design considerations include mosquito control and vegetation harvesting. Typical values of design criteria are presented in table 2.3

Table 2.3 Process Design Criteria for Free Water Surface Constructed Wetlands

Factor	Typical value
Detention time (d)	5 to 14
Water depth (m)	0.1 to 0.5
Hydraulic loading rate (mm/d)	7 to 60
Aspect ratio	2:1 to 10:1
Mosquito control	Required
Harvest frequency (yr)	3 to 5

A constructed wetlands is designed to use one or more of three types of flow pattern: plug flow, step feed, or recirculation. Plug flow is once-through flow down the cell length. Plug flow is now used for most municipal and acid drainage systems and requires minimal piping, energy use, operation, and maintenance (Steiner and Freeman,1989).

Constructed wetland systems can be considered to be attached-growth biological, and their performance can be estimated with first-order plug flow kinetics for BOD and nitrogen removal (Reed, Crites, and Middlebrooks, 1995). The average flow through the wetland can be calculated by the equation:

$$Q = \frac{LWdn}{t} \qquad (2.1)$$

where Q = the average flow through the wetland, (m^3d^{-1})

L = length of the wetland cell, (m)

W = width of the wetland cell, (m)

d = depth of the wetland cell, (m)

n = porosity, or the space available for water to flow through the wetland (0.75 for FWS system)

t = hydraulic retention times, (days).

Aspect Ratio

The aspect ratio (L:W) for FWS wetlands is important to the performance for removal of BOD, TSS, NH_3 and total nitrogen (WPCF, 1990). A very high aspect ratio was necessary to ensure plug flow conditions in the wetland and to avoid short-circuiting, and aspect ratios of at least 10:1 were recommended (Reed, Crites, and Middle brooks, 1995).

Hydraulic Retention Time (HRT)

The optimum HRT suggested by the previous research at Listowel should be 7 - 14 days. The long HRT can result in a stagnancy and leading to anaerobic conditions. Breen (1990) has pointed out that the HRT of 5 days has clearly maximized influent-rootzone contact and represented an optimal condition for plant nutrient absorption.

Vegetation Harvesting

Harvesting of the emergent vegetation is only required to maintain hydraulic capacity, promote active growth, and avoid mosquito growth. Harvesting for nutrient removal is not recommended (Reed *et al.*, 1988).

Mosquito Control

With FWS wetlands mosquito control is essential. Provisions include stocking with mosquito-fish, maintenance of aerobic conditions, use of biologocal controls, and encouragement of predators. At Arcata, California the FWS wetland produces less mosquito larvae than the previous unused marshy area because of the encouragement of habitat for shallows mosquitofish (Crites, 1994).

Soil and Organism in Constructed Wetlands

Soil

In FWS wetlands air/water interactions are very important as oxygen transfer to the wastewater is dependent almost entirely on atmospheric input. Soil/water interactions can also be important depending on the type of soil present (Brown, 1994).

Soil structure is an important component of wetland systems, especially for FWS system, because of its affect to hydraulic conductivity of the soil bed. The hydraulic conductivity should be about 10^{-3}- 10^{-5} m s^{-1}. Soil with some clay content can be very effective for phosphorus removal. Phosphorus removal in soil matrix can be a major pathway for almost complete phosphorus removal for many decades. In FWS wetlands, the only contact opportunities are at the soil surface, and the most active microbial activity occurs on the surfaces of the detrital layer and the submerged plant parts (Reed, Crites, and Middlebrooks, 1995).

Organism

A wide variety of beneficial organisms, ranging from bacteria to protozoa to higher animals, can exist in wetland systems (Reed, Crites, and Middlebrooks, 1995). Bacteria may be free-living in the water or attached to the surfaces (periphytic bacteria) such as submerged parts of the aquatic plants (roots, stems), peat, rock, sand or sediment at the bottom layer (benthic bacteria) (Rogers *et al.*, 1985).

Microorganisms living in the soil and roots of plants growing in the soil therefore are able to obtain oxygen directly from their surroundings. The root systems of plants growing in water-saturated substrates therefore must obtain oxygen from their aerial organs via transport internally in the plants (Brix, 1994).

Free-living (zooplankton), benthic or plant surface-invertebrates are found in wetland systems such as annelid worms, mollusks, crustaceans, insects, etc. On the other hand, those invertebrates and plants are food sources for small fish which also propagate in wetlands. The vertebrates and inverterates are important in the transfer of energy, nutrients and they also form part of grazing food chain in wetland ecosystems (Rogers *et al.*, 1985).

Evapotranspiration

Evapotranspiration is the sum of evaporation from the water surface and water loss by emergent plants (Kadlec, 1987). Evapotranspiration depends on controlling factors such as solar radiation, wind, relative humidity, air temperature and cover type (Hammer and Kadlec, 1983). Evaporative water losses in the summer months decrease the water volume of the pollutants in wetland and therefore the concentration of remainng pollutants tends to increase. Besides, when water volume decreases, the HRT increases and anaerobic condition may occure (Reed *et al.*, 1988).