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# Constructed Wetlands Review

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## ABSTRACT

Natural water purification system especially constructed has been commonly employed in Taiwan and worldwide nowadays. This paper has reviewed several papers written by the author.

***Keywords*:** Constructed Wetland; Natural Water Purification Systems; Heavy Metals; Organic Matter; Nitrogen

The papers written by the author have been demonstrated as followings:

In the paper published by T. Y. Yeh, T. Y. Ke, Y. L. Lin "Algal growth control within natural water purification systems: Macrophyte Light shading effects, water air, & soil pollution, 2011, Vol. 214, pp 575-586

Natural water purification systems are commonly used to treat wastewater in tropic regions, however, the water quality of effluent is fluctuated and is often failed to comply with regulatory water criteria due to the algae bloom. Separation of the algae is inevitable to produce high effluent quality and comply with effluent standards. Algal growth control measures including emergent and floating macrophytes as well as back cloth physical shading and algaecide application were investigated in this study and aimed to reuse the effluent for water resource conservation and groundwater recharge in tropical areas. The emergent and free-floating macrophytes shading on algal growth control have been demonstrated to be viable in batch experiments and field scale hybrid natural water purification systems including oxidation ponds and surface flow wetlands. Emergent macrophytes assisted controlling algal growth by preventing sunlight from reaching the water surface in surface flow wetlands. Results of this study can be referenced by similar hybrid constructed wetland systems to control algal activity and to prevent effluent deterioration.

Natural water purification systems such as constructed wetlands and ponds are considered as one of popular measures to treat domestic sewage for small communities in rural areas. Hybrid natural purification systems including oxidation ponds and constructed wetlands have been demonstrated to be less labor intensive, low operational cost, and easy to maintain methods to enhance surface water quality worldwide (Jing *et al*., 2004; Molle *et al*., 2008). Recently, this green remediation approach by employing natural water purification systems has drawn considerable attention in Taiwan due to the fairly low sewerage availability (Yeh and Wu, 2009). The algal growth deteriorating the effluent quality of the natural systems becomes the challenge of local water treatment engineering in order to reuse the treated water from natural systems. An appropriate algal growth control measure is inevitable to enhance the receiving water quality after treated by various natural water purification systems. Submerged macrophyte restoration was demonstrated to be an effective approach to reducing the nutrient loading and restricting algal bloom in fresh water bodies. The biomass of phytoplankton among macrophyte beds was lower than in the open water. This phenomenon has been attributed to shading, competition for nutrients, inhibition of sediment resuspension, and allelopathic substances excreted by macrophytes (Nurminen and Horppila, 2009). In addition, floating macrophytes suppressing growth of algae and enhancing disintegration of algal cells through decay has been attributed to the prevention of sunlight penetration in natural systems (Kim and Kim, 2000). Recent researches have showed that the polyethylene bag physical covering was effective to manipulate the phytoplankton community due to its modification of the light intrusion levels in the water column (Sinistro et al., 2007). Though, this physical covering approach might not be feasible to employ in


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large scale wetland systems for proper algal control. Shading of sunlight might be a feasible measure to control algal bloom in natural water purification systems.

Natural water purification systems including oxidation ponds and free water surface flow wetlands where biological oxygen demand reduction takes place by supporting algal growth have presented a challenge to maintain the con-sistently high effluent water quality. In natural systems, the bacteria decompose the biodegradable organic matter and release carbon dioxide, ammonia, and nitrates. Algae through photosynthetic process release oxygen enabling the bacteria to decompose organic wastes. Phytoplanktons are the primary producers and constitute the first level trophic status in aquatic food chain for all aquatic animals. Algae in the effluent showed up in the form of suspended solids and exerted an oxygen demand on the receiving stream via bacterial degradation. Therefore, excessive loss of algae from the natural system deteriorates the effluent quality. Separation of the algae is essential to produce lower concentrations of organic matters, suspended solids, and nutrients and to comply with the regulatory water criteria. In natural systems, algae play important roles as nutrient consumers and dissolved oxygen producers. Nevertheless, algae in effluents can exert an oxygen demand in receiving water and clog irrigation devices. The combination of oxidation ponds and subsurface flow constructed wetlands has been demonstrated as an effective measure to retain algae from pond effluents and further enhance the water quality (Melian *et al*., 2009). In this study, hybrid constructed wetlands including two free water surface flow wetlands following by a subsurface flow wetland were investigated to study the algal removal efficiency and related water parameters. The macrophyte shading effect on algae control within surface flow wetlands was particularly examined.

A high growth rate of phytoplankton in natural systems usually was caused by the influence of light and the continuous nutrient inflow. Algae can be washed out of the systems and cause an oxygen demand in the receiving waters by bacterial degradation. Algae in the effluent show up in the form of suspended solids and exert an oxygen demand on the receiving water by bacterial degradation. Therefore, algae should be removed in order to meet the water criteria and upgrade the effluent quality. The combination of oxidation ponds and constructed wetlands with macrophyte shading seems to results in an effective algal removal. To reduce the adverse effect of harmful algae, Chlorophyll-a concentration should be below 50 μg/L in raw water, otherwise the conventional water treatment facilities would be ineffective to remove algae. In-situ algal control was proposed to remove algae in water source area rather than in water treatment plant. A simple physical measure, light shading, has been demonstrated to reduce blue algal biomass during a pilot-scale study (Chen *et al*., 2009).

The role of macrophytes has also been demonstrated to be vital for pollutant removal within wetland systems (Southichak *et al*., 2006). Previous study has demonstrated that nitrate nitrogen reduction in wetland might be through two processes including nitrification/denitrification and nitrogen uptake by macrophytes (Mitsch *et al*, 2005). The role of vegetation within constructed wetlands also includes creating aerobic degradation environments around root zones via atmospheric diffusion, which is crucial for aerobic microbial degradation (Davis *et al*., 2005). The influence of the macrophytes that determines a strong light attenuation in the water column affects the microbial communities. Macrophytes and algae have an antagonistic relationship in aquatic ecosystems. Macrophytes inhibit algal growth by competing for the available nutrient supply. In addition, they reduce the amount of solar radiation penetration suppressing algal growth and prevent wind action to the water surface providing excellent conditions for particle settling (Kim and Kim, 2000).

The aim of this study was intended to investigate the impact of light shading on algal bloom control within natural water purification systems. Batch microcosm study and field-scale wetlands water quality investigation were carried out to verify the macrophyte shading effect on algal control. The variation of water parameters during the aforementioned experiments was also monitored.

In the paper T. Y. Yeh, K. F. Chen, C. L. Lin "Waste removal and oxygen condition in a natural water purification system"

Emergent incident of fish kill was occurred in the detention pond of natural water purification system. The objective of this study was revealed the cause of the incident. Novel measurements unprecedentedly employed in this study including SOD to measure sediment oxygen decay PCR to find out sediment microbial activity, SEM, EDX, and FTIR to view the macrophyte rhiyphere root surface to understand the pollutant adsorption. Algal bloom was the main reason to induce serious fish kill Particle size analysis demonstrated greater particles were setting in the upstream. Chlorophyll A , COD, SS, phosphorus, E coli were in descending of following the stream direction. The end of measuring point, detention pond, demonstrated the serious eutrophication which leads to diurnal pH and DO fluctuation to induce anoxic condition at night which induced fish kill. Sediment oxygen uptake (SOD) also measure to fine vertical oxygen profile. SEM, EDX, and FTIR results indicated the major functional groups of submergent macrophyte reed root were carboxyl, carbonyl, and phenol which could adsorb various pollutants.

Constructed wetlands, nature water purification systems and novel green remediation approaches, have commonly employed in Taiwan and worldwide for water polishing. Several constructed wetlands have been listed as nation wetlands and to be special protected and managed. Constructed wetlands possess organic matters (BOD and COD), particulate matters (SS), nutrients (Nitrogen and Phosphorus), heavy mental (Cu and Zn), pathogen idicator (E. coli) and pharmacypheutical personal care products (PPCPs) mitigation ability (Yeh *et al*., 2009; Cheng., 2006)Kao *et al*., 2010, Lan, S., Ju, F., & Wu, X., 2012., Valipour *et al*,2013 ). Constructed wetlands have long been a black box and pollution degradation was not revealed. Recently, numerous studies have conducted to reveal the black box.

A serious fish kill occurred in the University detention pond which induced water quality was significantly reduced. The university suspected toxic algae was the cause of fish kill. An investigation project was initiated to scrutinize fish kill and proposal of water related monitoring was conducted. The objective of this study was aiming to the oxygen status in the wetland system and the myth of fish kill. To our best literature review, none if any conducted the following novel measurements unprecedentedly employed in constructed wetland including SOD to measure sediment oxygen decay PCR to find out sediment microbial activity, SEM, EDX, and FTIR to view the macrophyte rhizhere root surface to understand the pollutant adsorption. By virtue of aforementioned resulted, real cause of fish kill can be revealed.

The objective of this study was mainly focused on the cause of fish kill in natural water purification systems related to oxygen concentration.. Algal growth influence factors were also monitored which was provided for water bodies eutrophication. This monitoring study can be referenced by natural water purification systems for fish kill and eutrophication.

In the paper published T. Y. Yeh “A Study and Analysis on the Physical Shading Effect of Water Quality Control in Constructed Wetlands” Journal of environmental protection, 2014

This study mainly utilized model basins to conduct relevant water quality analyses and tests to understand the influence of the shading effect of wetland plants in the natural water purification system on algae control and eutrophication of water bodies. The model basin tests are based on the physical shading effect in order to evaluate and further understand the influence of algae control and water quality parameters. The physical shading tests were conducted at different rates (100, 70, 50, 30, and 0%) and the research results indicate that the initial dissolved oxygen concentration of each group is between 5 - 7 mg/L. On Day 5, the average dissolved oxygen concentration of the 100 (aerobic) , 100 (anaerobic), 70, 50, 30 and 0% groups is respectively 9.22±1.24, 8.54±1.23, 18.8±3.74, 21.71±0.41, 22±0, and 22±0 mg/L while that of the 70, 50, 30, and 0% groups significantly increases. The initial concentration of Chlorophyll a of the 100 (aerobic) , 100 (anaerobic), 70, 50, 30 and 0% groups is, respectively, 5.27±0.93, 5.92±0.00, 7.9±5.59, 5.92±0.00, 7.9±5.59 and 13.82±2.79 μg/L. On Day 5, the average concentration of Chlorophyll a is, respectively, 57.27±11.17, 9.87±2.79, 244.86±50.34, 280.4±32.92, 329.77±15.55 and 250.78±32.21μg/L.

In general, the physical shading effect can prevent photosynthesis by algae in water by absorbing light and converting light into chemical energy for self-growth and proliferation that cause a rapid increase in the number of algae. The physical shading effect, however, cannot reduce nutrients; this leads to a high nutrient level in water bodies during the latter stages of the tests. After the introduction of the Carlson Tropic State Index (CTSI), the completely shaded water bodies at the initial stage of tests are mesotrophic water bodies that contain neutral nutrients. The partially shaded water bodies are eutrophic. In the latter stages of the tests, the former turned eutrophic while the latter turned mesotrophic. The main cause lies in the relatively higher weight CTSI placed on total phosphorous content.

Eutrophication of water bodies has been studied since 1970. It is an urgent water pollution issue that needs to be addressed. In the past, eutrophication often occurred in reservoirs, lakes, or watersheds where water bodies have a slow flowing speed. Eutrophication or hypertophication refers to the accumulation of nutrients due to the addition of external nutrients into the water system (lakes, reservoirs, and wetlands) (Kuo *et al.*, 2005). Eutrophication, according to nutrient concentration, can be divided into four types: oligitrophic, mesotropic, eutrophic, and hypertrophic (Nurnberg, 1996).

In recent years, eutrophication in water bodies mainly was the result of excessive human activities such as overdevelopment of watersheds, agricultural irrigation, and recreation that cause the addition of exogenous nutrients to local water bodies that sped up the eutrophication of the water bodies and caused serious damage (Wu *et al.*, 2006). The eutrophication phenomena include an increase of nutrient concentration and a rapid increase in the number of algae.

Generally, the treatment technologies of eutrophic water bodies can be classified into physical, chemical, and eco-technology. Commonly used technologies include aeration at the bottom layer to increase dissolved oxygen concentrations in the deeper layers, addition of an algae inhibitor called copper sulfate that inhibits the growth of algae by increasing the concentration of Cu2+, or the construction of wetlands that remove the carbon source and nutrients in the water (Cooke *et al.*, 1993; Kuo *et al.*, 2005). Among them, physical treatment requires huge amounts of energy to be effective and the addition of chemical agents increases treatment costs. Therefore, eco-technology treatment, a green technology, has gained high public support and at the same time, it requires lower amounts of energy, lower costs, and easy technological operations.

Eutrophication includes an increase in nutrient concentration as well as an increase in the number of algae (algal bloom). The extensive results of eutrophication are the death of a large number of animals, plants, and plankton, dramatic changes in dissolved oxygen concentration, changes in the eco-system and foul odors in the water bodies. Thus, if the nutrient concentration in water bodies can be controlled or algal bloom can be avoided, issues caused by eutrophication can be effectively rendered to prevent water quality and eco-system problems and to further achieve the purpose of water quality control.

Treatments for eutrophication mostly aim to remove the nutrients, such as nitrogen and phosphorus, in the water in order to improve eutrophication in water bodies. The mechanism of a constructed wetland system to treat eutrophication lies in the absorption of nitrogen and phosphorus nutrients by aquatic plants in the wetland system as well as the competition for the absorption of nutrients between aquatic plants and algae in water in order to control algae concentrations in water effectively. Algae in water, however, can use photosynthesis to convert light energy into chemical energy for self growth and aquatic plants can prevent the sun's ray from entering the water bodies as they grow, thereby creating the physical shading effect (Ke, 2010).

In the paper published T. Y. Yeh "Causes of fish kill in a natural water purification system" International journal of environmental science and technology, 2014

An incident of fish kill occurred in the detention pond of a natural water purification system. The objective of this study is to reveal the cause of the incident. Novel measurements unprecedentedly employed in this study include: SOD to measure sediment oxygen decay; PCR to find sediment microbial activity. Algal bloom was the main reason for the serious fish kill. Particle size analysis demonstrated that large particles were settling in the upstream region. Chlorophyll A, COD, SS, phosphorus and E coli were following the stream direction. The end of the measuring point, the detention pond, demonstrated the serious eutrophication which leads to diurnal pH and DO fluctuations which induce anoxic condition at night, which induced the fish kill. PCR and microbial optical investigation demonstrated that blue green algae were the predominant species. The results of this study can serve as reference for other natural water purification systems worldwide, particular for high luminance and temperature climate, particularly in tropical regions.

Constructed wetlands, natural water purification systems and novel green remediation approaches have been commonly employed in Taiwan and worldwide for water cleaning. Several constructed wetlands have been listed as national wetlands to be specially protected and managed. Constructed wetlands possess mitigation ability (Yeh *et al*., 2009; Kao *et al*., 2010) in regard to organic matter (BOD and COD), particulate matter (SS), nutrients (Nitrogen and Phosphorus), heavy metals (Cu and Zn), pathogen indicators (E. coli) and pharmaceutical personal care products (PPCPs). Constructed wetlands have long been a black box and pollution degradation was not revealed. Recently, numerous studies have been conducted to shed light on the black box.

A serious fish kill occurred in the University's detention pond which implied that the water quality was significantly reduced. The university suspected toxic algae as the cause of the fish kill. An investigation project was initiated to examine the fish kill and a proposal for water-related monitoring was accepted and conducted. The objective of this study was to examine algal blooms in the wetland system and the myth of such resulting fish kills. A literature review revealed that none conducted the following novel measurements unprecedentedly employed in constructed wetlands, including SOD to measure sediment oxygen decay; PCR to determine sediment microbial activity; SEM, EDX and FTIR to view the macrophyte rhizhere root surface in order to understand the pollutant adsorption. By virtue of the aforementioned results, the real cause of the fish kill could be revealed.

The objective of this study was mainly to focus on the cause of fish kill in natural water purification systems. Algal growth influential factors were also monitored for eutrophication of water bodies. This monitoring study can serve as reference for natural water purification systems in regard to fish kills and eutrophication.

In the paper T. Y. Yeh "Mass balance analysis within a pilot subsurface flow constructed wetland"

Mass balance was concluded in these pilot wetlands to investigate Cu and Zn microbial transformation, sediment and macrophyte accumulation, and adsorption onto the surface of plant and benthic sediment mechanisms employing submergent plant cattail and floating plant cotton rose. For Cu sediment, macrophyte, and effluent were accounted for 58.01 %, 4.74 %, and 22.39 %, respectively while for Zn, sediment, macrophyte, and effluent were 62.46 %, 1.81 %, and 14.45 %, respectively. The major sink of both metals within this pilot wetland spelled as sediment. The metal levels in sediment followed the flow direction descended indicated that sediment was merely saturated in terms of adsorption capacities. Cattail preformed better metal accumulation relative to cotton rose which indicated submergent plant was more prominent than floating plant in terms of metal accumulation. Storm runoff might bring out the sediment inducing the mass balance was not satisfactory. The errors of Cu and Zn were 14.86 % and 21.28 %, respectively. Nevertheless, this mass balance results still provides crucial reference for future studies. PCR DGGE, EDX, and SEM result revealed sediment and saprophyte root surface inner picture which is unprecedented accomplished in this study.

Mass balance is a pivotal important engineering technique to illuminated pollutant in and out flow, accumulation, reaction within the control volume. Wetland is generally regarded as a black box which mass balance can provide powerful tools to unveil the myth of the black box. Control volume needs to construct first and Influent, effluent, reaction and accumulation within the control volume need to account for next. First order degradation is commonly assumed to investigate microbial degradation. Influent, effluent, accumulation, reaction items all needs to convert to the mass to investigate if they are balanced.

Accumulation is usually accounted for sediment and macrophytes within the control volume of wetland system. Stead state is assumed to solve the differential equation to obtain pollutant transformation mechanisms. In this study, pilot subsurface flow wetlands are assumed to be a plug flow reactor which is completely mixing through flow direction while the previous control volumes were not mixed with the following control volume. The constrictions of evaluated target pollutant can be solved by assuming stead state and first order reaction kinetic equation.

The use of lagoon is in which photosynthetic plants, or macrophytes, are an integral part is relative new in wastewater treatment. This form of wetlands treatment used aquatic macrophyte as part of similar engineered systems to treatment wastewater. The prominent macrophte included water hyacinths, water primrose, and cattails , although many others are possible in the temperate zone. Although heterotrophic bacteria carry out BOD removal , wetlands treatment is successful because of the benefits of the macrophyte. The benefits include leaves and stems above the water shield the water column from sunlight reduce algal blooms. Stem and roots in the water column as canonized by biofilm and help accumulated a large bacterial population. Stems can help to capture colloids. Stems and roots may give oxygen during photosynthesis and stimulate bacterial metabolis. Wetland is efficient for nutrient removal, as well as removal of BOD and SS, Nutrient removal is a combination of microbial and macrohyte. The macrophyteic part is brought about by incorporation of N and P into the plant mass, which is harvested. Major removal of nitrogen, however, is more likely due to microbial nitrification and denitrification. Design of wetland remains rather empirical. A depth of about 105m and a length to wide ratio of 3:1 have been used successfully. Surface BOD loading of up to 220 kgBOD5 ha-d gave good BOD and SS removal. Natural water purification recently obtains paramount attention due to be green remediation approach and enables to landscape upgrade. Constructed wetlands, a nature water purification system recently views as a novel green remediation approaches which has popular and commonly employed in Taiwan for water polishing (Yeh *et al*., 2010). Several constructed wetlands have been listed as nation wetlands and to be special protected and managed. Constructed wetlands possess organic matters (BOD and COD), particulate matters (SS), nutrients (Nitrogen and Phosphorus), heavy mental (Cu and Zn), pathetic indicator (E. coli) and pharmacypheutical personal care products (PPCPs) mitigation ability (Yeh *et al*., 2009; Kao *et al*., 2010).

The objectives of this study are intended to illumine the black box pilot wetland through mass balance. To our literature review, few if any have conducted the wetland analysis using mass balance approach. Novel measurement techniques including PCR-DGGE, SEM, and EDX are conducted to investigate the microbial and physical chemical effect within the wetland pilot. The results of this unprecedented research can be referenced for future wetland securitization studies.

In the paper published T. Y. Yeh "Organic Matter and Nitrogen Removal within Field-Scale Constructed Wetlands: Reduction Performance and Microbial Identification Studies" Water environmental research, 2012

This study investigated organic matter and nitrogen reduction and transformation mechanisms within a field-scale hybrid natural purification system. The system included an oxidation pond, two serial surface-flow wetlands with a cascade in between, and a subsurface flow wetland receiving secondary treated dormitory sewage. The average biochemical oxygen demand (BOD) and chemical oxygen demand (COD) removal was 81 and 48%, respectively. Microbial degradation was the primary process contributing to organic reduction. Total Kjeldahl nitrogen

(TKN) and ammonium decreased from 7.1 to 3.9 and 5.58 to 3.25 mg/L, respectively, within the surface-flow wetlands. The results indicated that nitrification occurred within the aerobic compartments. The nitrate levels continued to decrease from 1.26 to 1.07 mg/L, indicating nitrate reduction occurred in the surface-flow wetland. Total nitrogen decreased from 8.61 to 5.12 mg/L, equivalent to a 41% reduction, within the surface-flow wetlands. Results revealed that denitrification might concurrently occur in the compartment of surface-flow wetland. Total nitrogen continued to decrease from 5.12 to 3.99 mg/L within the anoxic subsurface-flow wetlands through denitrification transformation. The significant total nitrogen reduction observed was 65%. The predominant reduction of total nitrogen might take place within the sediment of surface flow and the subsurface-flow wetland where denitrification occurred. The microbial identification results also indicated that nitrification/denitrification might occur concurrently within the sediments of surface-flow wetlands.

The results of this study show that hybrid wetland systems are a viable option for organic matter and nitrogen transformation and removal in tropical regions where tertiary wastewater systems are too costly or unable to operate. Treated water from these systems can comply with local surface water criteria rendering water for reuse and groundwater recharge.

Constructed wetlands are used for point-source wastewater treatment and nonpoint source water quality enhancement in Taiwan (Kao *et al*, 2001; Jing *et al*., 2004). Several researchers have demonstrated that hybrid constructed wetlands compared to single-stage wetlands are less labor intensive, have lower operational cost, and are easier to maintain. (Molle *et al*., 2008). Large treatment facilities to improve surface water quality typically are too expensive to construct and operate in rural areas. Different biological and physicochemical treatment processes have been used to remove pollutants from secondary treated wastewater and each has its own technical and economical limitations (Mayo and Bigambo, 2005). The wetland system is capable of removing various pollutants, organic matters, and nutrients (Lin *et al*., 2002; Ran *et al*, 2004).

Constructed wetlands are growing in popularity as a natural and economical alternative for purifying contaminated water. Constructed wetlands can be used effectively to remove excess nutrients and other pollutants in rural areas where wastewater treatment plants (WWTPs) are not feasible because of high cost of construction and maintenance (Kadlec and Knight,1996). Park *et al*. (2008) assessed surface-flow wetlands using Acorus and Typha plants to reduce organics, anions, and metals. In the Typha wetland, nitrate was removed efficiently with long retention times under an anoxic condition. Results of Park's research also showed significant organic matter and nitrogen reduction. Hybrid systems are more efficient compared to single horizontal or subsurface-flow wetland system. A single-stage constructed wetland might have limited space to achieve a high level of total nitrogen reduction because it cannot provide enough residence time for both aerobic and anaerobic nitrogen transformation (Li *et al*., 2008).

In one review, the author indicated that the advantages of horizontal subsurface-flow and vertical subsurface-flow systems can be combined to complement each other (Vymazal, 2007). It is possible for hybrid wetland systems to generate an effluent low in biochemical oxygen demand (BOD) that is fully nitrified and denitrified and, hence, has lower total nitrogen concentrations (Vymazal, 2007). Chung *et al*. (2008) studied subsurface horizontal-flow constructed wetlands to treat municipal wastewater.

This research found that nitrogen uptake accumulated primarily in aboveground plant tissues of the cattails and inflow nitrogen accumulated in soil and was lost via denitrification processes. The main mechanism of organic carbon reduction was related to microorganism activity in the soil. The results also indicated that plants provided a huge surface area and medium for attached microbial growth.

Microbial nitrification-denitrification, assimilation, plant uptake, ammonia volatilization, adsorption, organic accumulation, and sedimentation are potential nitrogen removal mechanisms in constructed wetlands (Poach *et al*., 2003). Microbial nitrification denitrification is the favorable and permanent mechanism for aqueous-phase nitrogen removal by converting ammonia to nitrogen gases that are emitted to the atmosphere. Nitrate reduction in wetland might be through two processes, including denitrification and nitrogen uptake by macrophytes (Gottschall *et al*., 2007). The latter process is important only if the plant is harvested (Mitsch *et al*., 2005).

Constructed wetlands are water purification systems that mimic the functions of natural wetlands by enhancing processes involving vegetation uptake, soil, and associated microbial degradation (Greenway, 2005). Wang *et al*. (2008) demonstrated that aerobic and anaerobic microbes might develop within the same aggregate, supporting nitrification and denitrification. Soil and plants are a complex environment system that acts as a reservoir for microorganisms, with their activity varying over space and time. In Wang's research, the rhizosphere of oxygen releasing wetland plants provided a niche for ammonium oxidizing bacteria in the nitrification process. The decomposition of plant litter in the sediment might exhaust the oxygen and provide an anaerobic environment that enhances denitrification. In addition to organic matter removal through microbial degradation, wetland systems also can be used as a nitrogen-removal alternative that uses a sequence of ammonification, nitrification, and denitrification (Matheson *et al*., 2002). Most current nitrogen removal research was conducted using single-stage, parallel wetlands receiving various inflow waters.

The connection rate to WWTPs is fairly low in Taiwan, where most domestic wastewater is either partially treated or primarily settled by septic tanks. Manure produced by the swine industry is another primary source of pollution in Taiwan (Lee *et al*., 2004).

Wastewater from swine operations either is untreated or minimally treated by anaerobic followed by aerobic biological processes. The effluent is then sprayed on fields or is discharged into surrounding waterways. If nitrogen in the effluent is applied in excess of plaint uptake rates, then it may contaminate the surface or groundwater through runoff and leaching. Recent groundwater monitoring data showed that elevated ammonium and nitrate levels

were detected in western Taiwan (Taiwan Environmental Protection Agency [TEPA], 2008). One option for nutrient removal might be to use constructed wetlands before land application or waterway discharge, especially for nitrogen and oxygen-demanding substances
(Kao and Wu, 2001; Poach *et al*., 2007).

Pollutant removal from contaminated waters occurs through complex processes in wetlands. Microbial identification studies might provide further understanding of these biological activities, particularly the mechanisms that remove organic material and nutrients in hybrid natural purification systems. The aim of this research was to study the reduction performance of organic matter and nitrogen within the treatment train of a natural purification system. Microbial identification was conducted to elucidate nitrogen transformation processes.

In the paper published T. Y. Yeh "Heavy metal removal within pilot-scale constructed wetlands receiving river water contaminated by confined swine operations " Desalination, 2009

Three parallel pilot-scale surface flow constructed wetlands were employed to investigate heavy metal removal receiving river water contaminated by swine confined-housing operations in Taiwan. Wastewater from swine operation contained elevated levels of copper and zinc due to their abundance in feed. Two macrophytes, namely cattail (Typha latifolia) and reed (Phragmites australis), were planted to observe their heavy metal removal efficiency. Significant total recoverable copper and zinc reduction for three tested wetlands were 80 and 91% for unplanted control, 83 and 92% for cattail, and 83 and 92% for reed wetland systems. Acid-soluble forms were 56 and 86% of total recoverable influent metals for copper and zinc, respectively. More bioavailable zinc was subjected to releasing back to aqueous environment. Heavy metals entering the studied systems as insoluble forms were settling from water column. Concentrations of metals were higher in the vegetated sediments than in the non-vegetated sediments. The sequential extraction results of sediments indicated that most retained metals were in less mobile fractions. Most of metal uptake by vegetation remained in root portions. Translocations of both copper and zinc for tested macrophytes were not prominent. The metal species in incoming water and metal fractionations in sediment were demonstrated as the major factors to influence plant metal levels. The performance of the studied wetland systems can comply with local water criteria rendering for further water reuse.

Constructed wetlands are engineered systems that have been designed to employ natural processes including vegetation, soil, and microbial activity to treat contaminated water. Constructed wetlands possess the merits of low-cost and low-maintenance, and are capable of removing various pollutants including heavy metals, nutrients, organic matters, and micro pollutants. In addition, constructed wetlands are recently used for treating various wastewater types including point source domestic sewage, acid main drainage, agricultural wastewater, landfill leachate, and non-point source storm water runoff. In Taiwan, 63 newly constructed full-scale wetland water purification systems were in operation to treat 338,000 m3 per day contaminated surface water.

Heavy metal contamination is one of the most serious environment problems throughout the world. The wastewater generated from confined swine operations is one of the primary pollution sources in Taiwan. The effluent is discharged in the surrounding waterways containing significant amounts of heavy metals such as copper and zinc. These metals are intentionally added in fodder to prevent diarrhea and to enhance immune systems of swine. The treatment facilities are not properly operated or even not in place for the swine operation. The manures of swine operation were visibly observed in the river water in this study area. The remediation options to treat large volume of low contaminated river are inevitable.

It might not be economical to build a concrete treatment plant to mitigate metal polluted river water. Recently, green remediation approaches, constructed wetlands, have gained drastically attention due to their pollution removal, recreational assets, and landscape aesthetic values in Taiwan. The potential of employing constructed wetlands to treat metal-containing wastewater has also received increasing attention worldwide. Wetland soils characterized by their reduced condition and high organic matter content can accumulate heavy metals.

Metals introduced into wetlands might exist in various particulate or dissolved forms while dissolved metals can adsorb onto particles, exist as complexes with inorganic and organic ligands, or be remained as the free ion state in solution. Metals are trapped within wetland compartments via numbers of mechanisms including plant uptake, cation exchange with soils, and particulate settling. Copper and other divalent metal cations are known to bind strongly to peats and humics, therefore wetlands are employed to trap metals before they reach receiving water.

The chemical forms of heavy metals associated with the settled solids can influence their fate. Many studies dealing with metals in the sediments focused on total concentration with no attempt to distinguish various forms in which metal might exist. In order to provide a complete picture for predicting the metal distribution, mobility, and bioavailability in settled solids, the employment of sequential extraction may be of great value. Many schemes have been proposed for the sequential extraction techniques.

Some of these schemes may be variants of one another with minor variations in the chemical extractants and operating conditions. The sequential extraction technique might not provide the precise separation of metals in settled solids into all specific chemical forms. Nonetheless, broad categories of heavy metals in sediments still can be generated by the sequential extraction. The major sink for metal removal within constructed wetlands was in sediment while plants might also assist the metal reduction.

The emergent macrophytes developed their roots in the reduced soil matrix where metals can be immobilized. The study also demonstrated that metal concentration in plant tissue where higher in roots than in stems and leaves [17].

The objectives of this research were to examine metal forms relative to bioavailability and to measure the partitioning of metals within the wetland compartments. Treatment performance of pilotscale wetland systems was characterized by investigating changes in aqueous constituent concentrations from inflow to outflow. In addition, the fraction of metals in sediments and the role of plants in heavy metal decontamination within tested wetland systems were studied. The evaluation of the extent of metals accumulated in different parts of tested macrophytes was also conducted.

In the paper published T. Y. Yeh “Pollutant removal within hybrid constructed wetland in tropical regions” Water science and technology, 2009

Hybrid constructed wetlands have received tremendous interests for water quality enhancement due to insufficient sewage treatment and groundwater deterioration in Taiwan. The main objectives of this study were to investigate pollutant removal efficiencies and mechanisms within field-scale hybrid natural purification systems. The studied hybrid constructed wetland systems include an oxidation pond, two serial surface flow wetlands with a cascade in between, and a subsurface flow wetland receiving secondary treated dormitory sewage. The average SS, BOD and COD percent removal efficiency was 86.7, 86.5 and 57.8%, respectively. The ratio of BOD to COD decreased from 0.65 in the initial aerobic compartment to 0.21 in anoxic parts of the systems, indicating most biological degradable materials were decomposed in the aerobic oxidation pond and surface flow wetlands. Heavy metal removal percentages of copper and zinc were 72.9 and 68.3%, respectively. Sedimentation and plant uptake are the possible sinks for metals retention.

Significant phosphorus removal was not achieved in this study. Total Kjeldahl nitrogen (TKN) and ammonium decreased from 4.08 to 1.43 and 3.74 to 1.21 mg/L, respectively, while nitrate nitrogen increased from 1.91 to 3.85 mg/L within the aerobic oxidation pond and surface flow wetlands. This result demonstrated nitrification occurring within aerobic compartments. The nitrate nitrogen continued to decrease from 3.85 to 1.43 mg/L within the anoxic subsurface wetlands mainly through denitrification transformation. Total nitrogen removal was from 7.61 to 3.61 mg/L, with the percentage removal of total nitrogen around 52.6%. The primary nitrogen removal and transformation mechanisms within the studied wetland systems were nitrification within aerobic followed by denitrificaiton within anaerobic systems. The emergent macrophytes enhance aeration through oxygen transferring that attributing the higher organic matter removal and nitrification rate. The hybrid wetland systems are viable options of pollutants transformation and removal in tropical countries, while tertiary wastewater systems are too costly or unable to operate. Effluent of purified systems can comply with local surface water criteria rendering for groundwater recharge.

Hybrid constructed wetland systems have been demonstrated to be less labor intensive, low operational cost, and easy to maintain methods to enhance surface water quality. This treatment train type of constructed wetlands might be one of viable options to enhance the water quality and have been primarily employed for rural or sewage treatment in tropical regions while concrete treatment facilities are too costly to construct and operate. Different biological and physicochemical treatment processes have been applied to remove pollutants from secondary treated sewage and each has its own technical and economical limitations. Conventional advanced wastewater treatment requires significant capital investments and consumes large amounts of energy.

The wetland system possesses the merits of low-cost and less labor intensive while it is capable of removing various pollutants including heavy metals, organic matters, and nutrients. Constructed wetlands are growing popularity as a natural and economical alternative for purifying contaminated water. Studies have been conducted to research on the removal efficiency of pollutants including organic matters, heavy metals, and nutrients within constructed wetlands (Kadlec & Knight 1996).

Results of previous researches have indicated that the removal of organic matter and nutrient nitrogen were promising. Particularly, hybrid systems are more efficient as compared with single horizontal or subsurface flow wetland system. Incorporating lagoons, surface flow wetlands, and subsurface flow wetlands into a treatment train has been demonstrated as an alternative for reducing nutrients and performing the function of disinfection in Australia. The treated wastewater from wetlands can be reused for irrigation and groundwater recharge
(Greenway 2005)

Discharging sewage effluent rich in pollutants (e.g., heavy metals) into water courses has problems including deteriorating water quality, inhibiting water reuse, impacting aquatic ecosystems and human health. Specifically, excess amounts of nutrients nitrogen discharge into rivers and streams, leading to eutrophiction and aquatic ecosystem impact due to low dissolved oxygen. In addition, elevated levels of nitrate in groundwater utilized for formula water might be concern about public health effects on humans especially infants while nitrate binds to hemoglobin and prevents its oxygen carrying inducing blue baby syndrome.

Manure produced by concentrated swine industries is one of the primary pollution sources of watercourses in Taiwan. The wastewater generated currently is either untreated or poorly treated by anaerobic followed by aerobic pollutant removal processes. The effluent is then sprayed on fields or discharged in the surrounding waterways. If nitrogen nutrient in the effluent is applied in excess of plant uptake rates, nitrogen nutrient may contaminate the surface or groundwater due to runoff and leaching.

The recent monitoring data showed that elevated ammonium and nitrate levels were detected in groundwater in western Taiwan. One option for nutrient removal might employ constructed wetlands prior to land application or waterway discharge (Kao & Wu 2001). The major processes are responsible for metal removal in constructed wetlands including binding to sediments and soils, precipitation as insoluble salts, and uptake by plants and bacteria. Wetland soils usually characterized as the reduced condition and high organic contents which enhance heavy metal removal to transform into less remobilization acting as natural sink. The role of macrophytes has also been demonstrated effective for metal removal within wetland systems (Southichak *et al*. 2006).

Microbial nitrification–denitrification, assimilation, plant uptake, ammonia volatilization, adsorption, organic accumulation and sedimentation are possible nitrogen removal mechanisms within constructed wetlands (Poach *et al*. 2005). Microbial nitrification- denitrification is the favorable mechanism for nitrogen removal by converting ammonia to nitrogen gases emitting to the atmosphere.

Nitrate nitrogen reduction in wetland might be through two processes including denitrification and nitrogen uptake by macrophytes. The latter process is important only if the plant is harvested (Mitsch *et al*. 2005). Constructed wetlands are water purification systems that mimic the functions of natural wetlands by enhancing processes involving vegetation uptake, soil and associated microbial degradation.

The role of vegetation within constructed wetlands also includes creating aerobic degradation environments around root zones via atmospheric diffusion (Davis *et al.*2005). Besides heavy metals and organic pollutant removal, wetland systems can also be employed as a nitrogen removal alternative that occurs through a sequence of ammonification, nitrification, and denitrification. Effluent from the wetlands can be percolated slowly to supply the underlying aquifer while the wetlands employed as the nitrogen removal of groundwater quality enhancement in Taiwan and similar regions. Pollutant removal from contaminated waters is usually through by a complex processes in the wetlands. The mechanisms for the removal of heavy metals, organic matters and nutrients need to be further elaborated.

The aim of this research intended to study the reduction rates of various pollutants including heavy metals, organic matters, and nutrients treated within the treatment wetlands.

The research was conducted to demonstrate the hybrid constructed wetlands were a viable option for further enhancing the quality of secondary treated sewage by reducing nitrogen nutrient and various pollutants.

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