A Consumer's Guide to Wetland Wastewater Treatment

(www.como.gov. Columbian constructed wetland)

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Abstract

Wastewater treatment is an essential part of human infrastructure. Wastewater from municipal, industrial, agricultural, and other sources contain harmful particulates, bacteria, and contaminates. In order to treat wastewater, humans have developed conventional methods that use advanced technologies for solid waste removal, microorganism reaction, and disinfection. An alternative to these conventional methods is the use of constructed wetlands. Wetlands work through a combination of microorganism interaction, plant and soil filtration, and aeration and settling to remove particulates and contaminants. The effectiveness of wetlands in treating wastewater is comparable to each stage of conventional treatment, except when a disinfectant such as chlorine or UV processing is used. Wastewater must also undergo a primary treatment method, primarily settling and aeration, before being released into a constructed wetland, so that suspended solids that would settle in the soil are removed. Based on a rigorous review of the engineering literature, we find that the the costs of a constructed wetland are considerably lower than conventional treatment plants, as much as 92% on average, except in the case of small single home septic tanks. The maintenance costs of a constructed wetland are also lower by approximately 99% on average. Several forms and many different designs of constructed wetlands exist that can be safely used for residential, industrial, rural, and urban use without presenting unreasonable danger to the public.

Introduction

Waste is an unavoidable aspect of life. As organic beings, the natural ecological process of converting food to energy results in waste, and it needs to go somewhere. As the human population grows and cities expand, waste treatment becomes a harder problem to solve. Conventional systems use multi-tiered and chemical mechanisms to transform wastewater and sewage into water that is clean enough to be released back into the ecosystem. While centuries of technology have given humankind the ability to treat waste in this fashion, the earth has been dealing with the waste of billions of species for eons. How does a lake stocked with thousands of fish remain clean enough for those fish to survive? The answer lies in the complex system of the wetland. Substrates, surface interaction, and aquatic plants all work together to break down, filter, and remove dangerous fecal matter and particulates. Natural wetlands have been used as discharge sites for sewage throughout human history, but it was not until the 1950’s that humans first attempted to harness the power of the wetland through artificial construction. In that decade, Dr. Kathe Seidel of Germany researched and tested the use of wetlands and wetland vegetation to treat wastewater, from this research the first constructed wetlands were born.

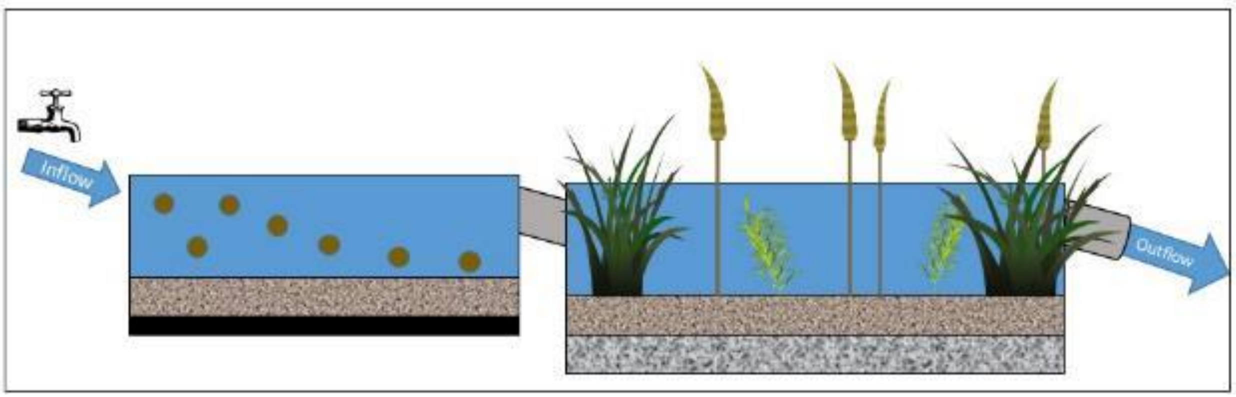
Conventional wastewater treatment systems range from a few thousand dollars for single family home septic tanks, to multi-million dollar municipal treatment systems. Treatment plants for agricultural and industrial uses can soar to even higher costs as the system inputs require complex processes to remove heavy metals, acids, and dangerous chemicals. These high costs can lead to intentional pollution and contamination of groundwater, and many areas are still recovering from both intentional and unintentional wastewater discharge. Constructed wetlands can provide a viable alternative to conventional treatment systems. The costs of both types of systems vary considerably depending on system size, components, geographic location, and end-state water quality requirements, but based on a review of a selection of fixed and variable costs, constructed wetlands are approximately 97% less costlyto construct and maintain than traditional municipal systems and require far less maintenance, energy inputs, and labor. They can be used in low-income and rural areas where capital for full scale conventional plants isn’t viable. They can replace septic tanks in off-the-grid homes, be used to treat contaminated water from mining discharge, and be used for a variety of agricultural applications including aquaculture and traditional ranching operations.

The U.S. Environmental Protection Agency (USEPA) currently restricts wetland wastewater treatment systems to tertiary treatment, and only allows wastewater to be treated in wetlands after it has already gone through primary settling treatment and some sort of secondary treatment usually involving aeration or facultative processes. However modern free water constructed wetland designs are composed of multi-tier systems that provide initial settling, aeration, filtration, and the natural ecological break-down of waste. With continued improvements in technology and research to understand the best inputs for constructed wetlands, wetland treatment systems can be used as primary treatment options for municipal, industrial, and agricultural wastewater. One of the limiting factors in the implementation of wetland treatment systems is the lack of knowledge on these systems and the lack of public acceptance due to the safety and aesthetics of such systems. This consumer guide explains the different types of wetland systems, how the system works, how it compares to conventional systems in both costs and performance, and analyzes the safety and aesthetic quality of wetland systems.

Literature Review

There are many different types and variations of constructed wetland treatment systems, each designed for use depending on variables such as placement area, surrounding demographics, budget, size, treatment level, and other requirements. The two most commonly used types of constructed wetland systems are the free water surface system and the subsurface flow system. Each of these two types can have various configurations to reach the desired level of treatment for the specific area they are being placed. The coarse materials and vegetation selected will also depend on what type of effluent is being treated and the desired outcome of the treatment. Quite often, the decision to build a subsurface flow system versus free-water is directly related to the impact of the system on the local public, and to address any aversion that might arise.

The free water surface (FWS) system is the most easily recognizable wetland treatment system and is generally what people envision when a CW (constructed wetland) is being discussed. This system is designed to interact with the atmosphere and most directly mimics a natural standing-water wetland, usually in the form of a marsh (EPA 832-F-00-024). This type of CW works best where surface area is abundant and a natural buffer exists to avoid negative public impacts. However, the size of FWS systems vary widely and their use can range extensively from primary on-site treatment of small septic tanks to large-scale advanced tertiary treatment for massive municipal waste loads. FWS in use for municipal systems range from around 1000 gallons per day to more than 20 million gallons per day. The applications for FWS systems continue to grow as technology advances, and use in primary treatment applications will require larger land tracts for treatment. The key benefits of this type of system are the increased effluent removal through submerged vegetation and discharge interaction with the atmosphere. FWS systems have been used for a wide range of water quality improvements including municipal waste filtration, mine tailing pollutant removal, and agricultural and industrial waste removal. The differences in particulate matter require adjustments in aquatic plants and coarse material, and the composition of the CW may be adjusted for each treatment type. Heavy metal and large chemical removal requirements require specific plants and processing requirements, while standard municipal effluent can be removed by more standard marsh treatments (T. Y. Chen, C. M. Kao, T. Y. Yeh, H. Y. Chen, A.C. Chao). The differences in composition are vast but all FWS work through a similar process.



(Figure 1 Multi-basin FWS)

FWS systems may involve a single pond or a multi-tiered pond depending on the type of effluent and the level of treatment desired. Most municipal treatment systems involve a single basin system with a single in and out flow, as primary settling and treatment occurs through conventional tank treatments and the CW is used as tertiary treatment. As shown in figure 1, in a multi-basin CW, the first pond where the effluent inflow occurs works as a settling tank similar to the conventional treatment methods. Solids and large particulates sink to the bottom of the pond and can be removed through dredging and drying. Settling basins may be lined with impermeable material, clay, or coarse filtration material depending on the engineering design and local discharge requirements. Vegetation may be present, but the high amount of particulate matter may limit growth or virility.

After the settling pond, or if a settling basin is not used, water flows to the secondary basin that is typically designed like a natural marsh. Flow occurs through gravity based on the engineering design of the tiered system, typically with a low velocity, 1 vertical, 3 horizontal

(1V:3H) designed slope or lower is most common and flow must be evenly distributed throughout the wetland for it to be effective (EPA 905/3-83-002). Coarse substrate may be designed for filtration but the current EPA requirements require that a National Pollutant Discharge Elimination System permit is acquired for wastewater treatment wetlands that allow for ground water infiltration. Semi-permeable clay or other dense soils may be used as the bottom layer, or the CW may be lined with impermeable material under the coarse substrate which is more typical. The depth of the soil layers depends on treatment requirements, desired particulate removal, vegetation needs, and available material. Coarse spalls and gravel mixtures are the most common. The bottom soil may involve several layers of different materials, and composition may vary widely depending on individual design aesthetics.

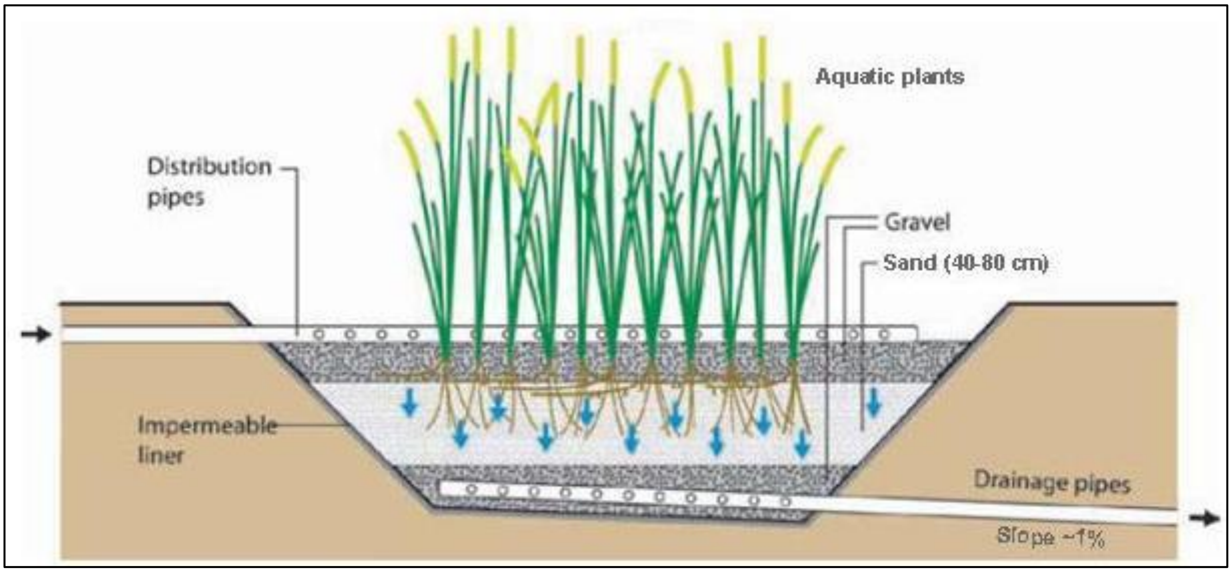
Emergent, semi-aquatic, and submerged vegetation is required for greatest particulate removal. Vegetation varieties depend greatly on water depth, effluent type and load, substrate, climate, and other factors. The most common emergent plant types found in constructed wetlands include cattail (*Typha* spp.) bulrush (*Scripus* spp.) and reeds (*Phragmites* spp.) (EPA 832-F-00-024). Submerged aquatic plants include elodeid types including *Elodea*, *Myriophyllum*, and *Ceratophyllum*, and isoetid types such as *Isoetes*, *Littorella*, and *Lobelia*. The most recognizable submerged plants are lilies and milfoils (H. Brix). Algae is also an important component of constructed wetlands and contribute significantly to water filtration, however the eutrophic conditions as a result of the effluent input and increased phosphorus can lead to algae blooms that reduce productivity. Water depth of at least six feet and proper vegetation management is required for higher productivity. Emergent plants remove many of the common pollutants, as well as trace metals, and complex organics, however, submerged plants are required for nitrogen removal due to the anaerobic conditions (EPA 832-F-00-024).

Interaction of the water surface with the atmosphere is the greatest benefit of the FWS system. Re-aeration of the water through interaction with the surface coupled with vegetation activity reduces the anaerobic environment and stimulates production. The removal of particulates is an integrated system involving substrate, vegetation, and surface interaction. Evaporation and complex chemical reactions through oxygenation filtrates the water column. Vegetation filtrates the water column through uptake in the root system, dead plants and previous growth litter provide organic matter inputs into the system. The littoral zone of the wetland is crucial aspect of the pollutant removal process and acts as a physical substrate for growth organisms essential to the treatment (EPA 832-F-00-024). Algae and microorganisms live in and interact with the organic matter and further break-down particulates (H. Brix). The even flow of the constructed wetland moves water in a directed manner to reduce the discharge of contaminates before treatment is completed, though it is crucial the wetland is large enough to handle the effluent load without overburdening the components or causing leakage of contaminants.

The designed water depth of the CW will depend not only on desired particulate removal, but also on the external benefits of the wetland system. Many FWS systems allow for recreational or aesthetic benefits. Deeper water depths are necessary in conjunction with shallow areas for the attraction of water birds and other wildlife. Aquatic invertebrates and fish species may be present in the systems; however, they should not be used for human consumption with standard effluent loads. Free water surface systems allow for a unique view of nature and may provide a pleasant view or park area for local residents. The aesthetic quality of the wetland greenspace and sports-hunting for water birds or other wildlife are external advantages of the FWS that are not present in sub-surface systems.

Some disadvantages of the FWS system include the large requirement for land, the accumulation of persistent particulates within the wetland, and the negative externality of occasional or persistent obnoxious odors. The land requirements vary greatly, but are generally larger than conventional systems in all compositions. A single family septic tank will require far less land inputs than a comparable CW and will tie up the use of the land surface unlike an underground septic system. A municipal system used for tertiary treatment can span for tens of acres, which may be difficult to implement in city areas with low land availability and high land costs. The odors generated from a FWS are typical of a natural marsh, with the decomposition of organic matter and aerobic and anaerobic activity. The input of effluent is not known to dramatically increase the noxious odor quality if primary and secondary treatment has already occurred prior to moving into the wetland, and if the wetland is significant in size and properly buffered from public residents. The marsh odor in itself may be significantly obnoxious as to reduce public acceptance of the FWS in certain areas, though small CW lagoons for storm water treatment may be better accepted. In addition, heavy metals and other contaminants can accumulate within the wetland benthic habitat and require infrequent periodic removal, which will increase variable costs.

Sub-surface CW systems work in a similar manner as FWS systems, except atmospheric interaction and fully-submerged aquatic plants are not present (figure 4). Emergent vegetation is still present and is an essential component of the treatment system. Coarse material and substrate is layered for the emersion of contaminated water through and under the ground surface. Generally, and as required by the EPA, an impermeable liner is used at the very bottom of the CW, with layers or coarse material above it. The water column is suspended underneath another layer of substrate that holds the rooting systems of the vegetation in place. The top layers of substrate may act as an initial filtration system for the effluent or inflow may be directed under the substrate layer. Sub-surface systems are generally used only for secondary or tertiary treatment, often referred to as 'polishing' and may be less successful as primary or sole treatment methods without a settling tank. The primary advantages of a subsurface flow CW is the ability to limit public access to partially treated wastewater (EPA 832-F-00-023). The lack of free standing water also eliminates the risk of creating a mosquito breeding ground and can reduce obnoxious odors.



(Figure 2. Subsurface Flow Wetland ("An Overview of Constructed Wetlands"**))**

The filtration process of the water column works through soil and plant interaction similar to a FWS system but with some individual differences. The interaction of vegetation occurs within the plant roots and the microorganisms present on the root systems and the coarse substrate. The planting medium and coarse material provide a benthic layer for microbial reaction, as a subsurface CW contains a larger surface area of coarse material, the microbial reaction rate can be moderately higher than a FWS system for most contaminants. This increased microorganism interaction can allow subsurface flow wetlands to polish effluent at faster rates than FWS systems and therefore be smaller than a FWS while still providing a similar filtration rate.

The range of sizes for subsurface wetlands is similar to FWS systems, with designs ranging in size from the treatment of single-septic tank effluent to the treatment of four million gallons per day for municipal wastewater systems. As of the year 2000, there are approximately 100 subsurface flow treatment systems within the U.S. treating municipal wastewater, and approximately 1000 small scale on-site systems for individual homes (EPA 832-F-00-023). The issues with primary treatment requirements can be resolved by the addition of an aerated or facultative treatment pond that pre-treats effluent prior to flowing into the subsurface CW. These can be located on or off site and are accompanied by the negative externality of obnoxious odors. An aerated treatment pond stimulates aerobic activity within the wastewater and can increase microbial reaction and initial particulate removal prior to CW flow. In this type of pond, water is aerated through the use of pumps and fountains, similar to figure 3. Aeration ponds may be coupled with settling basins or designed for suspended solid settling. Periodic sludge removal is required and must be disposed of properly, leading to an increase in variable costs.

(Figure 3. Kandahar Airfield, Afghanistan “Poo Pond”)

The primary advantages of subsurface flow wetlands over free water surface wetlands is the lower land input requirements that can significantly reduce costs in areas where land premiums are high. However, there are no secondary use benefits for a subsurface flow CW that are comparable to a FWS system, and the cost of coarse material for a subsurface flow CW is typically higher than an FWS system. FWS systems may be considered a good investment in areas that are in need or are appreciative of designated greenspace, and they can provide wildlife habitat and recreational opportunities that subsurface systems cannot. In addition, a subsurface flow CW requires vegetation exposure at the surface, and the surface land area cannot be used for other purposes unlike a conventional underground treatment system. When land costs are not a limiting factor, both FWS and subsurface flow wetlands have similar construction costs, excluding material costs. If the size of a subsurface wetland exceeds a flow rate of 60,000 gallons per day and public concerns are not a factor, it is generally cheaper to construct an FWS (EPA 832-F-00-023). Choosing a FWS system or a subsurface flow system depends primarily on public acceptance and needs.

The performance and effectiveness of constructed wetlands compared to conventional treatment methods is a primary concern for many consumers, along with concerns about safety and groundwater seepage for constructed wetlands. This understandable concern often stems from a lack of available information that is easy to decipher and understand. The United States Environmental Protection Agency has created multiple handbooks, guidelines, and requirements for the construction and operation of wastewater wetland treatment. Currently, constructed wetlands are approved only for tertiary treatment within the U.S., meaning raw, fully untreated, sewage cannot be discharged into either a constructed or natural wetland system. EPA standards also require the use of a NPDES discharge permit for wastewater with stipulations for wetland treatment. The safety risks associated with wetland use can be reduced or eliminated through different designs and treatment methods. Impermeable liners reduce the risk of groundwater seepage of partially treated waters, and engineered flow reduces the risk of partially treated water moving offsite. Flooding from storm surges is a concern that is generally addressed in the design phase of a CW, banks and levees must be designed to account for typical flood patterns of the area, and discharge into the CW must of flow controls to prevent overfill. In areas where public interaction with the CW is a concern, subsurface flow wetlands are a proper mechanism for use. With natural buffers, fencing, EPA requirements, and proper safety design, the risk of public contact with untreated wastewater in a CW treatment system is relatively low.

The effectiveness of a constructed wetland at removing harmful pollutants from wastewater has been studied extensively since the 1950’s. The design and components of the wetland can alter what particulates are removed and the level of filtration. Industrial and mine draining wetlands will require different inputs for their individual contaminants, but municipal waste water treatment focuses on the major contaminants in wastewater. These contaminants are: total suspended solids (TSS), Biochemical Oxygen Demand (BOD), total nitrogen (TN, fixed form), total phosphorus (TP) and trace levels of metals and complex organics including Total Coliforms (TC) and Fecal Coliforms (FC). Some studies also assess individual harmful bacteria levels, such as E.Coli. Ranges of removal for a FWS system are between a mean of 83-95% for BOD and TSS, mean TP removal range from 53-72%, and TC and FC mean removal is over 90% for all studies analyzed in this paper (M.L. Solano, P. Soriano, M.P. Ciria; T.Y. Chen, C.M. Kao, T.Y. Yeh, H.Y. Chen, A.C. Chao.; R. Lorion; J. Vymazal). A mine tailing wetland system removed 49% of iron, 46% aluminum, and 58% acidity in its first year of use (A.P. Jarvis, and

P.L. Younger.). A pilot-scale study for industrial wetland treatment systems showed removal efficiencies of 61% for COD, 89% for BOD, 81% for SS, 35% for TP, and 56% for TN, using a FWS system planted with an emergent wetland plant, *P. communis*, which is able to successfully maintain vigor and virility with steady industrial wastewater flow.

A conventional municipal wastewater treatment system typically involves two or three processing steps that involves settling, bacteria removal through microbial reaction, and UV application and/or chemical treatments. Sizes of conventional treatments range from individual septic tank systems designed to hold and break down waste through natural decomposition to large scale advanced urban treatment centers. Large municipal treatment plants often employ preliminary treatment systems, often in the form of grit screening which uses high flows for coarse material screening. Primary treatment occurs through the use of settling tanks which allow suspended solids to sink to the bottom or float to the top. Settled solids are dredged out or skimmed from the top of the tank in the form of sludge. Primary treatment can remove approximately 25-50% of BOD, 50-70% of TSS, and around 65% of oil and grease (FAO). Table 1 shows a comparison of quality parameters from raw sewage and primary treatment for three major California cities. In many sewage plants, the skimmed and dredged sludge is moved to a ‘digester’ where anaerobic and aerobic bacteria break down the organic matter. Some treatment plants harness the methane produced from digesters and process it into usable energy for on-site use or sale, providing a positive benefit to conventional treatment systems. Secondary treatment occurs through the use of microorganism reaction similar to a wetland system but with different activating inputs. Oxygen is supplied through a variety of aeration devices that differ from operation to operation. A typically secondary treatment basin will contain some type of media such as rocks, plastic, or wood. Microorganisms attach to the media and interact with the wastewater in the same natural wetland process, removing or processing particulates. BOD and SS removal is around 85% through this process, though very little TP, TN, and heavy metals are removed. Some plants use different tertiary treatment methods involving further biological treatment and processing. The final step required for advanced wastewater treatment is disinfection, involving a chlorine solution and/or UV treatment to remove any remaining bacteria or virus present.

The literature finds that conventional two-step wastewater treatment system removes similar levels of common contaminants as constructed wetlands. The addition of a chemical disinfection step can enhance conventional treatment beyond CW capabilities, however the effectiveness of wetland treatment combined with primary treatment is generally sufficient for irrigation and ground water release in many US locations, and far more contaminant removal than current treatment options in developing countries. The addition of disinfection at the end of wetland treatment can provide a similar level of contaminant removal, though with an increase in costs.

This paper uses information derived from multiple sources including scholarly research articles, technical manuals, and cost data derived from articles, construction manuals, and federal project cost estimates. Research articles include background information on the history of constructed wetlands, the different functions of wetland components, and how wetlands work to treat waste. Experimental designs include scale modeling and full-scale experiments on different wetland systems and components to treat different types of waste, including industrial waste, mining discharge, and municipal waste. Both the research articles and experimental designs include authors from China, India, the United Kingdom, Germany, and the United States. Technical manuals include the United States Environmental Protection Agency's (EPA)

Constructed Wetland Handbook, Constructed Wetland Manual, and Wastewater Technology Fact Sheet. These manuals include the EPA’s current guidance on wetland system implementation and requirements. Costs are derived from multiple sources and includes twelve sets of data for the two types of systems- conventional and constructed wetland. The data sources range from locations across the United States and include costs for construction (including labor and materials), land acquisition, annual maintenance (including parts and labor), and a miscellaneous category including additional required inputs such as permitting fees, and a fifth category for CW specific to federal project costs including National Environmental Policy Act documentation. Not all categories have complete information for each data set.

The findings of other studies are fairly consistent with the findings of this study, a paper prepared for the EPA by R. Lorion in 2001 reviewed the performance and costs of multiple wetland systems for various wastewater treatments including military ammunition sites, industrial waste, mine drainage, landfill leachate, and airstrip run-off. The study showed effective levels of contaminant removal and comparable cost data for the types of systems being employed. A pilot scale-study of industrial waste treatment conducted in China highlighted the importance of the use of submerged plants in the wastewater treatment process, and the effectiveness of the systems in treating difficult industrial discharge. A mine drainage treatment wetland in operation in the U.K. was assessed for performance by A. Jarvis and P. Younger and found to have continuously improved water quality and even remove heavy metals since its commissioning in 1997. The wetland cost approximately 26,000 U.S. dollars at the time it was built; the size and function of this wetland is comparable to the fish hatchery lagoon included in the cost data of this study in Appendix One.

Project Statement

Wetlands for wastewater treatment may be an important resource for a sustainable future because they harness the power of nature to reduce human waste. There are many questions that must be addressed to provide a better understanding of the relative benefits and costs of wetlands and conventional systems for wastewater treatment. With this goal in mind, this research addresses the following questions: What is a constructed wetland and how does it work? What are the benefits and costs of wetland wastewater treatment compared to conventional systems? Are they as effective and safe as other treatment methods, and what benefits do they produce for the public?

Approach

The approach for analyzing the costs of wastewater treatment…this project is to put together an informative paper that explains what wetland wastewater treatment systems are, the different types of systems used, and how these systems work. this paper discusses the different fixed and variable costs associated with wetland systems and compares them to conventional methods. The costs are associated with a wide range of projects, from single family home septic systems to millions of gallons per day treatment plants. The costs for two federal projects involving constructed wetlands are included. This research will provide an evaluation of data that compares a wetland system’s removal of pollutants to conventional methods and the EPA standards, including fecal matter, heavy metals, and particulates. One goal of this research is to evaluate the effectiveness of constructed wetlands as a secondary treatment method, analyze the costs relative to conventional systems, and evaluate if it would be a more feasible method of wastewater treatment in low-income neighborhoods and federal projects. The research will also discuss the external benefits of these systems, including habitat creation, environmental conservation, neighborhood self-sufficiency, increased ground-water recharge, and aesthetics.

Most importantly, this research will provide a solid explanation on the safety and effectiveness of this technique, including concerns about waste over-flow/run-off from the ponds, pathogens left in the treated water, and concerns about health safety when living near a treatment system.

I will estimate the costs of wastewater treatment…conduct my research by gathering results and findings from numerous studies and existing literature that have simulated or performed data collection on performing wetland treatment areas. The research objectives are to give an overview of the different systems and what their applications are. There are a lot of studies that have been done on wetland treatment effectiveness, which I will focus mainly on most common pollutants associated with urban waste including fecal matter, phosphorous, PCBs, and nitrogen, while also providing insight into the use for industrial and agricultural waste. The collection of data for cost averages is the main obstacle to the research results, costs vary considerably according to system size, components, geographic location, and end-state water quality requirements. Twelve sets of cost data from a variety of sources were gathered for the different systems and categorized into four categories: construction, land acquisition, annual maintenance, and external fees. Construction and land acquisition are fixed costs, and maintenance and external fees are variable costs. Two outliers were identified in the data including a septic tank system for an individual household and a multi-million-dollar conventional system for a major US city at the top of the cost spectrum. The outliers are included in the cost estimates, but I focus on the data in between the 1st and 3rd quartile to account for the outliers.

Along with the cost comparison, I included a brief overview of available federal grants and programs that may be used in conjunction with wetland wastewater systems, with lowered costs to both the consumer and the tax-payer.

Results

The difference in costs between conventional systems and constructed wetlands differs according to size, treatment options, and whether it is a public or private endeavor. Table 1 presents cost estimates of different systems for both conventional treatment plants and constructed wetlands. I analyzed the costs of twelve projects, six projects each for constructed wetlands and conventional systems. This includes small, medium, and large projects for constructed wetlands and conventional systems. The costs are separated into the following categories: construction and land acquirement (fixed costs), maintenance and miscellaneous fees (variable costs) and a separate addition category for federal projects to account for regulatory requirements such as NEPA documentation. The overall average total cost for a conventional system based on this data is around $9 million. The range of cost for initial construction includes a $5000 single family home septic tank and a $21 million regional waste treatment plant. On the other hand, the total average cost for wetland treatment systems is approximately $713,000, including the construction costs for a small fish hatchery lagoon for around $21,000 and a municipal subsurface flow system for around $230,000. The cost of land is the largest cost input for wetland systems, land ranges from zero cost for federally held lands to over a million dollars for a municipal FWS system in California. Land costs can also be high for conventional systems in urban areas. A one-million-gallon per day (GPD) facility in Massachusetts has a land cost of $1.5 million.

There is also a considerable difference between the percentage each category contributes to the total cost for each system. Conventional treatment plant construction comprises around 88% of the total cost, while for a wetland system construction is a mere 14% of the total cost. The highest contributor to cost for wetland systems is the land acquirement costs which contribute around 71% of the total costs. This input can vary considerably according to the desired GPD treatment level. A multi-million GPD conventional treatment plant can be placed on a few acres of land, while the same treatment level for a CW can require 100 acres or more, leading to significantly higher land costs. For example, a 20 acre 100,000 GPD FWS at a land cost of $1.2 million, expands to $6 million in land costs alone when the processing level requires 100 acres.

There is also a stark difference between maintenance costs for the two systems. While the maintenance costs of a conventional plant are 6% of the total costs, maintenance represents 1% of total costs for wetland systems. Over the course of ten years the total average maintenance costs of $530,206 for a conventional plant and $4,300 for a wetland treatment system accounts for a difference of around $5.2 million. This difference does not account for the potential increase in variable costs of a wetland treatment system if it is used for all stages of treatment including primary, which would require periodic dredging and solid contaminant removal.

Miscellaneous costs for conventional systems are quite low, as these variable costs that include such things as permitting are more standard than many wetland systems. The higher end of the cost data for wetland systems includes $115,000 in miscellaneous costs in order to build access roads for a FWS and a subsurface flow wetland. The restrictions on wetland emplacement based on available land and public acceptance is likely to lead to increased variable costs of this nature.

While the gap in costs is quite large between the two systems, the wetland systems compared may require primary treatment at a conventional site prior to entering the constructed wetland, and this treatment requirement is not included in the costs. At this time, there is not enough comparable data available to analyze the difference in costs between the different treatment stages for each system. As primary treatment through the use of wetlands becomes further developed and studied, this is expected to change.

Discussion and Conclusion

Constructed wetlands can provide a safe and effective alternative or supplement to conventional wastewater treatment systems for some reclaimed water uses with lower comparative costs, though the primary treatment requirements limits the application of wetland systems without a multi-stage design. The use of constructed wetlands in rural areas with low land costs and where centralized treatment facilities are unfeasible may provide a more flexible and natural alternative to traditional septic tanks. CWs can perform with similar effectiveness as conventional systems, especially when primary treatment mechanisms are incorporated into the wetland design. The use of CWs as primary treatment systems is scientifically possible with multi-tiered systems, however, the removal of sludge and biosolids would be required within the settling basin, which would increase costs and require conventional methods of sludge disposal. The presence of settling basins would lead to increases in odor that may limit the applicability of FWS systems in certain areas. This negative externality might be addressed through zoning applications in areas that are likely to have future development.

Constructed wetlands are relatively safe. The use of a free water surface wetland can increase greenspace in public areas and even provide recreational opportunities. In areas where public safety is a concern, the use of a subsurface wetland limits public interaction, which can lower safety risk and safety risk perceptions.

Multi-tiered systems allow for primary treatment in conjunction with wetland treatment, however odors and aesthetic issues make this option improbable in locations off-site of a treatment plant. The location of a constructed wetland will be limited by available land, cost restrictions, and public perception. Further education for consumers and insight into the nature and effectiveness of constructed wetlands can assist in alleviating aversion to CW use. The use of disinfection in conventional methods allows for increased contaminate removal in wastewater, the level of water quality with this step exceeds what a constructed wetland is able to produce. Further study and design techniques may allow a disinfection step to be added to the tail end of the wetland filtration process, possibly by flowing treated water out of the wetland and through a chlorine tank before the water is released or recycled.

The addition of a disinfection step along with a multi-stage wetland may provide a viable alternative to conventional treatment systems, though the costs of including this step are unknown at this time. Situating a primary settling and aeration system off site of the wetland, with the required piping for flow into the wetland is likely to increase costs, though there is not enough data to assess how the increased cost would compare to conventional methods at this time.

Constructed wetlands have been favored by federal projects for wastewater treatment in many applications, particularly for military assets. Wetland sewage treatment systems have been built by the Army Corps of Engineers in both Afghanistan and Iraq; a treatment pond on Kandahar Army Airfield in Afghanistan has been operational for over a decade, though it has been expanded in size to account for a larger population. These systems can continue to be used as sole treatment methods in military applications in countries where U.S. EPA’s restrictions are not required, and they may also have applicability as options in poverty or emergency stricken areas. Section 595 of the Water Resources Development Act of 1999 is a program designed to provide assistance to non-federal interests for carrying out water-related infrastructure and resource protection projects in rural Montana and Idaho. Typically projects include replacing decrepit wastewater treatment facilities that rural counties cannot afford to replace and are in imminent danger of failure. Wetland treatment systems may provide a budgetary relief for these projects, especially if primary settling equipment is still operational and the wetland system can be added to the existent plant.

Overall, there are still data gaps that will require additional studies and data generation to fill, such as disinfection systems and full-scale multi-stage wetland comparisons. However, the high percentage of difference in costs for wetland treatment systems compared to conventional systems shows that these methods are worth further exploration, especially as many cities and towns seek to upgrade ageing infrastructure and account for growing populations. Further exploration into increasing the effectiveness of wetland systems is also warranted, such as the pilot-scale study of industrial waste treatment in China. While these data gaps exist, the power of the wetland cannot be denied, the removal of contaminants is clear and use of wetlands to accompany primary conventional systems has a strong applicability in terms of both cost and effectiveness.

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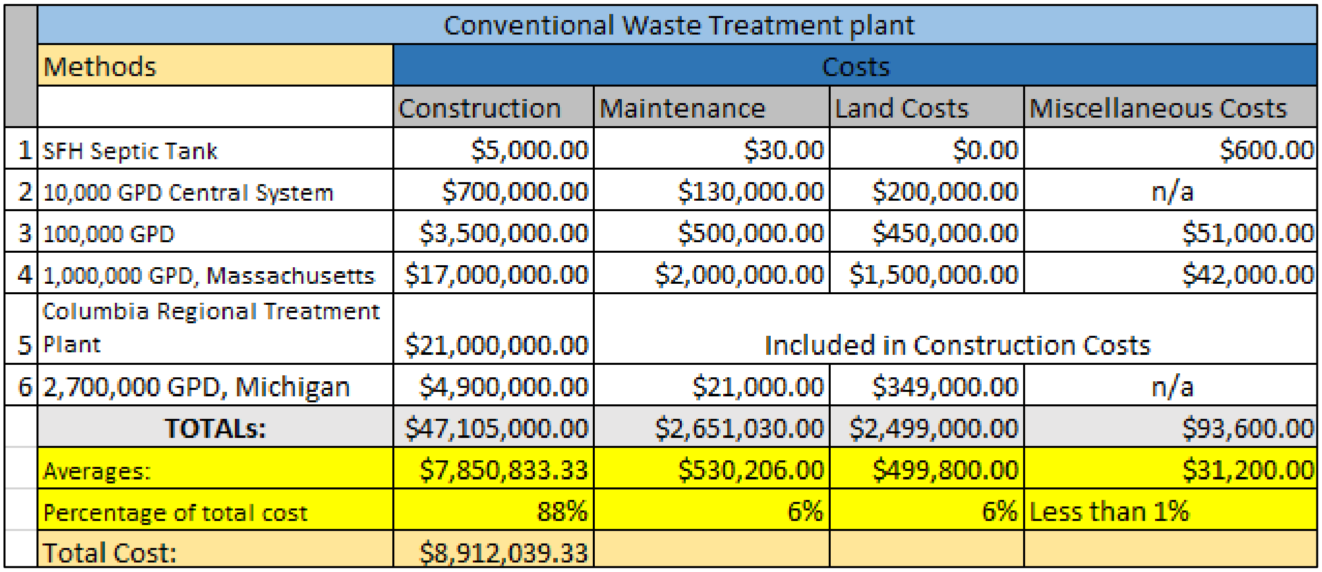
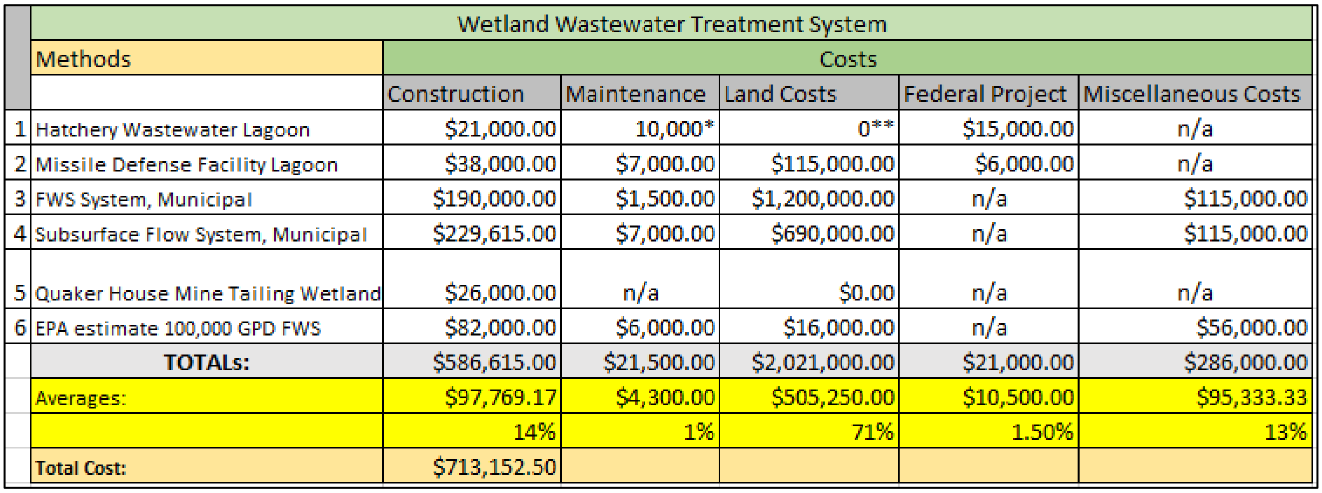
Appendix

Table 1



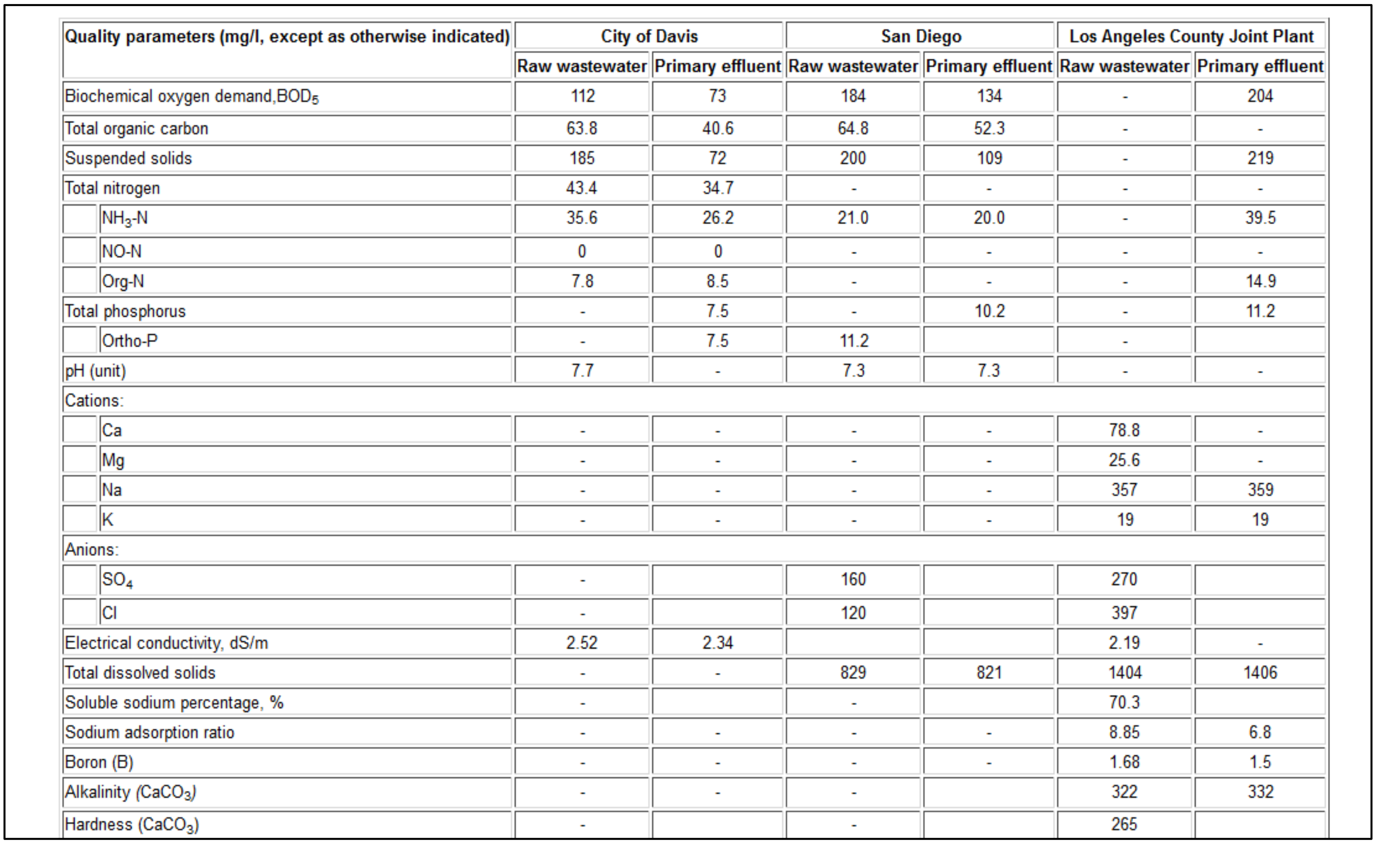
	Conventional Waste Treatment plant				
	Methods	Costs			
		Construction	Maintenance	Land Costs	Miscellaneous Costs
1	SFH Septic Tank	$5,000.00	$30.00	$0.00	$600.00
2	10,000 GPD Central System	$700,000.00	$130,000.00	$200,000.00	n/a
3	100,000 GPD	$3,500,000.00	$500,000.00	$450,000.00	$51,000.00
4	1,000,000 GPD, Massachusetts	$17,000,000.00	$2,000,000.00	$1,500,000.00	$42,000.00
5	Columbia Regional Treatment Plant	$21,000,000.00	Included in Construction Costs		
6	2,700,000 GPD, Michigan	$4,900,000.00	$21,000.00	$349,000.00	n/a
	TOTALs:	$47,105,000.00	$2,651,030.00	$2,499,000.00	$93,600.00
	Averages:	$7,850,833.33	$530,206.00	$499,800.00	$31,200.00
	Percentage of total cost	88%	6%	6%	Less than 1%
	Total Cost:	$8,912,039.33			



	Wetland Wastewater Treatment System					
	Methods	Costs				
		Construction	Maintenance	Land Costs	Federal Project	Miscellaneous Costs
1	Hatchery Wastewater Lagoon	$21,000.00	10,000*	0**	$15,000.00	n/a
2	Missile Defense Facility Lagoon	$38,000.00	$7,000.00	$115,000.00	$6,000.00	n/a
3	FWS System, Municipal	$190,000.00	$1,500.00	$1,200,000.00	n/a	$115,000.00
4	Subsurface Flow System, Municipal	$229,615.00	$7,000.00	$690,000.00	n/a	$115,000.00
5	Quaker House Mine Tailing Wetland	$26,000.00	n/a	$0.00	n/a	n/a
6	EPA estimate 100,000 GPD FWS	$82,000.00	$6,000.00	$16,000.00	n/a	$56,000.00
	TOTALs:	$586,615.00	$21,500.00	$2,021,000.00	$21,000.00	$286,000.00
	Averages:	$97,769.17	$4,300.00	$505,250.00	$10,500.00	$95,333.33
		14%	1%	71%	1.50%	13%
	Total Cost:	$713,152.50				

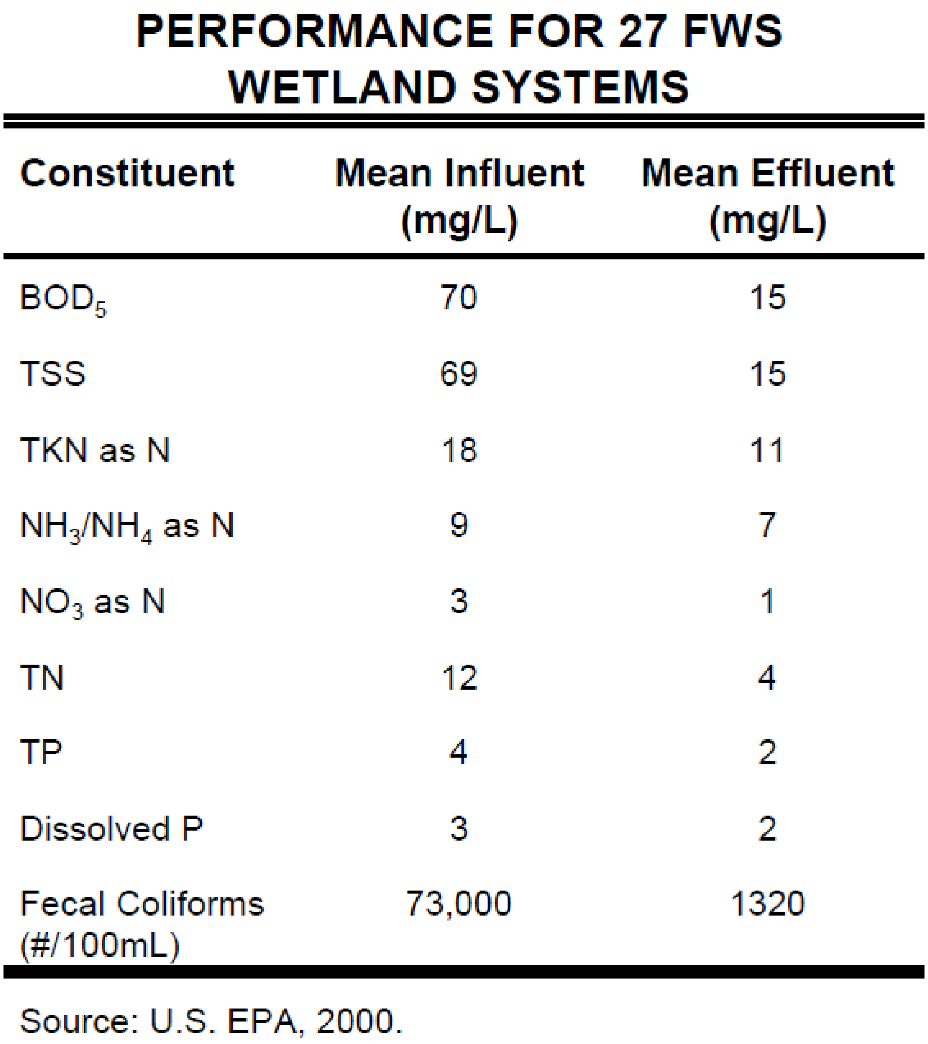
- All data sets rounded to nearest thousand
- *Maintenance costs include labor for performance review and documentation
- **Tribal Land held in Federal trust, zero cost for land attributed to this project
- GDP- Gallons per day

Appendix Two



Quality parameters (mg/l, except as otherwise indicated)	City of Davis		San Diego		Los Angeles County Joint Plant	
	Raw wastewater	Primary effluent	Raw wastewater	Primary effluent	Raw wastewater	Primary effluent
Biochemical oxygen demand,BOD_5	112	73	184	134	-	204
Total organic carbon	63.8	40.6	64.8	52.3	-	-
Suspended solids	185	72	200	109	-	219
Total nitrogen	43.4	34.7	-	-	-	-
NH_3-N	35.6	26.2	21.0	20.0	-	39.5
NO-N	0	0	-	-	-	-
Org-N	7.8	8.5	-	-	-	14.9
Total phosphorus	-	7.5	-	10.2	-	11.2
Ortho-P	-	7.5	11.2		-	
pH (unit)	7.7	-	7.3	7.3	-	-
Cations:						
Ca	-	-	-	-	78.8	-
Mg	-	-	-	-	25.6	-
Na	-	-	-	-	357	359
K	-	-	-	-	19	19
Anions:						
SO_4	-		160		270	
Cl	-		120		397	
Electrical conductivity, dS/m	2.52	2.34			2.19	-
Total dissolved solids	-	-	829	821	1404	1406
Soluble sodium percentage, %	-		-		70.3	
Sodium adsorption ratio	-	-	-	-	8.85	6.8
Boron (B)	-	-	-	-	1.68	1.5
Alkalinity ($CaCO_3$)	-	-	-		322	332
Hardness ($CaCO_3$)	-		-		265	

Table 2. Primary Treatment Contaminant Removal. (FAO)



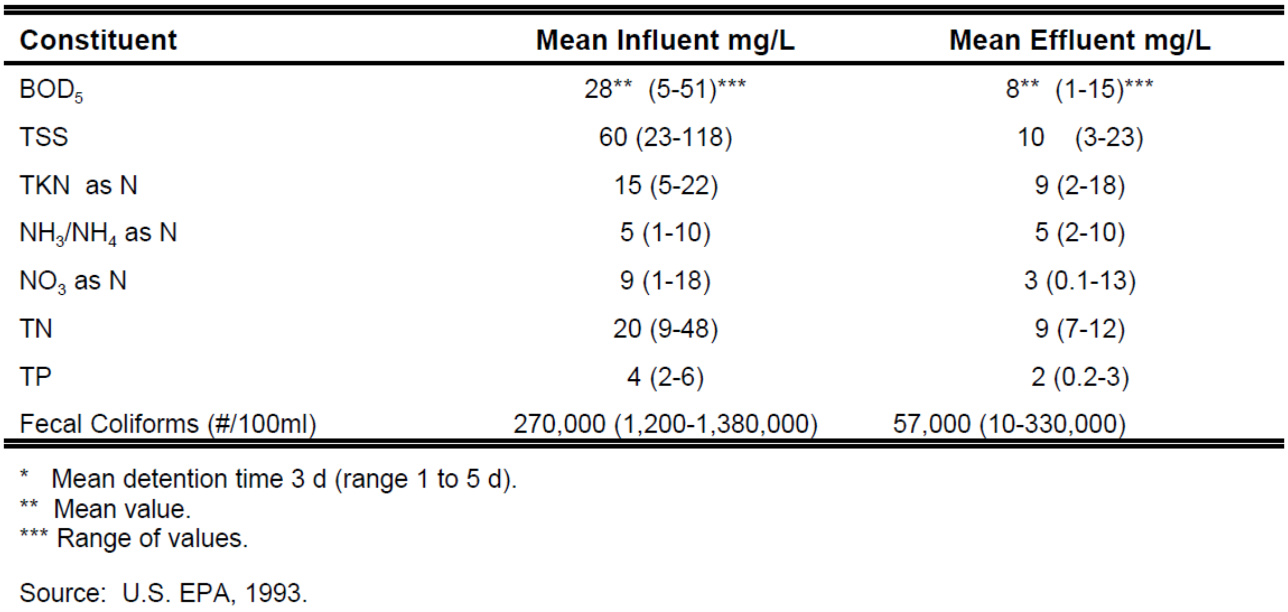
PERFORMANCE FOR 27 FWS WETLAND SYSTEMS

Constituent	Mean Influent (mg/L)	Mean Effluent (mg/L)
BOD_5	70	15
TSS	69	15
TKN as N	18	11
NH_3/NH_4 as N	9	7
NO_3 as N	3	1
TN	12	4
TP	4	2
Dissolved P	3	2
Fecal Coliforms (#/100mL)	73,000	1320

Source: U.S. EPA, 2000.

Table 3. FWS Performance, EPA

Performance for 14 Subsurface Flow Wetland Systems



Constituent	Mean Influent mg/L	Mean Effluent mg/L
BOD_5	28** (5-51)***	8** (1-15)***
TSS	60 (23-118)	10 (3-23)
TKN as N	15 (5-22)	9 (2-18)
NH_3/NH_4 as N	5 (1-10)	5 (2-10)
NO_3 as N	9 (1-18)	3 (0.1-13)
TN	20 (9-48)	9 (7-12)
TP	4 (2-6)	2 (0.2-3)
Fecal Coliforms (#/100ml)	270,000 (1,200-1,380,000)	57,000 (10-330,000)

* Mean detention time 3 d (range 1 to 5 d).
** Mean value.
*** Range of values.

Source: U.S. EPA, 1993.

Table 4. Subsurface Flow Performance, EPA