The Use of Constructed Wetlands to Treat Effluent

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ABSTRACT

The use of constructed wetlands to treat various types of effluent is becoming an increasingly popular practice. Depending on the application, the use of constructed wetlands can be a cost effective and ecological alternative to the traditional treatment processes of today. Before one can understand the intricate reactions and processes of a constructed wetland, it is necessary to gain an understanding of the simpler components that make up these systems. A clear understanding of the elementary elements is the foundation to understanding the complexity of the constructed wetland system. The purpose of this paper is to provide the foundation to understanding constructed wetland systems by providing an overview of the components of a constructed wetland, as well as descriptions, advantages, and disadvantages of the different types of constructed wetlands. This paper will also discuss design considerations, applications, and limitations of the constructed wetland systems as well as recent research findings concerning the performance of these systems under varying conditions and circumstances.

KEYWORDS

Constructed wetland, surface flow (SF), subsurface flow (SSF), substrate,.

INTRODUCTION

The first constructed wetland was built in Australia in 1904. Even though constructed wetlands have been around for over a century, the advancement in technology within the field, and the widespread use of these systems was incredibly slow. Today there are thousands of these systems in place all over the world, and the use of constructed wetlands over the traditional treatment processes is becoming an increasingly popular idea.

The increasing popularity can be attributed to the numerous benefits derived from the use of constructed wetlands. Similar to natural wetland systems, the benefits of constructed wetlands include: wildlife habitat, flood control, and improved water quality. Wetlands are considered one of the most fertile and productive ecosystems next to rainforests and coral reefs (Ramsar, 1971). Their implementation and integration is the next logical step in providing a world where human kind and nature can coexist symbiotically.

HYDROLOGY, THE CRITICAL DESIGN ASPECT

Hydrology is the most critical aspect one must keep in mind when designing a constructed wetland. It is the primary factor that determines whether a constructed wetland succeeds or fails. A balance between water entering and water leaving must be reached in order to maximize the efficiency of a wetland.

Simple water balance equation: $S=Q+R+I-O-ET$ (Davis)

S= Net change in storage
Q= Water contributed due to surface flow, which includes the inflow of storm/wastewater
R= Water contributed due to rainfall
I= Net infiltration
O= Outflow
ET = loss from evapotranspiration

Above are the variables one must take into account when designing a constructed wetland. However the listed items above are the basic considerations. The climate of the geographical area also plays an integral role in the design of constructed wetlands. Seasonal fluctuations in precipitation and temperature need to be accounted for. Increased rainfall and rapid snowmelts can lead to a higher velocity and volume of flow. This, in turn, increases the hydraulic loading rate and turbidity of the water while reducing the hydraulic retention and contact time. This can result in a drastic decline in the treatment efficiency of a constructed wetland.

Processes within a constructed wetland continue even in freezing temperatures. As long as the water within the basin does not freeze solid, sedimentation, decomposition, and microbial activity continue. The speed at which these processes occur however is substantially slower. It is important to take corrective action and implement countermeasures to maximize the efficiency during adverse weather conditions. A common practice is to raise water levels prior to freezing weather. Once a layer of ice forms on the top, the water level is dropped. This allows space for under-ice flow. Another common practice is to increase the size of the constructed wetland, or store the effluent in a pretreatment unit prior to, and during, winter months (Davis). This ensures that the effluent receives an adequate amount of retention time within the wetland. As stated above, snowmelts and heavy rains associated with spring time have a tendency to overload a constructed wetland and prevent proper treatment. Accounting for these natural events minimizes possible inconsistencies associated with constructed wetland treatment and maximizes the treatment capabilities.

COMPONENTS OF A CONSTRUCTED WETLAND

The design components of a constructed wetland are unique to its location. Once the hydrological design aspects are complete, the design of the actual structure can begin. A constructed wetland is made up of three components:

1. A basin containing water
2. A substrate
3. Plant life

A basin can be constructed by using the topography of the land and various grading operations. During the construction of a wetland it is important to remember that the soil lining the wetland be relatively impermeable. This will keep the effluent collected within the basin from seeping into the ground. Lastly, the location and size of the basin should be relative to the topography of the land and drainage area, meaning the wetland should be in a location where it can effectively collect and accommodate the amount of effluent collected. (Davis)

Substrates used in a constructed wetland are dependent on the site location and function of the constructed wetland. Various soil, gravel, sand, rock, and organic material are typically used as substrates. Selecting the proper substrate is a very important decision when designing a constructed wetland for a variety of reasons: (Davis)

1. Substrate permeability regulates the movement of water through the wetland.
2. Many chemical and biological transformations take place within the substrate
3. Substrates provide storage for many contaminants
4. In a saturated substrate, water replaces the atmospheric gases in the pore spaces and microbial metabolism consumes the available oxygen. Oxygen is then consumed faster than it is replaced by process of diffusion from the atmosphere thus making the substrates anoxic. This reducing environment is crucial for the removal of pollutants.

There are several criteria used in determining a suitable substrate. The cation exchange capacity (CEC), pH, and porosity of a substrate are extremely important properties to consider when choosing a substrate. More notably, these properties are crucial in the removal of heavy metals and nutrients within the effluent. The CEC is a measure of a soils capacity to hold positively charged ions. Soils with optimum CEC provide electrostatic bonding sites for cations (positively charged ions that include $Ca^{2+,}$ Mg^{2+}, Fe^{2+}, Al^{3+} and Mn^{2+}) The pH of the substrate helps determine the retention of heavy metals and nutrients. It also has a bearing on the plants and microbes ability to process the waste material within the effluent. Lastly, the substrate porosity determines the amount of soil/water contact that occurs. Generally, the coarser the substrate (sands and gravels) the higher the porosity, and the higher the porosity the less soil/water contact. The porosity of a substrate is the major factor that determines the effluent flow speed and the substrates ability to retain pollutants. The coarser substrates allow for faster flow speeds than the finer textured substrates, but are not as efficient in pollutant retention. (Davis)

The type of substrate is very important in determining the type of plant life that will predominant a constructed wetland. Vascular plants such as bulrushes, cattails, and reeds and non-vascular plants such as algae are the last main component to consider. Besides being aesthetically pleasing, the plant life within a constructed wetland conducts numerous functions: (Davis)

1. Vascular plants prevent erosion by anchoring the substrate and minimizing channel flow.
2. Vascular plants reduce the flow velocity; which in turn allows suspended materials/nutrients to settle.
3. The plant life cycle ends in death which creates organic matter and litter, thus continuing the cycle of life within the wetland.
4. Plants uptake carbon, nutrients and trace elements and incorporate them within their tissue.
5. The plant life carries out gas exchanges between the atmosphere and sediments

TYPES OF CONSTRUCTED WETLANDS

There are 2 different types of constructed wetlands:

1. Surface Flow Wetland (SF)
2. Subsurface Flow Wetland (SSF)

Each type has advantages and disadvantages associated with its use. The (SF) constructed wetland requires a shallow basin for the collection of effluent, a water control structure to sustain a shallow water depth, and a water surface above the substrate. The advantages of a (SF) constructed wetland are (Davis):

1. The aesthetic benefits it can provide
2. The natural habitat it can generate for a variety of species.
3. The design, construction, and required maintenance are relatively simplistic
4. The capital and operating costs are low.

The main disadvantages associated with the (SF) constructed wetland are:

1. The large land area required
2. The unpleasant odor that can be associated with certain types of effluent being treated.

The (SSF) constructed wetland is designed to have the water surface below the substrate. The substrate used is typically one with high porosity which is thought to increase surface area and treatment contact (Davis). The advantages of using (SSF) constructed wetlands include:

1. Ability to resist freezing conditions and overall tolerance to cold weather
2. Reduction in odor and possible pests (mosquitoes).
3. Ability to treat more effluent per area compared to the (SF) constructed wetland systems (Davis).

The main disadvantages of the (SSF) constructed wetland systems are:

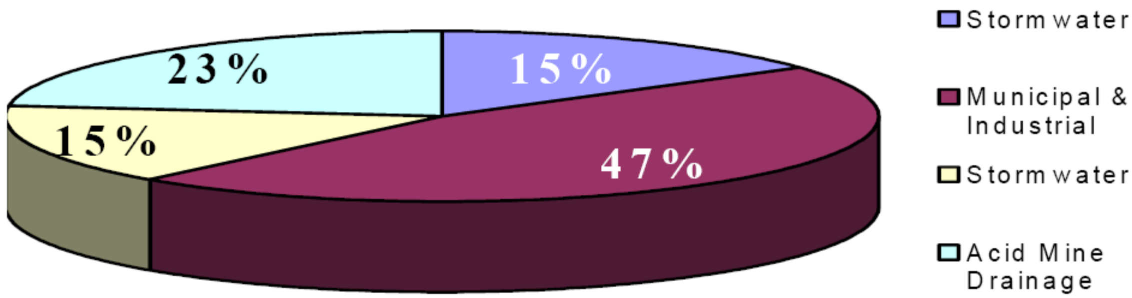
1. The cost of the (SSF) constructed wetlands is higher
2. Difficult to monitor
3. Maintenance and repairs are more difficult and costly
4. Many (SSF) constructed wetlands have experienced problems with clogging and undesired surface flows.
5. The (SSF) constructed wetland system is not as versatile as the (SF) constructed wetland system. In order for a (SSF) constructed wetland system to operate efficiently, it should be subjected to an effluent with a low solids concentration and consistent flow conditions (Davis).

The two types of constructed wetlands also differ in how the effluent is primarily treated. The (SF) constructed wetlands system relies on the plant stems, leaves, and rhizomes to treat the effluent. Having dense vegetation within the constructed wetland is critical to efficient treatment. However there are some minor problems associated with this method of treatment. The dense vegetation required has a tendency to limit the amount of oxygen diffusion into water which can be detrimental to aquatic organisms. (Fujita, 2005)

In a (SSF) constructed wetland system the effluent passes through a series of gravel beds and the treatment of the effluent is carried out primarily by plant roots. This method is generally more effective than the (SF) constructed wetland treatment system in removing BOD5 and phosphorus. (Fujita, 2005)

APPLICATIONS

The use of constructed wetlands has a variety of applications. Today constructed wetlands are used to treat both point and non-point sources. Point sources include industrial wastewater, municipal wastewater, and acid mine drainage. Non-point sources include storm water runoff. However, the use of these systems is not limited to just these types of applications. Constructed wetland systems are also used to treat agricultural wastewater, landfill leechate, and have even been used on hazardous waste sites to treat contaminated groundwater (ITRC, 2003). The U.S. Department of Defense uses constructed wetlands to treat aircraft and runway deicing chemicals as well effluent collected from wash racks (ITRC, 2003). The use of constructed wetland systems are even being used to treat raw sewage in several research studies in Europe. The application of constructed wetland systems as well as their implementation continues to grow.



The figure above displays the relative percentages of constructed wetland applications. Theses values were obtained from a sample of 650 constructed wetland systems, and only provide an estimate for the systems within North America (Kadlec and Knight, 1998).

DESCRIPTIONS OF THE COMMON APPLICATIONS

Before discussing the major applications of constructed wetland systems, it is important to understand what is entailed in the wastewater treatment process. The wastewater treatment process can be broken down into 4 sub-processes. It is important to note that not all effluent is subjected to all 4 sub-processes. It is purely dependent on pollutant concentration, treatment efficiency, and environmental discharge regulations (which dictate the maximum pollutant levels a particular effluent can have). The 4 sub-processes of wastewater treatment are pretreatment, primary treatment, secondary treatment, and advanced/tertiary treatment. Pretreatment involves the removal of large obstructive objects like sticks, rags, and other objects that are detrimental and sometimes damaging to the later treatment processes. Primary treatment is simply the removal of contaminants that settle or float. Secondary treatment is used to remove soluble BOD_5 and suspended solids remaining from the prior treatment processes. And lastly, Advanced/Tertiary treatment involves chemical treatment and filtration of the wastewater after the effluent has gone through the previous treatment processes (Davis and Cornwell, 1998). Constructed wetland systems are typically used for advanced/tertiary treatment of the effluent, with water polishing being the primary role of these systems. Water polishing is basically the removal of the suspended matter and color within the effluent with the goal of generating cleaner water. Constructed wetlands are typically used when consistent high quality effluent is not required (Vymazal, 1995).

The role of constructed wetlands varies depending on its application, and is not limited to just advanced/tertiary treatment. Below is a synopsis of the more common applications of constructed wetlands. The new directions of constructed wetlands will be discussed later in the paper.

Industrial Wastewater

The concentration of pollutants in industrial wastewater is typically high. It is often required that the wastewater undergo pretreatment, primary treatment, and in some cases secondary treatment prior to being discharged into the constructed wetland system. In industries such as pulp and paper plants, petroleum refineries, and textile mills, the use of constructed wetlands is used primarily for advanced/tertiary treatment. Typically the pretreatment as well as the primary and secondary treatment of the effluent is completed on site and then discharged into a wetland also on site. (ITRC, 2003)

Storm Water Runoff

As stated above, stormwater runoff is a non-point source. Which means the effluent is not collected from a specific discharge point. Depending on the placement of the constructed wetland, the system can possibly have the potential to collect a large amount of effluent. One must keep this in mind when designing and determining the proper location of the constructed wetland system. Constructed wetland systems used to collect and treat stormwater runoff carry out many important functions. The primary functions are treatment of contaminants and reducing peak discharges. (ITRC, 2003)

Stormwater can contain numerous contaminants, the more common ones are: (ITRC, 2003)

1. Oil, grease, and gasoline that leaked out of vehicles and onto the streets.
2. Pesticides, herbicides and fertilizers from urban and adjacent agricultural areas.
3. Sediment washed away from construction sites
4. Metals from a variety of sources such as rust, paint, and automobile exhaust

It is important to design a constructed wetland system to be able to accommodate large rainfalls. Failure to do so can lead to inefficient treatment as the effluent becomes diluted and passes through the system without sufficient contact time. The pollutants listed above have the ability to cause serious environmental harm. Proper treatment is crucial to minimizing the risk of generating potential environmental problems.

The reduction in peak discharges is also an important function. A properly designed constructed wetland should be able to complete three basic tasks. The first task is to collect all accumulated stormwater runoff. This is accomplished by placing the wetland in lower elevation in comparison to the adjacent land and allowing gravity to work. The second task is the absorption of water and nutrients from the collected runoff, which enables the constructed wetland to sustain itself. The third task is the release of excess water over an extended period time. The third task is an important flood prevention measure. It aids in preventing the massive discharges of water downstream that may result after a heavy storm or snow thaw. If built correctly, a constructed wetland serves as a self sufficient, low maintenance, natural flood control device (ITRC, 2003).

Acid Mine Drainage

The effects of mine drainage are widespread. In the United States over 12000 miles of rivers and streams and 180,000 acres of lakes and reservoirs are negatively affected by contaminated drainage from abandoned mines (Kleinmann, 2000). Mine drainage is defined as water that has come into contact with rock that contains reactive minerals. The majorities of these minerals are trace metals and iron sulfides. Water that has come into contact with rock located on leach pads may also pick up cyanide and excess acidity (Tech Report). These impurities within the drainage require treatment. The use of constructed wetland systems is extremely attractive because of their ability to accumulate metals. A 2-6% copper concentration was observed in some Canadian wetlands (Sobolewski, 1997). Wetlands also have the ability to endure trace metal concentrations of 1000mg/kg. During the 1980's it was observed that natural wetlands had the capacity to remove substantial amounts of metals (Eger et al., 1980; Weider and land, 1982; Eger and Lapakko, 1988). As a result the implementation of constructed wetland systems increased. Today these systems treat all types of mine drainage all over the country.

Municipal Waste Treatment

Roughly 90% of all wetlands treating municipal waste are less than 250 acres. Of these wetlands 82% treat one million gallons a day or less (ITRC, 2003). Tertiary treatment, or polishing of municipal wastewater, is the primary application for constructed wetlands treating municipal wastewater. Constructed wetlands provide an efficient means of removing suspended solids, BOD, organic compounds, metals, and nutrients such as nitrogen and phosphorus. The removal of these contaminants is accomplished by the natural physical, biological, and chemical reactions that occur within the wetland. (ITRC, 2003)

RECENT RESEARCH

Currently natural wetlands can be found on every continent except Antarctica. Their presence has played key roles in human survival and development. History has shown that natural wetlands offered our ancestors numerous benefits. These benefits included wildlife for hunting, vegetation and raw materials for harvesting, and in some cultures, a place to bury their dead (Ramsar, 1971). The idea to use wetlands to filter out and clean water is not a new idea. Thousands of years ago the Egyptians and the Chinese used natural wetlands to clarify liquid effluent (Fujita, 2005). However the use of man made wetlands to clarify effluent is little over a century old. The first constructed wetland was built in Australia in 1904. However the wide spread use of these systems wasn't adopted until the middle of the century when Europe and the United States started constructing them throughout the 1950's, 60's, and 70's (Fujita, 2005).

Constructed wetland systems, if designed correctly, are capable of taking on numerous types of contaminants with varying concentrations. Several research studies also conclude that as constructed wetlands age, they actually become more effective at removing certain pollutants. Both findings are major steps forward within the field, and are outlined below.

Research on the use of reed bed filters to treat sewage has been conducted in several European countries. The system below has been implemented in France and is capable of receiving raw sewage. The basic layout of the constructed wetland system consists of several type A filters used for primary treatment and type B or C filter for secondary treatment (Diagram in appendix A). The sewage is screened (< 2cm) prior to reaching the constructed wetland. The type A filters are then filled for 3-4 days and allowed to rest for 6-8 days (Fujita, 2005). This rest period allows for the mineralization of the total suspended solids (TSS), as well as the ability to sustain the aerobic conditions in the gravel and rhizomes (Boutin et al., 1997)

Below is a summary of results from a reed bed filter system in France after 15 months of operation. Readings were taken over a 48 hour period. It was noticed that the raw sewage effluent resulted in a sludge build up of approximately 1.5 cm a year in the type A filters.

Table 1 - Performance of New Generation Reed Bed Systems (conc. in mg/l)

	Total COD	d COD	BOD5	TSS	TP	P-PO4	TKN
Raw Sewage	495	190	215	225	8.5	6.4	42.8
Filter A outflow	92	70	0	18	5.8	5.3	19.6
Final Outflow	58	40	16	12	5.6	5.1	10.1
Removal (%)	87.5	80	92.5	94.5	40	28	76

(Fujita, 2005)

Since the implementation of constructed wetlands to treat effluent is relatively new idea, few results have been obtained on their performance over an extended period of time. A study undertaken in Switzerland evaluated one of the oldest constructed wetlands in the country, located at Centre for Applied Ecology at Schattweld. This particular system received greywater and liquid human waste (primarily urine). The readings and measurement were obtained over a 5 year timeline, below are the results. To summarize, no reduction in the efficiency of the constructed wetland system was seen over the 5 year period. The highest removal percentages for several of the pollutants increased with time (mainly the removal of NH4-N and total N). (Schonborn et al. 1997)

Table 2 - Performance of Swiss System after 10 years use (Conc in mg/l)

	Total COD	BOD5	TP	NO3-N	NH4-N	Min-N
Gray water	311	129.5	8.5	3	89.8	92.6
Sand filter out	31	0	3.1	50.7	1.9	62.2
Final Outfall	26.7	5.4	0.8	12.7	6.3	18.5
Removal (%)	91.4	95.8	90.6	-323.0	93.0	80.0

(Fujita, 2005)

In 1991, researchers conducted the "sugar experiment." The same wetland described above was loaded with significant amounts of glucose, an easily degradable carbon source. During the course of this experiment the phosphorus retention of the wetland was low, and an increased amount of iron leakage was observed. It was suggested that a correlation existed between these two findings (Schonborn et al. 1997). Glucose is a substance that is not typically found in wastewater. According to Dr. Say Kee Ong, the reason for the increased iron leakage was due to the reducing environment produced from the excessive amount of glucose added. When iron is reduced it converts from Fe^{3+} to Fe^{2+}. The Fe^{2+} ion has a much higher solubility and thus producing wastewater with a higher iron concentration. The purpose of the study, although not specifically stated, was to expose the wetland to unusual circumstances and evaluate its ability to cope with the abnormal conditions.

LIMITATIONS

The use of constructed wetlands is a fresh and ecological alternative to the current wastewater treatment processes. However, since the use of these systems is relatively new, and the technology concerning these systems is rather underdeveloped, many problems and limitations still exist. The major criticism is the lack of statistical data concerning the performance and treatment efficiency of constructed wetlands. Although numerous research and pilot studies have been completed, many still believe it is not enough. (FRTR)

Other criticisms include the performance of constructed wetlands under adverse weather conditions and the inconsistencies in treatment that may result. Cold temperatures slow the treatment processes, while dry spells and droughts, caused by high temperatures and / or lack of rain, have the potential to damage plants and limit their treatment ability. Heavy rainfalls and snow melts in the spring also have the ability to overload a constructed wetland system, which may result in inefficient treatment. Since the constructed wetland is subjected to conditions outside human control (like weather) there is a general reluctance to use these systems. (FRTR)

The last main criticism is the cost of building a constructed wetland. Depending on the location and application of the system, the land required to build one can rather large. Generally the cost of land is the main factor that determines whether a constructed wetland is economically feasible, and in some cases, the use of these systems is just too expensive to consider (Davis).

CONCLUSION

Continuing research and technological advances make the use of constructed wetlands to treat effluent more feasible everyday. However the manipulation and duplication of a natural occurring ecosystem is no small task. Understanding the design characteristics is crucial to understanding constructed wetlands. Establishing a water balance, in addition to selecting the appropriate size, location, substrate, vegetation and type of wetland are the key components to a successful and efficient constructed wetland system.

Research on constructed wetlands as an alternative to traditional treatment processes is on the up rise. Currently however, little is known on the full capabilities of constructed wetlands, their sustainability, and their effectiveness over time (FRTR). Currently researchers are seeking answers to these questions with hopes of increasing the effectiveness and use of constructed wetlands.

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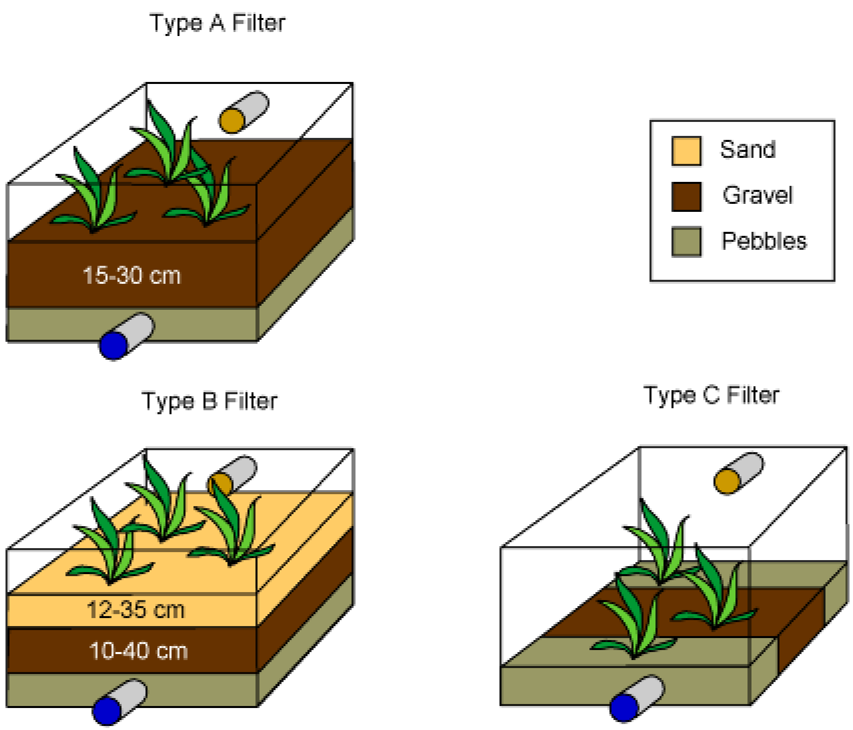
Appendix A


Type A Filter
15-30 cm
Sand
Gravel
Pebbles
Type B Filter
12-35 cm
10-40 cm
Type C Filter