Constructed Wastewater Wetland Systems and The Importance of Plant Communities

By

Samantha Steffen

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Introduction

Constructed wetlands have many potential benefits. Wetlands can provide no electricity, and low long-term cost aid to water purification compared to conventional wastewater plants. Wastewater treatment would benefit with the introduction of constructed wetlands. Using the proper techniques and pinpointing what type of wastewater will be used for a wastewater wetland will determine the type of flow and the plants needed for proper function. These treatment plants are also beneficial to the environment in terms of habitat and productivity. There are risks involved when adding a constructed wetland to the treatment process like invasive species growth, and high up-front costs. The plants chosen for a wetland can influence the efficacy of the wetland and can minimize risks.

In chapter 1, we describe different types of constructed wetlands, how they function, and a discussion of both positive and negative effects they may have. Chapter 2 explores impacts of plant selection on constructed wetlands and how important they are for the function of wastewater wetland treatment.

The Use of Constructed Wetlands for Wastewater Treatment

Abstract

Wastewater is usually treated through wastewater treatment plants, these plants are equipped with the tools to treat many types of wastewaters like domestic, pharmaceutical, mining, and more. Depending on the wastewater type, a wastewater treatment plant could benefit from a constructed wetland. Constructed and natural wetlands have been able to remove pollutants from wastewater without human intervention. The addition of a constructed wetlands onto the wastewater treatment process can lead to many beneficial factors. The natural biogeochemical process of a wetland are the same processes used by a wastewater treatment plant to remove contaminants. Using constructed wetlands also has some environmental benefits; wetlands are high productivity areas, and are an important habitat. Because wetlands are being lost due to anthropogenic activity, these constructed wetlands may help mitigate the loss of natural systems. There are some issues with constructed wetlands though. Constructed wetlands can take up a lot of space, and it also takes a few years before wastewater can be introduced into the constructed wetland. While maintenance costs are low, upfront cost to build a wastewater wetland can be high.

What is a Wetland?

Wetlands are distinct areas of land that are flooded intermittently or permanently with water. There are a few types of Wetlands. National Oceanic and Atmosphere Administration (NOAA) classifies them as marine (ocean), estuarine (estuary), riverine (river), lacustrine (lake), and palustrine (marsh). Some common names for wetlands are marshes, estuaries, mangroves, mudflats, mires, ponds, fens, swamps, deltas, coral reefs, billabongs, lagoons, shallow seas, bogs, lakes, and floodplains (NOAA, 2021). Wetlands can easily be characterized from other ecosystems because of flooding. They are either permanently, intermittently, or seasonally flooded resulting in soils that are mostly anoxic, although there is often a thin layer of oxygenated soil at the soil water interface (Scholz, 2016; Craft, 2016). Wetlands provide homes to unique vegetation that are adapted to the anoxic hydric soils. These soils, only found in wetlands, differ from other types of terrestrial soils because they can house anaerobic bacteria which are able to survive without the presence of oxygen which would normally not be present in oxygenated waters.

Wetlands are often legally protected because of their value to society (Described in the Functions and Services section below). The Value of a wetland can be calculated from the function ecological processes, human perceptions, location, human pressures, and the extant of the wetland (Mitsch et al,. 2000). In the 1960s the general public took note of the importance of wetland ecosystems. In 1972 the U.S. Congress added the 404 section of the Clean Water Act which made it harder to fill in a coastal wetland because a permit was required and approval by the Environmental Protection Agency EPA (Titus et al., 1988).

Figure 1: Coastal wetlands in Cedar Key, Florida. Water, ocean, coast. UF/IFAS Photo by Tyler Jones.

Functions and Services

Wetland Ecosystems can provide a suite of valuable ecosystem function and are hotspots for biodiversity. Species depend on wetlands because of their distinct environment. Wetlands can support high productivity for plants, but not high plant biodiversity; the population of plants that are able to live in wetlands are few because of the harsh conditions made by the environment. They can provide high volumes of food and with the shallow water, nutrient availability, and the high primary productivity, wetlands are an ideal habitat for a many species of animals. Wetlands also provide services to water purification, groundwater replenishment, shoreline and storm protection, water storage and flood control, and carbon processing and other nutrient and pollutants. The function wetlands can provide are globally disproportionate to the area the take up on earth; wetlands cover <3% of the globe and contribute up to 40% to the global annual renewable ecosystem services, of these services water quality ranks the highest (Zelder et al,. 2005).

Constructed Wetlands

Humans constructed wetlands to take advantage of ecosystem functions. Engineering, environmental, and recreation are just a few that benefit from constructed wetlands. Engineers are involved with wastewater treatment plant construction and may use the constructed wetland in part of their wastewater treatment plans. Environmental scientists can use these wetlands for future impact studies, or water resource management and as for recreation for those who are interested in wildlife conservation constructed wetlands provide shelter for many species.

Constructed wetlands are systems that use the natural processes of wetland vegetation, soils, and the microbes to improve water quality (EPA, 2000). They are designed to treat wastewater to remove contaminants and return the treated water back into the environment. Constructed wetlands provide a simple and effective wastewater treatment and can treat multiple types of wastewaters such as agriculture, industrial, domestic, and mining wastewaters. Constructed wetlands can be combined with conventional treatment technologies for higher treatment efficiency. There are a range of different mechanisms from physical, biological, biochemical, and chemical processes to aide in the removal of different types of waste. Because of constructed wetlands having merits in high sustainability, there has been increased research on the practical application on the operation of wastewater wetland facilities. The current research hopes to improve the design, performance, operation, and maintenance for improved environmental benefits (Mitsch et al,. 2000, Zelder et al,. 2005).

Types

There are a variety of constructed wetland types with each possessing different way to help wastewater treatment. The type explained here are horizontal flow, surface flow, and subsurface flow wetlands.

Surface flow wetlands are typically shallow with emergent, free floating, and submerged vegetation. The flow of the water is primarily over the sediment surface. Some of these types of constructed wetlands can contain monocultures such as cattails; other constructed wetlands will contain a more diverse plant community that are proven to be more adaptable to seasonal changes, water level, and water quality. These types of constructed wetlands are effective in the removal of organics through microbial degradation and the removal of suspended solids through filtration and sedimentation. The removal of nitrogen in variable because it is dependent on many factors like inflow concentration, chemical from of nitrogen, water temperature, seasonal variation, organic carbon availability, and dissolved oxygen concentration (Vymazal et al., 2011).

Subsurface flow wetlands feed water through an inlet and the water flow is slow because it travels through a porous medium under the surface of the planted vegetation bed and can flow in either horizonal or vertical direction. Wastewater is treated between the roots of the plants, because of this the system can clog easily for there is no water above the gravel line. Emergent plants are only planted in these types of wastewater wetlands. This system the wastewater comes into contact with various aerobic, anoxic, and anaerobic zones. These wetlands are typically more expensive to construct (Vymazal et al., 2011).

Horizontal flow constructed wetlands are used when the contaminated effluent from the waste treatment plant is delivered on top of the bed, the effluent then moves horizontally across the bed of the system. These systems are usually constructed for a specific purpose like a small domestic wastewater community. These systems are a type of hybrid version in between surface and subsurface flow. Horizontal flow systems are unable to provide nitrification through the treatment process because of the limited oxygen transfer capacity (Vymazal et al., 2011). Nitrification is the biological process used in wastewater treatment to convert ammonia to nitrite and nitrite to nitrate. Some other wastewater treatment plants can use denitrification in which nitrate is reduced to nitrogen gas.

Developing Constructed Wetlands

Construction of wetlands begins with earth moving, excavating, backfilling, and grading. The equipment and procedures used are very similar for constructing ponds and lagoons. Some aspects require special attention when building wetlands. To ensure that the flow is uniform through the wetland, flow from the wastewater or source needs to be calculated in order to make a slope suitable for the flow rate. Having inlet and outlet structures within the constructed wetland can control the flow path and water depth. Constructed wetlands while being built already have an impermeable layer so the permeable lay and the layer needed for root structures can then be added. Vegetation is a necessary component for the proper functioning of wastewater wetlands and also contributes to the appearance. Plant considerations are necessary because some type of plant work better than other in removing specific types of waste. So, depending on the type of wastewater, specific type of plants will be used.

Wastewater wetlands need to have a start up period before the treatment process can begin. Depending on the flora and fauna associated with the wetland usually a season or a year in enough to establish treatment objectives. This also gives time for the area to have more well-established vegetation and for the food web to develop.

Pros and Cons of Wetlands in Wastewater

Constructed wetlands can provide many benefits in comparison to their conventional wastewater treatment counterparts. Where land is available at a low cost, they are less expensive to construct that traditional wastewater systems. They require much less maintenance and less expensive to operate since there is no need to watch over the natural systems vs. the wastewater treatment plants which are under daily 24-hour surveillance to make sure they are running properly (Wu, Haiming, et al 2015). The addition of the constructed wetland to the traditional wastewater plants offers an environmental enhancement for the facility. Added discharge from the wastewater plant can augment surface water sources for surrounding water bodies and ensures flow, enhancing the local natural aquatic resource (United States of America, Environmental Protection Agency, 2000). Habitat is an important factor when constructing wastewater wetlands; constructing more habitat area is beneficial for the local flora and fauna and leads to more area for recreational activities like birdwatching, hiking etc. (Wu, Haiming, et al, 2015). Many natural wetlands are lost at rapid rates; by using treatment wetlands we can effectively replace the lost habitat and reduce the impacts made on other natural areas. Treatment wetlands are also great for the increase in groundwater recharge and improve water availability for the future (Omondi, et al 2020).

High costs and lack of suitable land can make creating wetlands impractical (Omondi, et al, 2020). When designing a constructed wetland there are possible issues that may arise. Topography can impact the cost when constructing a wetland for wastewater. If an area has a slope, it can reduce the pumping costs because of the existing hydraulic gradient already supported by the natural landscape. Building a landscape to mimic a sloped form would cost a lot and take time. Constructed wetlands may not be able to treat some types of complex pollutants (Vymazal et al., 2011). For example, most constructed wetlands aren’t suited for the removal of Phosphorus unless specific media with high sorption are used. They also can take a lot more space than a conventional wastewater treatment plant.

Conclusion

Artificial or constructed wetlands could play a beneficial part in the treatment of multiple wastewater types. Other benefits from building wetlands are land reclamation or land mitigation for lost natural areas. Constructed wetland also offer space for native and migratory species, although this is not the main reason why they are constructed. There are many examples of these constructed wetlands working in harmony with wastewater treatment plants around the world. Some examples of wastewater wetlands in Florida are Sweetwater wetlands Park, Wakodahatchee Wetlands, and Blue Heron Water Reclamation. With more natural wetlands being decimated, using constructed wetlands is a way to retrieve lost habitat and use it for something that wetlands do naturally already, removing waste.

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Constructed Wetlands and the Importance of Plants

Abstract

Plant communities impact the functions of constructed wetlands. The Flora of wetlands can provide the right conditions for microorganisms to live and grow, and these microbes are responsible for the nutrient cycling that is essential for constructed wetland function. Plants have other functions in constructed wetlands rather than just being a home for microbial flora. They stabilize the wetland substrate, increase dissolved oxygen in the water, and the death of a plant provides litter which gives the microbes with organic carbon. Plants also provide food and habitat for animals. Plant selection for constructed wetlands can therefore influence function, determining which plant species can be beneficial is crucial to the function of constructed wetlands. Further, there are important practical considerations that influence plant selection. It takes time to establish new plant species before the wastewater can be introduced to the system. Some species take longer or shorter period of time is needed for plants to acclimate, grow, fill in the wetlands, and kickstart the biogeochemical processes necessary for constructed wetlands to function. Some plants grow too quickly and dominate the ecosystem. The flow of the constructed wetland also needs to be taken into account when choosing and growing plants for use in constructed wetlands. Flow rate and total inundation can affect the stability, growth, and survival of plants, and tolerance is species specific.

Introduction

Constructed wetlands need plants to function. Both vascular and non-vascular plants are important for constructed wetlands (EPA, 2000). Photosynthesis by both plants and algae increases the dissolved oxygen in the water which affects the nutrients and metals (EPA, 2000, Vymazal et al, 2011). The function of plants in wetlands is to grow and die; the growth of the plant provides the wetland with vegetative mass that can potentially deflect flows and provide places for microbial growth. The death of the plant creates litter and releases organic carbon to fuel the microbes. Plants can also influence wetland function by stabilizing the substrates and enhancing substrate permeability which is important for the wastewater effluent to flow effectively through the soil and not endanger the public. Without a stable substrate wastewater could leak into place where potable water is collected, this may cause this water to become unpotable or sickness to occur within the community. Plants can also decrease erosion EPA, 2000, Mitsch et al, 2000). In wetland design there is limited information on the performance of specific wetland plant species. While plants can have different functions, other factors can have larger influence on constructed wetland performance. When comparing two sites dominated by different species their performance appeared the same for wastewater treatment , the biomass rather than biodiversity was the important factor when determining the overall quality of treatment (Vymazal et al, 2011, Wu et al, 2015).

Constructed Wetland Plants and Flow Types

Different types of constructed wetlands will have different types of substrates that dictate the types of plants that can live there; for example, subsurface wetlands will tend to have plants that can handle substrate like gravel or sand to provide ample room for microbial activity. Subsurface wetlands can potentially use less vegetation when comparing Surface flow wetlands because of differing flow rates(Wu et al, 2015). Surface flow wetlands generally treat domestic, agriculture, and other wastewater that have high organic matter. Subsurface flow wetlands have been known to be planted with very diverse vegetation similar to a natural marsh (Wu et al, 2015). The type of constructed wetland, and the wastewater the wetland is treating can help determine the plants that would be most beneficial to the system.

Constructed Wetland Plant Components

Plant communities in constructed wetlands can determine the wetland overall function and traits. Free-floating aquatic plants, like duckweed, primary purpose in wetlands is to uptake nutrient and shading for reduction in algal growth. Dense mats of free-floating plants can limit oxygen diffusion from the atmosphere (EPA, 2000). Rooted floating aquatic plants are great for providing structure for microbial attachment and for releasing oxygen into the water during the day, If the float aquatic plant is too close together, they will also limit oxygen diffusion from the atmosphere. Submerged aquatic vegetation also can provide structure for microbe attachment and provide oxygen to the water column. Emergent aquatic vegetation provides structure and can enhance the flocculation and sedimentation (EPA, 2000). Shading can also come from these types of plants which also deters algal growth and can be a good insulator during the winter months. Shrubs and trees in the area aren't known to have treatment function for constructed wetlands but, they do provide shelter and food for animals in the area, also beauty aesthetic for humans. Phosphorus and Metals can be sequestered in dead plant material in wetland sediments which is beneficial in the wastewater treatment process (EPA, 2000).

Some recommend species for emergent plant for constructed wetlands would be listed on the table below (EPA, 2000).

Arrow arum *Peltandra virginica*	Full sun to partial shade. High wildlife value. Foliage and rootstocks are not eaten by geese or muskrats. Slow grower. pH: 5.0-6.5.
Arrowhead/duck potato *Saggitaria latifolia*	Aggressive colonizer. Mallards and muskrats can rapidly consume tubers. Loses much water through transpiration.
Common three-square bulrush *Scirpus pungens*	Fast colonizer. Can tolerate periods of dryness. High metal removal. High waterfowl and songbird value.
Softstem bulrush *Scirpus validus*	Aggressive colonizer. Full sun. High pollutant removal. Provides food and cover for many species. of birds. pH: 6.5-8.5.
Blue flag iris *Iris versicolor*	Attractive flowers. Can tolerate partial shade but requires full sun to flower. Prefers acidic soil. Tolerant of high nutrient levels.
Broad-leaved cattail *Typha latifolia*	Aggressive. Tubers eaten by muskrat and beaver. High pollutant treatment, pH: 3.0-8.5.
Narrow-leaved cattail *Typha angustifolio*	Aggressive. Tubers eaten by muskrat and beaver. Tolerates brackish water. pH : 3.7-8.5.
Reed canary grass *Phalaris arundinocea*	Grows on exposed areas and in shallow water. Good ground cover for berms.
Lizard's tail Saururus cernuus	Rapid grower. Shade tolerant. Low wildlife value except for wood ducks.
Pickerelweed *Pontedaria cordata*	Full sun to partial shade. Moderate wildlife value. Nectar for butterflies. pH: 6.0-8.0.
Common reed *Phragmites australis*	Highly invasive; considered a pest species in many states. Poor wildlife value. pH: 3.7-8.0.
Soft rush *Juncus effusus*	Tolerates wet or dry conditions. Food for birds. Often grows in tussocks or hummocks.
Spikerush *Eleocharis palustris*	Tolerates partial shade.
Sedges *Carex spp.*	Many wetland and several upland species. High wildlife value for waterfowl and songbirds
Spatterdock *Nuphar luteum*	Tolerant of fluctuating water levels. Moderate food value for wildlife, high cover value. Tolerates acidic water (to pH 5.0).
Sweet flag *Acorus calamus*	Produces distinctive flowers. Not a rapid colonizer. Tolerates acidic conditions. Tolerant of dry periods and partial shade. Low wildlife value.
Wild rice *Zizania aquatica*	Requires full sun. High wildlife value (seeds, plant parts, and rootstocks are food for birds). Eaten by muskrats. Annual, nonpersistent. Does not reproduce vegetatively.

Choosing plants with a low tolerance for a high nutrient load will not be beneficial for a constructed wetland because they will be exposed to a continuous inflow of nutrient through the treatment process. Perennial plants are of higher preference when choosing which plant types will be successful since annual plants may require additional plantings. Monocultures are also to be avoided due to possible decimation by insects or diseases, greater diversity will lead to greater diversity of animals and encourage plant growth (Wu et al, 2015). Some ecologists are concerned about the unknown consequences of relocating this stock to new area. Plants can become adapted to the local pathogens and mutualistic species when these plants are transplanted their survival and growth can dimmish. As for the state of Florida, they recommend a 50-mile radius for finding donor plants (EPA, 2000). Plant communities in constructed wetlands rarely maintain the species contribution and variety by their original design (EPA, 2000, so monitoring and continued maintenance are important.

The most common plants used in constructed wetlands are bulrushes (Scirpus), spikerush (Efeocharis), sedges (Cyperus), rushes (Juncus), common reed (Phragrnites), and cattails (Typha) (EPA, 2000). For wastewater treatment wetlands the density of the vegetation matters more than the species of plant selected. The plant species chosen should try and mimic the communities of nearby wetlands because they are more likely to do well in the area (EPA, 2000).The plants always need to be local according to the US Army Corps of Engineers; they also recommend that plants should be transferred from areas within 100-milse latitude, 200 longitude and 1000 feet in elevation(EPA, 2000, Wu et al, 2015, Vymazal et al 2011).

Planting Techniques and Selection for Constructed Wetlands

There are a few ways to develop a plant community for constructed wetlands. Plants can be grown from seed. Plants can be grown from rhizomes or tubers, and adult plants can be transplanted. All these planting techniques have advantages and disadvantages.

Plant sources are often based on budget. Seeds are often the least expensive but there are some tradeoffs. They are the least reliable when planting. Seed germination can be low since germination and survival require a saturated surface and water levels in wetlands vary so a consistent saturated surface is not guaranteed (EPA, 2000, Wu et al, 2015). Scarification and stratification are techniques used to increase seed germination (EPA, 2000, Wu et al, 2015). Stratification is the process to simulate germination by altering environmental conditions in which the seeds are stored . Scarification is breaking the outer seed coat before planting. Both techniques are energy intensive. Instead of collecting, storing, and manipulating seeds, managers can use wetland soil with an intact seed bank. If there is a wetland nearby and the proper approval in obtained the wetland soil can be removed and used as a source of plant for the constructed wetland (EPA, 2000). Cores of 3-4 inches or 8-10 cm in diameter can be transplanted (EPA, 2000, Wu et al, 2015). Seeds of many wetland species are viable for years when they are buried under the sediments so soil cores are great seed donors for wetland plants but can also contain other things, like some undesirable species. In some cases, seeds colonize a new wetland naturally. Seeds can often be moved by rain and wind into new areas. (EPA, 2000, Wu et al, 2015).

Plant parts like tubers and rhizomes can also be used to establish plant communities in constructed wetlands.. These materials can be obtained from commercial nurseries or donor wetland sites. When using plant parts like rhizomes and tubers, these can be collected during the fall season because growth has usually stopped (EPA, Zelder et al, 2005). The entire root needs to be taken along with some soil; the soil helps the constructed wetland be inoculated with microbes. The rhizomes after collection are then cut into lengths of two to three nodes and place in moist substrate like peat or sand. These are stored at cool temperature, around 4-5 deg C, until they are needed for planting (EPA, 2000). Storing the tubers and rhizomes at cooler temperature also can enhance growth for spring planting.

Other ways to plant a constructed wetlands consider older, established plants. Adult plants can be purchased from nursery's and planted manually. Alternatively, cores with intact plants from an established wetlands can promote the healthy development of the constructed wetland. Some disadvantages of using the soil cores are the time it takes to transplant, and the cost associated with all of the transporting, collecting, and planting of the cores in the constructed wetland. The soil from the donor wetland can also contain propagules of some undesirable species (EPA, 2000, Wu et al, 2015). Cores can also be unpredictable whether the core is dominated by a rhizome spreading species, you may have a constructed wetland with just that one species. Rhizomes spreading species can spread from each cutting of the rhizome, when moving the soil cores rhizomes can be cut into pieces during this process and each piece will produce and new plant. Once the soil cores have been moved to the site, they should be kept moist and not flooded until germination is complete (EPA, 2000, Wu et al, 2015). Storing plants in too dry or warm conditions can be detrimental to the constructed wetland project. Also collected them too early in the season and immediately transplanting them can lead to a negative mortality rate for the rhizome and tubers. Manual collection is mainly used unless a vast quantity in needed machine collection is not practical (Wu et al, 2015, Vymazal et al, 2011).

Maintenance Control

The start of building a constructed wetland is much like babysitting, it needs care and patience and needs to be monitored before it can be used for wastewater. Maintaining water level in the most critical part for plant survival when establishing a constructed wetland during the first year. Wetland plants when they are young cannot tolerate deep water, this is a common mistake (EPA, 2000). Too much water creates more problem during the first growing season because of the lack of oxygen the plant needs for their roots. Some other protection may be needed to prevent grazers like geese, deer, and black birds from grazing on the new seedlings. Plants also need time to established themselves before wastewater is introduced to the constructed wetland system (Wu et al, 2015, Zelder et al,2015, Vymazal et al, 2011). They need time to overcome the stress of planting before the stress of wastewater. It may take up to two growing seasons before wastewater will be added. Water level and water quality are the key factors to watch when trying to establish plants to a constructed wetland. Vegetation also needs to be inspected regularly and invasives should be removed. Avoid the use of herbicides and only use in extreme circumstances, herbicides can damage the emergent vegetation (EPA).

Conclusion

Constructed wetlands can provide a little maintenance, no electricity, and low long-term cost when compared to a traditional wastewater system. Both floating, submerged, and emergent aquatic plants are needed for a wastewater wetland to function properly. The plants play an important role when establishing the constructed wetland for wastewater use and providing the area with structure and room for the growth of microorganisms which are the sources to clean wastewater. The type of plants used need to be from a native source, so there are many options when starting to plant the wetland. Problems can arise when using different source and many times the predetermined constructed wetland ends up looking entirely different than the original plans. Invasive and aggressive plant species need to be avoided at all costs. Things to keep in mind when planting a constructed wetland are control flow for the first couple of years, using native plants, providing them with plenty of space, and not introducing them to higher nutrient levels too soon otherwise they will not be able to endure the shock.

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