

# Wetlands as a Tool for Water Treatment<sup>1</sup>

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## Introduction

Wetlands are transitional areas between land and water that encompass a broad array of environments, including marshes, bogs, swamps, floodplains, and tidal and riparian zones. Each of these environments have slow-moving, shallow waters at or near the soil surface at least part of the year, including during the growing season. The hydraulic conditions, the plant communities, and the unique aerobic-anaerobic interface between the oxygenated surface waters and oxygen-depleted saturated soils support various physical, chemical, and biological processes that improve water quality (Kadlac and Wallace 2008).

Wetlands are often referred to as “nature’s kidneys” because of their ability to remove pollutants from water via storage in the soil and vegetation, as well as through losses to the atmosphere. Studies evaluating the effectiveness of wetlands to treat wastewater have been conducted since the mid-20<sup>th</sup> century (Mitsch and Gosselink 2007). Today, natural wetlands and manmade (constructed) wetlands are used globally to treat contaminated water, where contaminants refer to any constituent in the water that can cause human or environmental harm. Wetlands treat wastewaters from many different origins including agricultural production, stormwater runoff, mining, petroleum refineries, pulp and paper mills, and landfill leachates (DuPoldt et al. 2000). These pollutants include physical contaminants (e.g., suspended sediment), chemical contaminants both organic (e.g., petroleum hydrocarbons, pesticides, pharmaceuticals)

and inorganic (e.g., heavy metals, excess concentrations of nutrients), and biological contaminants (e.g., viruses, pathogens). Some of these contaminants, such as nutrients, may only be harmful above a certain threshold. Nutrients become problematic when high concentrations of nitrogen or phosphorus cause excessive plant and algae growth. During the decomposition process, microorganisms feeding on detritus from dense stands of aquatic plants and algae use available oxygen in the water column, leading to low dissolved-oxygen concentrations that can cause fish kills.

In the state of Florida, treatment wetlands are used for a variety of purposes and at varying scales, from individual residential lots (e.g., septic systems) to a combined 57,000 acres of constructed stormwater treatment areas designed to reduce phosphorus loads flowing into the Everglades. The purpose of this article is to provide the reader with a general overview of the function and structure of large-scale treatment wetlands and the services they provide. It is not intended to be used as a guide for wetland design or construction.

## Natural versus Constructed Wetlands

In the United States, the use of natural wetlands to improve water quality was pioneered by researchers in Florida and Michigan, states that contain large acreages of natural wetlands (Mitsch and Gosselink 2007). Today, natural wetlands are considered waters of the United States, and

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federal regulations discourage their use for wastewater treatment. Current regulations only allow natural wetlands to receive wastewaters that have undergone extensive water treatment by conventional processes at wastewater treatment facilities. Therefore, existing natural wetlands receive wastewaters that have undergone secondary or tertiary treatment (Kadlec and Wallace 2008). The process of treating wastewater in treatment wetlands after it has undergone secondary or tertiary wastewater treatment is known as “polishing.” Polishing is often a final step to reduce concentrations of contaminants in wastewater before discharging it to local surface waters. In natural wetlands, wastewater should be well distributed throughout the wetland for effective treatment, and the natural hydrology of the wetland should be understood and mimicked to support local flora and fauna.

Although natural wetlands may still be used today as part of wastewater treatment, it is a more common practice to construct a treatment wetland. Constructed wetlands are designed to mimic the natural biological, chemical, and physical processes of a wetland while allowing for greater flexibility and control. Constructed wetlands can provide some or all of the functions of secondary and tertiary treatment (Kadlec and Wallace 2008). In the United States, there are approximately one thousand constructed wetlands in operation that receive a wide range of wastewaters (US EPA 2017). Generally, they are built in uplands or outside of floodplains by establishing water control structures to create a desired hydrologic flow path. Although treatment wetlands require a large amount of land, they are more cost effective to operate and maintain than conventional methods of wastewater treatment because they require little energy and operational attention (Kadlec and Wallace 2008).

Due to its flat topography and frequent rainfall, Florida contains a larger acreage of wetlands than any state other than Alaska and has a long history of regulating natural and constructed wetlands for the treatment of domestic wastewater. The *Wetland Application Rule* (Chapter 62-611, F.A.C.) classifies wetlands into categories. These categories determine the quality of effluent water leaving the wetland system and offer greater protection to the natural wetlands (FDEP 2018). According to the Florida Department of Environmental Protection, there are 17 natural wetlands (6,200 acres) and 21 constructed wetlands (4,000 acres) used for water treatment in the state, the majority of which are free water surface flow wetlands (FDEP 2017).

## Types of Constructed Wetlands: Surface and Subsurface Flow

There are two major types of constructed wetlands, free water surface flow (FWSF) or subsurface flow (SSF). The two differ in their hydrology, and the type constructed will depend on specific contaminant removal, design, and/or regulatory needs. Free water surface flow wetlands contain a shallow layer of surface water that flows over a vegetated soil surface (Figure 1). In subsurface flow wetlands, the water flows beneath the soil surface through a porous medium, either vertically or horizontally, and roots penetrate the soil (Figure 2).

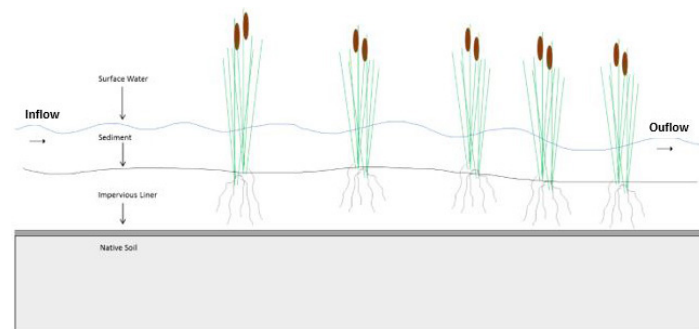


Figure 1. Diagram of a Free Water Surface Flow Wetland. Credits: modified from Mitsch and Gosselink (2007)

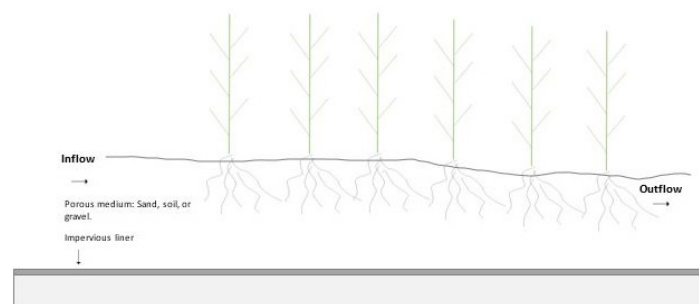


Figure 2. Diagram of a Subsurface Flow Wetland Credits: modified from Mitsch and Gosselink (2007)

Free water surface flow wetlands can be natural or constructed. They look like natural wetlands and are similar in that they include open water and floating, submerged, and emergent vegetation. They also provide many of the same functions as natural wetlands, including providing habitat for wetland flora and fauna. As surface waters flow through the wetland, particles settle, and chemical and biologic processes retain and transform contaminants. Surface flow systems represent about 60% of treatment wetland systems in North America (Wang et al. 2006, Finny 2000). They are generally less expensive than SSF wetlands to construct and maintain (Hunt and Poach 2001), although they do require more land area, especially if the wetland is designed to remove nutrients (e.g., nitrogen, phosphorus). Because of their size requirements, FWSF wetlands are often used as polishing systems for wastewater.

Subsurface flow wetlands are constructed wetlands that provide habitat for certain species of emergent vegetation and act as a filter by removing solids and nutrients from water as it flows through a saturated porous sand, gravel, or soil medium. Bacteria along with emergent aquatic vegetation uptake and transform contaminants as water flows through the wetland. Some of the advantages of SSF wetlands are that they prevent public contact with partially treated wastewater, they do not provide mosquito breeding habitats, they require less land area, and they reduce odors (US EPA 2017). Major disadvantages are that they are difficult and expensive to construct and that they are prone to clogging.

Hybrid systems use both surface and subsurface water flow. These systems are useful in providing both the aerobic and anaerobic conditions necessary to support the bacterially driven water treatment processes. As a result, hybrid systems can be more effective at treating certain contaminants.

## Wetland Soils

Wetland soils differ from terrestrial soils because of the influence of water. Wetland soils are often saturated, resulting in anaerobic conditions. Microbial decomposition of organic matter occurs at a much slower rate under oxygen-limited conditions. These low-oxygen, anaerobic conditions coupled with the high biological productivity associated with wetlands lead to an accumulation of organic matter as shown in Figure 3. These soils are important for the functionality of the wetland and provide support for aquatic plants, a low-permeable substrate for water movement, storage for contaminants, and the foundation for chemical and biological transformations associated with the unique anaerobic-aerobic interface between the soils and water (Kadlac and Wallace 2008).

## Wetland Vegetation

Wetland plants are adapted to an abundance of water and the low levels of oxygen that occur as a result of saturation. Aquatic vegetation or aquatic macrophytes are aquatic plants or algae large enough to be visible to the naked eye. General types of aquatic vegetation include free-floating, floating-leaved, submerged, and emergent (Florida Lake-watch 2001). The type of aquatic vegetation present impacts the wetland's function and treatment of contaminants.

Free-floating aquatic vegetation (FAV) are not attached to wetland soils but float on the top of the water column. Common types of FAV found in Florida include duckweed

(*Spirodela* spp.), water lettuce (*Pistia stratiotes*, non-native) and water hyacinth (*Eichhornia crassipes*, non-native). Floating-leaved plants are attached to the wetland soil and contain leaves that float on the top of the water surface. Examples include water lilies (*Nymphaea* spp.) and American lotus (*Nelumbo lutea*).

Submerged aquatic vegetation (SAV) usually remains beneath the water surface. Most submersed plants are rooted to the bottom, but some species such as coontail (*Ceratophyllum demersum*) are free floating in the water column. Common types of SAV found in Florida include muskgrass (*Chara* spp.), southern naiad (*Najas guadalupensis*) and eel grass (*Vallisneria americana*).

Emergent aquatic vegetation (EAV) are rooted plants that grow above the surface of the water. They are found in saturated soils often along a shoreline or in shallow waters. Common types of EAV found in Florida include cattails (*Typha* spp.), arrowheads (*Sagittaria* spp.) and sawgrass (*Cladium jamaicense*), the dominant plant of the Florida Everglades. Wetlands perform many important biological, physical, and chemical functions, and the collective removal or degradation of environmental contaminants by plants is called phytoremediation.



Figure 3. These soils were dug up along a topographic gradient in Gainesville, Florida. Soils a and b were higher in elevation compared to soils c and d. Subsequently soils c and d are darker in color due to increased organic matter content as a result of longer periods of inundation.

Credits: Jay Capasso, UF/IFAS



Figure 4. A treatment wetland facility in Martin County. Pictured are the SAV species waterthread pondweed (*Potamogeton* spp.) and the EAV species spikerush (*Eleocharis*) and fireflag (*Thalia geniculata*). Credits: Lisa Krinsky, UF/IFAS



Figure 5. Floating aquatic vegetation (water lettuce) growing throughout an agricultural field ditch in an experiment in the Everglades Agricultural Area. Credits: Jay Capasso, UF/IFAS

## Biotic Processes in Treatment Wetlands

The primary means of phytoremediation is through biological removal processes, the most well-known of which is plant uptake. Plants take up contaminants from surface waters or saturated wetland soils through their roots. Aquatic vegetation can take up different contaminants including essential elements (e.g., nutrients) and non-essential elements (e.g., metals, organic contaminants). When plants die, the dead plant material accumulates on the bottom of the wetland as detritus. The contaminants that were previously stored within the plants' biomass may be lost through leaching and decomposition of the detritus. These contaminants are then recycled back into the water column.

To prevent the recycling of contaminants, vegetation may be subsequently removed, a term called phytoextraction.

In addition to uptake, aquatic vegetation has the capacity to reduce pollutant toxicities through metabolic processes (Dhir 2013). For example, plants have been found to degrade and volatilize toxic forms of mercury Hg (II) by transpiring it into a less toxic elemental gaseous form Hg (0) through the process of phytovolatilization (Wang et al. 2012, Dhir 2013). Aquatic vegetation can also phytostabilize contaminants by binding them into organic forms, making them less bio-available even after subsequent decomposition of aquatic vegetation (Dhir 2013).

Physically, aquatic vegetation also affects wetland water treatment processes. Floating and emergent plants provide shade, affecting algal and SAV growth and moderating the temperature of the water column. Vegetation helps to dissipate wind and wave action. The calm, low-energy conditions increase the “hydraulic residence time,” or the length of time water spends in the wetland interacting with various natural water treatment processes. Stands of aquatic vegetation promote the removal of suspended solids (particulates) from the water column. Emergent and submerged vegetation also helps to stabilize the sediment within the root zone and inhibit the resuspension of sediments from the bottom (Brix 1997).

Aquatic vegetation affects the diffusion of oxygen in the water column (Kadlec and Wallace 2008), which can have an impact on microbially mediated reactions. For example, thick stands of floating aquatic vegetation limit the diffusion of oxygen into the water column, which results in low oxygen conditions that favor natural chemical reactions that remove or transform harmful contaminants such as sulfate reduction, methanogenesis, and de-nitrification (Faulwetter et al. 2009). Denitrification and nitrification are important processes in wetlands in terms of water purification. These processes occur when inorganic nitrogen (e.g., nitrate and ammonium) can be metabolically transformed to nitrogen gas, which is then lost to the atmosphere. Denitrification converts nitrate ( $\text{NO}_3^-$ ) to nitrogen gas ( $\text{N}_2$ ) through the removal of oxygen. The conversion of ammonium to nitrogen gas occurs in the sequential process of nitrification, the conversion of ammonium ( $\text{NH}_4^+$ ) to nitrate ( $\text{NO}_3^-$ ) through the addition of oxygen, followed by denitrification. Nitrification occurs in oxygenated, aerobic areas, whereas denitrification occurs in anaerobic regions. Oxygen diffusion from the roots of EAV can result in aerobic conditions that support microbial-driven processes such as decomposition and nitrification. In some situations, EAV can create conditions for nitrification and denitrification by limiting

oxygen diffusion on the surface of the water column while diffusing oxygen to parts of the root zone (Brix 1993). As with plants, microorganisms can take up and store contaminants. Microorganisms also mediate most of the transformations of contaminants that occur in wetlands (Kadlec and Wallace 2008). The metabolic functions of bacteria are especially important for organic contaminant removal. Wetlands provide habitat, carbon, and aerobic and anaerobic environments for microorganisms to conduct these reactions.

## Abiotic Processes in Treatment Wetlands

Wetland soils contribute to water treatment through their ability to retain contaminants. Due to their high organic matter content, wetland soils have a high cation exchange capacity, meaning they can bind and exchange positively charged ions. This is an important process in treating heavy metals like copper, chromium, lead, and zinc. Although wetland soils act as sinks and transformers of contaminants, they can also become sources of contaminants (Bhadha 2012). This occurs when soils adsorb high concentrations of a contaminant and then release the contaminant back into the water column. For example, wetland soils can become sources of phosphorus over time when high amounts of phosphorus are adsorbed relative to the soils' iron, aluminum, and calcium content and subsequently released back into the water column. Environmental conditions, such as changes in pH and redox potentials, also influence phosphorus retention in wetland soils. Therefore, treatment wetlands should be monitored over time for their effectiveness in water treatment.

While sorption is the most important abiotic chemical process in wetlands, photo oxidation and volatilization of compounds also may occur. In photo oxidation, energy from the sun breaks down and oxidizes compounds. Volatilization involves the breakdown of contaminants into a gaseous state which is then lost to the atmosphere.

## Other Services Provided by Treatment Wetlands

Although the primary goal of treatment wetlands is to improve water quality, they also provide services beyond water treatment. Treatment wetlands protect against flooding, provide water reuse, and reduce odors associated with wastewater. They also can be aesthetically pleasing, provide habitat for wildlife, and provide recreational value. Treatment wetlands provide habitat for wetland fauna such

as fish, waterfowl, amphibians, beavers, and alligators. Many treatment wetlands are open to the public and can provide passive and active recreational opportunities for bird-watching, fishing, and hunting. Both natural and constructed wetlands provide sites for people to learn about the ecological value of wetlands.

## Orlando Easterly Wetlands (Case Study)

One of the larger constructed wetlands in Florida is the Orlando Easterly Wetlands. The city of Orlando constructed the wetland in the 1980s to provide an effluent site for domestic wastewater that had already been partially treated through conventional processes at the Iron Bridge Regional Water Reclamation Facility for environmental enhancement (FDEP 2017). Because domestic wastewater loads were increasing due to a rising population, the city could no longer discharge wastewater effluent into natural areas due to high nitrogen and phosphorus levels.

The Orlando Easterly wetlands are FWSF wetlands that contain various forms of free-floating, floating-leaved, submerged, and emergent aquatic vegetation. Surface waters take about 40 days to flow through the 1,200 acres of wetlands before they are discharged into a canal bound for the St. Johns River. Water tests are conducted daily by automatic samplers and tested at the Environmental Laboratory at Iron Bridge Water Reclamation Facility. The Orlando Easterly Wetlands' capacity to treat domestic wastewater outperformed expectations, receiving wastewater for 13 years before phosphorus removal capacity declined (Black and Wise 2003, Wang et al. 2006).

However, in order to maintain water treatment efficiency, management operations have been conducted to manage soil and vegetation so that phosphorus levels do not accumulate to high levels in the wetlands. These management operations include the harvesting of large amounts of wetland soil and vegetation with heavy machinery such as bulldozers and depositing it offsite as a soil amendment (Wang et al. 2006).

The Orlando Easterly Wetlands provides services beyond water treatment. The wetland also serves as a public park known as the Orlando Wetlands Park that is open 365 days of the year from sunrise to sunset. This park is located in Christmas, Florida, and provides recreational opportunities such as hiking, bird watching, an annual festival complete with live music and wildlife shows, and habitat for 30 animals species listed on the Florida Wildlife Conservation Commission's Threatened and Endangered Wildlife list.

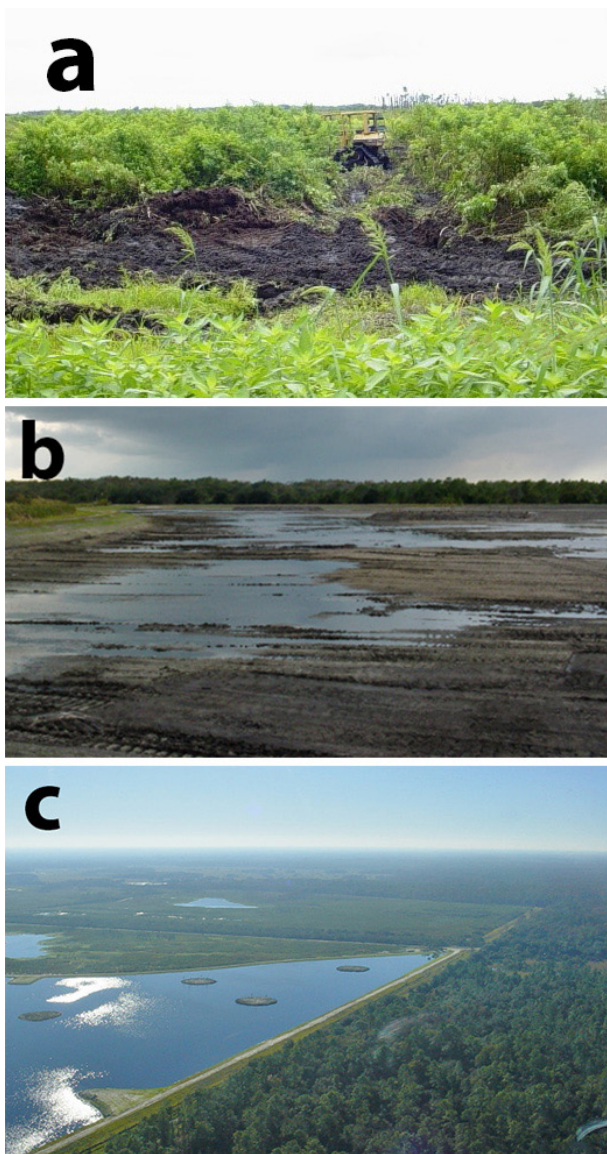


Figure 6. The dredging process at Orlando Easterly Wetlands. a) Machinery removing wetland soil and vegetation; b) this section has become re-flooded after wetland soil and vegetation were removed; and c) aerial view of this section of wetlands over a year after completion of the dredging process.  
Credits: James Jawitz, UF/IFAS

## Conclusion

Wetlands are an essential part of the Florida landscape that can be used to improve modern-day water quality issues. Through the treatment of domestic wastewater, non-point source pollution and stormwater runoff, wetlands can provide a low-cost and natural alternative to conventional water treatment. However, they can also provide other services that benefit the Florida economy through their educational, floodwater storage, recreational, and aesthetic value. We hope that this article can inform policy makers and members of the Florida public about treatment wetlands whose communities may already contain or be considering implementation.

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