Advanced Technologies for Wastewater Treatment Utilizing Constructed Wetlands

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The authors are members of the University of Florida team that won the 2002 Student Design Competition sponsored by the Florida Water Environment Association and competed nationally at the recent World Environment Federation's Technical Exposition and Conference. The article describes the team's award-winning design project.

For the past seven years, the Florida Water Environment Association (FWEA) has sponsored a design competition among Florida universities with environmental programs. This year's problem involved the Wakodahatchee Wetlands, a constructed wetland designed by CH2M Hill to treat a portion of the Southern Region Water Reclamation Facility's (SRWRF) secondary wastewater effluent.

Completed in 1996, the wetland replaced a rapid infiltration basin. This modification introduced several benefits, including surficial aquifer recharge, wildlife habitation, sustained biological diversity, recreational areas, and environmental education (Wakodahatchee Wetlands, 2002). The natural mechanisms within the Wakodahatchee Wetlands reduce nutrient levels in the effluent, providing advanced biological treatment.

A goal of the Palm Beach County Water Utilities Department (PBCWUD) is to discharge the wetland effluent into the nearby Lake Worth Drainage District's L-30 Canal. Currently, there is no permit for surface-water discharge, so the wetlands effluent is deep-well injected (FDEP Permit No. FLA041424-001-DWIP, July 30 1998). The purpose of the design team's project was to investigate cost-effective alternative technologies to provide additional treatment utilizing wetlands that could achieve effluent quality levels that would meet FDEP's standards for disposal to the L-30 Canal.

The Wakodahatchee Wetlands is located approximately one mile east of the SRWRF in Palm Beach County (PBCWUD, 1999). The wetland was constructed on a 56-acre site with 39 acres comprising the wetted wetland surface area. It is designed to handle up to three MGD of activated-sludge effluent that has been chlorinated but not filtered (PBCWUD, 1999).

The Wetlands

The wetlands consist of eight cells, separated by earthen berms. Wastewater influent flows into six of the eight cells. Water levels in the cells can be individually controlled, maximizing operational flexibility and facilitating maintenance. The cells range from 2.3 to 10.9 acres in size, with an average cell length-to-width ratio of 3:1. At normal operational conditions, the water depth is 0.5 to 1.5 feet. The depth can reach up to two feet during periods of heavy precipitation.

Twenty-eight deep zones, up to five feet in depth and variable in width, are located throughout the cells. They are oriented transversely to the direction of flow to prevent channeling. The function of the deep zones is to retain suspended solids and provide a habitat for fish and birds (Bays et al., 2000).

Secondary effluent from the SRWRF is distributed to cells AG, B, C, D, E, and F by a splitter box (**Figure 1**). Flow enters cell H from cell AG. The outflows from cells B, C, D, E, and F are collected by a channel that flows into cell I, while outflow from cell H goes directly to cell I. Currently the wetland effluent from cell I is disposed of through a deep-well injection system located at the site.

Wetland marshes comprise about 70 percent of the total wetland area. Vegetative species native to South Florida were used extensively in the wetland design. The emergent zones of the wetland were planted with bulrush, duck-potato, arrowhead, spike rush, fire flag, and pickerelweeds. The upper edge of the marsh zone was planted with herbaceous species that include saw grass, fakahatchee grass, and gulf muhly grass.

Planted along the marsh edge are several forested species, including cypress, pond apple, carolina willow, red maple, and buttonbush. The upland berms that separate the various cells were planted with dahoon holly, sable palm, saw palmetto, cocoplum, live oak, mahogany, and slash pine. Melaleuca and brazillian pepper were pre-existent at the site, but were removed prior to construction because they are considered exotic species in the state of Florida (Bays et al., 2000).

Influent and effluent rates for the wetlands averaged 1.4 MGD and 0.85 MGD, respectively, between November 1996 and August 1998. A hydrologic balance indicated that 0.45 MGD of the wastewater influent percolated through the sediments of the wetland and into the groundwater, while 0.1 MGD was lost through evapotranspiration (Bays et al., 2000).

One of the main objectives in the construction of the wetland was to educate the public about the benefits of wetlands as an ecological resource. A three-quarter-mile boardwalk was constructed throughout cells B, C, and AG with signs describing the vegetation and wildlife. Over 100 different bird

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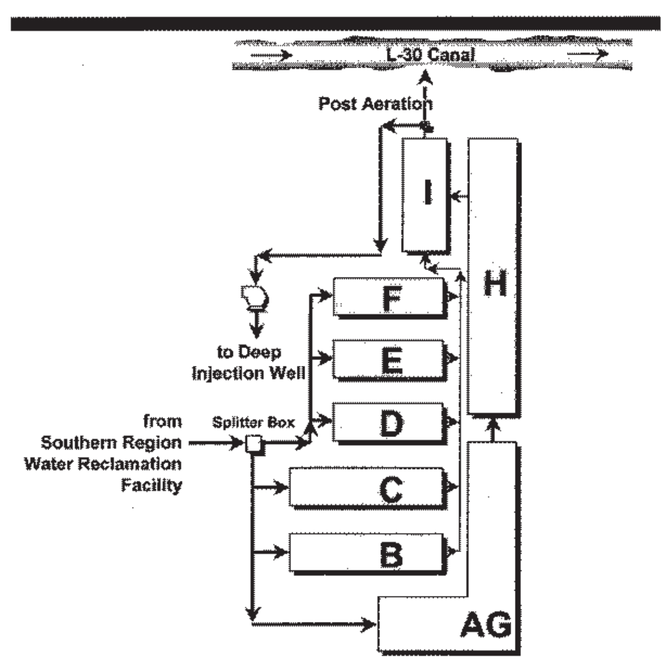

Figure 1: Flow Scheme for Wakodahatchee Wetlands*

Figure courtesy of CH2M Hill(2000)

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species have been identified in the wetland, including 13 species that are considered by state and federal agencies as commercially exploited, threatened, or endangered. Several different types of native mammalian, reptilian, and amphibious species have created habitats in the wetland (Bays et al., 2000).

The L-30 Canal

Classified as an impaired water body, the L-30 Canal is one of many canals in the Lake Worth Drainage District (LWDD). Created by a special act of the Florida Legislature, the LWDD is a water management district operating under the authority of Chapter 298 of the Florida Statutes. The district operates and maintains a series of "L" canals in Palm Beach County to provide drainage and flood protection, control saltwater intrusion, and supply water for agriculture. Water flow in the canals is minimal, except during large rain events, when water can enter Lake Ida and Lake Osborne.

Certain restrictions are placed on the L-30 Canal as an impaired water body, a designation given to any water body in the United States that does not attain water-quality standards, as defined in 40 CFR Part 131 of the Clean Water Act, due to an individual pollutant, multiple pollutants, pollution, or an unknown cause of impairment.

A critical restriction applied to the L-30 Canal is the Total Maximum Daily Load (TMDL), which is used to control the quantity of a substance that is allowed to be discharged into a water body. TMDLs are part of written plans and analyses established to ensure that a given water body will attain and maintain water-quality standards, including consideration of reasonably foreseeable increases in pollutant loads. In order to determine a TMDL, background readings of several parameters, such as total nitrogen, total phosphorus, pH, temperature, BOD5, dissolved oxygen, and turbidity, must be taken to establish the current condition of the water body.

Permitting

The SRWRF permit allows for discharge of up to 3.0 MGD (annual average daily flow) by rapid infiltration basins (FDEP Permit, 1998). The permit further stipulates that the infiltration basins, which originally consisted of three percolation ponds, have been converted to a constructed wetland (the Wakodahatchee). The Wakodahatchee Wetlands are allowed to receive secondary treated effluent from the SRWRF.

Palm Beach County has established that the quality of the SRWRF effluent (wetland influent) must be maintained at minimum technology-based effluent limitations (TBEL) to preserve the ecological balance of the wetland. Furthermore, effluent discharge into the L-30 Canal can not be initiated until a full analysis of the treated and receiving waters is completed and appropriate permits are granted (Bays, 2001).

Pretreatment

In order to comply with current standards for discharge into the L-30 Canal, the nutrient levels present in the wetland effluent must be less than the average nutrient background concentration in the L-30. The current concentration levels in the Wakodahatchee Wetlands are shown in **Figure 2**.

Average Flow (Mgal/d)		Average TP concentration (mg/L)		Average TN concentration (mg/L)	
In	Out	In	Out	In	Out
1.20	0.85	2.12	1.46	28.03	8.43

Figure 2: Nutrient concentrations present in the Wakodahatchee Wetlands.

The current background concentrations for total nitrogen and total phosphorus in the L-30 Canal are 1.9 mg/L and 0.24 mg/L, respectively (CH2M Hill, 2000). Since nitrogen removal can be easily implemented through aeration and hydraulic retention times, we will focus on removal of total phosphorus as our limiting factor.

It was determined through calculations that to achieve the goal of the design team, 55 percent of the phosphorous in the influent to the wetland must be removed before it reaches the wetland. One approach to reducing phosphorous is alum dosing. There were concerns about introducing chemicals directly into the wetland; therefore, the alum dosing will take place within the treatment plant. This will be a costly endeavor, but if wetlands are to be utilized in wastewater treatment with the goal of discharging to surface waters, chemical pretreatment or large amounts of land will be necessary. This option would designate one process train of the SRWRF for alum dosing. The capacity of the SRWRF will not be affected, but the system will be expensive to implement. The cost of liquid alum has been priced as $149 per ton (Longview, 2001). The annual chemical cost for alum dosing to treat 7.5 MGD has been calculated at $64,000.

Nutrient Removal Mechanism

In natural wetland systems, nutrients are removed biologically through plant uptake. The two basic types of vegetation used in constructed wetlands are emergent and submerged. Emergent vegetation can effectively remove nutrients from the water column and is more aesthetically pleasing, but surficial overgrowth can be problematic. In the presence of abundant nutrients, emergent plants can rapidly spread across the surface of the water, blocking sunlight to both plant and animal species within the water column. This sunlight deprivation can stunt photosynthetic activity, eventually leading to anoxic (oxygen deprived) conditions in the water.

Currently the dominant vegetation present in the Wakodahatchee Wetlands is emergent. The potential of nutrient removal in a wetland is determined by a first-order uptake rate (k, see calculations on page 31) (Kadlec and Knight, 1996). The reported nutrient removal rate for emergent vegetation in the Wakodahatchee Wetlands is currently 4 m/yr (CH2M Hill, 2000).

Submerged aquatic vegetation (SAV) efficiently removes nutrients due to its vertical position in the water column. The incorporation of limerock (LR) berms within SAV can optimize phosphorus removal by adding another dynamic to the system: precipitation and settling.

There are two important mechanisms for nutrient removal that are achieved by the SAV/LR system. First, plants uptake nutrients and store them in their tissues. The second and most important mechanism that drives the SAV/LR consists of chemical changes due to the photosynthetic activity of the SAV. Through the removal of CO_2 during photosynthetic activity, the SAV has the capacity to increase pH and dissolved oxygen in the water column. According to previous studies, this increase can result in a pH range from 8-10. Within this range, the phosphorous present in the system can react with the calcium in the limerock to form a marl-like precipitate that will accumulate within the sediments. These mechanisms allow SAV/LR systems to achieve k values in the range of 30 to 40 m/day (South, 2001).

Proposed Wakodahatchee Changes

As shown in **Figure 3**, the proposed design calls for the influent of the Wakodahatchee to enter cells B, C, and AG, which will continue to be operated in parallel. The effluent of cells B, C, and AG will be collected and will become the influent of the SAV/LR system, which will occupy cells D, E, F, H, and I, and will also continue to operate in parallel. The effluents will be collected and discharged into the L-30 Canal.

As illustrated in **Figure 4**, limerock berms will be positioned at the input to each cell and at the end of each shallow region, allowing for the separation of deep and shallow components.

Wetlands Modeling and Design Calculations

The first step in modeling a wetland is the preliminary sizing. The goal of preliminary sizing is to obtain a rough idea of the size of wetland required, or to determine whether the targeted water-quality goals can be met. The wetland size may be limited by such factors as geography, a lack of suitable construction sites, or regulatory limitations such as natural upland or wetland areas that cannot be altered.

Each targeted water-quality goal gives rise to a specific wetland area necessary for the reduction of that pollutant to the target level. The required wetland area will be the largest of the individual required areas. Calculations based on the k-C* models have been organized by the water-quality parameters (**Table 1**). The general form of this model is (Kadlec and Knight, 1996):

$$\ln\left(\frac{Ce - C^*}{Ci - C^*}\right) = -\frac{k}{q} \qquad (1)$$

Where: Ce = outlet target concentration, mg/L
Ci = inlet concentration, mg/L
C*=background concentration, mg/L
k=first-order aerial rate constant, m/
q=hydraulic loading rate, m/yr

Rearrangement and a unit conversion give the area required for a particular pollutant:

$$A = \left(\frac{0.0365Q}{k}\right)\ln\left(\frac{Ci - C^*}{Ce - C^*}\right) \qquad (2)$$

Where A = required wetland area, ha
Q = water flow rate, m^3/d

The first-order aerial rate constant, k, can also be solved for by rearranging (2):

$$k = \left(\frac{0.0365Q}{A}\right)\ln\left(\frac{Ci - C^*}{Ce - C^*}\right) \qquad (3)$$

Finally, the concentration of all pollutants is computed from the model using the largest area found from (2):

$$Ce = C^* + (Ci - C^*)e^{\left(\frac{-kA}{0.0365Q}\right)} \qquad (4)$$

Where Ce is the outlet concentration in mg/l.

Table 1 illustrates these calculations for influent data obtained for the Wakodahatchee Wetlands and target effluent concentrations corresponding to the background values of Canal L-30. In this calculation the aerial rate constants, k, for each water-quality parameter were obtained from CH2M Hill data (Bays et al., 2000).

Figure 3: Revised Wetland Flow Scheme

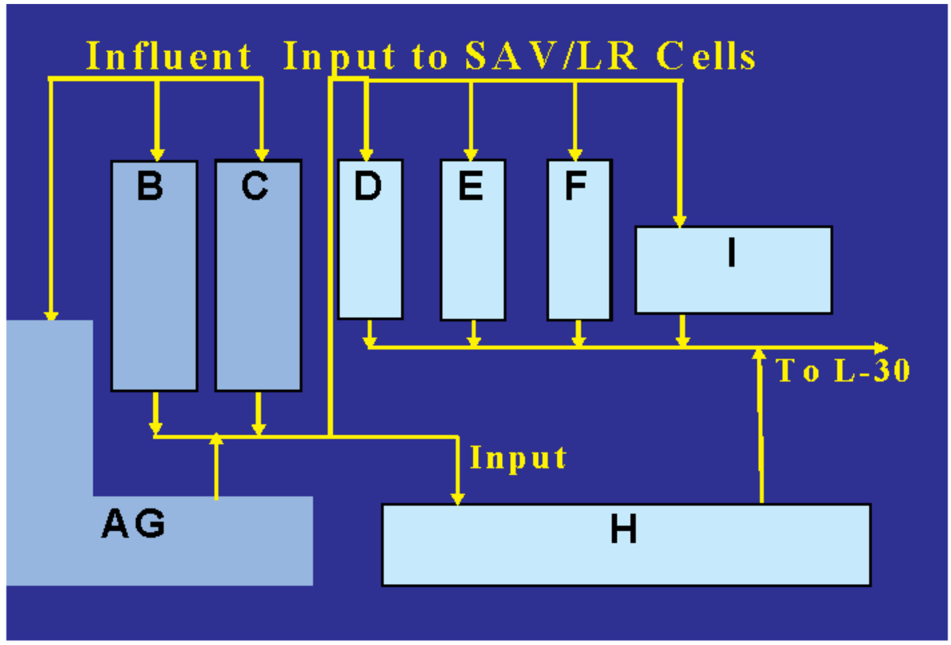
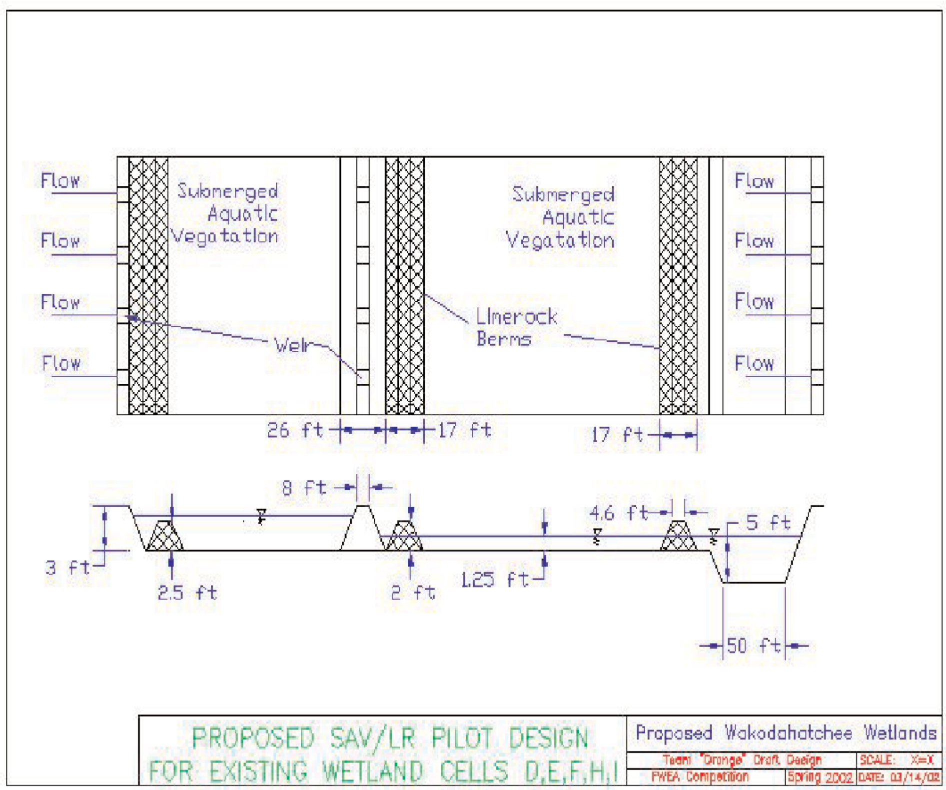


Figure 4: Schematic of SAV/LR Pilot Cells



Benefits and Disadvantages of SAV/LR System

Among the many benefits associated with the SAV/LR System, the biggest would be the preservation of the wildlife habitat established in the Wakodahatchee Wetlands. No additional land would be needed to implement this design, maintaining a low cost. A possible 10-fold increase in phosphorus removal is another added benefit. Finally, this design would allow about 1-2 MGD to be treated through the wetlands and discharged into the canal (DBEL, 1999).

A possible disadvantage of the SAV/LR design is the potential for short-circuiting within the cells, which can impair treatment performance. Another disadvantage is that aquatic invasive species, such as Typha sp., can invade the SAV region, reducing the available dissolved oxygen and not allowing efficient phosphorus uptake by the SAV.

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Table 1: Summary of Design Calculations

Treatment Unit	Unit Characteristics	Influent P	Effluent P	Cumulative Removal
Alum Pre-treatment *	1 mol Alum added per mol influent P	2.12 mg/L	.95 mg/L	55%
Emergent Wetlands**	Area=88,988 m^2 k=4	.95 mg/L	.77 mg/L	64%
SAV/LR System**	Area=68,907 m^2 k=30	.77 mg/L	.22 mg/L	90%

*Based on Al3+/P dose vs. P residual relationship from Henze et al. (1995)

**Based on Kadlec/Knight model (Kadlec and Knight, 1996)

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Conclusion

The SRWRF sends an average 1.4 MGD through the Wakodahatchee Wetlands for biological nutrient removal. The goal of the project was to increase nutrient removal efficiency within the wetland to help the SRWRF obtain a permit for surface-water discharge into the L-30 canal located directly north of the constructed wetland.

The limiting parameter for this design was total phosphorus. Modeling was done using the k-C* method developed by Kadlec and Knight and recent new technologies being used in the Everglades Restoration Project.

This design incorporates chemical pretreatment with alum, emergent wetlands, submerged aquatic vegetation, and lime rock berms to efficiently remove approximately 90 percent of phosphorus within the system.

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Table 2: Cost estimates for implementing the SAV/LR system.

Table 2: SAV/LR Cost Estimate									
			Unit Prices						Total
Item	Quantity	Unit	Labor	Material	Equipment	Total	Year of Source	Adjusted Total (3% inflation rate)	Estimated Cost
CAPITAL COSTS									**$503,248.76**
01 Pretreatment - Alum Addition to SRWRF									**$53,756.66**
Alum feed system	1	each				$40,000.00	1992	$53,756.66	$53,756.66
02 Limerock Berms									**$131,022.11**
South Florida Limerock	4,119	cuyd		20		$20.00	2002		$82,374.00
Limerock freight cost	9,190	ton	4.54			$4.54	1999	$4.96	$45,592.85
Limerock berm construction	1,398	yd	2			$2.00	1999	$2.19	$3,055.26
03 Submerged Aquatic Vegetation	17	acre				$5,108.00	1999	$5,581.65	**$94,888.04**
04 Pump Station									**$23,295.64**
PVC pipe, class 160, sdr 26, 8" diameter	100	lnft	5.21	7.75	0	$12.96	2002		$1,295.64
Pump Station Wetwell	1	each	4000	6000	1000	$11,000.00	2002		$11,000.00
Drainage Pump	2	each	184.06	3815.94	0	$4,000.00	2002		$8,000.00
Power service for pump station (w/ close pole connection)	1	each	605.49	2394.51	0	$3,000.00	2002		$3,000.00
05 Flow Splitter									**$31,867.06**
Flow Splitter Concrete Structure	1	each	10000	15000	2000	$27,000.00	2002		$27,000.00
Hydraulic structures, slide gate, self contained, ab & grout,12" x 12"	4	each	385.53	1925	123	$2,433.53	2002		$4,867.06
Construction General Conditions	10	%							**$33,482.95**
06 Construction Contingency (20 % of Capital Construction Costs)							2002		**$73,662.49**
07 Project Management & Permitting (15% of Capital Construction Costs & Contingency)							2002		**$61,273.80**
ANNUAL OPERATION & MAINTENANCE COSTS									**$75,316.36**
01 Alum Pretreatment									**$66,917.51**
Liquid Alum	427	ton		149		$149.00	2002		$63,652.80
Alum Feed System	1	each				$2,020.00	1992	$2,714.71	$2,714.71
Power for Feed System ($0.08 per kWh)						$550.00	2002		$550.00
03 SAV	17	acre				$57.00	1999	$62.29	**$1,058.85**
04 Pump Station									**$7,340.00**
Annual Maintenance						$3,840.00	2002		$3,840.00
Power for Drainage pump ($0.08 per kWh)						$3,500.00	2002		$3,500.00
Grand Total (for 1 year of service)									**$578,565.12**

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