Water Quality and Supply Issues? There's A Wetland for That!

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For many in the environmental profession, their experience with wetland ecosystems has been in the context of avoiding and minimizing impacts during the design, permitting, and construction of various infrastructure and land development projects. Most engineers and scientists are at least familiar with the extensive local, state, and federal permitting that is required when natural wetlands are encountered on project sites. Part of the reason that wetlands are protected is for the flood attenuation, water quality improvement, and wildlife habitat values they provide.

Over the last half century, recognition of the intrinsic water quality functions provided by natural wetlands has led to the intentional design of wetland projects, both natural and constructed, to meet specific water quality and supply objectives. In Florida, and across the United States, treatment wetlands have been used to provide secondary and tertiary treatment and disposal of industrial and municipal wastewaters, for the treatment and management of agricultural and urban stormwater, and for the beneficial reuse of high-quality reclaimed water.

Representative Florida treatment wetland projects are described as a demonstration of their broad applicability to improve water quality, create wildlife habitat, and provide recreational and educational opportunities. General performance expectations, operations and maintenance requirements, and permitting considerations are also briefly described.

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Table 1. Wetland Removal Processes and Estimated Performance Limits for Common Water Quality Parameters

Water Quality Parameter	Removal Mechanisms	Performance Limit
Organic Matter (BOD and COD)	Sedimentation UV photolysis Microbial degradation	BOD < 3 mg/L
Suspended Solids	Sedimentation Filtration/Interception Microbial degradation	TSS < 5 mg/L
Nitrogenous Compounds (Organic N, NH_3, NH^{4+}, NO_3^-, NO_2^-)	Sedimentation Volatilization Adsorption UV photolysis Microbial uptake and transformation Plant uptake	TN < 1.0 mg/L NOX < 0.1 mg/L
Inorganic and Organic Phosphorus	Sedimentation Precipitation Adsorption Plant and microbial uptake	TP < 0.02 mg/L
Pathogens (bacteria, viruses, protozoa, helminths)	Sedimentation UV photolysis Microbial predation	Fecal Coliforms < 200 colonies/100 mL
Metals	Sedimentation Precipitation Adsorption Ion Exchange Plant and microbial uptake	< Class III Water Quality Standards
Petroleum hydrocarbons (fuels, oil and grease, alcohols, BTEX, TPH) Synthetic hydrocarbons (PAHs, chlorinated and non-chlorinated solvents, pesticides, herbicides, insecticides)	Sedimentation Volatilization UV photolysis Adsorption Microbial degradation Plant uptake	Varies
Contaminants of Emerging Concern (pharmaceuticals, personal care products, etc.)	Sedimentation UV photolysis Adsorption Plant and microbial uptake Microbial transformation	Varies

Treatment Wetlands Background

While previously considered by some to be an experimental or unproven technology, treatment wetlands have been studied in great detail during the last 30 years. At the present point in the evolution of the technology, design methods are well-established and performance can be reliably estimated for a wide range of water quality parameters. Numerous technical references are available that describe the performance of treatment wetlands for a wide range of applications. An abridged list of references includes the following:

- *Treatment Wetlands* (Kadlec and Knight, 1996)
- *Constructed Wetlands for Livestock Wastewater Management* (CH2M and Payne Engineering, 1997)
- *The Use of Treatment Wetlands for Petroleum Industry Effluents* (API, 1998)
- *Treatment Wetland Habitat and Wildlife Use Assessment Project* (CH2M,1998)
- *Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment* (USEPA, 1999)
- *Constructed Wetlands for Pollution Control Processes, Performance, Design, and Operation* (IWA, 2000)
- *Constructed Wetlands Treatment of Municipal Wastewaters* (USEPA, 2000)
- *Use of Constructed Wetland Effluent Treatment Systems in the Pulp and Paper Industry* (Knight, 2004)
- *Small-Scale Constructed Wetland Treatment Systems Feasibility, Design Criteria, and Operations and Maintenance Requirements* (Wallace and Knight, 2006)
- *Treatment Wetlands* (Kadlec and Wallace, 2009)

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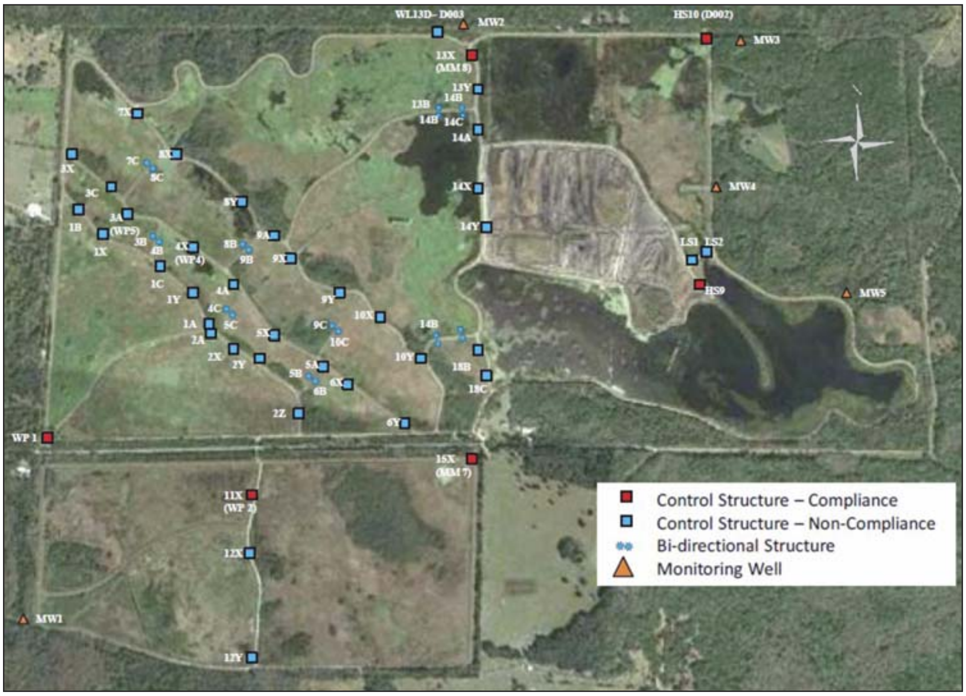

Figure 1. Orlando Easterly Wetlands Site Plan and Monitoring Locations (Rothfield, 2016)

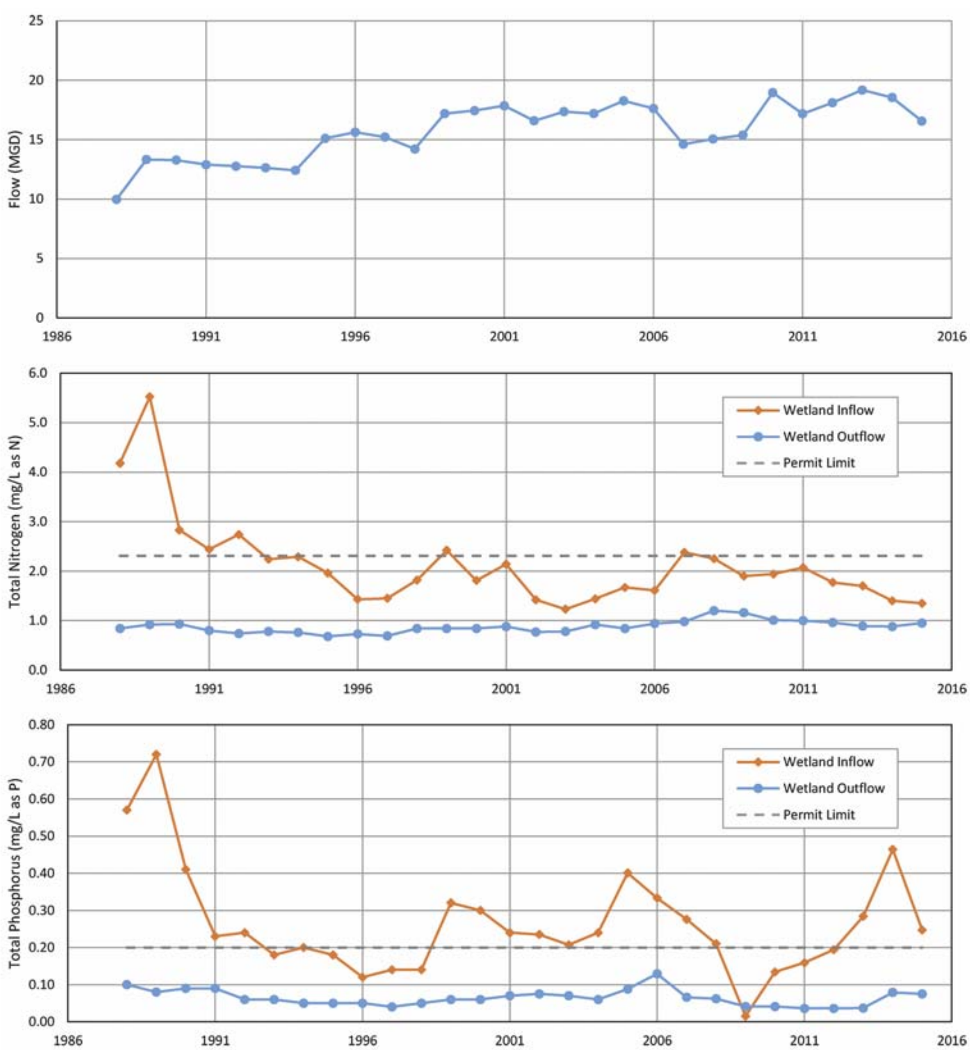

Figure 2. Historical Flow, Total Nitrogen, and Total Phosphorus for the Orlando Easterly Wetlands (Rothfield, 2016)

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- *Evaluate Wetland Systems for Treated Wastewater Performance to Meet Competing Effluent Water Quality Goals* (Brooks et al., 2011)

Wetlands are widely applicable as a water quality improvement technology because they naturally provide a suite of pollutant removal mechanisms that include physical, chemical, and biological processes. Treatment wetland performance is best described by first-order equations that estimate outflow concentration as a function of the inflow concentration, hydraulic loading rate (flow divided by surface area), removal rate coefficient, and, for some constituents, an irreducible background concentration (Kadlec and Wallace, 2009). Modifiers for hydraulic efficiency and temperature effects are also incorporated when appropriate.

The use of simple concentration or mass removal efficiencies, as is common with stormwater best management practice sizing approaches, is inadequate for wetland design purposes, especially when specific permit standards must be met. Table 1 summarizes the dominant wetland pollutant removal mechanisms and the approximate limits of the technology for common water quality parameters.

Operations and Maintenance Requirements

Unlike conventional wastewater treatment systems, treatment wetlands have few moving parts that provide operational control. Treatment wetland operation is primarily based on establishing and maintaining a water depth regime and hydraulic loading rate that is within the hydrologic tolerance of the desired plant community. Water level management and water quality monitoring are the key components of a treatment wetland operational plan. Because wetlands typically have hydraulic residence times measured in weeks or months, the impact of operational adjustments may take some time to become evident at the wetland outfall.

Treatment wetland maintenance requirements include routine inspections of flow delivery and water control structures, embankment mowing, and vegetation management. Active control of less desirable wetland plant species may be important when treatment systems are open for public access or are highly visible, but can be minimal for closed systems. With appropriate design, construction, and management, treatment wetlands can be expected to provide an operational lifespan of several decades before rehabilitation may be necessary.

Regulatory Considerations

In Florida, the use of natural wetlands for effluent polishing and disposal is regulated under Ch. 62-611 of the Florida Administrative Code (F.A.C.). The "wastewater-to-wetlands rule" establishes allowable hydraulic loading rates and inflow water quality limits that are intended to preserve the structure and function of the natural wetland being used for water quality enhancement. The rule requires detailed baseline and operational monitoring for water quality, hydrology, vegetation cover, fish, and benthic macroinvertebrates.

The operation of constructed domestic or industrial treatment wetlands is not regulated under Ch. 62-611, but rather is permitted under domestic and industrial wastewater rules (Chs. 62-600 and 62-620) with receiving water limits established under Ch. 62-302. In cases where the wetland is classified as a "reuse system," elements of Ch. 62-610 also apply.

Most stormwater treatment wetland projects (new construction and retrofits) are permitted under the Statewide Environmental Resource Permit (SWERP) rules because they involve changes to existing drainage patterns, but may not require the establishment and documented compliance with specific water quality standards at the point of discharge to the natural receiving system.

Selected Florida Wetland Projects

Selected Florida treatment wetland projects are summarized to demonstrate the applicability of the technology for a variety of source waters.

Municipal Wastewater Treatment: Orlando Easterly Wetlands

The Orlando Easterly Wetlands (OEW) was implemented in 1987 to meet stringent nutrient limitations for effluent discharged from the Iron Bridge Water Reclamation Facility to the St. John's River and its tributaries. The Florida Department of Environmental Protection (FDEP) established total nitrogen (TN) and total phosphorus (TP) limits of 2.31 and 0.20 mg/L, respectively, for surface water discharges and upgrading of Iron Bridge facility to advanced wastewater treatment (AWT) standards and providing final effluent polishing in a treatment wetland, which was determined to be the city's most cost-effective, long-term solution. The total capital cost for land acquisition, pipeline construction (12 mi from the Iron Bridge facility to OEW), wetland creation, and planting was about \$21.5 million. Annual operational costs were reported to be about \$450,000, excluding compliance monitoring (Mark Sees, personal communication, Feb. 16, 2016).

The approximately 1,200-acre system is comprised of 18 individual wetland cells spanning a range of wetland plant community types (Figure 1). The system is currently permitted to receive 35 mil gal per day (mgd) of AWT effluent from the Iron Bridge facility. Figure 2 shows the annual average discharge from the OEW and inflow and outflow TN and TP concentrations (Rothfield, 2016).

For the period from 1988 through 2015, the OEW treated 15.7 mgd. Inflow TN declined in 1990 after AWT upgrades were completed and averaged about 1.9 mg/L between 1990 and 2015; outflow TN concentrations from the OEW averaged 0.88 mg/L. Inflow and outflow TP averaged 0.23 and 0.06 mg/L, respectively. The OEW outflow annual average TN and TP concentrations have consistently been well below the regulatory standards.

The OEW system is one of few large-scale municipal wastewater treatment wetlands in the United States that has undertaken sediment and vegetation removal maintenance actions to improve hydraulic efficiency and extend system life. These actions have included burning accumulated thatch, excavating and removing accreted organic sediments, and transitioning open water areas to submerged aquatic vegetation (SAV).

Public access and recreational use of the OEW system is an important part of the city's overall management plan. The park-like system is open year-round and attracts over 15,000 visitors annually. The city has also partnered with the University of Florida for collaborative research studies that have resulted in publication of several graduate-level projects and theses.

Industrial Wastewater Treatment: PurEnergy LLC

PurEnergy LLC operates a 15 megawatt (MW) biomass-fueled power-generating facility in the Florida panhandle. Operation of the facility produces an intermittent discharge of nonprocess boiler blowdown, noncontact cooling water, and neutralized reverse osmosis brine. Because the effluent discharge is typically much warmer than the background stream temperature, raw well water was historically used for temperature adjustment. Event-based stormwater discharges from ash pile sedimentation ponds and drainage ditches blend with the industrial effluent and discharge to an unnamed tributary of a major rural creek system.

In 2012, a treatment wetland system was designed in response to periodic exceedances of effluent limitations for acute toxicity, copper, pH, temperature, unionized ammonia, and specific conductance. The design approach followed the first-order P-k-C model described by Kadlec and Wallace (2009) using conservative removal rate coefficients for ammonia of 14.7 meters per year (m/yr) and for copper of 25 m/yr. Sizing for ammonia removal established the final surface flow wetland area of 4.6 acres. At the design average discharge rate of about 0.1 mgd and average operating depth of about 0.75 ft, the nominal hydraulic residence time was estimated to be approximately 11 days.

Energy balance calculations were prepared to estimate the amount of effluent cooling that could be expected in the treatment wetland. The design for pH and toxicity was presumptive, in that by sizing for copper and ammonia removal, the resulting residence time would be adequate to neutralize final effluent pH and reduce the likely cause (unionized ammonia) of prior toxicity violations. Specific conductance was not expected to be changed with passage through the wetlands, except by dilution with rainfall.

Project construction commenced in October 2012, with the first of two cells completed and receiving continuous effluent flow by September 2013; the second cell became operational in January 2014. The total construction cost, including engineering and permitting, was about \$300,000. Operational costs consist of electrical power for pumping to the wetland, water quality sampling and analysis, periodic embankment mowing, and routine report preparation for FDEP, and have not been quantified.

The fully completed project has now been in continuous operation for about three years, during which time the average inflow rate was about 0.12 mgd, exceeding the design assumption of 0.1 mgd. In spite of the increased flow, water quality performance has been excellent for the primary design parameters. Wetland total ammonia concentrations were reduced from about 0.16 mg/L (as N) to below the laboratory detection limit of 0.1 mg/L (as N). Wetland outflow unionized ammonia concentrations have averaged less than 0.001 mg/L. Total copper concentrations were reduced by an order-of-magnitude from about 0.03 mg/L to 0.003 mg/L. Wetland inflow and outflow pH averaged 8.06 and 7.24 standard units, respectively. All required effluent toxicity tests were passed with no mortality observed in the test organism populations. Specific conductance declined from about 1,400 to 1,200 µmhos/cm. Effluent temperatures were reduced by about 5°C during the summer months.

As part of the renewal process for the facility's industrial wastewater discharge permit, a

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detailed temperature study was conducted to document daily temperature variability at the inflow to the wetland, at the wetland outlet, and in nearby reference stream systems. This analysis showed that the wetland effluent was cooled to the maximum extent possible based on local climate conditions, and that forced additional cooling by blending cooler groundwater with the effluent (one previously recommended alternative) was not an environmentally sound use of the resource and would not increase protection of the receiving aquatic ecosystem. The FDEP agreed with this finding and removed temperature from the permit conditions when the permit was reissued in October 2015.

Stormwater Treatment: Everglades Agricultural Area and Stormwater Treatment Areas

Based on the documented success of long-term treatment wetland projects across the U.S. and cost-effectiveness analyses comparing wetlands to conventional treatment approaches in the early 1990s, the South Florida Water Management District (SFWMD) began constructing large treatment wetlands, or stormwater treatment areas (STAs), to reduce phosphorus loads delivered to the Everglades protection area from Lake Okeechobee and the canal systems of the Everglades agricultural area (EAA). The prototype system, known as the Everglades Nutrient Removal Project (ENRP, later renamed STA-1W) was designed using a first-order, steady-state equation, with the goal of achieving a long-term average outflow total phosphorus (TP) concentration of 50 parts per bil (ppb). Data collected from ENRP and other Florida treatment wetlands were used to develop and calibrate the dynamic model for stormwater treatment areas (DMSTA), which has become the primary planning and design process model used for all subsequent STA projects.

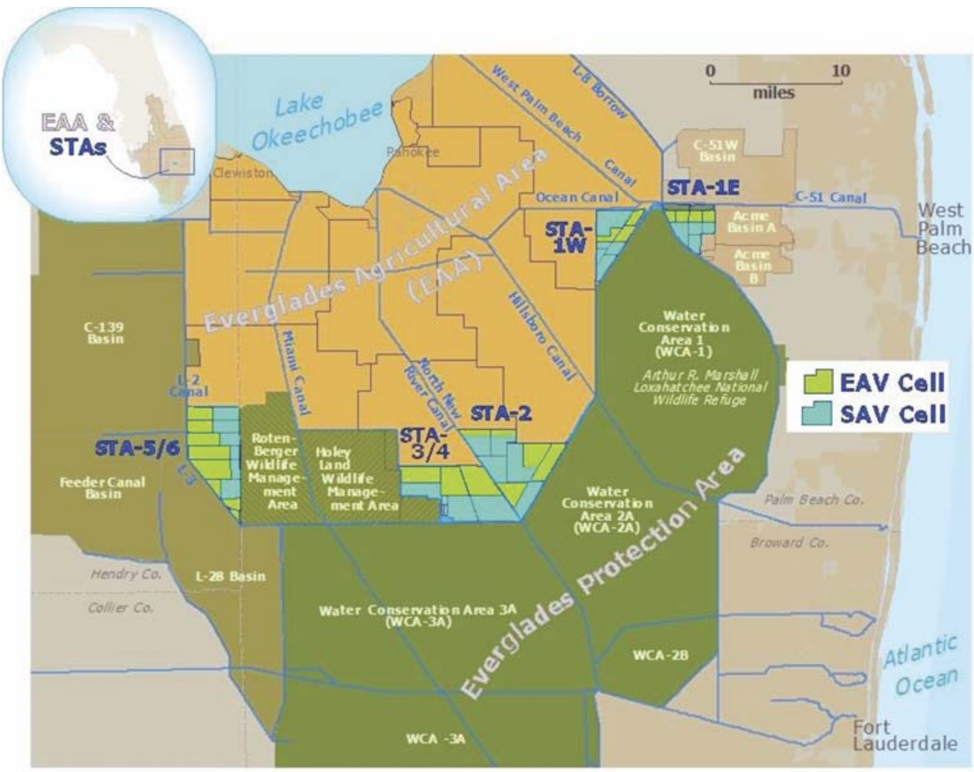

Figure 3. Location Map for the South Florida Water Management District Everglades Agricultural Area Stormwater Treatment Areas (SFWMD, 2016)

Table 2. Period-of-Record Operational Performance Summary for the South Florida Water Management District Everglades Agricultural Area Stormwater Treatment Areas (SFWMD, 2016)

Parameter	STA-1E	STA-1W	STA-2	STA-3/4	STA-5/6	Combined
Area (acres)	4,994	6,544	15,495	16,327	13,685	57,045
Start	09-2004	10-1993	06-1999	10-2003	12-1997	--
Inflow (acre-feet)	1,228,609	3,945,593	4,415,155	5,566,628	2,304,475	17,460,459
Inflow TP (ppb)	171	175	98	108	185	135
Outflow TP (ppb)	43	47	21	16	66	32
Inflow TP (mt)	259.8	852.4	533.0	741.8	525.4	2,912.4
Outflow TP (mt)	61.9	235.1	120.0	113.3	161.6	691.9
TP Retained (mt)	198.0	617.2	413.0	628.5	363.8	2,220.5
% TP Retained	76	72	77	85	69	76

Data from indicated start date through April 2016

At present, SFWMD has constructed over 57,000 acres of STAs to improve water quality leaving the EAA (Figure 3). Individual STA systems range in size from about 5,000 to more than 16,000 acres. The STA-3/4, at about 16,300 acres, is the largest treatment wetland system in the world. Each STA consists of multiple compartments or cells, which range from 242 acres (STA-5/6 Cell 6-3) to 3,456 acres (STA-3/4 Cell 1B) in size (SFWMD, 2016).

Over the operational period of record, the EAA STAs have treated about 5.6 tril gal of agricultural runoff, reduced loads by 76 percent by retaining about 2,220 metric tons (mt) of TP, and reduced TP concentrations from a flow-weighted mean inflow value of 135 ppb to a flow-weighted mean outflow value of 32 ppb (SFWMD, 2016). Table 2 provides period-of-record operational data for the individual STAs. The total program cost has exceeded $1.8 billion (SFWMD, 2014).

Through an intensive data collection and research program driven by the need to maximize treatment effectiveness and minimize outflow TP concentration, SFWMD has made significant contributions to the treatment wetlands knowledge base. One of the key study areas has been related to the differences in TP performance as a function of wetland plant community type. Site-specific research-scale work that began in the late 1990s showed that SAV provided the capability of achieving lower-outflow TP concentrations than emergent aquatic vegetation (EAV). Other key research efforts have focused on the stability of TP in newly accreted wetland sediments, the effects of tropical weather systems on wetland structure and performance, and the management of systems across highly variable hydrologic conditions.

Municipal Wastewater Treatment and Groundwater Recharge: Ichetucknee Springshed Water Quality Improvement Project

A relatively recent development in treatment wetland technology in Florida has been

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the use of wetlands to reduce nutrients before water infiltrates to potable water aquifers. These groundwater recharge wetland systems operate similarly to rapid infiltration basins (RIBs), but maintain wetland hydrology and vegetation. De facto infiltrating systems in South Florida (the Wakodahatchee Wetlands and Green Cay Wetlands) have proven effective at providing reliable treatment and infiltration over a 10- to 20-year time frame. More recently, several higher-rate demonstration-scale systems were constructed and monitored by Gainesville Regional Utilities (GRU). Data from these demonstration wetlands showed exceptional nitrogen removal capacity at sustainable infiltration rates, making the concept a viable alternative to spray irrigation or RIB disposal systems (WSI, 2012; WSI, 2013). These recharge wetland systems have also been permitted to take advantage of excess capacity in dry stormwater retention areas. By providing both treatment and disposal in the same project footprint, groundwater recharge wetlands offer utilities, industry, and water managers a cost-effective alternative to replenish aquifer levels with high-quality water.

The recently completed Ichetucknee Springshed Water Quality Improvement Project (ISWQIP) in Lake City was the first large-scale conversion of an existing spray field to a groundwater recharge wetland. The $5.6 million project was cooperatively funded by FDEP, Suwannee River Water Management District, Columbia County, and City of Lake City. Effluent from the city's St. Margaret's Water Reclamation Facility meets current effluent limitations, but the project was implemented under the Santa Fe River Basin Management Action Plan (BMAP) to reduce regional TN loads and provide beneficial recharge to the Upper Floridan aquifer and the Ichetucknee Springs system.

The project consists of nine interconnected wetland cells totaling about 120 acres of effective treatment area. Applied effluent travels through the wetland cells before recharging the aquifer through two soil modification zones that were installed when the spray field was constructed in the mid-1980s and through natural breaks in the confining clay layer that separate the surficial sands from the underlying limestone formation. Wetland water quality process modeling prepared during the design and permitting phase (Table 3) estimated that the wetland surface water compartment would reduce TN from about 6.4 to 1.0 mg/L, and nitrate+nitrite-nitrogen, the target parameter for springs protection, from about 1.9 to 0.2 mg/L, at an annual average flow of 1.2 mgd (WSI, 2015).

Table 3. Estimated Annual Average Inflow and Outflow Concentrations for the Ichetucknee Springshed Water Quality Improvement Project (WSI, 2015)

Parameter	Annual Average Concentration (mg/L as N)	
	Inflow	Outflow
Organic Nitrogen	1.9	0.8
Ammonia Nitrogen	2.6	0.04
Nitrate + Nitrite Nitrogen	1.9	0.2
Total Nitrogen	6.4	1.0

Conclusions

The projects described illustrate some of the ways that treatment wetlands have been used to enhance water quality and supply in Florida, but there are also other local examples, such as using coastal wetlands for reverse osmosis brine disposal and constructed marshes to reduce algal solids and nutrients from eutrophic lake waters, that are not described. The ability to cost-effectively transform a wide variety of pollutants into harmless end products, while creating valuable wildlife habitat and providing opportunities for passive recreation and education, make treatment wetlands an obvious alternative to consider for any water quality improvement project.

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