ORANGE COUNTY FLORIDA EASTERN SERVICE AREA RECLAIMED WATER WETLANDS REUSE SYSTEM

Larry N. Schwartz*, Peter M. Wallace**, Paula M. Gale***, Willard F. Smith†, James T. Wittig*, and Stephanie L. McCarty*

* Camp Dresser & McKee Inc., 4603 NW 6th St, Gainesville, FL, USA
** Ecosystem Research Corporation
*** University of Florida, Soil and Water Science Department
† University of Florida, Center for Wetlands

ABSTRACT

As part of an integrated multiple reuse program reclaimed water is discharged to a system of natural and created wetlands before ultimate discharge to a river. A research plan has been required to determine the long-term effects of reclaimed wastewater on the wetlands, their waste recycling efficiency and the impact on downstream waters. This paper presents results from three years of this monitoring and research program which show the wetlands reuse system to function well, with no adverse impacts on wetlands or receiving waters.

KEYWORDS
Cypress wetlands, nutrient removal, polishing processes, water reuse.

INTRODUCTION

In the Eastern Service Area of Orange County, Florida, direct discharge to surface waters has been eliminated through implementation of an integrated multiple reuse program. A key to success of the reuse program is the quality of the reclaimed water produced at the wastewater treatment facility. The Eastern Service Area Wastewater Treatment Facility (ESAWWTF) uses a 5-stage Bardenpho biological treatment process to produce reclaimed water meeting advanced wastewater treatment (AWT) standards. The ESAWWTF produces reclaimed water of higher quality than AWT effluent quality limits of 5 mg L⁻¹ biochemical oxygen demand (BOD₅), 5 mg L⁻¹ total suspended solids (TSS), 3 mg L⁻¹ total nitrogen (TN), and 1 mg L⁻¹ total phosphorus (TP). The integrated multiple reuse program includes rapid infiltration basins, industrial cooling at an electrical generating facility, and a wetlands system.

The reclaimed water wetlands reuse system consists of a combination of overland flow and created and natural wetland areas (Figure 1). Reclaimed water is distributed to a 50-ft wide overland flow area, which increases dissolved oxygen, provides dechlorination and nutrient uptake. The distribution system provides individual zone application and rotation as well as sheet flow. The distribution created wetland is a 35- acre wetland that lies adjacent to the overland flow area. Reclaimed water flows through this wetland into a natural pond cypress-dominated swamp, referred to as the treatment wetland, and is then recollected and...
redistributed to the 45-acre redistribution created wetland. The reclaimed water then flows to a natural hardwood-dominated swamp, referred to as the jurisdictional wetland, and then to additional natural pond cypress-dominated swamps, referred to as the exit wetlands, with ultimate discharge to the Big Econlockhatchee River via an unnamed tributary.

![Diagram of wastewater wetland treatment system layout.](image)

**Fig. 1.** Wastewater wetland treatment system layout.

The reclaimed water wetlands reuse system was permitted pursuant to a Florida Department of Environmental Regulation rule to provide for the experimental use of wetlands for low-energy water and wastewater recycling. The rule requires the implementation of a research plan to determine the long-term ecological effects of the application of reclaimed water to the wetlands, the waste recycling efficiency of the wetlands and the impacts to downstream waters. Therefore, on behalf of Orange County, Florida, Camp Dresser & McKee Inc. (CDM), in conjunction with the University of Florida (UF) and Ecosystem Research Corp. (ERC), implemented the research plan. The research plan includes an intensive monitoring and sampling program for a control wetland and the wetlands reuse system for surface water, biological and soil parameters, as well as the development of a comprehensive water budget.

The annual average discharge to the wetlands reuse system was limited to 3.5 mgd for an initial evaluation period. As the system was permitted to evaluate the effects of increased hydraulic loading, an increase in the annual average discharge to 6.2 mgd can be established. The increase in the permitted discharge capacity will be based on monitoring and research results indicating that there are no adverse impacts on the wetlands or downstream waters and that permit limits for discharge from the system have been met. The permitted discharge limits from the system are 2 mg L⁻¹ for TN and 0.2 mg L⁻¹ for TP. The discharge of reclaimed water to the wetlands reuse system began in March 1988. Results from three years of the monitoring and research program (through February 1991) are presented below (CDM 1992).

**SUMMARY OF MONITORING AND RESEARCH RESULTS**

**Ecology of Created Wetlands**

A total of 33,200 trees representing 10 species and 66,400 herbaceous and grass seedlings representing 11 species were planted in the created wetlands. Water depth in these wetlands exceeds that in the overland flow area and provides wetland habitat and wildlife diversity. The growth and survival of both tree and
herbaceous species planted in the created wetlands, as well as the contribution of rapidly invading species, is evaluated in the monitoring and research program. After the first year, a total of 185 species were observed in the distribution created wetland and 186 species were observed in the redistribution created wetland. Greater reclaimed water addition in the first year would have increased survival rates of obligate wetland species in the created wetlands.

Growth in the distribution created wetland was greater than growth in the redistribution created wetland and greatest in the area adjacent to the overland flow area in the first and second years. This could have been in response to elevated nutrient levels, differences in other physicochemical parameters, or to an abundance of water in this area. The created wetlands are diverse ecosystems providing extensive wildlife habitat. Constant water supply to these wetlands has ensured great success in community establishment through volunteer colonization of native plants adapted to wet conditions.

Considerable changes in frequency of occurrences for many species has occurred in both created wetland systems. The drier distribution created wetland has a significantly greater number of shrub species, forming an essentially dense closed canopy and greatly reducing herbaceous ground cover. The wetter redistribution created wetland has limited shrub growth, with the predominantly herbaceous wetland species typically found in wet prairie type systems.

Ecology of Natural Wetlands

The control and jurisdictional wetlands are best described as mixed hardwood swamps, whereas the treatment and exit wetlands are pond cypress-dominated systems. The importance value of the most common species for individual quadrats and for each wetland for all viability categories have been determined. A comparison of the relative importance of each species to the total importance value was made for all three years. After three years of reclaimed water application, the general dominance of species and importance value rank has been maintained in each natural wetland. Little change has occurred in the size-class frequency distribution of the most common woody species in any of the wetlands. Qualitatively, the most noticeable change that has occurred in the herbaceous flora is the increased cover of duckweeds and related floating aquatic species that have developed in the treatment and jurisdictional wetlands.

Aquatic and benthic macroinvertebrates were sampled in the water column and in the substrate of the natural wetlands with a modified stovepipe sampler on a seasonal schedule. Macroinvertebrate populations in the wetlands were typical of those found in other forested wetland systems in the southeastern United States. A composite diversity index for each wetland was calculated by combining all the species and the number of individuals in each species into the Shannon-Weaver Diversity Index formula. Gross changes in structural and functional attributes of the macroinvertebrates in the wetlands did not occur and no consistent seasonal pattern for any of the diversity indices was exhibited during the sampling period. Seasonal patterns of total macroinvertebrate abundance were similar in all the natural wetlands, although the magnitude of population size varied among wetlands.

The diversity indices increased overall in all the wetlands during the third year of the study, with the macroinvertebrate communities in the jurisdictional wetland displaying the higher diversities in each sample event. Of the twelve seasonal composite samples collected in the four wetlands, ten had diversities of 3.0 or higher. The two sample diversities below 3.0 occurred in the control wetland.

The overall numbers of pollution-sensitive species were highest in the control and exit wetlands. There was good water quality in all wetlands as there were organisms in all pollution tolerance classes (established by the Florida Department of Environmental Regulation) in each wetland for all sample events. No sample displayed a distribution which would be indicative of a stressed or degraded condition. The effect of reclaimed water on the water quality of the experimental wetlands in terms of macroinvertebrate populations is positive as reflected in the healthy and diverse communities present and the presence of pollution-sensitive species.
Fish were sampled with lift-nets and throw-traps in the natural wetlands to obtain density, biomass, sex, Shannon-Weaver Diversity, feeding guild, type (sport, rough, and forage), size class distribution, and length to weight relationships. Fish populations sampled in the wetlands represent a typical fish assemblage for central Florida. The control, jurisdictional, and exit wetlands contained the greatest number of fish species. This is due to their connectivity to other surface water bodies. Connectivity to adjacent waters is also important to the reestablishment of fish populations after dry-down conditions have occurred. Water level is an important factor controlling the presence of fish species in terms of density, biomass and diversity in the wetlands.

Relative to the other wetlands, the fish community was limited in the treatment wetland. The treatment wetland is isolated from migration from downstream systems. Fish moved out of the forested portion of the treatment wetland to an adjacent marsh area where there may be more oxygen, food and water.

Fish density was variable during the first and second years, and, although fish densities decreased initially in the wetlands, significant increases occurred in the second and third years. These results suggest that the discharge of reclaimed water produced an increase in the number of fish in these wetlands above that which would have occurred without the discharge. Fish biomass, a measure of productivity, also increased during the three-year study period and exhibited trends similar to fish density. There was no significant decrease in average fish biomass in all the wetlands between the first year and subsequent years. Average fish biomass increased significantly in the exit wetlands between the first and third years, indicating a positive effect on fish productivity in these wetlands.

Fluctuations in fish diversity in the control wetland were most likely the result of differential recovery rates among species after dry-down. Fish diversity in the jurisdictional and exit wetlands changed little during the three-year study period, and changes that did occur may be related to water depth. Regarding dominance by fish type, there was a 2% increase in sport fish in the third year in the jurisdictional wetland. Sport fish only occurred in the first year in the control wetland. There were no species of rough fish present in the control or jurisdictional wetlands throughout the study, and the greatest percentage in both wetlands were primarily forage fish. These wetlands are important in the production of forage fish that support downstream fisheries through export to the Big Econlockhatchee River. Overall the discharge of reclaimed water to the wetland reuse system has been beneficial to fish populations. Sustained annual increases in fish density and biomass indicate that the wetlands are functionally capable of supporting fish populations above the capacity present before discharge began.

Soils

The created wetlands have primarily mineral soils and the natural wetlands have primarily organic soils characterized by reduced conditions. The chemical characteristics of both soils are typical of natural soils of the region. Seasonal changes in soil Eh (redox potential) and solution chemistry were the result of hydrologic variability in the wetlands.

After the first year of operation soil pH increased in the distribution created wetland. This occurred because flooding causes pH to increase as the soil becomes more reduced, and because of the buffering effect of reclaimed water in these poorly buffered soils. The concentrations of nitrogen, phosphorus, and metals either decreased or did not significantly change in the distribution created wetland over this time period. After two years of operation, no significant changes in soil physicochemical properties were observed due to nutrient loading from the discharge of reclaimed water to the system. Nutrient concentration data and phosphorus fractionation data indicate that the soils have experienced a slight reduction in labile (readily available) nutrient forms with reclaimed water additions. This is most likely due to removal through plant uptake and dilution.

In the first year of the study, low concentrations of extractable phosphorus in created wetland soils suggested that these soils were undersaturated with phosphorus and may have additional capacity to retain phosphorus in reclaimed water. Therefore, in the third year, the capacity of the wetland soils to retain phosphorus was
estimated using phosphorus adsorption isotherms. On a weight basis, the organic soils in the natural wetlands have measured phosphorus retention capacities that are tenfold higher than those associated with the mineral soils, in the created wetlands. Since the flow through the wetlands is overland and infiltration into the soil profile is somewhat limited, it is better to compare the phosphorus retention of the wetland soil on an area basis. On an area basis, there is no difference between phosphorus retention capacity of the organic and mineral soils.

Data collected during the second year suggested that denitrification was a significant loss mechanism in these soils. Experiments were conducted during the third year to measure the denitrification potential of surface soil samples collected from each of the wetlands. The rate of denitrification was rapid in all of the samples. This indicates that denitrification can be a significant nitrogen loss mechanism in these soils. Complete reduction of NO\textsubscript{3} to N\textsubscript{2} occurred in the samples collected from the distribution created wetland, treatment wetland, and redistribution created wetland. However, the final step in the reduction process appeared to be inhibited in the samples collected from the jurisdictional and control wetlands. This could have been the result of the lower pH of these samples below the optimum range for denitrification.

**Chemical Water Quality**

The results of field water quality sampling indicate that at all sample stations, the mean annual DO concentration is generally always stratified with respect to water depth with water column concentrations of TOP DO > MIDDLE COLUMN DO > BOTTOM DO. DO was measured in this fashion to show that differences in DO concentrations are most often greater between water depths at a given sample location than occur between a given depth at various locations within a wetland. This is not only apparent in annual mean concentrations at each station but is consistent on a monthly basis at all stations within all wetlands. The DO concentrations range difference from the top of the water column to the bottom of the water column has been slightly reduced in response to reclaimed water application. Seasonal variations in DO concentrations occur within both the control and jurisdictional wetlands with highest values for each station typically from October to March. During the six-year period in which DO concentrations have been monitored in the control wetland, the concentrations are generally very low with the annual mean typically below 2.0 mg L\textsuperscript{-1}. Wetlands with humic colored water typically have low DO concentrations. The mean annual DO concentrations in the jurisdictional wetland in background and operational periods were higher than those in the control wetland and there has been very little change in response to reclaimed water application.

DO concentrations in the created wetlands were higher than in the natural wetlands and large variations in daily DO concentrations occurred in these shallow water systems due to substantial photosynthetic oxygen production. Reclaimed water was substantially modified by passage across these shallow water created wetland systems.

The results of diurnal measurements in the control wetland over the three-year period show a general decline occurring from sunrise to sunset. However, sunset seems to trigger an unexplained phenomenon in which there is a rapid release or generation of oxygen in the wetland. Increases of greater than 2.5 mg L\textsuperscript{-1} occurred in less than 1 hour. This pattern of post-sunset peaks persisted throughout the year and is probably due to a photochemical-mediated consumption of dissolved oxygen during daylight hours and concomitant photosynthetic production. Unlike the results obtained from the control wetland, the predominant trend associated with DO in the jurisdictional wetland over the three-year period is midday maximum DO concentrations with minimum concentrations occurring at night. The difference in the DO concentrations between the control and jurisdictional wetland are primarily related to the diurnal cycle. Generally, DO is higher in the jurisdictional wetland during the day, in contrast to the control wetland, which experiences highest DO at night. The range of fluctuation between these wetlands is similar. The overall results indicate there is heterogeneity in a wetland with regard to DO concentrations while, at the same time, there is homogeneity in a wetland with regard to diurnal DO fluctuations. The net resulting DO concentration observed is dependent on the intrinsic dominating mechanism occurring within any given area of the wetland.
Surface water pH was found to vary seasonally and also with respect to sample location within the control wetland, the treatment wetland, and the jurisdictional wetland. It appears that lower pH values are maintained in the control wetland following a period of drydown. The mean pH in the jurisdictional wetland in the 1988 preapplication sampling was 4.88. In the first year operational monitoring it was 5.21. In the second year operational monitoring it was 6.01, and in the third year operational monitoring it increased slightly to 6.07. There is a definite trend showing that the pH in the jurisdictional wetland will continue to rise with continued reclaimed water application, and based upon data from other wetland systems will probably stabilize between pH 6.0 and 7.0. The increase in pH in the jurisdictional wetland has not caused a negative impact in terms of the measured biological indicators. The mean pH values in the created wetlands were always above 6.2 and were greater in the distribution created wetlands than in the redistribution created wetlands. These high values may be in response to photosynthetic production reducing CO₂ within the water, causing pH to increase. Photosynthesis in these wetlands may contribute to increased pH in downstream natural wetlands within the wetlands reuse system.

Lower average BOD values were found at most stations in the second year due to lower concentrations in the reclaimed water and dilution, the result of a large increase in the average flow to the system. Lower average BOD values in the experimental wetlands than in the control wetland indicates assimilation within these wetlands. The highest average BOD values occurred in the treatment wetland, likely due to the accumulation of organic matter. During the third year, slightly increased average BOD values were found at most stations due to a longer dry season and the low rate of reclaimed water discharge.

TSS data indicate some variability throughout the three-year study, but essentially all of it can be attributed to fluctuations in natural particulate material in the wetlands. The highest average TSS values occurred in the treatment wetland, likely due to control of outflow from this wetland. The decrease in average TSS values in the redistribution wetland and in the exit wetlands indicates that these wetlands are providing final polishing primarily through sedimentation.

The inflow to the system has the highest measured annual average conductivity and the distribution created wetland had similar values as the inflow. After the reclaimed water enters the treatment wetland, conductivity decreases as the reclaimed water is diluted with ambient waters. A comparison of the data indicates higher average conductivity values in the redistribution created wetland, jurisdictional wetland, and the exit wetlands in the third year as compared with the first and second years. This may be due to the longer dry season in the third year. Although at a lower rate, conductivity still decreased with passage of reclaimed water through the system, indicating that assimilation is still occurring in the system. As with conductivity, average potassium values decreased with distance from the inflow but at a reduced rate over the three year study period. Total residual chlorine levels were less than the detection limit of 0.1 mg L⁻¹ downstream of the distribution created wetland, indicating that dechlorinization occurs rapidly in the system. Total and fecal coliforms were variable in all three years of the study but were never greater than 1600/100 mL.

From the beginning of the study, no iron was detected in the reclaimed water inflow. The background iron level in the experimental wetlands has been diluted by reclaimed water and precipitation. Dilution decreased as water moved through the system as average iron levels showed a gradual increase through the system. Increases in the concentration of iron in the wetlands may be the result of changing redox conditions. Lead concentrations above the detection limit have never been measured in any of the wetlands. Cadmium was never detected in the first and second years and once at the detection limit in the third year in the experimental wetlands. Zinc and nickel were infrequently detected in the experimental wetlands and always at levels near the detection limit. Lead, cadmium, zinc and nickel were never detected in the jurisdictional or exit wetlands.

The average nitrate+nitrite concentration decreased rapidly as reclaimed water moved through the distribution created wetland. Once reclaimed water entered the treatment wetland, the average nitrate+nitrite concentrations approached the detection limit of 0.01 mg L⁻¹, except in the exit wetland which had an average concentration of 0.03 mg L⁻¹. This rapid reduction indicates the efficiency of nitrate+nitrite assimilation in the system over the three-year period. In the first and second years, the average total
ammonia concentrations in the experimental wetlands did not exceed background concentrations. Increased average total ammonia concentrations occurred in the treatment wetland and in the jurisdictional wetland during low flow periods in the third year. Little total ammonia assimilation occurred in the system in the third year, probably due to the low level of total ammonia input to the system and low flow conditions which may favor ammonia accumulation in the system.

Average total nitrogen values in the reclaimed water were similar in the second and third years and were approximately 50% lower than in the first year. This was due to the decrease in the average total ammonia concentration in these years. Therefore, the average concentration of organic nitrogen has been similar over the three-year study period. In the third year, the average total nitrogen values in most of the system including the discharge from the system were less than in the control wetland. As long as the total nitrogen in the inflow remains at low levels, it appears as though the flow to the wetland system can be increased without increasing the total nitrogen discharged from the system.

Average total phosphorus values in the reclaimed water decreased from 0.50 to 0.21 then 0.1 mg L\(^{-1}\) over the three-year study period. Although no reduction in average total phosphorus concentration occurred with passage through the distribution created wetland in the first year, the average total phosphorus concentration did decrease rapidly with passage through the rest of the system and remained near control wetland levels. Similar results occurred in the second year except the decrease in concentrations were not as substantial. Further dilution of the inflow in the third year provided very little phosphorus input to the system and therefore very little phosphorus assimilation took place. This suggests that phosphorus assimilation may be controlled by the equilibrium phosphorus concentration in the surface water. Although small in magnitude, the decrease of phosphorus to background levels occurred by the time water reached the redistribution created wetland.

Regarding discharge limits, the total nitrogen concentration in the discharge was 1.68 mg L\(^{-1}\), which is below the 2.0 mg L\(^{-1}\) discharge limit. The total phosphorus concentration in the discharge was 0.13 mg L\(^{-1}\), which is below the 0.2 mg L\(^{-1}\) discharge limit. Therefore, annual average limits for discharge to or from the wetland reuse system were not exceeded over the three-year study period.

Hydrology

An understanding of the hydrology of this wetland system is essential in order to understand its chemical and biological dynamics. Chemical budgets for wetlands are ultimately dependent on the hydrologic budget. A model of hydrologic processes is presented in terms of a water budget or water balance. A water budget prepared for the wetland reuse system included the following components: precipitation, reclaimed water application, surface runoff, subsurface flow, vertical percolation, storage changes, and evapotranspiration.

Annual precipitation in the first, second, and third years was above normal, below normal, and normal, respectively. The average application rate of reclaimed water to the entire system in the first, second, and third years was 0.6 in. wk\(^{-1}\), 1.2 in. wk\(^{-1}\), and 1.1 in. wk\(^{-1}\), respectively. Surface outflow in the first, second, and third years was 41.9 in., 60.6 in., and 46.0 in., respectively. Evapotranspiration determined in the water budget compared well with the vegetated Penman and the Thornthwaite Methods for estimating potential evapotranspiration.

During the first year, precipitation was the most significant hydrologic inflow to the system. During the second and third years, reclaimed water application was the largest hydrologic inflow to the system. Surface discharge was the largest outflow from the system in the first (55%) and second years (57%). However, in the third year, evapotranspiration (48%) became the predominant outflow from the system. Surface discharge (45%) was still a major outflow component from the system. Vertical percolation was a relatively minor component of the budget on a monthly and annual basis. Groundwater flow, changes in soil storage, and detention storage were relatively minor components of the annual budget, but were significant components in individual months.
Two hydrologic compartments were evaluated for water and mass balance analyses. The first compartment, totaling 139 acres, consists of the distribution created wetland, the treatment wetland, and the surrounding uplands. The second compartment, totaling 192 acres, consists of the redistribution created wetland, the jurisdictional wetland, the exit wetlands, and the surrounding uplands. Tables 1a and 1b present the results of the mass balance analyses for TN and TP, respectively, for each year and on a cumulative basis and for each compartment and the total system. The mass balance calculations indicate that the entire wetlands reuse system assimilated 34% of the nitrogen and 73% of the phosphorus added during the three-year study period. Percent retention of nitrogen and phosphorus both dropped during the third year. However, these lower retention levels are probably the result of low loading to the system rather than low assimilation capacity for this system.
SUMMARY

Results from three years of the monitoring and research program indicate that the systems performance has met permit and design expectations. Beyond this immediate goal, the research program is yielding important data that will contribute to our knowledge of wetlands in general and to the development of performance guidelines for reclaimed water applications to natural and created wetland systems.

Wetlands have been successfully created, providing diverse plant communities and wildlife habitat. Constant water supply to these wetlands has ensured great success in community establishment through planting and volunteer colonization of native plants adapted to wet conditions. After three years of reclaimed water application, vegetation diversity and species composition are being maintained in the natural wetlands. The effect on macroinvertebrate populations in these wetlands is positive, as reflected in the healthy and diverse communities present and the presence of pollution sensitive species. The effect on fish populations has been beneficial, as these wetlands support downstream fisheries in the Big Econlockhatchee River above the capacity before discharge began.

The potential for phosphorus adsorption in the soil in the created and natural wetlands has been established as well as a nitrogen loss mechanism in the system. Future research is aimed at determining the relative roles of these nutrient loss pathways and that of plant uptake. At current reclaimed water loading rates, the distribution created wetland would be capable of removing solution phosphorus for another 20 years. Phosphorus in surface water was reduced to background levels by the time water reached the redistribution created wetland. Final treatment is complete after passage of reclaimed water through the first compartment of the system.

The wetlands reuse system is an effective treatment system as indicated by mass balance analyses and compliance with permitted discharge limits. New wetlands have been created, and, although there have been changes in dissolved oxygen and pH, vegetation and macroinvertebrate diversity and fish populations have been maintained in the natural wetlands with the application of reclaimed water. In addition, the discharge from the system to the tributary of the Big Econlockhatchee River has enhanced the water quality of this river. The wetlands reuse system is functioning well with no adverse impacts on the wetlands or the receiving waters and is a successful component of the Orange County, Florida, integrated multiple reuse program.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Orange County Public Utilities Division in Orange County, Florida, for having the vision to implement the emerging technology of wetlands reuse and water quality enhancement.

REFERENCES