Operating experience with constructed wetlands for wastewater treatment

Robert L. Knight

ABSTRACT: Constructed wetlands are treating a variety of municipal, industrial, and runoff wastewaters. The growing interest in this technology is based on 20 years of research demonstrating the beneficial effects of wetlands on water quality, particularly their ability to assimilate carbonaceous and nitrogenous wastes. Constructed wetlands are an attractive option for applications where a land-intensive, "natural" treatment technology is desired and where ancillary wildlife benefits will enhance a project's overall environmental balance sheet. This paper summarizes design and operating experience from constructed wetlands representing a variety of applications, including pilot systems in place at several U.S. pulp mills.

KEYWORDS: Construction, design, effluent treatment, land use, operations, paper industry, pulp industry, waste management, wastewater.

Wetlands have been used to treat a variety of wastewaters over the past 16 years (*1–4*). Suitable natural wetlands, as well as constructed wetlands, are integral components in treatment processes for municipal and industrial wastewaters and for urban and agricultural storm waters.

Wetlands provide a "natural" treatment technology compared with the conventional water-treatment technologies that are generally proposed and implemented. Each approach has its pros and cons. The natural approach is land intensive but energy efficient, using solar/biological energy flows. Conventional approaches require less space, but they are energy intensive, relying primarily on fossil fuels. Land-intensive wetland treatment systems also have the potential to provide a buffering and filtering function that can assimilate and reduce the variability inherent in conventional treatment processes, which are relatively small in volume and thus have short hydraulic residence times. Besides their potential to reduce energy demands and treatment by-products such as chemical sludges, wetland treatment systems may provide other benefits related to plant production and wildlife habitat (*5*).

Because of these potential benefits, several large pulp and paper companies are evaluating constructed wetland systems for treatment of mill effluents. One full-scale system is currently in use at Weyerhaeuser's Columbus, MS, pulp mill. The system is a constructed wetland of about 70 acres that contains 33 cells and is designed to reduce biochemical oxygen demand (BOD) by 50–60% in a flow of 20 million gal/day. Design of this wetland treatment system was based on over two years of pilot studies (*6*). Other pilot systems are currently under study by Georgia-Pacific (*7, 8*), Champion International Corp., Bowater Inc. (*9*), and Pope and Talbot Inc. (*10*).

While interest in the use of wetlands for effluent management in the pulp and paper industry is clearly growing, there is understandable caution in implementing this technology because of the lack of information about operational performance and potential problems. Some of this uncertainty can be alleviated by examining the wealth of information on the use of wetlands for treatment of municipal wastewaters. Over 300 natural and constructed wetland treatment systems are currently operating in North America, with most of these systems located in the United States. Some natural wetland treatment systems have been operating for as long as 16 years, and full-scale constructed wetlands have operated up to seven years.

Operating and design experience from All North American wetland treatment systems is currently being assembled into a wetland treatment database that eventually will provide a common basis for designing and operating new wetland treatment systems (*11*). Pretreated municipal wastewaters and pulp mill effluents share several characteristics, including similar concentrations for key constituents. Consequently, the information in this

Knight is senior environmental scientist at CH2M Hill, 7201 N.W. 11th Place, Gainesville, FL 32602.

database should be applicable to the pulp and paper industry and should help accelerate development of this new alternative for treatment of mill effluents.

The success of new wetland treatment systems will be greatly enhanced if they are designed by engineers who have reviewed the experience derived from similar projects. This paper summarizes design and operating experience from several constructed wetlands representing a variety of applications for this relatively young treatment technology. These anecdotal descriptions are augmented by a brief summary of information from the database that contains information from 127 wetland treatment systems now in operation.

Project case histories

At least five constructed wetland treatment pilot studies have been conducted with pulp mill effluents in the United States. Each of these systems, as well as three full-scale municipal treatment systems, are briefly described.

Pulp and paper experience

Weyerhaeuser. Weyerhaeuser has been evaluating the use of constructed wetlands for wastewater treatment since 1988 (*6, 12*). Studies included laboratory and field-scale tests of subsurface-flow wetlands utilizing gravel substrates. Excellent treatment was observed in these systems. However, operational requirements and system costs led to modification of these units to a surface-flow configuration for full-scale implementation.

Georgia Pacific. Georgia Pacific has been studying constructed wetlands treatment on a pilot basis since 1989 at its bleached kraft mill near New Augusta, MS. This pilot wetland facility includes three wetland cells, each 0.32 acres in size, and each receiving variable flows of final mill effluent. Research at this site has focused on the relationship between hydraulic loading and constituent removal rates (*7*) as well as on the factors that influence survival and growth of wetland plant species in pulp mill effluents (*8*). Preliminary findings indicate that surface-flow constructed wetlands can provide polishing of BOD, TSS, and nutrient concentrations at hydraulic loading rates less than about 5 cm/day (20 acres/million gal/day). These studies also demonstrated that torpedo grass is not a suitable plant species for these systems at water depths greater than about one foot.

Champion. Champion International Corp. is currently testing constructed wetlands as one of several alternatives for complying with stringent receiving-water standards. At its Pensacola bleached kraft mill, Champion has constructed a 3.5-acre surface-flow constructed wetland pilot system consisting of six cells with variable length–width ratios, open water areas, and plant communities. This system has been operating since June 1991 and has helped to confirm land area requirements and suitable wetland plant species for a full-scale treatment wetland.

Bowater. A pilot study of constructed wetland treatment for BOD, TSS, and color was conducted at Bowater's Southern Division paper mill in Calhoun, TN, starting in 1989 (*9*). Six cells planted with cattails were tested at hydraulic loading rates between 3.1 cm/day and 9.4 cm/day. Some color removal (10–50% reduction) was observed in cells inoculated with compost from an old sawdust pile.

Pope and Talbot. Pope and Talbot has constructed a five-acre pilot wetland system at its mill in Halsey, OR. The pilot system consists of 10 cells, has been planted with cattails and bulrush, and is being operated in an effort to determine pollutant-removal potential for full-scale application.

Municipal projects

Incline Village, NV. The first large-scale constructed wetland treatment system to be built in the United States is located south of Carson City, NV. The system treats a flow of about 1.3 million gal/day from the city of Incline Village located on Lake Tahoe. The constructed wetland consists of eight large cells, subdivided into a total of 21 separate subcells. The 320-acre constructed wetland area provides zero surface discharge of effluent through evaporation and infiltration. The small volume of water that infiltrates (about 10% of the average flow) is highly renovated following passage through the constructed wetlands (*13*). This facility includes a total area of 770 acres, with about 104 acres of this area in natural, warm-water wetlands. The occurrence of perennial water in an arid region at the wetland treatment system provides nesting and wintering habitat for hundreds of ducks and geese each year.

West Jackson County, MS. Municipal wastewater from the gulf coast area of Mississippi is treated and disposed via a natural land-treatment facility that includes both spray irrigation and constructed wetlands treatment (*14*). An average flow of about 1.6 million gal/day is currently treated with 350 acres of irrigated hay fields and 56 acres of constructed wetlands. The wetlands are divided into seven cells arranged in three parallel trains of two or three cells. These cells are planted in cattails and bulrush and also have "deep zones" arranged perpendicular to the flow path to help redistribute the effluent as it flows through the cells. Water depths at the West Jackson County constructed wetlands are maintained relatively shallow (less than one foot) to promote aerobic conditions in the water column and at the soil surface. This aerobic condition is essential for nitrification of ammonia nitrogen in wetlands. Operation of this system has indicated that loading of total Kjeldahl nitrogen is the key to predicting compliance with final ammonia limits in a constructed wetland.

Ironbridge, FL. The constructed wetland treatment system in Ironbridge provides final polishing for a design flow of 20 million gal/day of advanced treated municipal wastewater from the city of Orlando. The system began operation in 1987, has 17 cells with a total area of about 1220 acres, and includes parallel flow paths through the first two thirds of the treatment area (*15*). Plant communities change along the length of the system from cattail–bulrush marsh, to mixed marsh with a variety of plant species, to open-water lake areas.

Through a combination of low concentrations of influent constituents and a low hydraulic loading rate, this wetland treatment system provides effective polishing of nutrient concentrations down to about 1.0 mg/L total nitrogen and 0.1 mg/L total phosphorus.

Some lessons

Experience from the West Jackson County facility and other constructed wetland treatment systems may be helpful to companies considering this wastewater-treatment technology. Successful plant establishment in constructed wetlands is dependent upon (a) contractor experience, (b) control of water depths through system design and water availability, (c) site preparation, with adequate top soil placed in the wetland cells to provide a suitable rooting medium; and (d) healthy plant stock. Initial successful plant establishment can be followed by poor plant growth and eventual mortality if water depths exceed the site-specific tolerance of the plants. Plant health can also be affected by insects and by wildlife such as muskrats and nutria. These problems can be minimized by hiring experienced people to design, build, and operate constructed wetland treatment systems.

Experience from the Ironbridge wetlands provides several lessons:

- Plant communities will arrange themselves according to water depth and nutrient conditions, regardless of efforts at human intervention.
- Application of highly pretreated wastewaters to a wetland may increase constituent concentrations for substances that occur at high soil concentrations (such as phosphorus and organic nitrogen).
- Wildlife populations will be attracted to large-scale constructed wetlands, and it may become necessary to alter management of the facility to accommodate communities of threatened or endangered species.
- Open water/lake areas in constructed wetlands will generate suspended solids (primarily planktonic algae), which may result in high total nutrient levels in the outfall if these lakes are not separated from the outfall by shallow, marsh-dominated areas.

These lessons and other pieces of practical information related to implementation of this technology have appeared in papers (*16, 17*) and design handbooks (*18–20*).

Database of wetland treatment systems

North American wetland treatment systems have a wide variety of engineering designs, wetted areas, flow rates, inflow water qualities, plant communities, hydrologic regimes, effluent limitations, and monitoring requirements. Part of this variety is due to the site-specific characteristics of different wastewaters. However, the principal explanation for this diversity is that there are no widely used guidelines for designing wetland treatment systems.

Three recent wetland design guides (*18, 19, 21*) are useful compilations of information, but none are inclusive of all necessary design considerations. In the absence of a proven, consistent design approach, engineers interested in applying the wetland technology have had to evaluate a variety of empirical design techniques, relying on rules of thumb or conducting pilot studies to develop design criteria for a new wetland treatment system. A database of design and operating information for wetland treatment systems is being developed to provide a unified basis for designing future wetland treatment systems (*11*).

The first phase of the development of the North American Wetland Treatment System Database was completed in September 1991. This preliminary effort includes approximately one-third of the existing wetland treatment systems in North America. The database contains information about natural and constructed wetlands receiving municipal wastewaters, industrial wastewaters, and storm waters. Under the constructed category, the database includes both surface-flow and subsurface-flow wetland treatment systems.

Individual database files have been developed to summarize existing information about wetland treatment systems in seven categories.

- Site information (name, location, EPA region, etc.)
- System characteristics (number of cells, natural or constructed, design area and flow, etc.)
- Permit conditions (criteria, seasonal limits, flow limits, etc.)
- Wetland cell information (design criteria, plant species, etc.)
- Operational data
- Published reports and scientific articles about individual sites
- Names of people knowledgeable about the site.

So far, the database contains information about 96 sites with a total of 127 separate systems—89 municipal systems, 22 industrial systems, 5 stormwater systems, and 11 hybrid systems. Of these, 84 are constructed wetlands, 44 of which are surface-flow systems.

The database is to be expanded to encompass the remaining operational wetland treatment systems. This information then will be used to develop design criteria. In the meantime, a summary of the design and operating data from this collection of operational systems is useful for comparison with ongoing conceptual designs.

Table I summarizes the major design criteria from the 44 surface-flow constructed wetlands currently in the database. While all design criteria are variable, the averages presented in this table are considered to be representative of the potential and constraints for this technology. The most critical criterion on this list, hydraulic loading rate, determines the wetland area required to treat a given flow, and consequently sets the cost of a full-scale wetland treatment system. This design criterion is highly dependent upon inflow water quality and wetland effluent limitations. However, a hydraulic load of about 5 cm/day (about 20 acres/million gal/day) will provide effective reductions of BOD and TSS in most pretreated wastewaters. Much lower hydraulic loading rates (1.0–1.5 cm/day) are typically necessary to provide effective nitrification and nutrient removal in constructed wetlands.

Table II summarizes operational data for constructed wetland treatment systems included in the database. These data reflect the results from a variety of designs, loading rates, and operational approaches, and they should only be considered as order-of-magnitude-type concentration reductions and not as firm estimates of system performance. Clearly, some wetlands perform better than these average numbers, and some perform worse. Constructed wetlands are particularly effective for consistent removal of BOD, TSS, and total nitrogen. They are less effective for nitrification of ammonia and highly variable in their ability to reduce total phosphorus concentrations.

I. Design summary for constructed wetland treatment systems*

	Average	*Range*
Total area, ha	23	0.1–486
Hydraulic load, cm/day	4.2	0.0001–19.5
Aspect ratio	17	0.7–84
Cell number	2	1–17

*Based on data from 44 sites with surface-flow wetlands

II. Performance summary for constructed wetland treatment systems*

	Average concentration, mg/L *Inflow*	*Outflow*
BOD_5	57	16
TSS	59	20
NH_3	10.6	7.9
Total nitrogen	16.0	8.2
Total phosphorus	5.05	2.88

*Based on data from 8 to 33 systems

Summary

Constructed wetlands provide a relatively new technology for "natural" treatment of municipal and industrial wastewaters and for storm water. Because this technology is so new, the experience level of professionals in this field is highly variable and may be based on inconsistent design approaches. Current efforts to develop a consistent repository for design and operational performance data from all North American wetland treatment systems will help increase the consistency and effectiveness of future designs.

Engineers in companies that are contemplating designing a wetland treatment system would be well advised to gather as much information as possible about the long-term and short-term performance of pilot and full-scale systems now in operation. A thorough review of the available information may help the engineer avoid pitfalls encountered by previous designers.

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Received for review Jan. 15, 1992.

Accepted May 22, 1992.

Presented at the TAPPI 1992 Environmental Conference.