A Winning Combination

Innovative MBR technologies and reclaimed-water dispersal systems overcome challenges to wastewater treatment in North Carolina coastal areas — meeting strict regulations, protecting nearby ecosystems, and appealing to residents

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Waterfront Communities and Effluent Management

Since 2005, McKim & Creed has worked with private developers to find environmentally sound wastewater solutions at six new upscale waterfront communities. Each of the 200- to 300-ha (500- to 800-ac) properties was developed for single-family homes and located on waterfront property adjacent to the Atlantic Intracoastal Waterway or interconnecting tidal creeks. The communities consisted of between 200 and 1100 individual lots, 40% of which featured water frontage on coastal estuaries, marinas, man-made lakes, freshwater wetlands, or high-quality shellfish waters.

Lot sizes varied from 0.1 to 0.6 ha (0.3 to 1.5 ac), and most of the developments included site amenities, such as yacht or clubhouse facilities, marinas, boat ramps, lakes and water features, community centers, swimming pools, tennis courts, fire rings, and hiking and biking trails. The typical cost for individual lots within these developments ranged from $100,000 to $1.2 million.

Due to the remote location of each new community, connecting to an existing municipal collection system was not feasible. Therefore, management strategies for handling treated effluent had to be developed before selecting and designing an appropriate treatment process. The fact that each site was located in close proximity to sensitive and ecologically diverse coastal marshes made an environmentally acceptable solution more complex.

Effluent management alternatives that were considered included

- direct discharge to "waters of the state" via a new National Pollutant Discharge Elimination System permit;
- disposal of biologically treated effluent via low-rate spray irrigation to land;
- beneficial reuse of reclaimed water onsite via independent spray or drip irrigation on lawns, planting beds, common areas, or via individual residential irrigation systems; and
- direct groundwater discharge to surficial aquifers via excavated infiltration basins designed as site amenities.

Environmental concerns in recent years have caused the North Carolina Department of Environment and Natural Resources to pass stringent regulations that effectively preclude new direct discharges from wastewater treatment facilities in coastal counties. This made the option of obtaining a new permit for surface water discharge essentially infeasible.

Land application by spray or drip irrigation was technically feasible but would have required the developer to set aside 25% to 40% of the total buildable area for a dedicated land application system. In addition, effluent management via dedicated spray irrigation systems in the North Carolina coastal plain typically requires between 40 and 90 days of storage for wet weather periods.

Irrigating common areas or individual lots with advanced tertiary effluent was a viable but expensive alternative and required between 40 and 90 days of wet weather storage. These storage basins also would have been difficult to design into the communities, because their widely fluctuating water levels would make them aesthetically unattractive.

After extensive soils mapping, geotechnical evaluations, pump testing, and aquifer modeling,

Table 1. Projected Influent Parameters

Influent parameter	Flow or contaminant concentration
Flow	
Average day design influent	0.1 mgd to 0.5 mgd
Peak day flow peaking factor	2.0
Peak hour flow peaking factor	2.5
Carbonaceous biochemical oxygen demand concentration	225 mg/L
Total suspended solids concentration	240 mg/L
Total nitrogen concentration	40 mg/L
Total phosphorus concentration	7 mg/L

Table 2. Finished Reclaimed-Water Quality

Effluent parameters	State effluent standard for direct groundwater discharge	Finished reclaimed-water quality
Flow		
Average day effluent	—	0.1 to 0.5 mgd
Peak day flow peaking factor	—	2.0
Peak hour flow peaking factor	—	2.5
Carbonaceous biochemical oxygen demand concentration	< 10 mg/L	< 5 mg/L
Total suspended solids concentration	< 5 mg/L	< 5 mg/L
Total nitrogen concentration	< 4 mg/L	< 4 mg/L
Total phosphorus concentration	< 2 mg/L	< 2 mg/L
Turbidity	< 10 NTU	< 0.2 NTU
Fecal coliforms	14 CFU/100 mL	Nondetect

down to 0.05 µm in size and serve as a physical barrier to bacteria, *Giardia*, and *Cryptosporidium* oocysts. The high-quality water produced by MBRs is fully compliant with regulatory requirements for beneficial use. The finished reclaimed water is subjected to UV disinfection, and sodium hypochlorite is added to the finished water to inhibit regrowth. This process creates multiple barriers to remove oxygen-consuming organics, suspended and colloidal solids, nitrogen, phosphorus, and pathogens reliably and consistently.

Each MBR facility was designed with dual aerobic digesters to stabilize and provide 45 days storage for biosolids produced by the process. Waste activated sludge is periodically pumped to the aerobic digesters to be aerated and mixed continuously. After several waste cycles, the operator can temporarily deactivate the aeration system, allow solids to settle, and decant the supernatant (via telescoping valves) back to the influent pumping station. This decanting process enables the operator to thicken sludge from 0.75% solids to 2% or 3% solids. The thickened Class B biosolids are periodically transferred from the first digester to the second digester, which functions as an aerated holding tank for short-term storage (45 days) and further stabilization. Upon documentation of 38% volatile solids reduction, the Class B digested biosolids are transferred to tank trucks and land-applied to permitted agricultural fields.

All the unit processes, including the MBRs and digesters, are covered, and the off-gas is treated via a centralized absorptive odor-control system. Appurtenant to the MBR treatment facility is a new control building containing an operator office, analytical laboratory, restroom, electrical room, and chemical storage and feed rooms.

MBR Package Plant

Three of the six satellite MBR systems designed by McKim & Creed utilized these MBR package plants manufactured by Siemens, which are modular, factory-assembled, three-stage BNR processes. In this system, the combined wastestream is pumped from an in-line flow-equalization basin and enters the first BNR stage, the primary anoxic cell, where denitrifying microorganisms convert nitrate–nitrogen (produced in the subsequent aerobic process and continuously recycled back to the primary anoxic basin) in the absence of elemental dissolved oxygen (DO) and in the presence of carbon (influent biochemical oxygen demand). The denitrified mixed liquor then flows over a weir into the second-stage aerobic basin.

Microorganisms in the aerobic stage convert wastewater organics to biological cell mass in the presence of DO and convert biological nitrogen to ammonia–nitrogen. At the same time, other aerobic organisms in the mixed liquor convert ammonia–nitrogen to nitrate. The supervisory control and data acquisition (SCADA) system automatically controls positive displacement blowers and adjusts airflow to fine-bubble dif-

Table 3. Construction Costs for Reclaimed-Wastewater Treatment and Dispersal Systems (0.15 to 0.5 mgd)

Component	Cost
5-day lined earthen upset basin	$0.75 to $2 per design gal/d
Membrane bioreactor with BNR	$12.50 to $16 per design gal/d
Odor control (including tank covers)	$1.50 to $2.50 per design gal/d
Control building	$0.65 to $1.50 per design gal/d
SCADA, instrumentation, telemetry	$1.75 to $2.50 per design gal/d
Class B biosolids digestion and 45 days storage	$2.25 to $3 per design gal/d
Reclaimed water infiltration basin and groundwater control system	$3.25 to $4.50 per design gal/d
Total	**$22.65 to $32 per design gal/d**
Average cost per residential lot	***$9000 to $12,800***

SCADA = supervisory control and data acquisition system.
BNR = biological nutrient removal.

rent to biological regrowth in the pumping station and reclaimed-water transmission lines.

The SCADA system paces the sodium hypochlorite feed pumps to maintain a free chlorine residual concentration between 0.5 and 0.75 mg/L prior to discharge into the infiltration basins. In addition, the SCADA system automatically monitors reclaimed-water turbidity at the discharge point to confirm that the reclaimed-water turbidity never exceeds permit requirements. In the unlikely event that turbidity exceeds 10 NTU, the reclaimed water is automatically diverted back to the 5-day lined upset basin for retreatment. The reclaimed-water pumps are controlled by the SCADA system and convey reclaimed water to the two infiltration basins to maintain a preset "normal pool" elevation.

MBR Batch Process

The Aqua Aerobic MBR system operates in a similar fashion to a conventional sequencing batch reactor (SBR) in that influent wastewater is directed to only one basin at a time. While the first basin is filling, the second basin undergoes alternating anaerobic, anoxic, and aerobic cycles for biochemical oxygen demand oxidation and BNR. The system includes both fine-bubble diffused aeration and floating direct-drive mixers. This combination makes it possible to optimize BNR by separating the aeration function from the ability to maintain solids in solution. The entire process is fully automated. Another advantage of batch technology is that it is not necessary to construct a separate influent flow-equalization basin; equalization volume can be readily incorporated into the individual SBRs.

Unlike a conventional SBR, however, this batch MBR process lacks the classic settle, decant, and waste cycles. Instead, mixed liquor is pumped directly into the adjacent membrane tank at the end of the biological cycle, where submerged microfiltration membranes function as a liquid–solids separation process. Solids are separated from the reclaimed water via an outside-in microfiltration process using hollow-fiber membranes. These membranes are individually sealed at the top, and membrane bundles are potted in fiberglass at the bottom only. This arrangement allows fibrous material to flow freely upward, along the membranes and out from between the fibers, and back into the mixed liquor. Top-potted membrane bundles, however, tend to collect fibrous material at the top, resulting in increased fiber breakage.

Like the Siemens MBR design, permeate is drawn continuously through the individual hollow-fiber membranes via a vacuum produced by the permeate pumps. The membranes remove solids and colloidal particles down to 0.05 micron, thus physically removing 100% of pathogenic bacteria, protozoa, and nematodes. The membrane operating tank functions similarly to the Siemens system, in that it is continuously mixed and aerated via a coarse-bubble sparger, which is integral to the lower membrane header. Solids are automatically wasted from the system during each cycle.

The downstream unit processes — including UV disinfection, continuous monitoring, and chlorination — are accommodated similarly to the Siemens system. The SCADA-controlled pumps convey the reclaimed water to one or more groundwater infiltration basins.

Groundwater Infiltration Basins

The reclaimed water is used to maintain the water level in two or more unlined earthen basins dug in soils capable of infiltrating the entire aver-