

# Cost and Performance Evaluation of BNR Processes

Gerald W. Foess, Paul Steinbrecher, Kenneth Williams, and George S. Garrett



The use of biological nutrient removal (BNR) processes is expected to increase in Florida because of growing concerns about the effects of nitrogen and phosphorus on the stimulation of undesirable aquatic growth in surface waters and the potential adverse health effects of nitrates in groundwater.

In the Florida Keys, degradation and eutrophication of canal and nearshore waters led Monroe County to require all new and expanding wastewater treatment facilities to meet Advanced Wastewater Treatment (AWT) or Best Available Technology (BAT). However, the county lacked the information it needed to determine what discharge limitations could reasonably be imposed under these requirements, given the large number (nearly 300) of wastewater treatment plants with small flows and limited operational oversight. Experience had demonstrated that DEP AWT limits of 3 mg/L for nitrogen and 1 mg/L for phosphorus could be achieved by large plants, but there was no assurance or expectation that such stringent limits could be achieved by small plants. Additionally, no specific BAT standards existed.

A study was commissioned by Monroe County, with support and financial assistance from DEP, to determine BAT effluent limitations for treatment plants with permitted design capacities in the range of 2,000 to 100,000 gpd. The summary provided in this article includes a review and ranking of BNR technologies and proprietary equipment on the market with respect to costs, performance, and other factors. Information was derived from equipment suppliers, DEP and EPA databases, technical literature, and visits to operating facilities.

## Small-Flow Nutrient Removal Facilities in the U. S.

Table 1 contains a nationwide list of full-scale facilities in the 2,000 to 100,000 gpd range that are designed to meet total nitrogen or phosphorus limits, as derived from DEP and EPA databases and input from 85 equipment suppliers. The most common phosphorus limit is 1.0 mg/L, ranging from 0.1 to 2.0. The most common nitrogen limit is 10 mg/L, ranging from 3 to 14. Florida has imposed the most stringent nitrogen limits on plants in this size range.

**TABLE 1. U.S. WWTPs WITH NUTRIENT REMOVAL PROCESSES CAPACITY ≤ 0.1 MGD**

Location	P Removal	N Removal
Arkansas	—	1
Arizona	—	1
California	—	1
Colorado	10	3
Connecticut	—	1
Florida	8	16
Indiana	3	—
Maryland	2	1
Massachusetts	—	2
Michigan	4	5
Minnesota	15	—
New Jersey	8	4
New Mexico	—	3
New York	5	12
Pennsylvania	—	11
<b>TOTAL</b>	<b>55</b>	<b>61</b>

Sources: U. S. EPA Permit Compliance System; FDEP WAFR database; Equipment Suppliers

## Site Visits

Nutrient removal systems in the size range of 2,000 to 100,000 gpd are almost universally furnished as pre-engineered, factory- or field-assembled package systems. Approximately 25 systems available on the market were evaluated, followed by visits to 17 operating treatment plants in Florida, New York, New Jersey, and Massachusetts. The plants represented diverse technologies and covered a spectrum of sizes within the range of interest. Information was gathered on plant performance, actual operation and maintenance costs, actual capital costs, and the level of operator staffing. The collected information was subsequently used in the evaluation of

Gerald W. Foess, Ph.D., P.E., and Paul Steinbrecher, P.E., are with CH2M HILL in Deerfield Beach. Kenneth Williams, P.E., is with CH2M HILL in Key West. George S. Garrett is with the Monroe County Marine Resources Department, Marathon.

alternative systems.

## Nutrient Removal Systems Evaluated

The following biological nitrogen removal systems, which were considered representative of the diverse technologies on the market and applicable to small treatment systems, were selected and evaluated.

1. MLE (2-Stage) Continuous-Flow Suspended-Growth Process
2. 4-Stage Continuous-Flow Suspended-Growth Process
3. 3-Stage Continuous-Flow Suspended-Growth Process
4. 4-Stage Sequencing Batch Reactor (SBR) Suspended-Growth Process

**TABLE 2. SELECTED NUTRIENT REMOVAL SYSTEMS**

System Description	Representative Suppliers	Achievable Effluent Quality BOD/TSS/TN/P <sup>1</sup> (mg/L)
1. MLE Process – continuous-flow suspended-growth process with an initial anoxic stage followed by an aerobic stage	Smith and Loveless U. S. Filter/Davco Aeration Industries Zenon Environmental The McNeil Company	10/10/10/2  (5/5/10/1 with filtration)
2. Four-Stage Process – continuous-flow suspended-growth process with alternating anoxic/aerobic/anoxic/aerobic stages	Smith and Loveless U. S. Filter/Davco Zenon Environmental The McNeil Company	10/10/6/2  (5/5/6/1 with filtration)
3. Three-Stage Process – continuous-flow suspended-growth process with alternating aerobic/anoxic/aerobic stages	Smith and Loveless U. S. Filter/Davco Zenon Environmental The McNeil Company	10/10/6/2  (5/5/6/1 with filtration)
4. SBR Suspended-Growth Process – batch process sequenced to simulate the four-stage process	Aqua-Aerobics Purestream, Inc U. S. Filter/Jet Tech Babcock International Fluidyne	10/10/8/2  (5/5/8/1 with filtration)
5. Intermittent-Cycle Process – modified SBR process with continuous influent flow but batch, four-stage, treatment process	Schreiber Corporation Austgen-Biojet Cromaglass Corporation AES	10/10/8/2  (5/5/8/1 with filtration)
6. MLE and Deep-Bed Filtration Process – Alternate 1 followed by attached-growth denitrification filter	U. S. Filter/Davco Purestream, Inc. Aeration Industries	10/5/6/1 (process includes filtration)
7. Submerged Biofilter Process – continuous-flow or intermittent-cycle process using one or more submerged media biofilters with sequential anoxic/aerobic stages	Tetra Technologies, Inc. WWSI Smith and Loveless	20/20/12/2  (5/5/12/1 with filtration)
8. RBC Process – continuous-flow process using RBCs with sequential anoxic/aerobic stages	CMS Group WWSI	20/20/12/2  5/5/12/1 (with filtration)
9. Conventional Secondary Treatment – continuous-flow activated sludge process (no enhanced nutrient removal; included for basis of comparison)	Smith and Loveless U. S. Filter/Davco Aeration Industries Zenon Environmental The McNeil Company	10/10/X/X  5/5/X/X (with filtration)

5. 4-Stage Intermittent-Cycle Suspended-Growth Process
6. MLE Process followed by Deep Bed Filtration Process
7. Submerged Biofilter Process
8. Rotating Biological Contactor (RBC) Process

CBOD	10 mg/L
TSS	10 mg/L
N	10 mg/L
P	1 mg/L

In each case, the recommended method of phosphorus removal was chemical precipitation. In addition, effluent polishing filtration would be provided in each system, except System 6, which already incorporates the deep bed filtration process for nitrogen removal.

Table 2 presents a description of each system, representative equipment suppliers, and estimated achievable effluent quality. Also included for comparison is a conventional secondary treatment plant (System 9).

Two of the systems identified above (Systems 1 and 6) were determined to be potentially applicable for retrofitting nitrogen removal to existing WWTPs, and evaluated separately. These were identified as (1) System 1R—MLE (2-Stage) Continuous-Flow Suspended-Growth Process, and (2) System 2R—Deep Bed Filtration Process.

The MLE process (System 1R) can be retrofitted to an existing plant by adding an anoxic basin upstream of the existing plant, re-directing the influent flow to this basin, and adding recirculation pumping from the existing aeration basin to the new anoxic basin. Alternatively, an anoxic zone could be created within the existing aeration basin by adding a baffle wall, but that would reduce the capacity of the plant. New chemical feed facilities for phosphorus removal could also be added.

In System 2R, a deep-bed filter would be added downstream of the existing package plant, replacing any existing filtration facilities. New pumping facilities to pump secondary effluent to the deep bed filter would be required, as well as methanol feed facilities and chemical feed facilities for phosphorus removal.

### Performance Comparison

As indicated in Table 2, all of the systems are generally considered capable of meeting effluent BOD and TSS concentrations similar to large plants. Achievable effluent nitrogen concentrations range from 6 to 12 mg/L, with the 4-stage and 3-stage processes and the deep-bed filtration process (Systems 2, 3, and 6, respectively) being the most effective. Chemical phosphorus removal in all of the alternative systems is expected to achieve effluent limits of 2 mg/L without filtration and 1 mg/L with filtration.

Achievable permit limits for the MLE retrofit system (System 1R) were considered comparable to the corresponding new-plant MLE system (System 1). Achievable permit limits for the deep-bed filtration retrofit system (System 2R) were also estimated to be similar to those for the corresponding new-plant system (System 6), but with a somewhat lesser N removal capability because the retrofit system did not incorporate an MLE process.

As a result of this performance assessment, DEP provided to Monroe County the following BAT limitations (annual average basis) applicable to new and expanding facilities with permitted design capacities of less than 100,000 gpd (source: DEP correspondence to Monroe County Commissioners dated May 12, 1998):

### Cost Comparison

Tables 3 and 4 compare costs for the nine new-plant and two retrofit alternatives, respectively, for five different treatment capacities. The cost summary includes the estimated construction cost, annual O&M cost, uniform annual cost, and unit cost (\$/1,000 gallons). Uniform annual costs were determined using an interest rate of 6 percent for a 20-year period. The unit cost was determined by dividing the uniform annual cost by the number of 1,000 gallons of wastewater treated per year, at 80 percent capacity utilization.

Construction costs for the new-plant alternatives include all required facilities for a new plant on a new site. Filtration was included for all of the systems except the base case secondary treatment system. In general, the conventional suspended-growth nutrient removal technologies have the lowest construction costs for capacities exceeding approximately 10,000 gpd. The attached-growth processes construction costs are competitive at the smallest system sizes of 4,000 and 10,000 gpd. A generally poor correlation exists between the construction cost of alternatives and nitrogen removal performance.

**TABLE 3. COSTS OF NUTRIENT REMOVAL SYSTEMS – NEW PLANTS**

System	Treatment Facility Design Capacity				
	4,000 (gpd)	10,000 (gpd)	25,000 (gpd)	50,000 (gpd)	100,000 (gpd)
<b>1 MLE</b>					
Construction Cost, \$	\$ 261,000	\$ 311,000	\$ 422,000	\$ 601,000	\$ 874,000
Annual O&M Cost, \$/yr	\$ 30,400	\$ 35,500	\$ 49,400	\$ 66,600	\$ 100,100
Uniform Annual Cost, \$/yr	\$ 53,200	\$ 62,600	\$ 86,200	\$ 119,000	\$ 176,300
Unit Cost, \$/1,000 gal	\$ 61.8	\$ 29.1	\$ 16.0	\$ 11.1	\$ 8.2
<b>2 Four-Stage</b>					
Construction Cost, \$	\$ 336,000	\$ 368,000	\$ 475,000	\$ 666,000	\$ 968,000
Annual O&M Cost, \$/yr	\$ 52,500	\$ 57,600	\$ 73,800	\$ 95,900	\$ 132,300
Uniform Annual Cost, \$/yr	\$ 81,800	\$ 89,700	\$ 115,200	\$ 154,000	\$ 216,700
Unit Cost, \$/1,000 gal	\$ 95.0	\$ 41.7	\$ 21.4	\$ 14.3	\$ 10.1
<b>3 Three-Stage</b>					
Construction Cost, \$	\$ 291,000	\$ 333,000	\$ 441,000	\$ 627,000	\$ 913,000
Annual O&M Cost, \$/yr	\$ 35,900	\$ 41,900	\$ 56,400	\$ 76,200	\$ 115,900
Uniform Annual Cost, \$/yr	\$ 61,300	\$ 70,900	\$ 94,800	\$ 130,900	\$ 195,500
Unit Cost, \$/1,000 gal	\$ 71.2	\$ 32.9	\$ 17.6	\$ 12.2	\$ 9.1
<b>4 SBR</b>					
Construction Cost, \$	\$ 336,000	\$ 381,000	\$ 482,000	\$ 697,000	\$ 966,000
Annual O&M Cost, \$/yr	\$ 28,000	\$ 34,100	\$ 49,100	\$ 67,600	\$ 100,000
Uniform Annual Cost, \$/yr	\$ 57,300	\$ 67,300	\$ 91,100	\$ 128,400	\$ 184,200
Unit Cost, \$/1,000 gal	\$ 66.5	\$ 31.3	\$ 16.9	\$ 11.9	\$ 8.6
<b>5 Intermittent Cycle</b>					
Construction Cost, \$	\$ 229,000	\$ 374,000	\$ 584,000	\$ 861,000	\$ 1,026,000
Annual O&M Cost, \$/yr	\$ 28,000	\$ 34,100	\$ 49,100	\$ 67,600	\$ 100,000
Uniform Annual Cost, \$/yr	\$ 48,000	\$ 66,700	\$ 100,000	\$ 142,700	\$ 189,400
Unit Cost, \$/1,000 gal	\$ 55.7	\$ 31.0	\$ 18.6	\$ 13.3	\$ 8.8
<b>6 MLE + Deep Bed Filtration</b>					
Construction Cost, \$	\$ 308,000	\$ 368,000	\$ 486,000	\$ 664,000	\$ 958,000
Annual O&M Cost, \$/yr	\$ 36,900	\$ 42,700	\$ 58,100	\$ 75,900	\$ 111,400
Uniform Annual Cost, \$/yr	\$ 63,800	\$ 74,800	\$ 100,500	\$ 133,800	\$ 194,900
Unit Cost, \$/1,000 gal	\$ 74.1	\$ 34.7	\$ 18.7	\$ 12.4	\$ 9.1
<b>7 Submerged Biofilters</b>					
Construction Cost, \$	\$ 247,000	\$ 296,000	\$ 450,000	\$ 847,000	See Note (1)
Annual O&M Cost, \$/yr	\$ 19,500	\$ 24,400	\$ 41,100	\$ 60,400	See Note (1)
Uniform Annual Cost, \$/yr	\$ 41,000	\$ 50,200	\$ 80,300	\$ 134,200	See Note (1)
Unit Cost, \$/1,000 gal	\$ 47.6	\$ 23.3	\$ 14.9	\$ 12.5	See Note (1)
<b>8 RBCs</b>					
Construction Cost, \$	\$ 263,000	\$ 342,000	\$ 527,000	\$ 868,000	\$ 1,092,000
Annual O&M Cost, \$/yr	\$ 20,400	\$ 25,900	\$ 43,400	\$ 61,500	\$ 89,400
Uniform Annual Cost, \$/yr	\$ 43,300	\$ 55,700	\$ 89,300	\$ 137,200	\$ 184,600
Unit Cost, \$/1,000 gal	\$ 50.3	\$ 25.9	\$ 16.6	\$ 12.7	\$ 8.6
<b>9 Baseline – Secondary Treatment</b>					
Construction Cost, \$	\$ 183,000	\$ 223,000	\$ 303,000	\$ 461,000	\$ 671,000
Annual O&M Cost, \$/yr	\$ 22,000	\$ 26,500	\$ 39,200	\$ 52,100	\$ 78,000
Uniform Annual Cost, \$/yr	\$ 37,900	\$ 45,900	\$ 65,600	\$ 92,300	\$ 136,500
Unit Cost, \$/1,000 gal	\$ 44.0	\$ 21.3	\$ 12.2	\$ 8.6	\$ 6.3

Note: (1) Exceeded manufacturer's sizes

**TABLE 4. COST SUMMARY FOR RETROFIT SYSTEMS**

System	System Design Capacity				
	4,000 (gpd)	10,000 (gpd)	25,000 (gpd)	50,000 (gpd)	100,000 (gpd)
<b>R1 Anoxic Tank for MLE Upgrade</b>					
Construction Cost, \$	21,000	24,000	39,000	57,000	80,000
Annual O&M Cost, \$/yr	12,100	12,600	13,400	18,700	21,100
Uniform Annual Cost, \$/yr	13,900	14,700	16,800	23,700	28,100
Present Worth, \$	159,800	168,500	192,700	271,500	322,000
Unit Cost, \$/1,000 gal	16.1	6.8	3.1	2.2	1.3
<b>R2 Deep Bed Denitrification Filter</b>					
Construction Cost, \$	109,000	121,000	147,000	163,000	213,000
Annual O&M Cost, \$/yr	17,600	18,200	20,300	24,800	28,600
Uniform Annual Cost, \$/yr	27,100	28,700	33,100	39,000	47,200
Present Worth, \$	310,900	329,800	379,800	447,500	541,000
Unit Cost, \$/1,000 gal	31.5	13.3	6.1	3.6	2.2

For the retrofit alternatives, only the new facilities needed for nitrogen and phosphorus removal are included. Although the deep bed denitrification filter retrofit alternative provides somewhat better nitrogen removal percentage than the MLE retrofit alternative, it is approximately two to four times more costly, depending on capacity.

O&M costs were developed by individually considering operations labor, electricity, maintenance and repairs materials and labor, solids handling and disposal, administration labor, laboratory analytical requirements, and chemical costs. For the retrofit alternatives, only the increase in these costs associated with the addition of nitrogen and phosphorus removal facilities was estimated. Assumptions were as follows:

- Operations labor - labor at \$36/hour (includes overhead), with minimum staffing per F.A.C. 62-699.310
- Electricity - \$0.10/kW-hr
- Maintenance and repairs materials and labor - 3 percent of capital costs/year
- Solids handling and disposal - liquid haul at \$0.17/gal
- Administrative - 5 percent of the sum of the operations labor, electricity, and maintenance and repairs costs
- Laboratory - commercial rates applied to required monitoring parameters in F.A.C.62-0699.310
- Chemical costs - alum for P removal at \$1.80/lb; Symclosene (chlorine) at \$2.50/lb; methanol at \$0.15/lb

For the new-plant alternatives, the data show that the two attached-growth processes (Systems 7 and 8) have the lowest O&M costs, which was due to lower costs for electricity, solids handling, and laboratory analyses. These processes are also simpler to operate than suspended-growth processes. O&M costs are highest for the four-stage (System 2) and deep-bed filtration (System 6) systems because they are the most complex to operate and maintain. For the same reason, the deep-bed retrofit alternative (System 2R) has higher estimated O&M costs than the MLE retrofit system (System 1R).

On a unit cost basis, the nutrient removal systems with filtration included are approximately 20 to 40% more costly than a conventional secondary treatment system without filtration. For the two lowest new-plant capacities analyzed (4,000 and 10,000 gpd), the attached-growth processes (Systems 7 and 8) appear to have clear life-cycle and unit cost advantages over the other nutrient removal technologies. These alternatives are followed by the intermittent-cycle, MLE, and SBR systems (Systems 5, 1, and 4) in a middle cost range. The highest cost systems in this flow range are the four-stage (System 2) and denitrification filter (System 6) systems. As plant capacity increases to approximately 25,000 gpd or greater, the total cost advantage of the attached-growth systems begins to disappear. The four-stage continuous-flow process (System 2) is consistently more costly than all other technologies across all facility sizes.

For the retrofit alternatives, the annual and unit costs of operating a denitrification filter are nearly twice those of retrofitting and operating an MLE system.

**Ranking**

Weighted rankings for the seven new treatment plant alternatives and the two plant retrofit alternatives were prepared using five criteria that considered both cost and non-cost factors associated with the ownership, operation, and performance of small-flow nutrient removal treatment plants. The criteria evaluated were unit cost, nitrogen removal performance, process control flexibility, ease of operation, and land requirements. For each criterion, a relative score of 1 (less favorable) to 5 (very favorable) was assigned to each alternative. The raw scores for each criterion were then multiplied by a weighting factor to amplify the rankings of more important criteria relative to those of less important criteria. The results are summarized in Tables 5 and 6 for the new-plant and retrofit systems, respectively.

For the new-plant alternatives, the three-stage system (System 3) was ranked the most favorable based on its moderate costs, process control flexibility, and ease of operation. The MLE and deep-bed filtration systems (Systems 1 and 6, respectively) were ranked second and third, respectively. The SBR and intermittent-cycle systems (Systems 4 and 5, respectively) were ranked in a tie for fourth. The four-stage system (System 2) was ranked fifth, while the attached-growth systems (Systems 7 and 8) were ranked in a tie for sixth.

Among the two retrofit alternatives, the MLE system (System 1R) had the best ranking, primarily due to more favorable unit costs and ease of operation. ■

**TABLE 5. RANKING OF NUTRIENT REMOVAL ALTERNATIVES FOR NEW WWTPs**

No.	System Alternative	Weighting Factor					Raw Score	Weighted Score	Ranking
		Unit Cost	Nitrogen Removal	Process Control/Flexibility	Ease of Operation	Land Required			
		30%	30%	15%	15%	10%	100%		
1	MLE	4	4	3	3	3	17	3.6	2
2	Four-stage	1	5	5	2	3	16	3.2	5
3	Three-stage	3	5	4	3	3	18	3.8	1
4	SBR	3	4	3	3	4	17	3.4	4 (tie)
5	Intermittent Cycle	3	4	3	3	4	17	3.4	4 (tie)
6	MLE + Deep Bed Filtration	2	5	5	2	3	17	3.5	3
7	Submerged Biofilters	3	2	2	4	5	16	2.9	6 (tie)
8	RBC	3	2	2	4	5	16	2.9	6 (tie)
<i>Total Possible Points</i>							25	5	

Note: Scores: 1 (Less Favorable) to 5 (More Favorable)

**TABLE 6. RANKING OF RETROFIT NUTRIENT REMOVAL ALTERNATIVES**

No.	System Alternative	Weighting Factor					Raw Score	Weighted Score	Ranking
		Unit Cost	Nitrogen Removal	Process Control/Flexibility	Ease of Operation	Land Required			
		30%	30%	15%	15%	10%	100%		
1	Anoxic Tank, MLE Upgrade	4	4	3	3	3	17	3.6	1
2	Deep-Bed Benite Filter	2	4	3	2	4	15	3.0	2
<i>Total Possible Points</i>							25	5	

Note: Scores: 1 (Less Favorable) to 5 (More Favorable)



# Strategies For Procurement of a 6.0 MGD Wastewater Treatment Facility

Harold E. Schmidt, Jr., J. Richard Voorhees, Jon D. Fox, and Peter A. Korelich

**I**n 1980 New Smyrna Beach constructed a 4.0 MGD pure oxygen high-rate activated sludge wastewater treatment plant that discharged to the Indian River Lagoon system. To comply with House Bill 3247, the *Indian River Lagoon Act*, in 1991 the city upgraded the plant to provide advanced secondary treatment and a public access reclaimed water system. Additional expansions were necessitated by population growth in the service area.

Alternative methods of process optimization to upgrade the existing facilities included pilot testing various configurations to reduce nitrogen and phosphorus. Because of site constraints and process equipment optimization to meet the effluent criteria required by the regulatory agencies, the city decided to make various improvements to the wastewater transmission system and to construct a new 6.0 MGD treatment facility. The deadline to have the new facility on line was June 30, 1999, per an imposed Consent Order.

The improvements to the wastewater transmission system consisted of permitting and design of two wastewater pump stations, with pumping capacities of 3.0 and 15 MGD, and various improvements to existing stations. The city's engineering staff provided in-house design for 95,200 linear feet of 12-, 24-, and 30-inch diameter pipelines for raw wastewater, reclaimed water, and potable water transmission mains.

Development of the new facility consisted of site selection, ecological assessments, and resolution of various site zoning issues. Engineering service included permitting and design of a pretreatment structure, a five-stage biological nutrient removal wastewater treatment system, secondary clarifiers, continuous backwash deep bed filters, and high-level disinfection. The nutrient removal system consisting of fermentation, first anoxic, aeration, second anoxic, and reaeration basins.

The design was to provide advanced levels of treatment because of the effluent requirements for wet weather discharge into the Indian River Lagoon system and Class I reliability requirements. Also included was a Class B sludge stabilization facility consisting of sludge holding, sludge thickening, and lime stabilization.

The reclaimed water reuse system consisted of a 6.0-million-gallon substandard effluent storage tank, a 2.0-million-gallon reclaimed water storage tank, and high-ser-

Harold E. Schmidt, Jr., P.E., is a vice president, J. Richard Voorhees, P.E., and Jon D. Fox, P.E., are associates, all with Hartman & Associates, Inc., Orlando. Peter A. Korelich, P.E., is the chief engineer for the New Smyrna Beach Utilities Commission.



vice pumping. The reclaimed water high service pumping facilities consisted of five vertical turbine pumps ranging in capacities from 450 to 2,000 gpm. Ancillary facilities included a new administration building, a laboratory for both wastewater and potable water, motor control centers, and other miscellaneous facilities.

The overall wastewater management program was funded using a combination of methods. It included funds from the city's mandated facility surcharges and renewal and replacement accounts, utility system revenue bonds, the State Revolving Fund, and a grant from the St. Johns River Water Management District.

## Objectives

The success of a wastewater management design depends on development of a thorough and coordinated set of engineering drawings and specifications, selection of equipment, choice of contractor, and owner's commitment to proper operation. A project still may not meet all expectations because of hidden problems that enter into the project as contractors prepare the bids. Our goal was to develop a format that prevented poor quality or misapplied equip-

ment from being included in the project, while maintaining a high level of competition between the equipment manufacturers and suppliers.

The method of procurement itself can become an impediment to a successful project. The conventional open format commonly used in the bidding of wastewater management systems generally encourages selection of only the lowest priced materials, methods of construction, and equipment. Problems sometimes develop and extend through construction and operation. For example, when the term "or equal" is added to a well-written specification, it may become vague to the reader. During the bidding process, the contractor will receive many quotes from many suppliers of the equipment named in the specifications and/or interpreted as an "equal" to the specified equipment, and thus must select the lowest priced equipment or package to be selected for the project. Therefore, little consideration is given to the equipment that best meets the requirements of the project. Most important, needs of the owner, who must operate and maintain the facilities, are ignored. Based on information from the U.S. Accounting Office, one of the most signifi-

cant factors in the failure of wastewater treatment facilities to adequately meet the effluent limitations for which they were designed has been inferior process equipment.

Our experience indicated that there was no one best means of procurement and bidding format. During our initial stages, we evaluated five methods individually and in combination:

1. *Conventional open bid.* Competition is encouraged because the contractors are free to negotiate with all interested parties. However, this method also permits the contractor the opportunity to offer products that while complying with the salient requirements of the specifications and project intent may not be the exact equipment or process envisioned in the design. This process also encourages prebid packaging, post bid shopping, and may lead to the possibility of disputes during construction.
2. *Base bid.* Contractors are required to base their prices on equipment named on a fixed list. Competition tends to be discouraged, except among the named "base bid" manufacturers. Because the products and equipment in the base bid have been evaluated in the design process, fewer problems tend to arise during construction and start-up phases. Bid protests may occur because suppliers are not listed in the specifications or bid form.
3. *Base/substitute bid.* The contractor is allowed to enter equipment names and deduct amounts to the bid package. The bids can be evaluated either before or after the substitutions have been included. Similar to the base bid format, competition is limited and generally prebid packaging is discouraged. The concerns with bid protests are similar to the problems that could be encountered with the base bid process.
4. *Evaluated bid.* Equipment is selected based on total cost, life-cycle cost, or some other method of evaluation. This format maintains equipment selection with the owner and designer, provides for competition, tends to eliminate prebid packaging, and fulfills all the legal requirements for bidding of federally funded projects. Since the project is designed around a specific type of equipment, disputes are generally minimized during construction.
5. *Pre-selection of major equipment.* This method is very similar to the evaluation bid format since the engineer and owner play a critical role in selecting not only the type, but also the brands of equipment installed. The primary difference is that it does not generally permit competition, since the equipment has already been chosen prior to the bid; however, it

leaves open the possibility for a fair competition during the equipment proposal process.

It was determined that a combination of methods 2 and 5 provided a number of advantages, such as:

1. Equipment selection decisions stay with the owner and engineer.
2. New and innovative processes and equipment are encouraged.
3. Pre-bid packaging and post-bid shopping are discouraged.
4. Disputes during construction are minimized.
5. The method is legal and enforceable.

A number of primary components of the wastewater facilities were evaluated during the pre-selection/evaluation process. The premise of the pre-selection process was to select the major pieces of equipment prior to bidding. With the bidding format process chosen, the contractor was still required to purchase the equipment and be responsible for its installation, as with typical construction contracts.

The process equipment that was determined to be the most important components of the wastewater treatment facilities to meet the effluent limitations contained in

the Consent Agreement and was therefore evaluated and pre-selected prior to bidding included the biological nutrient removal process, the method of filtration, and the instrumentation package. The primary area of our evaluation was the biological nutrient removal wastewater treatment process, since it was the heart of the system.

A number of biological nutrient removal treatment processes were evaluated, including the Eimco 5-stage Bardenpho process, Kruger Bio-Denitpho process, Envirex Orbal Simpre process, and sequential batch reactors. Each of the process suppliers was invited to submit proposals on technical merit and cost. The criteria for the process evaluation, identical for all proposals, included influent and effluent characteristics, operating conditions, and site considerations.

Evaluations of technical proposals were based on capital and operating costs, labor and maintenance requirements, operating experience and reliability, the ability to meet the effluent criteria, performance guarantees, and other miscellaneous items (e.g., odors, aerosols). Moreover, during the process proposal stage of the project, we visited a number of wastewater facilities that utilized the treatment processes to develop a subjective analysis of them.

It was determined that an Eimco 5-stage

Bardenpho facility was the biological nutrient removal treatment process that met the requirements for the UCCNSB.

The methods of filtration that were evaluated were travelling bridge and continuous backwash deep bed filters, and they were evaluated in a similar fashion to the biological nutrient removal processes. It was determined that the continuous backwash deep bed filters were the most appropriate method of filtration for this project and site.

The evaluation of the instrumentation package was more difficult because of the many suppliers available. Since the primary goal was to select a system that could efficiently operate with the selected biological nutrient removal process, one of the key evaluation criteria was experience with other biological nutrient removal processes. It was determined that the Kruger instrumentation package met all the requirements of the evaluation.

Since Kruger and Eimco are competitors in the marketing of biological nutrient removal process equipment, it was thought that integrating the Kruger instrumentation package with the Eimco equipment would be difficult. It was quite the contrary, since both organizations, along with the project team, worked effectively together to develop a successful instrumentation package that met the needs of the project.

This was the first project in the United States to successfully integrate the Eimco Bardenpho treatment technology with the Kruger controls and instrumentation system in a bidding package.

We believe that this method of pre-selection of the major process equipment enabled the city and the project team to select the most appropriate equipment for the project. It also enabled the project design team to work with the city and the various suppliers and determine what will work best for the facility. Since the project required the selection of specialized equipment, it was determined that this method of pre-selection was useful.

At the preliminary and 60-percent-final design stages, the project underwent an intensive value engineering study to identify potential savings in capital and/or operating costs. A savings of approximately \$540,000 was realized.

When the design was completed the engineering drawings were forwarded to five major general contractors for a feasibility and constructability review. Additionally, the review process provided information regarding special construction techniques, alternative layouts, and other cost saving measures. The information from the five reviews was evaluated and, where possible, incorporated into the final bidding documents.

## Results

The project went out for bid in September 1997. Nine bids, ranging from \$16,156,705 to \$18,725,000, were received. The low bid by Indian River Industrial Contractors, Inc., of Jacksonville resulted in a cost per gallon of \$2.69. As of September 1998, the project is approximately 70 percent complete. It has had one change order—to add two additional filters to enable the treatment of an additional 1.0 MGD from the cooling tower of a proposed new electrical power plant that will be constructed adjacent to the project site. The \$214,882 cost of the change order will be

borne by the owner of the power plant. The wastewater treatment facility is currently in the process of being re-permitted to treat an average daily flow of 7.0 MGD. Using the rerated flows and the additional costs from the change order, the cost per gallon was now \$2.33.

The design and bidding format allowed the owner and engineer to implement a program that meets project needs, will minimize disputes during construction, and is cost effective. Compared to recent bids from similar sized and type facilities in Florida, savings of at least \$4,000,000 were realized. ■