Do You Need Tertiary Filters at Your Wastewater Plant? Which Technology Should You Pick & Why?

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In Florida, the requirements for both high-level disinfection and advanced wastewater treatment (AWT) dictate the need for tertiary wastewater filtration. Traditionally plants have used traveling hood automatic backwash (ABW), upflow continuously backwashed, or deep-bed granular media filters. Newer filter designs such as membrane filters, series upflow filters, high-rate disk filters, and synthetic media filters are available that offer the potential of lower costs, enhanced water quality or smaller footprints.

If implemented in their current forms, current regulatory initiatives by water management districts, the Florida Department of Environmental Protection (FDEP), and and the U.S. Environmental Protection Agency (EPA) relative to reuse, numeric nutrient limits, and stormwater treatment will encourage utilities in Florida to look closely at these newer filtration technologies to facilitate the production of high-quality reclaimed water for public-access reuse, aquifer recharge, aquifer storage and recovery, or other types of high-value reuse.

The city of Daytona Beach's Westside Regional Wastewater Treatment Plant has a permitted capacity of 15 million gallons per day (mgd) average day flow and uses traveling hood granular media filters to filter secondary effluent, followed by ultraviolet (UV) light for high-level disinfection. Reclaimed water is pumped to the reuse distribution system or to the Halifax River during periods of low demand for reclaimed water. The facility has experienced operational issues with its current filters and decided to perform an evaluation of options (including newer innovative technologies) for renovating or replacing the existing filters. This article provides the results of an economic evaluation of the capital and operations lifecycle costs for several alternatives for renovating or replacing the existing filters.

Description of Existing Filters

The Westside Regional Wastewater Treatment Plant has four traveling hood filters, each rated at an average hydraulic loading rate of 2.0 gallons per minute per square foot (gpm/ft^2) and a peak hydraulic loading rate of 5.0 gpm/ft^2. Each filter has an effective filtration area of 1,309 ft^2 (with 42 individual cells), and is designed to treat an average flow of 3.76 mgd and peak flow of 9.36 mgd (total of 15 mgd average day flow and 37.5 mgd peak flow).

The cells are separated by partition walls made of fiberglass reinforced plastic (FRP). Each filter has an influent channel that runs longitudinally along the side of the filter and conveys the water to each of the 42 cells via six-inch diameter ports centered along the width of each cell. The traveling hood assembly sits on the partition walls, thereby isolating each cell for backwash while the other cells continue to filter water. The traveling hood has one pump to backwash each cell individually while filtration continues in the other cells.

The filters have 16 inches of sand on top of two inches of pea gravel. The filter sand/gravel is supported by ABS media support panels. Underneath the media support panels in each filter is one common clear well for the filtered water. The ABS media support panels are supported by concrete walls that run longitudinally along the bottom slab.

The underdrain support panels include uniformly distributed underdrain nozzles to convey the filtered water to the common effluent plenum and to aid in evenly distributing the backwash water that is pulled back through the media by the backwash pump mounted on the traveling hood.

Within the clear well of each of the four filters, there are three eight-inch diameter PVC headers with half-inch diameter holes to distribute air evenly during periodic air backwashes (the operations manuals suggest operating this system once a month for a 15 minutes per filter). Air is supplied by means of a multistage centrifugal blower to one filter at a time.

Historical Performance of Existing Filters

Presently, the Westside Regional Plant treats an average day flow of about 7.1 mgd with peak flows of about 22 mgd. At these flows, the hydraulic loading rate per filter with all four filters on line equates to 1.0 gpm/ft^2 (average) and 2.9 gpm/ft^2 (peak).

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Historical data from the plant shows that the existing traveling hood filters are lightly loaded hydraulically and the water quality of the secondary clarifier effluent fed to the filters is excellent, with total suspended solids (TSS) concentrations averaging about 2.0 mg/L. The TSS concentrations in the filter feed rarely exceed the maximum permitted level of 5.0 mg/L. Historical data shows that filter effluent TSS values were below the permit limit of 5.0 mg/L 99.9 percent of the time.

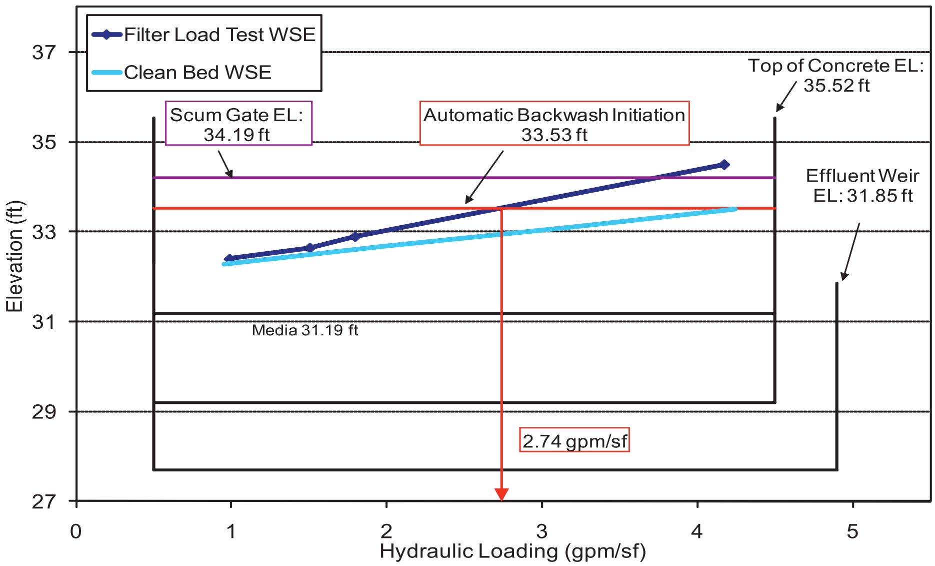
The average plant effluent turbidity has also been well below 2.0 NTU 99 percent of the time over the past three years. Even so, effluent fecal coliform counts in the plant effluent occasionally exceed permit limits. The filter problems contributed to the high fecal coliform concentrations; however, deficiencies in the UV disinfection system that have since been corrected were the principle cause of the high coliform counts.

Physical Condition of Existing Filters

The performance of the existing filters has deteriorated over the past few years, primarily from deterioration of the mechanical equipment, the filter internal structures, and the condition of the filter sand. The existing filters suffer from two major problems and several lesser problems that together place an unacceptable burden on the plant staff, decrease filter capacity, and likely contribute to

Continued on page 10

Figure 1. Measured Water Surface Elevations in Filter No. 4 during the filter load test at increased hydraulic loading rates at the Westside Regional Wastewater Treatment Plant



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occasional permit violations. The two major problems are inadequate backwashing of the filter sand and deterioration of the filter components.

There has been failure of most of the FRP partition walls, allowing short-circuiting during the backwash process by not allowing the hood to form a good seal on each filter cell. Several areas within the filter cells have experienced a complete loss of filter sand. As a result, the filter underdrain nozzles in these locations are exposed, allowing direct short-circuiting of an unknown amount of the filter feed into the clear well.

Inadequate cleaning of the filter sand has led to high hydraulic head losses and therefore excessive frequency of backwashing, loss of sand, and periodic failure of underdrain components. Lesser problems include leaks in water stops and construction joints in the concrete of the filter structure, problems with the filter controls that cause unnecessary backwashing, and minor surface cracks and crevices in the exterior walls of the filter structure.

Also, the operating staff has not used the periodic air backwash system because of issues during the filter start-up, during which the blower system apparently damaged the media support plates and the underdrain system. This air backwash system was eventually fixed and demonstrated to operate well, but the existing filters at the plant operated for nearly a decade with few reported operating issues or permit violations. Only within the last couple of years has the plant experienced recurring failures of certain components of the filtration system, requiring the plant staff to take filters off line for repairs while operating with only three filters most of the time.

Performance Testing of Existing Filters

To assess the performance of the existing traveling hood filters, a filter load test was performed. This test included taking filters off line sequentially and measuring the head loss across the filters and water-quality parameters at the influent and effluent of the filters. Increased hydraulic loading on the filters resulted in increased head loss across the filter and degraded effluent water quality.

Figure 1 shows a graphical representation of the rising water-surface elevations measured in one of the four filters during a load test with increasing hydraulic loading rates. As shown in the figure, the maximum hydraulic loading rate the filter could handle without overflowing the scum gate was less than 2.8 gpm/ft^2. Also, based on current filter operating settings, it takes 112 minutes to backwash one filter (all 42 cells), so a lag time exists after a filter reaches maximum head loss until it is completely cleaned.

Sieve analysis performed on one sample from one of the filters showed variation in the effective size and uniformity coefficient (U.C.) for the sand when compared to the original specification per the system manufacturer's operations and maintenance manual. The effective size of the current filter sand is slightly smaller (actual sand has effective size of 0.5 mm and a 90th percentile grain size of about 1.6 mm, compared to the specified effective size of 0.55 mm) and the gradation of grain sizes is less uniform than the sand originally specified (U.C. of actual sand is 1.7, compared to a U.C. of 1.5 for specified sand). Use of this sand increases the head loss through the filter and the loss of sand during backwashing.

Perhaps the greatest impact of the current sand characteristics is on the upflow velocity needed to fluidize the filter bed. Minimum fluidization velocities correlate with the 90th percentile sand size, and a 90th percentile size of 1.6 mm should require an upflow velocity of about 30 gpm/ft^2. This is significantly higher than the original design (the design is based around 16-20 gpm/ft^2), and beyond the capacity of the existing backwash pumps.

Based on the filter load test, it was concluded that the existing filters, in the as-is condition, can treat about 20-22 mgd without overflowing the scum gates and could overflow the structure when peak flows exceed 28-30 mgd with all four units in service. The filters do not have a bypass around the structure, and any rise in the water surface elevation because of filter upsets could result in water overflowing the filter structure onto the ground.

Analysis of Filtration System Alternatives

Currently there are several commercially available proven filtration technologies for wastewater applications that can provide a smaller footprint, less maintenance, more efficient backwashing, or better effluent quality. Available filtration technologies were reviewed and eight alternative methods for renovating or replacing the existing filters at the Westside Regional Treatment Plant were selected for detailed evaluation.

Technologies were selected that would fit well within the existing plant processes while representing a broad spectrum of technologies. The filtration system alternatives selected for improving the tertiary filtration at the plant are:

- **Alternative 1**: Existing traveling hood filters repaired/rehabilitated.
- **Alternative 2**: New deep-bed granular media filters.
- **Alternative 3**: New low-pressure membrane system using in-vessel pressure membranes.
- **Alternative 4**: Existing filters retrofitted with cloth media laterals

Continued on page 12

Continued from page 10

- **Alternative 5:** New cloth media disk filters.
- **Alternative 6:** New high-rate disk filters
- **Alternative 7:** New compressible synthetic media filters
- **Alternative 8:** New series, upflow filters

Each filtration alternative was sized to handle an average flow of 15 mgd and a peak flow of 45 mgd. Conceptual sizing for each alternative approach was based on industry standard hydraulic loading rates at average and peak conditions. Each alternative was sized to be able to treat 75 percent of the peak hour flow with one unit out of service, thereby meeting EPA Class 1 reliability criteria.

The following paragraphs briefly describe each alternative. In addition, Table 1 presents the key design characteristics for the eight alternatives considered in the analysis, while Table 2 presents the typical removal of particles and pathogens for the various filter types.

Table 1. Key Design Characteristics for the Various Filtration Alternatives

Filter System Alternative	Peak Loading Rates	Backwash Quantity (as % of average day flow)	Backwash Duration (minutes)	Hydraulic Head (feet)	Power Use (kilowatt-hours per year)	Land Required (ft^2)
Alternative 1	2 gpm/ft^2	2 to 5%	48 (w/o indexing)	0.5 to 2.5	70,000	19,000
Alternative 2	5 to 8 gpm/ft^2	2 to 5%	24	6.0 to 9.0	66,000	12,900
Alternative 3	20 to 40 gfd	5 to 10%	6	23 to 35	4,800,000	12,800
Alternatives 4 & 5	6.5 gpm/ft^2	2 to 5%	6	1.5 to 2.0	20,000 to 30,000	4,200 to 19,000
Alternative 6	16 gpm/ft^2	2 to 4%	5	3.0 to 4.0	260,000	1,800
Alternative 7	30 gpm/ft^2	5%	30	3	997,000	3,500
Alternative 8	4 gpm/ft^2	0.5 to 2%	Not known	4	Not Estimated	15,000

Table 2. Typical Removal of Particles and Pathogens for Various Types of Filters

Type of Filter	Minimum Size Particles Removed (1) (µm)	Log Removal Fecal Coliform	Log Removal Protozoan Cysts	Log Removal Virus	Effluent Turbidity, (NTU)
Traveling Hood ABW	1 to 10	4.0(2)	0.7 to 1.0(2)	0 to 1.2	<2
Deep Bed	1 to 10	2.5(2)	0.4 to 1.5(2)	0 to 1.3	<2
Low-pressure membranes	< 0.1	3 to 9	6 to 9	0.5 to 4	<0.1
Cloth media	1 to 10	3.0(2)	0.4 to 0.5(2)	0 to 0.6	<2
High rate disk	1 to 10	3.0(3)	0.4 to 0.5(3)	0 to 0.6 (3)	<2
Synthetic media	1 to 10	Not known	Not known	Not known	<2
Continuous backwash series upflow	0.1 to 1	Not known	7	Not known	<0.1

Notes:
(1) The minimum particle size that can be removed depends on the characteristics of the filter medium, and the type and performance of the upstream treatment processes.
(2) Levine, et al., 2008. The influent to the ABW filters was pre-chlorinated which could have affected the results for fecal coliform. The influent to the other filter types was not pretreated with any chemicals.
(3) Based on recent pilot testing performed for approval under California Title 22 requirements, the high rate disk filters performed very similar to the cloth media filters. Hence performance is assumed similar for pathogen removal.

Alternative 1: Existing traveling hood filters repaired/rehabilitated

Under this alternative, repairs or modifications, along with any necessary expansion to the existing filters, were considered. As pointed out earlier, the existing filters in their current condition can treat a peak flow of only about 22 mgd. Figure 1 shows that the existing filters can not handle flow rates in excess of 2.8 gpm/ft^2.

Very few regulatory or industry standards exist for allowable hydraulic loading rates on traveling type filters. Performance criteria established by California Recycled Water Criteria (Title 22) for tertiary filters limits the hydraulic loading rates to no more than 2.0 gpm/ft^2 in traveling hood automatic backwash filters. Taking into consideration the design and operation of the existing filters and problems with the filters, the project team recommended that the existing filters be operated at hydraulic loading rates of 2.0 gpm/ft^2 or less at peak flow conditions.

At 2.0 gpm/ft^2, the flow through each filter will be about 3.8 mgd, and with all four filters in operation, the total capacity of the existing filters will be about 15 mgd. Increasing the capacity of the existing filters to provide a peak flow capacity of 45 mgd will require the addition of eight filters of the same size as the existing filters (16 feet wide by 87 feet, 9 inches long), thus providing a total effective filtration area of 15,708 ft^2. This alternative will also require replacement or refurbishment of the existing filter equipment and repairs to the existing containment structure.

Alternative 2: New deep-bed granular media filters

The second alternative considered was adding deep-bed granular media filters to replace the existing automatic backwash traveling hood filters. Deep-bed filters are installed at the city's other facility, Bethune Point Wastewater Treatment Plant, and hence would provide similarity in the equipment between the two plants.

This design was based on a maximum hydraulic loading rate of 5.5 gpm/ft^2 with clarified secondary effluent with an influent TSS concentration of 20 mg/l or less. With all units in service, the hydraulic loading rate at peak flow of 45 mgd would be 5.6 gpm/ft^2. With one unit out of service, the filters would be able to treat 75 percent of the peak flow (33.75 mgd) at a hydraulic loading rate of 4.9 gpm/ft^2.

Intermediate pumping for clarifier effluent will be required to make this system fit within the existing hydraulic profile for the facility. This analysis assumed the construction of a new submersible pump station.

Alternative 3: New low-pressure membrane system

Continued on page 14

Table 3. Engineer's Estimate of Total Net Present Worth costs for the Filtration Alternatives Evaluated[1]

Filtration Alternative	Major Equipment Cost	Total Project Cost[2]	Total O&M Cost	Media or Membrane replacement	Total Net Present Worth[3]
Alternative 1[3][4]	$3,310,000	$16,249,000	$107,029	$1,044,000	$18,661,000
Alternative 2	$2,250,000	$13,166,000	$106,801	Negligible	$14,531,000
Alternative 3	$13,500,000	$33,418,000	$536,788	$10,416,000	$50,697,000
Alternative 4 [4]	$2,380,000	$8,187,000	$104,372	$269,000	$9,790,000
Alternative 5	$3,800,000	$14,808,000	$103,748	$456,000	$16,591,000
Alternative 6	$2,850,000	$10,915,000	$119,400	$600,000	$13,041,500
Alternative 7	$5,770,000	$17,409,000	$167,305	Negligible	$19,548,000
Alternative 8	$8,870,000	$32,650,000	$102,500[5]	Not Known	$33,961,000

Notes:

1) The above cost estimate is a Class 5 "Order-of-Magnitude" estimate per the *Recommended Practice 18R-97 Cost Estimate Classification System for the Process Industries*, published in 1998 by the Association for the Advancement of Cost Engineering (AACE). The expected accuracy range for Class 5 estimates is within +50 percent to -30 percent.
2) Total Project Cost includes installation cost (10 to 25 percent of equipment cost); concrete cost ($650/yd^3) as applicable; building cost ($125/ft^2) as applicable; project contingency (10 to 30 percent); contractor general conditions, overhead and profit; sales tax; escalation costs and engineering and administration costs.
3) Net present costs were calculated for a period of 20 years, using a unit power cost of $0.065/kilowatt-hour, an average hourly rate for labor of $25 and a discount rate of 4.7 percent.
4) Rehabilitation of existing traveling hood filters assumed replacement of all filter internal components such as under-drains, media supports, cell partition walls, sand media, traveling hood, backwash pumps etc. Additionally eight new traveling hood filters would be added to treat the peak flow of 45 mgd.
5) Power cost for Alternative 8 was not estimated.

Continued from page 12

For this alternative, a pressurized in-vessel membrane filter system was chosen as a typical example of a tertiary low-pressure membrane filter. The design was based on an operational flux of 40 gfd (gallons per day per ft^2) and a recovery of 90 percent. A total of 20 trains or racks would be required.

A 400-micron inline, self-cleaning strainer installed upstream from the membrane racks would protect the membranes from large particulate matter. The evaluation assumed the membrane system would be enclosed inside a concrete masonry unit (CMU) block building (116 feet by 110 feet, > 12,800 ft2). Clarifier effluent would be pumped to the membrane system via a new submersible pump station.

Alternative 4: Retrofit existing filters with cloth media laterals

Replacing the existing filters with cloth media laterals would require similar repairs to the concrete structure as in Alternative 1 to stop any leaks. All existing filter components would be removed and the floor of the existing filters would be rehabilitated and leveled for placement of the cloth media laterals and all required filter components.

Three of the existing filters would be retrofitted with six diamond-shaped cloth media laterals in each filter. A new traveling hood equipped with backwash pump, vacuum valves and other components would travel longitudinally, similar to the existing hood, to clean the laterals at a preset head loss or water level. The laterals would be approximately 32 inches high and 80 feet long.

The total surface area for the 18 diamonds to be installed would be 5,515 ft^2. This would provide a hydraulic loading rate of 5.6 gpm/ft^2 at the peak flow of 45 mgd. With one filter out of service (six laterals) the effective surface area would be reduced to 3,676 ft^2 and the hydraulic loading rate would be 6.4 gpm/ft^2 at the flow rate of 33.75 mgd, meeting Class 1 reliability. This alternative would not require any intermediate pumping as the new laterals would be retrofitted within the existing concrete structure.

Alternative 5: New cloth media disk filters

Under this alternative, new cloth media disk filters would be constructed and the existing ABW filters would be taken offline. Each disk filter unit would include 12 disks with an effective filter area of 645.5 ft^2.

A total of eight units are required to provide a total effective filter area of 5,165 ft^2 to treat the peak flow of 45 mgd. This would provide a hydraulic loading rate of 6.05 gpm/ft^2 at the peak flow of 45 mgd. With one entire filter out of service, the effective surface area would be reduced to 4,518 ft2 and the hydraulic loading rate would be 5.2 gpm/ft^2 at the flow rate of 33.75 mgd meeting the Class 1 reliability.

Based on preliminary hydraulic calculations, no intermediate pumping would be necessary to add the disk filters between the existing clarifiers and the subsequent UV disinfection system.

Alternative 6: New high rate disk filters

Under this alternative, the existing filters would be replaced with new micro- media disk filters. Each filter has a total of 24 disks with 530 ft^2 of dynamic filtration area.

The major difference between the micro-screen disk filters and the other disk filters is that the disks are always rotating, and are fed at angles less than 90^o. This is the basis for "dynamic tangential filtration." The flow pattern is "inside-out" with the feed passing through the filter mesh and freely falling into a filtrate zone below and flowing out of the unit.

If at any time the level in the feed zone rises above a pre-set limit, a level sensor initiates operation of the wash water pump and the back of the screen mesh is sprayed by low-pressure water between 20 and 60 psig water for typically 5-10 seconds. The target filtration rate for this filter is 16 gpm/ft^2, compared to the 6.5 gpm/ft^2 for cloth media filters described above; therefore, for this application a total of four units with a total filtration area of 2,120 ft^2 would be required. This would provide a hydraulic loading rate of 4.92 gpm/ft^2 at the average flow of 15 mgd.

With one entire filter out of service, the effective surface area would be reduced to 1,590 ft^2 and the hydraulic loading rate will be 14.75 gpm/ft^2 at the flow rate of 33.75 mgd meeting the Class 1 reliability. Similar to Alternative 5, no intermediate pumping would be necessary between the existing clarifiers and the subsequent UV disinfection system.

Alternative 7: New compressible synthetic media filters

This filtration system is a high-rate, upflow system that uses compressible, synthetic fiber spheres as the medium for filtration. A standard system includes painted steel vessels, galvanized steel internals, an air supply for backwashing the filter media, and PLC controls.

Media is held in place between a fixed lower perforated plate and an upper moveable perforated plate. The target filtration rate for this system is 30 gpm/ft^2. A total of 21 units, each with a foot print size of 49 ft^2 would be required. The units would have a maximum operating height of 22.5 feet. Intermediate pumping of clarifier effluent would be required to fit this system within the existing hydraulic profile of the facility.

Continued on page 16

Table 4 .Weight and Scores for Economic and Various Non-Economic Criteria for the Filtration System Alternatives Evaluated

Criteria	Weight[1]	Filtration Alternatives Evaluated[2][3]				
		1	2	3	4	5
		Rehab/ Expand Existing	Deep Bed Filters	Low-pressure Membranes	Rehab w/ Cloth Laterals	Cloth Medium Disk Filters
Equipment reliability	4	1(4)	4(16)	4(16)	2(8)	2(8)
Process complexity	2	4(8)	4(8)	3(6)	4(8)	3(6)
Compatibility with existing facility	4	5(20)	5(20)	3(12)	5(20)	5(20)
Ability to recover from plant upset	4	1(4)	4(16)	1(4)	2(8)	2(8)
Additional land area required	2	1(2)	3(6)	3(6)	5(10)	4(8)
Permitting complexity	1	5(5)	5(5)	5(5)	5(5)	5(5)
Full-scale experience	3	1(3)	5(15)	3(9)	1(3)	2(6)
Chemical requirements	2	5(10)	5(10)	2(4)	5(10)	5(10)
Backwash quantity	3	2(6)	4(12)	1(3)	4(12)	4(12)
Construction complexity	2	5(10)	3(6)	3(6)	4(8)	4(8)
Power use	3	5(15)	5(15)	1(3)	5(15)	5(15)
Requires additional pumping	3	5(15)	5(15)	1(3)	5(15)	5(15)
Ability to enhance removal of nutrients	2	1(2)	1(2)	3(6)	1(2)	1(2)
Ability to enhance removal of microconstituents	2	1(2)	1(2)	3(6)	1(2)	1(2)
Capital cost	5	4(20)	4(20)	1(5)	5(25)	4(20)
Present worth annual costs	5	5(25)	5(25)	1(5)	5(25)	5(25)
Total Points	235	151	193	99	176	170

Notes:
(1) Criteria were weighted based on overall significance of the criteria to the feasibility of the alternative evaluated. The criteria with most significance received a weight of 5 and those judged to have the least significance received a weight of 1.
(2) Each alternative was given a score of 1 to 5, with 1 the least favorable and 5 the most favorable.
(3) Scores in parenthesis are total weighted score.

Continued from page 14

Alternative 8: New series upflow filters

Under this alternative, the existing filters will be replaced with a new continuous backwash series upflow filter system. Each module consists of two continuously self-cleaning sand filters in series. Each sand filter is designed to serve a different function within the process.

The first-stage filter uses larger sand grain size to give it more solids handling capacity. In this stage, coagulation, flocculation, and separation take place within the filter bed. The second unit acts as a polishing filter, using a smaller sand size and providing higher removal efficiencies.

The third component of the system is a gravity settler, which treats reject from both filter stages. Average reject effluent volume is 0.5 percent of the feed flow.

For the Westside Regional Treatment Plant application, a total of 11 filter cells for each stage (total of 22 filter cells) would be required, providing a total filtration area of 13,200 ft^2. With one filter cell out of service from each of the two stages, the effective filtration area would be reduced to 12,000 ft^2 and the hydraulic loading rate would be about 4 gpm/ft^2 at the flow rate of 33.75 mgd meeting Class 1 reliability.

Economic Analysis for Alternatives

For each alternative, capital and annual operation and maintenance costs were estimated and a net present worth value was calculated, assuming a 20-year operating period. The results of the economic evaluation are presented in Table 3.

Ranking of Filtration Alternatives

The alternatives were compared using both economic and non-economic parameters, and a weighted evaluation matrix was created ranking the alternatives. Only the top five alternatives were considered for the ranking analysis.

A list of key characteristics or criteria that might influence the choice of a filtration system was identified. Each evaluation criterion was assigned a subjective weight from 1 to 5, based on the perceived overall significance of the criterion to the project. The criteria with the most significance received a weight of 5 and those with the least significance received a weight of 1.

Each alternative was individually scored for each criterion on a scale of 1 to 5, depending on how the alternative was judged to perform relative to that criterion, with 1 being the least favorable score and 5 being the most favorable score.

The estimates for capital and operating costs, land area, and power consumption were converted to a numeric score, based on a linear interpolation between the lowest estimate and the highest estimate. Other qualitative criteria were scored based on a combination of published past performance data and the subjective opinion of the project team with input from the city staff. The numeric scores for these criteria were then included in the matrix scoring table.

For each alternative, the score for each criterion was then multiplied by the criterion weight and multiplication products were summed to obtain the overall score for the alternative. The best alternative is the one with the highest score. Table 4 presents the summary of the ranking analysis.

Conclusions

From the work done for this study, three feasible alternatives for replacing the existing filtration system were identified. These are deep bed filters, cloth lateral filters, and cloth disk filters. Based on the weighted matrix evaluation performed, deep-bed filters are the preferred alternative; however, there was not a significant difference between the three top ranked alternatives.

From a capital cost standpoint alone, the alternative to retrofit the existing filter structures with cloth media laterals (Alternative 4) is the least expensive, followed by the deep-bed filters (Alternative 2). The high-rate disk filters (Alternative 6) also offer an economical option; however, it was not considered in the detailed evaluation.