Comparison of Water Quality Parameters from South Florida Wastewater Treatment Plants Versus Potential Receiving Waters

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There are four basic alternatives for the disposal of the effluent from wastewater treatment plants in Florida: ocean outfalls, surface discharges, deep well injection, and reuse. The discharge options are governed by the following sections of the Florida Administrative Code:

- All reuse and land application systems must be operated and maintained in accordance with the applicable provisions of Chapter 62-610.
- All underground injection effluent disposal systems must be operated and maintained in accordance with the applicable provisions of Chapter 62-528.
- All surface water discharge systems must be operated and maintained in accordance with the applicable provisions of Chapter 62-4.

Effluent requirements are summarized in Table 1.

Ocean outfalls have been used by large coastal utilities throughout the world for many years. In Florida there are six open ocean outfalls, all in Dade, Broward, and Palm Beach counties, disposing of more than 400 MGD of wastewater effluent. Character and velocity parameters were defined for ocean outfall plumes and the subsequent dispersal into the ocean environment based on extensive studies during the Southeast Florida Ocean Outfall Experiment of 1991.

Surface discharges are used primarily in north Florida where there are rivers or other large water bodies that allow dilution of the effluent as a part of removal from the plant site. A primary target of the Clean Water Act of 1972 and heavily regulated today, surface discharges differ from ocean outfalls in that they tend to be much shallower, so the differential density separation and the ratio of the discharge to the receiving water flow is generally much less. Because of the lack of flowing river bodies in south Florida, surface discharges are not an option for most south and southwest Florida utilities.

Deep wells are the option chosen by many south Florida utilities. The depth for the injection horizon varies, but it requires one or more confining units that separate the receiving formation from potential potable water supplies. Because of the geological characteristics of the formation, injection zones typically exist south of Tampa Bay. Over 200 MGD of effluent are disposed of via deep wells in Florida. The deep well option, like ocean outfalls, does not conserve the freshwater resource; the resource is lost. However, there is a potential to recover a portion of the effluent at some future date, provided regulations are amended.

Increased use of reclaimed water is a specific goal of the State Comprehensive Plan and an issue that has been encouraged by the state legislature as an important item to address in assuring adequate future water supplies throughout the state. The assurance of adequate water supplies at the proper time is especially critical in south Florida and southwest Florida, both of which have subtropical climates with distinct wet and dry seasons. The dry season occurs in the winter months when the tourists are most prevalent. Water production for many utilities increases substantially to meet tourist and part-time resident demands. The wet season occurs in the summer months when 70% or more of the rainfall occurs. This is the time of lowest demands by the population because the winter tourists have returned home. Most of the water is routed to the ocean; storage of excess water in reservoirs is not feasible because the flat terrain would require enormous land areas. In addition, what minimal capacity for storage that does exist is reserved for hurricane flooding.

Treatment Objectives

Both ocean outfall and deep well disposal require secondary treatment. Reuse requires advanced secondary treatment, while surface discharges often require advanced wastewater treatment including nutrient removal.

Secondary treatment is directed principally toward the removal of biodegradable organics (CBOD) and suspended solids through the use of activated sludge processes, fixed film reactors, extended aeration, or modifications/combinations of these processes. A secondary treatment facility will typically have a bar screen, and it may have primary clarifiers ahead of a secondary biological treatment process.

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Disinfection is normally included. Secondary wastewater plants are designed to achieve an effluent prior to discharge containing not more than 25 mg/L CBOD and 30 mg/L TSS, or 85% removal of these pollutants from the wastewater influent, whichever is more stringent. Appropriate disinfection (usually with chlorine) and pH control of the effluent is normally required.

Advanced secondary treatment in Florida requires the employment of all secondary processes plus filtration and high-level disinfection (residual over 1.0 mg/L after a given period of time). Typically the filtration step uses gravity sand/anthracite filters designed to achieve an effluent after disinfection containing not more than 5 mg/L TSS. Advanced secondary treatment is often confused with advanced wastewater treatment. However, the latter assumes nutrient removal, which does not occur through simple filtration.

Advanced wastewater treatment includes treatment processes necessary for the removal of nutrients, toxic compounds, TSS, and organics. Typically, AWT includes advanced secondary treatment plus nutrient removal (nitrification, de-nitrification and phosphorous removal). On an annual basis, effluent quality is limited to CBOD of 5 mg/L, TSS of 5 mg/L, total nitrogen of 3 mg/L, and phosphorous concentrations of 1 mg/L.

Table 1 outlines the effluent limitations defined in the rules for each alternative disposal method.

Current Discharge Quality

Data were obtained from utilities, hydrogeologists, consulting engineers,

Table 1

Constituent	TS mg/L	CBOD mg/L	TN mg/L	TP mg/L
AWT	5	5	3	1
Secondary Treatment — Deep Wells	20	20	n/a	n/a
Secondary Treatment — Surface Waters	25	25	n/a	n/a
Secondary Treatment — Ocean Outfalls	30	30	n/a	n/a

and the files of DEP in West Palm Beach. The data are from locations in southeast Florida, except that AWT samples were obtained from southwest Florida, because no AWT facilities exist in southeast Florida.

Table 2 shows a summary of data averages for:

- Current drinking water standard;
- Open ocean;
- AWT effluent;
- Reclaimed water;
- Secondary effluent;
- Ambient waters from the effluent injection zone;
- Floridan aquifer lower and upper monitoring zones;
- The aquifer storage and recovery (ASR) injection zone (Upper Floridan); and
- Biscayne aquifer monitoring zone.

In each case, the average value for each effluent sample, regardless of the parameter, has an average concentration below that of drinking water. This is not the case for the natural aquifer and ocean environments.

Data were not available for water quality in the canal system, although this quality is expected to vary dramatically depending on the time of year (flushing occurs in the summer and stagnation in the winter). While no one currently discharges to canals in southeast Florida, it is assumed, based on practices in southwest Florida, that AWT standards would have to be met, hence the FGUA results for AWT. Data for organics, herbicides, and pesticides are not shown because none was detected in the samples reviewed. Injection and monitoring zone

Table 2

Parameter Name	Drinking Water MCL	Open Ocean	AWT	Reclaimed Water Analysis	Secondary Effluent	Effluent Injection Zone	Lower Monitoring Zone	Upper Monitoring Zone	ASR Injection Zone	Biscayne Monitoring Zone
Inorganic Analysis										
Arsenic (mg/L)	0.05	0.003	0.0013	0.0032	0.0027	0.0096	0.0073	0.0049	0.0022	0.0148
Barium (mg/L)	2	0.05		0.0936	0.0234	0.1844	0.3633	0.089	0.4038	0.2442
Cadmium (mg/L)	0.005	ND	0.0001	0.0013	0.001	0.0041	0.0122	0.0654	0.0019	0.001
Chromium (mg/L)	0.1	ND	0.0007	0.0029	0.0046	0.0135	0.0225	0.0063	0.0104	0.0039
Cyanide (mg/L)	0.2	ND		0.0018	0.0153	0.006	0.0085	0.0043	0.0023	0.0039
Fluoride (mg/L)	4	1.4	0.94	0.42	0.79	0.7	0.86	1.47	1.58	0.19
Lead (mg/L)	0.015	0.004	0.0003	0.0012	0.0044	0.069	0.108	0.0216	0.0022	0.0093
Mercury (mg/L)	0.002	ND	0.0001	0.0003	0.00005	0.0003	0.0007	0.0012	0.0004	0.0003
Nickel (mg/L)	0.1	0.00013	0.0021	0.0045	0.0105	0.023	0.0355	0.0248	0.0044	0.0025
Nitrate (mg/L)	10	n/a		3.69	3.82	0.42	0.07	0.04	0.03	0.19
Nitrite (mg/L)	1	n/a		0.013	0.5745	0.0093	0.0248	0.0124	0.0063	0.005
Selenium (mg/L)	0.05	0.0001	0.0009	0.0035	0.0044	0.6374	0.0073	0.0036	0.0046	0.0006
Sodium (mg/L)	160	10560	64	75	114	8062	5514	1357	1215	80
Antimony (mg/L)	0.006	ND		0.1417	0.013	0.003	0.0188	0.0097	0.004	0.0014
Beryllium (mg/L)	0.004	ND		0.0041	0.0006	0.0075	0.0099	0.005	0.0008	0.0001
Thallium (mg/L)	0.002	ND		0.0009	0.0016	0.3049	0.013	0.0065	0.0008	0.0005
Secondary Analysis										
Aluminum (mg/L)	0.2	ND		0.05	0.0739	0.1996	0.9166	0.7443	0.1625	0.8226
Chloride (mg/L)	250	18980	82.2	116.9	151.8462	15302.5	9897	2203.3	2448.4	176.2
Copper (mg/L)	1	0.0004	0.0033	0.0207	0.004	0.2099	0.0323	0.1324	0.0104	0.005
Iron (mg/L)	0.3	0.002	0	0.1772	0.183	3.1507	4.4503	19.2939	1.0791	0.4204
Manganese (mg/L)	0.05	0.01		0.0237	0.0178	0.0384	0.046	0.027	0.0431	0.0131
Silver (mg/L)	0.1	ND		0.001	0.0017	0.037	0.008	0.005	0.0039	0.0028
Sulfate (mg/L)	250	2560	179.5	76.2	56.6231	2379.2	1117.9	401	521.8	38.8
Zinc (mg/L)	5	0.01	0	0.0229	0.0141	0.0076	0.0145	0.059	0.0822	0.0247
Color (PtCo units)	15			33	43.9091	7.4	6.3	12.6	12	21.9
Odor (TON)	3			2.5	10.9533	1.2	3.3	2.1	13.5	0.7
pH	6.5-8.5			7	6.8625	7.7	7.9	7.7	7.5	8.1
TDS (mg/L)	500	36000		528	550.7143	28682	18328	4128	5240	533
Foaming Agents (mg/L)	1.5			0.1429	2.5175	0.08	0.2534	0.118	0.0735	0.1933
Trihalomethane Analysis										
Total THMs (ug/L)	80			26.85	61.5838	0.1668	0.65	0.5	2.6065	0.0261
Radiological Analysis										
Gross Alpha (pCi/L)		15		3.1667	0.4	9.675	7.3	4.1	24.66	5.55
Miscellaneous Analysis										
Ammonia-N (mg/L)	-	n/a			8.7532	3.7663	0.561	0.6442	0.575	
Nitrogen, total (mg/L)	-	0.9		13.3	17	9.35	0.881	1.33		
Nitrogen, organic (mg/L)	-				1.584	0.9975	0.374	0.432	0.3067	
Nitrogen, total Kjeldahl (mg/L)	-			4.075	9.7833	5.5267	0.474	0.678	0.83	
Ortho-phosphate (mg/L)	-				1.4309	0.2337	0.045	0.0225	0.1333	
Phosphorus, total (mg/L)	-			1.375	1.3271	0.2708	0.2607	0.1292	0.255	
BOD (mg/L)	-				8.3	4.3	5.4	7	1.4	
Total Coliform (col/100ml)	-				394.0714	33.5	7	0.5	6	
Water Temperature (°C)	-				25.3333	22.8	23.5	24.3		24.4

Numbers are the average of the means of the measurements calculated with non-detects as zero and non-detects at their detection limit values

data were intended to be results prior to injection, which appears to be the case generally.

The first observation drawn from the data in Table 2 is that chlorides, sodium, total dissolved solids, sulfates, and gross alpha all increase with depth in the aquifer system as expected — each of those constituents normally increase with depth and the data merely verify what has been found previously. The constituents are all markers for deteriorating water quality caused by upconing under potable water supply wells.

Many constituents, including arsenic, barium, cadmium, lead, nickel, beryllium, aluminum, and iron, discharged from wastewater treatment plants were well below ambient background amounts in the aquifer system and similar to the ocean, which indicates that wastewater processes and industrial pretreatment programs are reducing metallic pollutant loads significantly. In addition, the industrial base present in the service area is relatively small and only minor amounts of metals may be present.

Fluoride was found in quantities similar to that found in background groundwater, which is not surprising since fluoride is added to the potable water source and exists in the raw water. Chromium, zinc, mercury, and manganese were found in the same general quantities in all samples. Mercury and chromium are metals used in industrial processes but are found in the wastewater only in very small quantities. The presence of zinc is likely a result of contact with potable water piping (galvanized pipe).

Several constituents were found at higher concentrations in the wastewater than in the receiving waters. Nitrogen-based compounds (nitrate, nitrite, ammonia, and organic nitrogen) and phosphorous-based compounds are wastewater-related nutrients that are found in the secondary effluent in higher concentrations than the receiving waters.

Nutrients are absorbed and used by plants and can be problematic if discharged in high concentrations. The current discharge standards were developed to define a point where the existence of nutrients was not harmful to the ecosystem. In such circumstances, the nutrients often act as tracers for the migration of effluent in receiving waters.

Other nutrient sources, such as stormwater and agricultural runoff, normally have much higher quantities of nutrients than wastewater effluent discharges. The sources of the nutrients in agricultural runoff and stormwater are fertilizers.

Receiving waters may experience excessive growth of certain plant species if nitrogen and/or phosphorous concentrations are too high. One or the other is usually the limiting factor on the growth of plants (which is why they are major parts of commercial fertilizers).

Conclusions

The survey indicated that large treatment plants in south Florida are performing well and that routinely monitored constituents are not an issue, despite periodic arguments to the contrary. No adverse health effects from the current priority pollutants or nutrients are anticipated, and no adverse impacts should be expected in the receiving waters.

The fate of pesticides, solvents, and cleaners is less well studied. None was detected in the effluent. Some have been implicated as endocrine disruptors, such as PCBs, phthalates, and pharmaceutically active substances. More study and better analytical techniques are necessary to fully understand their impacts, if any, and the concentrations that actually may exist in south Florida wastewater treatment plants.

Constituents currently well studied that may pose a threat to humans and the ecosystem include microorganisms, nitrosamines, and pharmaceutically active substances. Their quantities are not known in south Florida wastewater effluent. Recent regulations approved by Congress reflect an increasing public concern regarding endocrine disruption from both natural and synthetic chemicals. ■

Glossary of Common Terms Used in This Publication

ASR	aquifer storage and recovery
AWT	advanced water treatment
AWWT	advanced wastewater treatment
AWWA	American Water Works Association
BOD	5-day biochemical oxygen demand
BOD_x	BOD test based on other than 5 days
CBOD	5-day carbonaceous BOD
COD	chemical oxygen demand
cfm	cubic feet per minute
cfs	cubic feet per second
CWA	Clean Water Act
DEP	Florida Dept. of Environmental Protection
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FAC	Florida Administrative Code
fps	feet per second
FSAWWA	Florida Section of AWWA
FWEA	Florida Water Environment Association
FWPCOA	Fla. Water & Pollution Control Operators Assoc.
GIS	Geographic Information System
gpcd	gallons per capita per day
gpd	gallons per day
gpm	gallons per minute
hp	horsepower
I/I	Infiltration/Inflow
MGD	million gallons per day
mg/L	milligrams per liter
MLSS	mixed liquor suspended solids
MLTSS	mixed liquor total suspended solids
NPDES	Nat. Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
ORP	oxidation reduction potential
POTW	public-owned treatment works
ppm	parts per million
ppb	parts per billion
PSC	Public Service Commission
psi	pounds per square inch
PVC	polyvinyl chloride
RO	reverse osmosis
SCADA	supervisory control and data acquisition
SJRWMD	St. Johns River Water Mangement District
SFWMD	South Florida Water Management District
SRWMD	Suwannee River Water Management District
SSO	sanitary sewer overflow
SWFWMD	Southwest Florida Water Management District
TDS	total dissolved solids
TMDL	total maximum daily load
TOC	total organic carbon
TSS	total suspended solids
USGS	United States Geological Survey
WEF	Water Environment Federation
WRF	water reclamation facility
WTP	water treatment plant
WWTP	wastewater treatment plant

Performance of In-line Monitors in Assessing Microbial Breakthrough

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Recent waterborne outbreaks of cryptosporidiosis in the United States and Canada have caused increased concern by water utility managers about the performance of their surface water treatment systems. *Cryptosporidium* oocysts, as well as cysts of other parasitic protozoa found in surface waters, such as *Giardia lamblia*, are resistant to disinfection. To control occurrence of pathogens in the finished water, utilities must rely on physical removal processes, with filtration serving as the primary barrier for protection. A water treatment plant utilizing a source potentially contaminated with cysts must seek to achieve the best possible filtrate quality.

The initial degradation phase of a filter following a backwash, often exhibiting elevated effluent turbidity and particle counts, potentially provides an opportunity for the breakthrough of cysts and other microbes. Logsdon et al. (1985) investigated the removal of *Giardia* cysts from spiked Ohio River water, in a conventional treatment pilot plant employing several types of filter media. The results indicated that the cysts passed the filter in higher concentrations during the first 30 to 35 minutes after backwashing than during the steady, ripened filter operation. As turbidity initially broke through, filtrate cyst concentrations increased by a factor of 20 to 40, while turbidity increased by a factor of only 3 to 10.

Bucklin et al. (1991) studied the penetration of coliform bacteria through municipal filters under normal operational conditions of a treatment plant. Elevated levels of bacteria were observed during the initial part of filter runs following backwash. The highest levels (60 coliforms/100 ml) were observed during the flow-through time for the interface of the backwash remnant and filter influent water (first 30 minutes).

Current technologies do not provide operators with an absolute, real-time indication of the presence of specific pathogenic microbes. Modern microbiological assay techniques require time for sample analysis, which may include incubation time. In-line instruments are available that utilize optical methods for real-time measurement of turbidity and particle count and size information. Installed at individual filters, continuous turbidity and particle count monitors can be used to monitor ripening and breakthrough. The optical methods (turbidity and particle counts) may not reliably indicate microbial presence.

Turbidity is an aggregate light scatter response of a cloud of particles. Particle counting evaluates individual particles and has the advantage of providing size specific information, allowing focus on the particle size ranges of interest.

In a survey of several treatment plants, LeChavallier and Norton (1992) found that occurrences of cysts of *Giardia* and *Cryptosporidium* in plant effluent were related to episodes of high particle counts (limit of detection 5µm) in filter effluent.

Oocysts of *Cryptosporidium* are thought to be classified within the 3 - 5 µm particle size range, while *Giardia* cysts are believed to reside within the 7 - 15 µm particle diameter range.

The goal of our study was to evaluate the performance of two in-line, continuously flowing monitors of particulate content in providing filter operators with a real-time indication of the potential for breakthrough of microorganisms, including encysted microbes.

Microbial quality of the effluent was assessed using endospores of aerobic spore forming bacteria and heterotrophic plate counts. Endospores are similar in size and nature to oocysts of *Cryptosporidium parvum* and served as a surrogate for persistent pathogenic microbes.

Analysis of Filtration Performance

Measurements of filter effluent quality included the following parameters:

Turbidity is the expression of the optical property that causes light to be scattered and absorbed rather than transmitted without a change in direction or intensity through a sample (Standard Methods: 1995). Correlation of turbidity measurement with measures of particulate number or mass concentration is usually not attainable because the size, shape, and refractive index of the particles affect the light scattering properties of the suspension.

Some particles, such as those of powdered activated carbon, absorb visible light. Humic substances can absorb light and cause negative interference.

Nephelometers are turbidimeters designed to measure intensity of light scattered at 90 degrees to the direction of the incident light. They are the standard instruments for measurement of low turbidity. Formazin polymer is used as the primary standard reference suspension, and the turbidity of a specified concentration of formazin is defined as 4000 NTU.

Particle Count and Size Distribution can be measured by electronic instruments. In most particle counting instruments, particles pass through a sensing zone where they are sized and counted individually. Instruments create an electronic pulse that is proportional to the size of the particle. The instrument pulses are classified by magnitude and counted within each class, resulting in a particle size distribution.

Several available instrument types include light blockage, light scattering, and electrical sensing zone. Instruments vary in the characteristic being sensed, lower and upper size limits of detection, degree of resolution of the size distribution, and maximum particle number that can be measured accurately. Instruments capable of continuous flow monitoring, batch sampling, or both are available. Resolution is a measure of an instrument's ability to distinguish between particles of different sizes. Because most sample particles are non-spherical and different instruments respond to different characteristics of particles, different size distributions result from different instruments.

Endopores are resistant dormant structures formed by benign mesophilicbacteria consisting primarily of species of the genus Bacillus. Motivated by outbreaks of waterborne disease associated with the parasitic protozoans *Giardia lamblia* and *Cryptosporidium parvum,* Rice et al. (1996) proposed the use of endospores of aerobic spore forming bacteria as microbial surrogates to evaluate WTP removal of resistant biological particles. Traditional bacterial indicators such as coliforms do show correlation with parasites in source waters. However, encysted protozoans do not necessarily exhibit the same degree of removal or inactivation in a WTP, and thus the correlation does not hold for finished water. Direct monitoring of encysted protozoans is difficult because the concentrations can be variable and often low. Analytical procedures are time consuming and subject to problems related to specificity and recovery.

Endospores are ellipsoidal to spherical in shape and are of approximate dimensions 0.5 x 1.0 x 2.0 µm (volume equivalent diameter of 1.2 µm) and

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are thus similar to oocysts. The spores are resistant to various environmental pressures, such as heat or chemical oxidants. The size of endospores coincides with minima in particle removal efficiencies of both the flocculation and filtration physical separation processes (1 µm).

Endospores are ubiquitous in surface waters, present in sufficient amount to allow their use as surrogates in most WTPs using surface water sources. Unlike other bacterial indicators, they persist throughout the entire treatment process, detectable in even chlorinated, finished drinking water.

Indigenous endospores are of similar size and surface charge to oocysts (Rice et al: 1996), and are environmentally resistant. Enumeration is conducted via a simple and reliable procedure. Turnaround of results is relatively rapid (24 hours). The endospores do not propagate within the treatment process. Monitoring of spore removals has an advantage over the use of particle counting for assessing the removal of cyst-sized particles. Only spores are counted where particle counts are subject to errors associated with cyst sized agglomerates of smaller particles, as may occur when particles detach in filters.

Heterotrophic Plate Count (HPC) is a widely accepted gross measurement of total heterotrophic bacteria. Analysis was conducted by the pour plate method in accordance with Standard Methods (1995) Section 9215. The EPA Drinking Water Research Division laboratory performed the HPC analysis within 24 hours of sample collection.

Experimental System

The experiments took place at a pilot filtration plant located at a 110 MGD, AADF conventional surface water treatment plant. A combination of alum and polymer was used for coagulation in the full-scale process. The pilot filtration plant received settled water from the full-scale process.

Filters columns were 4 inches in diameter and constructed from transparent PVC pipe. The filters were equipped with continuous monitors for measurement of headloss, effluent turbidity, and particle counts. All measurement signals were sent to a computer data acquisition system (Water Quality Software Vista by Pacific Scientific), where the measurements were displayed and recorded to a database. The software allowed collection of data at frequencies of up to 1 minute intervals.

Two pilot filters, described in Table 1 were used in the study; the filter designs are described as a rapid sand filter (RS) and high-rate deep-bed filter anthracite (HRDBA), respectively.

In-line Continuous Turbidimeter

The Hach Model 1720C Low Range Process Turbidimeter is a continuous monitoring nephelometric turbidimeter for low range measurement. It is capable of monitoring turbidity in the range of 0.001 to 100.0 NTU. Calibration is performed with formazin.

The instrument consists of a control unit, head assembly, and turbidimeter body. The electronics, including the keyboard and 4 digit LED display, are housed in the control unit. Optical components (lamp and photocell) are contained in the head assembly. Sample turbidity is continuously displayed by the LED display during operation. The instrument outputs an analog signal for use with the data acquisition system and chart recorder. Recorder output minimum and maximum values in NTUs are programmed at the keyboard; settings of 0 and 5.0 NTU were used.

The turbidimeter body is the unit through which the sample water flows and is measured. The optical head assembly is placed in the body with the photocell submerged in the sample. The internal bubble trap channels the sample through a series of baffles, allowing removal of entrained bubbles.

In-line Particle Counter

The particle counter we employed was a Met One Model 215W Liquidborne Laser Particle Counter that utilizes the light obscuration principle of operation to count and size particles. The lower size limit of detection is 2 µm equivalent spherical diameter and particle counts in 6 size ranges are provided: 2-3, 3-5, 5-7, 7-10, 10-15, and 15+ microns. The dynamic size range is 2 - 400 microns. Coincidence error is less than 10% at 16,000 particles per ml.

Experimental Approach

The overall approach was to characterize the quality of the initial effluent following variable backwash practices in a series of consecutive filter runs. For each backwash phase, the filter was washed employing a differing, predetermined backwash technique. The proposed backwash schemes were designed to result in varying conditions with respect to the degree of solids removal from grains and quality of the backwash remnant water. A single experimental "set" consisted of a dirtying run followed by a backwash, then a new run, during which the initial effluent was sampled. The new run was then allowed to proceed and become the dirtying run for the next "set." The initial effluent of a run was sampled at high frequency for turbidity, particle counts, endospores, and HPC throughout the period of initial degradation until the filter ripened. In-line monitor measurements were compared to effluent microbial character over the range of conditions.

Table 1. Pilot Filter Column Specifications

Filter	RS	HRDBA
Media	Sand	Anthracite
Effective Size, mm	0.5	1
Uniformity Coefficient	1.5	1.6
Total Bed Depth, in.	32	76
Loading Rate, gpm/sf	2.5	5

Endospores serve as a surrogate only, which is distinct from the role of an indicator organism. As such, the degree of removal of endospores is used to assess treatment performance. The spores themselves are harmless soil microbes and their presence at any absolute concentration does not indicate the presence of pathogens. Endospores are used as a relative parameter to assess removal efficiency (i.e. log removal) and effluent levels of spores (C) must be considered in relation to influent levels (C_0). Filter effluent endospore levels are presented by normalizing to settled water spore levels (C/C_0), which represents the fraction passing.

Normalized effluent spore concentration, to be denoted by S^1, is defined as the actual effluent concentration of spores divided by the average concentration in settled water. Since backwash remnant water constitutes the initial volume of water to pass the filter bed, normalized endospore concentration (S^1) may be larger than 1 during the initial breakthrough period of filtration.

Total particle counts greater than the detection limit of 2 µm are abbreviated as TPC. As described above endospore levels normalized to the SET concentration are abbreviated as S^1 and heterotrophic plate counts are abbreviated as HPC.

Efficacy of In-line, Continuous Monitors for Indication of Microbial Breakthrough

In all cases, initial effluent normalized spores exhibited behavior typical of initial breakthrough. Initial concentrations were elevated, peaked at some maximum value at approximately 8 and 6 minutes (for RS and HRDBA filters, respectively), then progressively improved due to displacement of the backwash remnant water and ripening. Heterotrophic plate count information was more sporadic but displayed similar behavior.

Experimental data from the microbiological characterization and the continuous particulate monitors is shown in Figures 1 and 2 for a unique run performed by the RS filter with a poor effluent condition.

Experimental data from the microbiological characterization and the continuous particulate monitors is shown in Figure 3 and 4 for the HRDBA filter with a poor effluent condition.

In both cases, initial effluent yielded high concentrations of endospores (relative to settled water) and heterotrophic bacteria. At the peak the RS filter effluent had 4.3 times more spores than was in the average unfiltered settled water. The ratio of this peak to that of the stable filter effluent spore content is approximately equal to 12. For the HRDBA filter, the maximum spore concentration relative to average filter influent was 8.2 which is approximately 37 times that in the corresponding stabilized filter effluent. For the RS filter the effluent HPC maximum was 1650 cfu/mL which was 5.3 times more than that in the steady effluent. The HRDBA filter exhibited a maximum HPC of 1250 cfu/mL, which was 6.4 times that of the stable effluent.

The turbidity data provided good agreement with the time of the occurrence of spore and HPC breakthrough. For the RS filter the maxima in spore concentration and turbidity both occur at run time of 7 to 8 minutes and the turbidity indicates the relative improvement to that of the stable effluent at a run time of approximately 20 minutes.

Good agreement also exists for the times of breakthrough and ripening for spores and turbidity in the HRDBA filter. For these experimental trials, HPC bacteria levels seemed to observe the general trends produced by effluent spores and the turbidity monitoring information.

The particle count information indicates a less extensive breakthrough of total particles (larger than 2µm equivalent sphere diameter). For the RS filter, there is no apparent degradation in quality associated with initial breakthrough indicated by the particle counter; levels of filter's initial effluent TPC don't exceed that of the stable filter operation in the run, when turbidity spores and HPC have improved. For the run data presented for the HRDBA filter, TPC information does indicate an increase in effluent levels of particles > 2µm, which corresponds well to the time of elevated levels of spores, turbidity, and HPC. The magnitude of the particle breakthrough appears far less pronounced, however. The maxima in spores, HPC, and turbidity are 37, 6, and 12 times higher than that corresponding to steady filter operation.

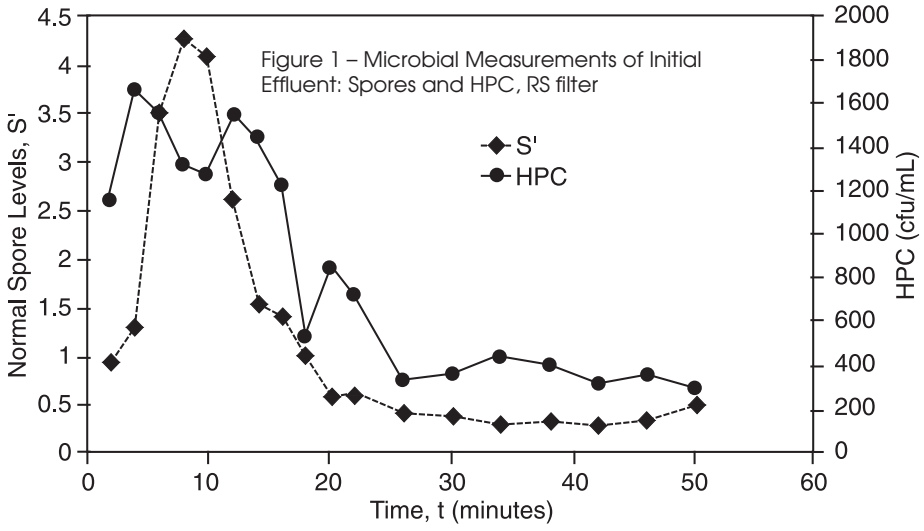


Figure 1 – Microbial Measurements of Initial Effluent: Spores and HPC, RS filter

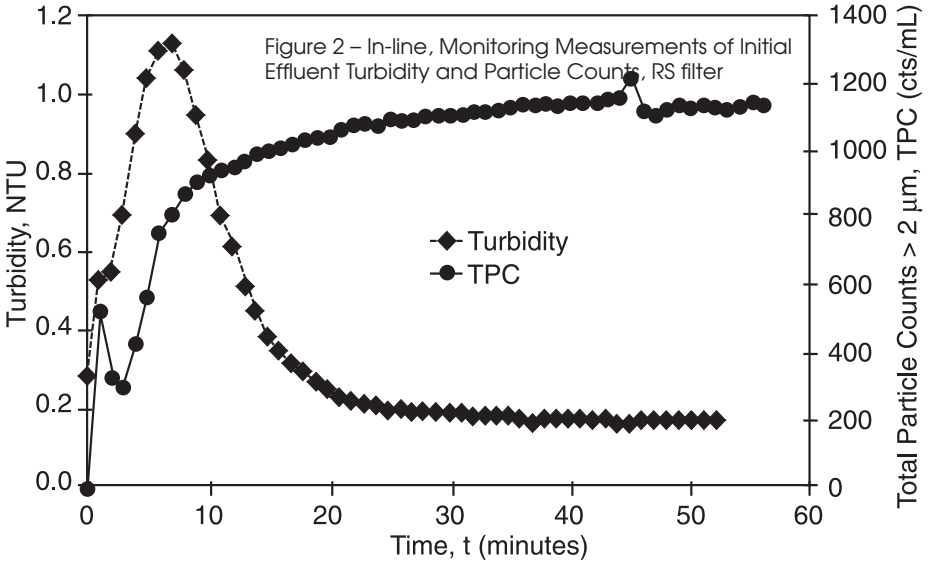


Figure 2 – In-line, Monitoring Measurements of Initial Effluent Turbidity and Particle Counts, RS filter

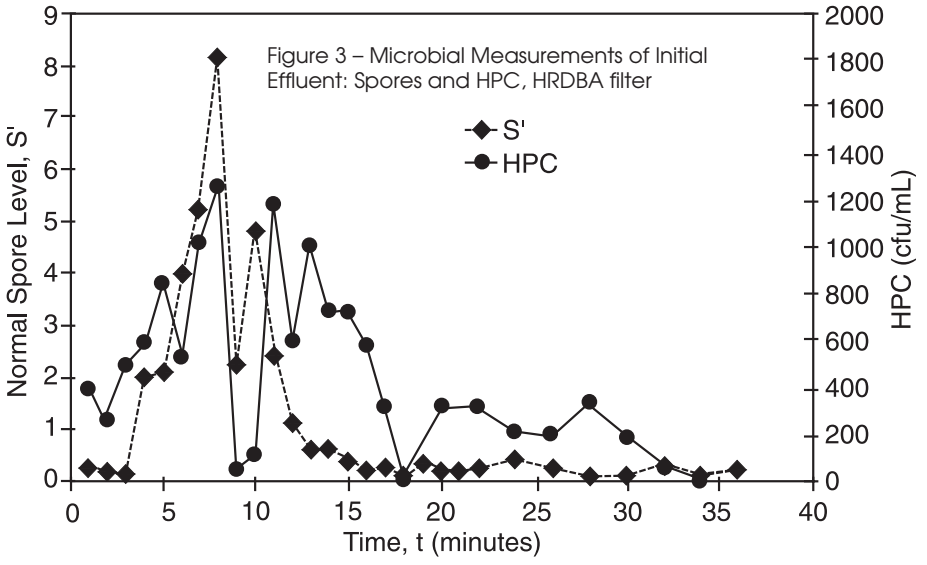


Figure 3 – Microbial Measurements of Initial Effluent: Spores and HPC, HRDBA filter

Particle count information indicates a peak factor of only 2.

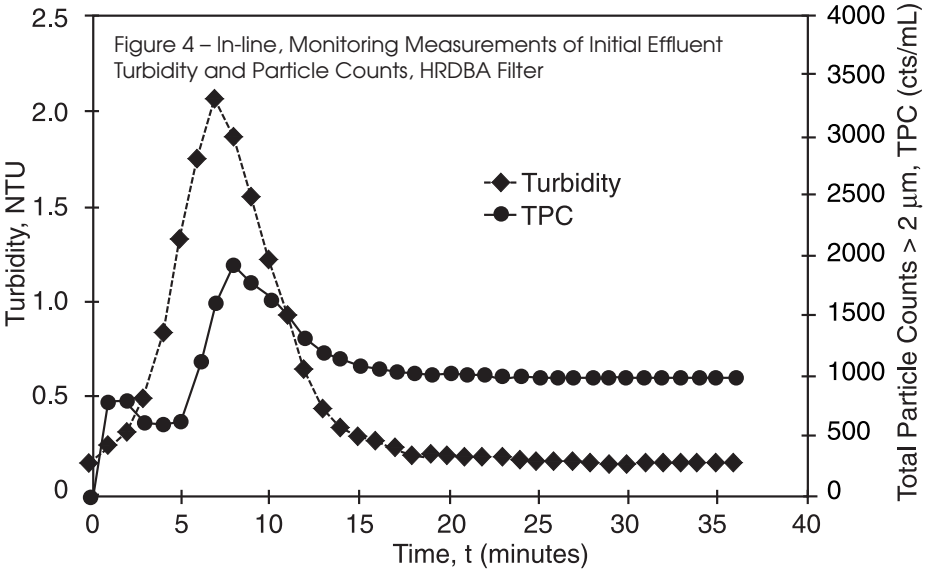
The behavior exhibited in the above examples for each filter is generally representative of the relative responses of the continuous turbidimeter and the on-line particle counter. Turbidity provided the best overall indication of the microbial quality with respect to the magnitude of the breakthrough (peak) and its duration for ripening and improvement. The relationship was strongest for endospores.

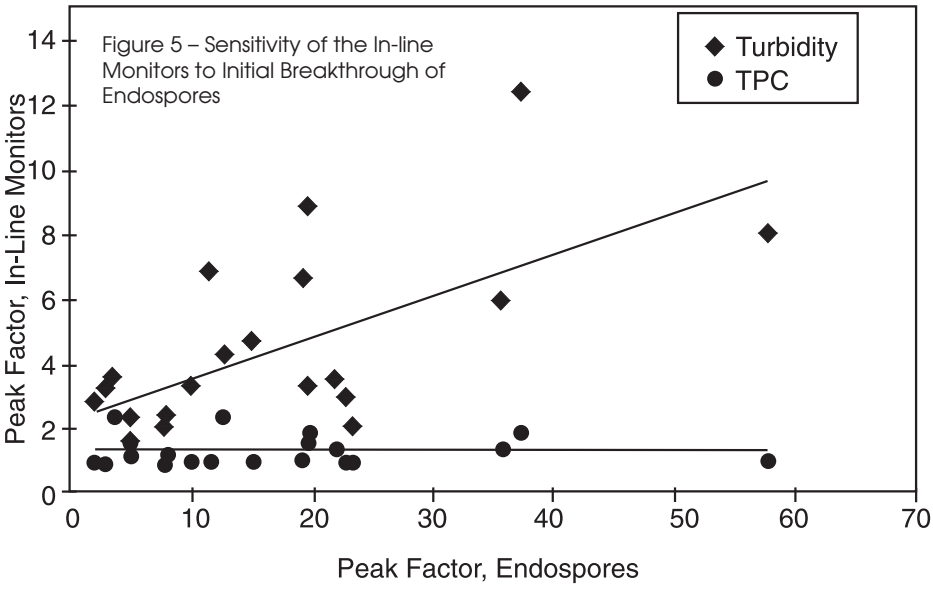
Hargesheimer et al. (1992) report that particle counting is more sensitive than turbidity in indicating particle breakthrough in filters. However, the experimental data reported show only instances of particle breakthrough occurring at the end of a filtration cycle after an extended period of filtration. Researchers and water treatment plant operators must realize that the differences between this phenomena and the initial degradation in effluent quality at the onset of filtration. After extended period of operation, the pore space in the filter is reduced by the accumulation of solids.

Breakthrough results from passage of particles through the filter due to increased pore velocity or breaking off of previously captured particles. Initial breakthrough results from backwash remnant water and clean bed filtration conditions. Sensitivity of particle counts to the former does not necessitate sensitivity to the latter.

The lack of agreement of total particle counts and turbidity may be due to the limitation of the particle counter's lower size limit of detection of 2 µm. Sethi et al. (1996) demonstrated that for particle size distributions with a higher proportion of smaller particles, such as a power law size distribution with a slope coefficient (ß) of 4, the majority of the turbidity would be due to the response of sub-micron particles. The particle counter is unable to detect smaller sub-micron particles.

If the initial effluent contains a high proportion of smaller particles, turbidity and particle results will likely not correlate well. Hargesheimer et al. (1992) characterized the particle size distributions in initial filter effluent and found that ß was elevated compared to the later periods of stable operation.





Sensitivity of In-line Instruments to Initial Breakthrough of Microbes

For the RS filter, initial spore levels were produced in excess of that of the corresponding filter run's stable effluent by a factor of 2 to 22. For the HRDBA filter, spores varied in excess of the stable effluent by a factor of 3 to 58. One method to evaluate the sensitivity of the on-line monitors is by comparison of the corresponding peak factors of these two optical detection methods. The ideal on-line monitor would exhibit peak measurement values in proportion to that of the microbial parameters, alerting treatment plant operators and managers to a potential threat in real time.

The peak factors of turbidity and TPC are compared to that of initial effluent spores in Figure 5. A similar plot comparing the performance of the on-line monitors with respect to heterotrophic plate counts is also presented in Figure 6.

As shown in Figure 5, the maximum in-line turbidity measurements relative to that exhibited by stable filter operation consistently vary proportionally with elevated effluent endospore levels. Thus the turbidimeter is apparently more sensitive to breakthrough of endospores than is the particle counter used in this study. The relation is always less than 1:1 such that spore breakthroughs in excess of stable operation 10 fold do not produce a corresponding 10 fold increase in turbidity response. The particle counter is apparently insensitive to the penetration of spores. As shown in Figure 6, both the turbidimeter and the particle counter seem incapable of providing an indication of breakthrough of heterotrophic bacteria.

Correlation of Initial Effluent Microbial Parameters to Optical Parameters

In this analysis the initial effluent of the filter has been arbitrarily selected as the first 125 gal/sf of production. This corresponds to a period of time less

than 50 and 25 minutes for the RS and HRDBA filters, respectively.

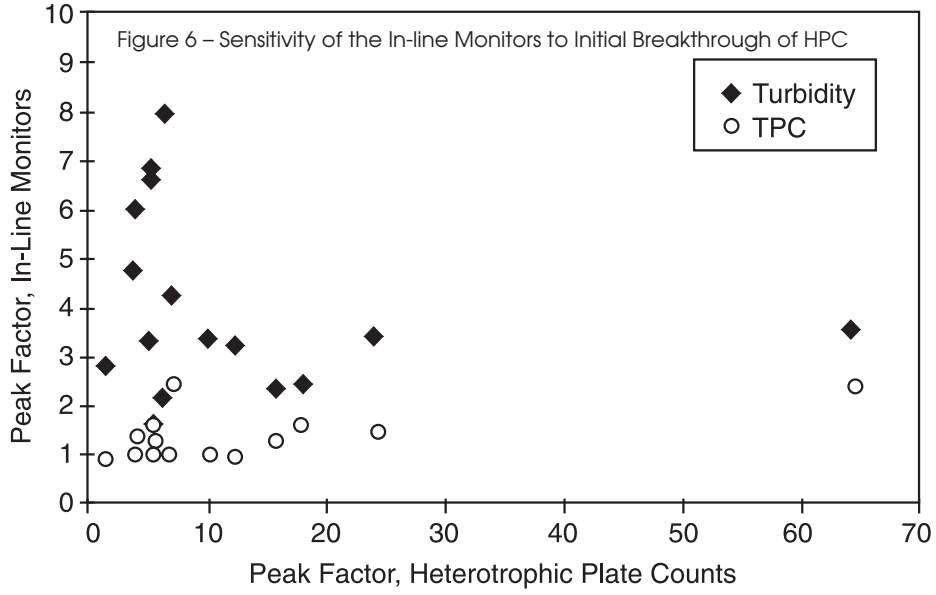
Monitoring data for initial effluent turbidity and TPC are compared to measured levels of spores and heterotrophic plate counts. Since spores must be considered relative to that of the source water (settled), normalized spore concentrations are utilized.

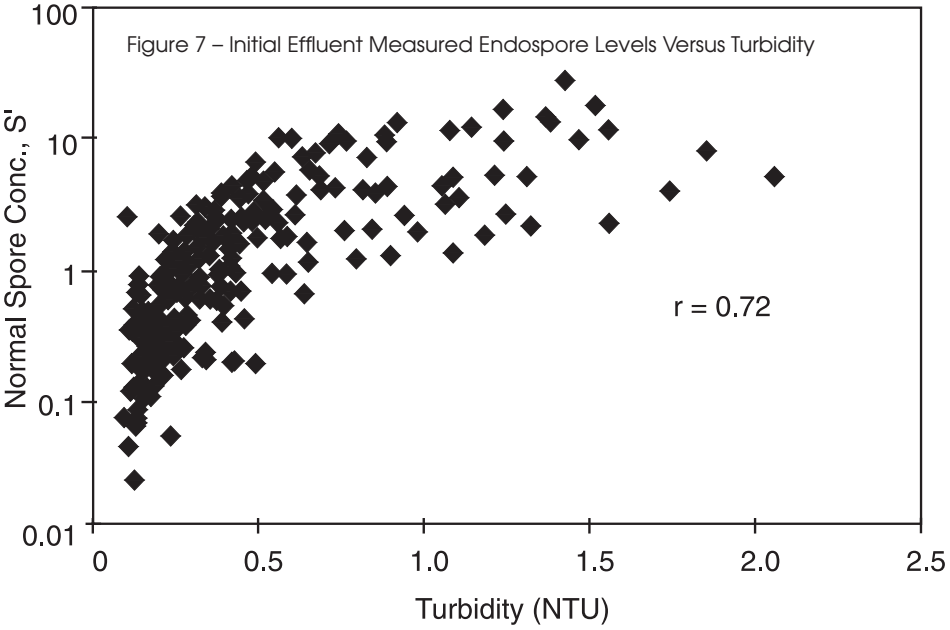
In the course of the investigation, extensive data were collected over a wide range of conditions affecting initial breakthrough. A total of 363 data points were collected involving the simultaneous characterization of spores, turbidity, and particle counts in the initial 125 gal/sf of production water. Likewise a total of 287 data points were accumulated for heterotrophic plate counts. This provides a sufficient population from which the correlation can be assessed.

The combined data from both filters were used to calculate coefficients of correlation (r) between the optical measurements and the microbiological parameters. The results of the statistical evaluation are summarized in Table 2.

It can be seen that turbidity provided the strongest relation to spores (normalized) in the initial effluent water. A plot of the initial effluent turbidity versus spores is also provided in Figure 7. From the correlation coefficient of r = 0.72, 52% of the variability of the endospore levels can be explained by changes in turbidity. Total particle counts seemed to have little correlation with the relative levels of endospores in the initial effluent water. The corresponding relationship for total particle counts versus endospores is shown in Figure 8.

No appreciable correlation between turbidity and HPC and TPC and HPC was found. Both optical methods were incapable of serving as a surrogate indicator for the presence of heterotrophic colony forming units. It is interesting to note that measured bacterial counts of initial effluent water (cfu/mL) frequently exceeded the measured total particle counts (cts >2 µm/mL). A HPC versus TPC semi-log plot has been provided in Figure 9. In the graph a solid line represents 1:1 relationship. Out of 286 data pairs, there were 137 instances in which HPC actually exceeded the total particle counts>2µm. The lower size limit expected for bacterial flocs is reportedly





0.5 µm (James M. Montgomery Consulting Engineers: 1985). Apparently many bacterial flocs passing the filters were of size below the lower size limit of detection of the particle counter. The turbidimeter can detect the combined presence of smaller sub-micron particles. However the turbidimeter measurements were also poorly correlated with HPC levels in the initial effluent. This might result from the low refractive index of biological particles (estimated as $m_w \approx 1.05$) compared to those of mineral composition ($m_w \approx 1.50$), which greatly reduces the nephelometric turbidity response as demonstrated by Sethi et al. (1996).

Since endospores average 1-2 µm in diameter, the particle counter likely can not detect the actual endospores, as the spores would be indistinguishable from background noise to the sensor.

It is acknowledged that results may be specific to the season in which testing was conducted, the specific treatment plant, and the types of turbidimeter and particle count sensor employed. Differences in design specifications have been shown to provide significant differences in turbidimeter response (Sethi et al., 1996; Hargesheimer et al., 1992). Likewise different particle count sensors, employing different principles of operation produce or exhibiting differences in resolution will produce highly variable results with respect to both

Table 2. Correlation Coefficients: Optical Parameters Versus Microbes

Parameter	Normalized Endospores S[1]	Heterotrophic Plate Counts, HPC (cfu/mL)
Turbidity (NTU)	0.72	0.08
Total Particle Counts >2 µm,		

sizing and count information (Sethi et al.: 1996).

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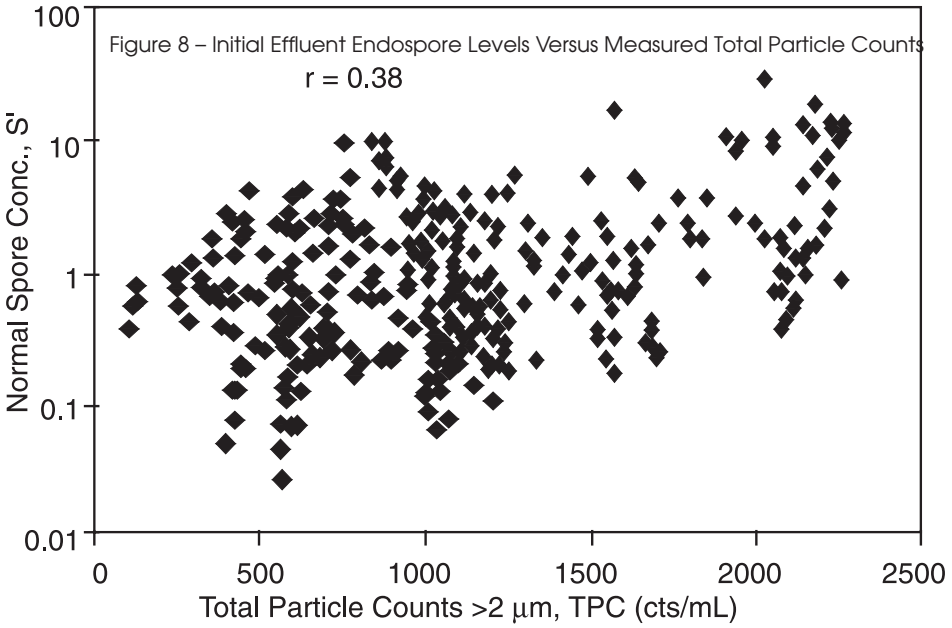

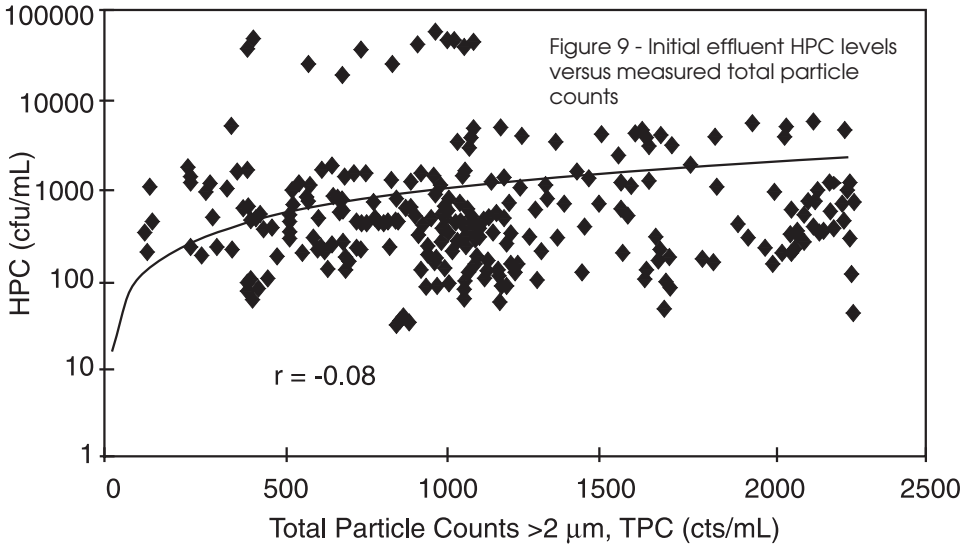

FWEA Focus *from Page 22*

Access to WEF experts — If you have a question about a process, an operations problem, or a new product, you can contact other water quality professionals through the WEF Website. WEF has over 100,000 members in 77 member associations in 31 countries. Therefore, you have thousands of resources at your fingertips, and it's likely that someone will have experience with almost any problem or issue you might encounter.

Networking Opportunities — You can meet and get to know other professionals in our industry. If you are in the utilities business, such contacts can be helpful in learning about how others approach specific operations or management issues. If you are a consultant or vendor representative, such contacts can be invaluable for developing new business.

Leadership Development — By participating in one of FWEA's committees, local chapters, or student chapters you can gain valuable experience in organizing and leading committees, which will enhance your leadership capabilities and your professional standing.

Friendships — Even though I'm listing this one last, I think it's one of the greatest benefits of getting involved in FWEA. Participating in FWEA committees and local chapters is a great way to meet some fantastic people. I have had the opportunity to become friends with some great people that I wouldn't have otherwise even met.

I'm sure that you have other benefits you can add to this list. The important thing is that we tell other potential members about the benefits of membership in FWEA and WEF. I can personally attest to the value of my involvement in FWEA in my professional growth and development over the years. I recommend it to everyone who has an interest in preserving and protecting Florida's water environment. If you have any thoughts or suggestions on other benefits of participating in FWEA, please send them to me at mike.cliburn@jacobs.com. I would like to hear from you. ■