Pennsylvania's filtration evaluation program

By identifying weaknesses and optimizing treatment, Pennsylvania has greatly improved performance at its surface water plants.

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Pennsylvania's Department of Environmental Protection (DEP) initiated a statewide filter plant performance evaluation (FPPE) program for safe drinking water and completed 506 FPPEs at 290 surface water treatment plants. Only 39 percent of the plants were rated "acceptable" for performance at the program's inception in 1988, but by 1996 the percentage had increased to 91 percent—demonstrating that assistance to these systems could lead to successful improvements and decreased risks from waterborne protozoa. The percentage of positive *Cryptosporidium* (presumptive) samples of the finished water dropped from 35 percent in 1990 to <5 percent in 1996. Positive *Cryptosporidium* samples have remained below 5 percent in the last five years. The 90th percentile of particle count data showed a postfiltration count of 50/mL in the 3- to 18-µm size range as the threshold for acceptable performance. Because optimized performance is a goal of the FPPE program, the concentrations of 3- to 18-µm particles should remain below 10/mL to minimize breakthrough of pathogenic protozoa. The DEP considers turbidity of <0.1 ntu from each filter as a more optimum level of filter plant performance.

Pennsylvania has greatly improved drinking water quality through an ongoing evaluation program for surface water treatment plants. The goal of the program is to optimize plant performance in a state that once led the nation in the number of waterborne disease outbreaks.

The program's necessity was made obvious during the late 1970s and early 1980s, when hundreds of thousands of Pennsylvania residents suffered—either through illnesses, boil-water advisories, or water use restrictions—from waterborne giardiasis outbreaks that directly affected several major communities. That began to change in 1984, when the Pennsylvania General Assembly passed the Safe Drinking Water Act, which authorized the state's Department of Environmental Protection (DEP) to ensure that treatment facilities delivered safe and reliable water to consumers. When the giardiasis outbreaks occurred in succession, the DEP became especially

PHOTOS: PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Bill Loy (forefront), an operator at the Altoona Horseshoe Curve plant, explains to Don Greenfield how a reactor clarifier performs under various water quality conditions.

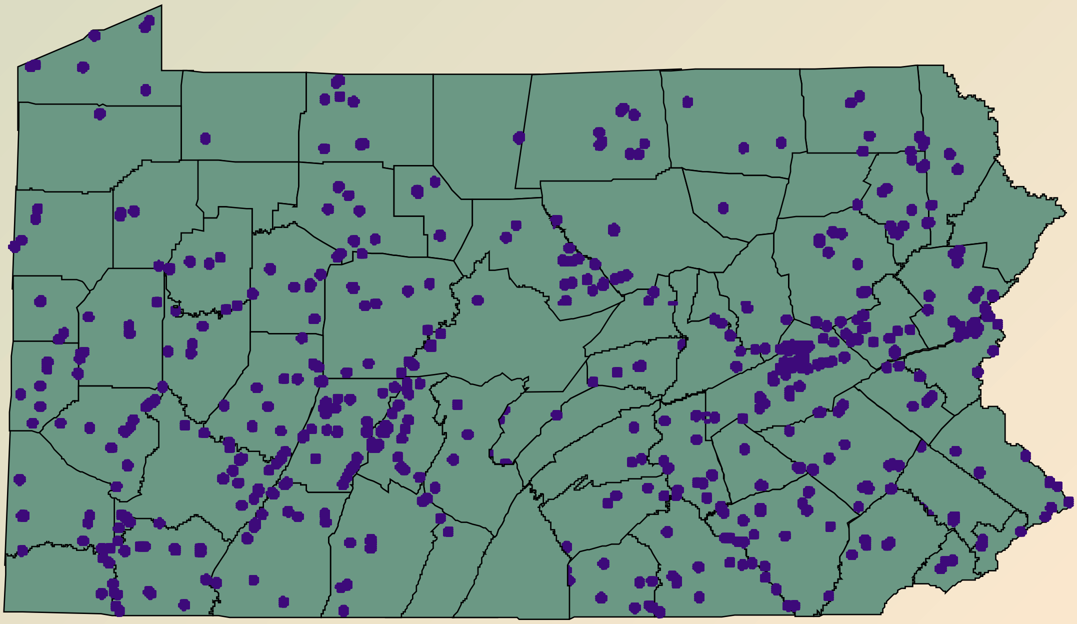
concerned about acute health threats from protozoa, bacteria, and viruses in drinking water supplies*. In fact, adoption of Pennsylvania's mandatory surface water filtration regulation caused a dramatic decline in risks from waterborne giardiasis and cryptosporidiosis.

For example, the number of public water systems using unfiltered surface water sources decreased from 277 in 1985 to fewer than 30 in 1996. Conversely, the state's surface water treatment plants increased from 204 in 1988 to the current level of 320 plants (Figure 1). Fewer than 20 percent of the state's plants were built before World War II. No doubt this investment in water system facilities has enhanced the safety of drinking water by reducing the public's exposure to organisms resistant to disinfection, such as *Giardia* and *Cryptosporidium*.

Today, surface water treatment plants provide water to more than 8 million of Pennsylvania's 12 million residents. Twenty treatment plants (6 percent) serve

*Visit DEP's web site at http://www.dep.state.pa.us (see "information by subject," then "water management" and "water supply management").

FIGURE 1 Locations of surface water treatment plants in Pennsylvania



≥100,001 people; 85 (27 percent) serve between 10,001 and 100,000 people; and 71 (22 percent) serve between 3,300 and 10,000 people. The remaining 144 plants (45 percent) provide water to fewer than 3,300 people. Eighty-four of the 320 filter plants are investor-owned, and 236 are municipally operated. Fifty-four percent of the plants use conventional treatment processes, 23 percent use package treatment systems, 13 percent have direct filtration facilities, 8 percent use slow-sand technology, and the rest use diatomaceous earth or other types of filtration. These facilities obtain raw water from reservoirs or lakes (42 percent), rivers (26 percent), and streams (29 percent).

Since 1988, the DEP has conducted detailed evaluations of the state's surface water treatment plants. The ongoing filter plant performance evaluation (FPPE) program is a way to determine a plant's effectiveness in removing pathogens and pathogen-sized particles from incoming raw water. The evaluation includes an on-site survey of filter plant operations and general physical conditions and in-line turbidimeter and particle counter instrumentation. It also involves sampling raw and filtered water for laboratory evaluation. Although FPPEs capture a snapshot of filter plant performance, they also entail review of monitoring records to gain a long-term picture. Pennsylvania is one of only a handful of states conducting these types of extensive filter plant evaluations.

In the FPPE process, DEP staff members rate the plants as acceptable or unacceptable for their ability to remove pathogenic protozoa. Each rating is based on a structural and operational survey, water quality data, and the microscopic laboratory evaluation. The purpose is to determine whether facilities and operating practices are sufficiently reliable to deliver water of acceptable quality to consumers. The evaluations also provide technical assistance for improving the plant's performance.

Two central office staff members specialize in surveying the water treatment process. Each is assigned about half of Pennsylvania's 320 surface water treatment plants. The DEP's regional technical staff and some county health department employees pursue improvements at the facilities via inspections and followup support. The specialized teams finish about 60 evaluations each year.

The following information provides a summary of evaluation tools and findings from 506 FPPEs at 290 filter plants over nine years.

FIGURE 2 Sample results form for the microscopic particulate analysis of filter plant influent and effluent

Microscopic Particulate Analysis

Public water supply: ABC Water Co. **ID:** 4140084
Filtration system: Conventional
Collector: Don Greenfield **Received date, time:** 8/13/96, 9:00a.m.

Raw Water		Finished Water	
Sample number:	1731103	Sample number:	1731104
Sample location:	Phillips Creek	Sample location:	Filter 2
Date collected:	8/12/96	Date collected:	8/13/96
Gallons:	350	Gallons:	960
Temperature:	14°C	Temperature:	14.6°C
Turbidity:	1.1 ntu	Turbidity:	0.03 ntu
Total sediment volume:	1.4 ml	Total sediment volume:	0.01 ml
Size range:	0–500 µm	Size range:	0–30 µm
		Free chlorine:	0.3 mg/L

Particulate debris observed

Inorganic amorphous debris, algae (unicellular and filamentous) diatoms, protozoa, fungal elements pollen, plant debris

Quantification—particulate debris*

Fine particle debris:	1+		
Giardia-sized debris:	1+		
Large particle debris:	1+		
Cellular debris:	0		
Diatoms:	0	Algae:	0
Rotifers:	0	Protozoa:	0
Nematodes:	0	Crustacea:	0
Insects:	0	Other:	1

Raw Water		Finished Water	
Giardia:	5 verifiable cysts	*Giardia*†:	No cysts seen
Cryptosporidium:	4 oocysts	*Cryptosporidium*‡:	No oocysts seen

Filtration performance rating: 1 — 1 = acceptable; 2 = unacceptable

Comments:

Analylzed by R.L. Diehl **Date of analysis:** 8/16/96

**Quantification figures based on a 300-gal sample.*
†Giardia *cyst identification is based on size, shape, and at least two identifiable internal structures.*
‡Cryptosporidium *oocysts are considered "presumptive" unless noted.*

Evaluators collect information on facility design, operation, and process control

Inspection focuses on critical stages of treatment. An FPPE usually requires a full day or a day and a half to complete. DEP staff members obtain information about the facility and review overall operation and treatment processes to detect any operational and plant deficiencies. The inspection focuses primarily on the more critical stages of treatment, including chemical pretreatment, filter operation, and features of the filter run and backwash. The sidebar on page 70 lists questions the evaluation team asks during the on-site review. The questions can be adapted to any treatment scheme.

FPPE Questions Encompass Facility, Processes, and Storage

Facility. What are the age and general physical condition of the facility? What are the design flow capacities of individual major unit processes?

Chemical pretreatment and process control. How does the operator adjust and confirm proper chemical dosages (e.g., does the operator check and calibrate the chemical feed equipment often enough)? What tests do the operators use (e.g., jar tests, streaming current monitors), and how often do they conduct the tests? Can the operator easily calculate the dosages and understand proper math and conversions?

Process monitoring. Where does the operator collect water quality information in the plant? Are the water quality parameters appropriate for the unit process? Does the operator use information obtained from these tests to ensure optimization of each major unit process?

Floc characteristics and settling. Does sedimentation occur where intended for the type of facility? Is sludge removal frequent enough to prevent short-circuiting? Is the sedimentation effluent (settled water turbidity) consistently less than 2.0 ntu throughout the year and no greater than 5.0 ntu, despite fluctuations in raw water turbidity?

Filter runs. Is the filter effluent turbidity from each filter consistently less than 0.1 ntu throughout the year, despite variability of the raw or settled water turbidity? Does the operator consider all three criteria (turbidity, head loss, and time) when establishing backwash timing? Do frequent startups occur on dirty filters?

Backwash. During a wash, does the operator ensure thorough cleaning of the filter media, adequate flow rates and media expansion, and lack of dead spots or boiling? Does backwash wastewater recycling to the head of the plant affect overall performance?

First run. How does the operator minimize turbidity breakthrough when placing a filter back into service? Is the filter-to-waste (rewash) time adequate? Is the magnitude of the postbackwash turbidity spike less than 0.2 ntu, and is its duration less than 20 minutes?

Filter evaluation. Is the surface of the filter media free of mounds, cracks, and mud? Are the effective size, uniformity coefficient, and weight loss percentage within specifications?

Disinfection. Do $C \times T$ levels meet criteria established in Pennsylvania's Filtration Rule and the US Environmental Protection Agency's guidance manual for surface water systems?

Monitoring equipment. Is the proper in-line and benchtop equipment available and calibrated for accurate water quality monitoring?

Water storage. Is adequate storage available?

The evaluator also obtains details about process control. Emphasis is placed on the operator's ability to accommodate various raw water conditions—e.g., does he or she properly adjust coagulants in response to high raw water turbidities? In addition, the evaluator determines whether operators consistently optimize all major processes (e.g., flocculation, sedimentation, filtration, and disinfection).

The operator's water quality monitoring program is also important. Do personnel check appropriate water quality parameters at various points in the treatment scheme? Ultimately, the evaluator must carefully assess the operator's process control capabilities not only during the FPPE but during seasonal or other events that change raw water quality.

Sampling and analytical procedures described. During FPPEs, DEP staff members collect at least two high-volume samples using a plastic housing, a 1-µm (nominal) filter, a garden hose, and a water meter. The raw water sample usually contains 300–1,000 gal (1.3–3.8 m^3); the finished water sample includes 600–1,000 gal (2.6–3.8 m^3).The flow rates through both samples are usually about 1 gpm (0.07 L/s) or less. The preferred sampling point for finished water is immediately after one of the plant's filters to include all phases of the filter run.

Samples arrive at the laboratory within 24 hours in double bags packed in ice. Laboratory staff process the samples within 48 hours after collection and use a fluorescent antibody technique to analyze for *Giardia* and *Cryptosporidium*. Microscopy includes differential interference contrast to confirm protozoa. In many samples, the microscopists examine the entire pellet for the presence of *Giardia* cysts and *Cryptosporidium* oocysts. Overall, the DEP's analytical procedures for protozoa are similar to those outlined in the Information Collection Rule, except that the well slide method is used rather than the membrane filter method.

Laboratory workers conduct a microscopic particulate analysis of the finished water to evaluate filter plant performance. This analysis includes semiquantification of organic and inorganic categories (Figure 2). The microscopist assesses several specific groups of particles and microorganisms including fine particulate debris (1–5 µm, or *Cryptosporidium*-sized), *Giardia*-sized debris (6–19 µm), large debris (20–>100 µm), cellular plant debris, diatoms, algae, other protozoa, insects, crustacea, nematodes, and rotifers. They score the debris amounts as follows: none (0), rare (1+), few (2+), moderate (3+) and many (4+). The procedure is not fully quantitative and does not represent the filter plant's percentage (log) removal capabilities.

The laboratory defines acceptable filter plant performance as the presence of *Giardia*-sized or other large-diameter particles and organisms in concentrations at no more than the 2+ level. Acceptable filtration performance ratings therefore do not entail 100 percent removal of all particles or organisms. Ratings of 3+ or 4+ for one or more of the particulate groups result in an unacceptable filtration performance rating.

The microscopic particulate analysis is not the single deciding factor of filter plant performance but is one component that assists the evaluator in determining performance. Other components are a comprehensive survey of plant operations, structural conditions, and water quality data.

FIGURE 3 Annual results of filter plant performance evaluations (1988–96)

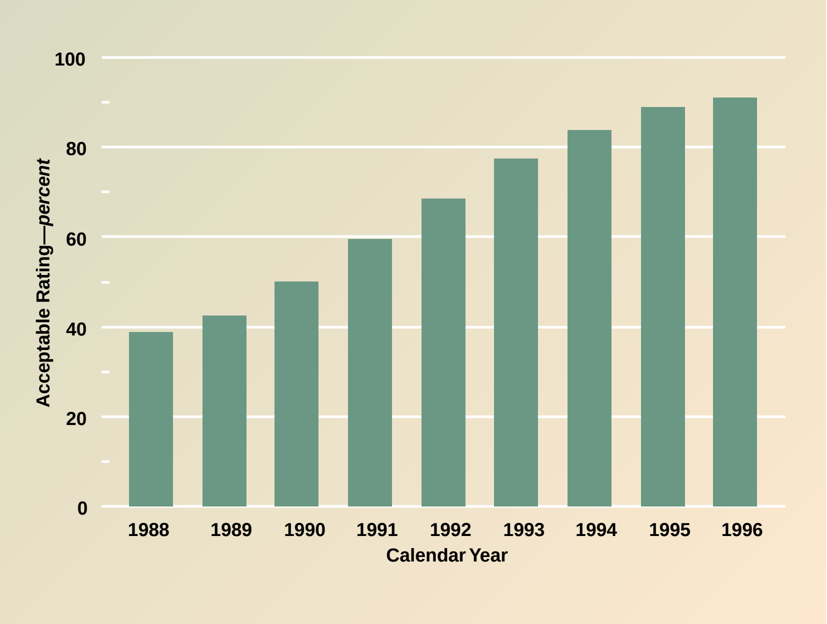
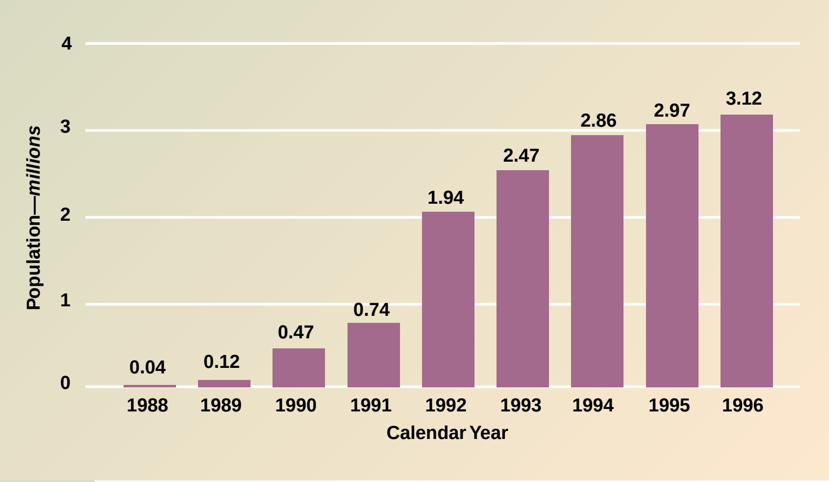


FIGURE 4 Cumulative population benefits from improved filter plants



During the FPPE sampling period, the evaluator connects an in-line turbidimeter and particle counter at the finished water sampling point (filter effluent) to obtain turbidity and particle count profiles. Particle size ranges include 3–18 µm, and results appear as counts per millilitre. Flow rates through this light-obscuration model remain near 70 mL/min (±10 percent). A laptop computer continuously records all turbidity and particle count data. In most cases, these information profiles contain up to 24 hours of data. Eventually, DEP staff members graph the trends in followup reports.

Training and pilot evaluations precede fully operational program. From a program management perspective, the FPPE program began in Pennsylvania in 1987 with training and pilot evaluations. In 1988, the evaluation team completed 77 FPPEs. In 1996, the goal was 60 FPPEs. Today, two employees continue to conduct the evaluations and prepare final reports.

While developing this program, Pennsylvania enjoyed an advantage because the DEP maintained a fully equipped laboratory and two trained microscopists to analyze for *Giardia*. This resulted in minimal training and expenses to upgrade the laboratory for conducting microscopic particulate analysis on 110–140 samples per year for the FPPE program. During maturation of the program, other related initiatives such as technical assistance, a newer expanded evaluation program, and a *Cryptosporidium* response strategy have reduced the FPPE program to about 1.4 full-time employees. As always, the DEP's inspection staff and other compliance assistance personnel

FIGURE 5 Filter effluent turbidity levels during filter plant performance evaluations

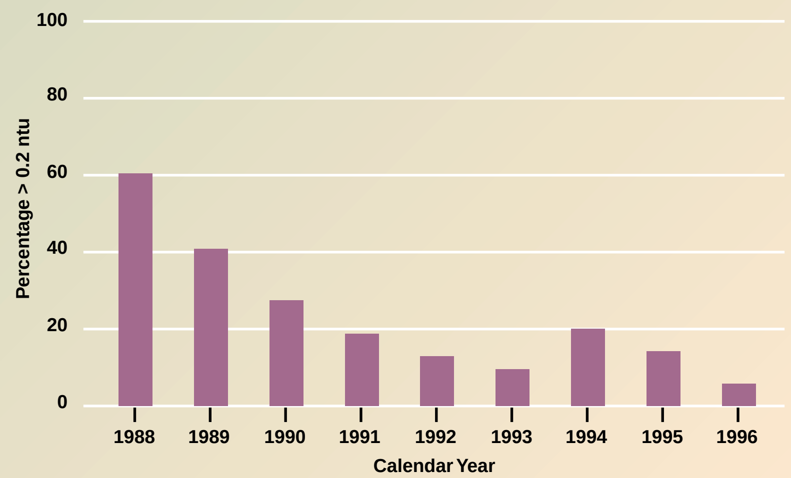
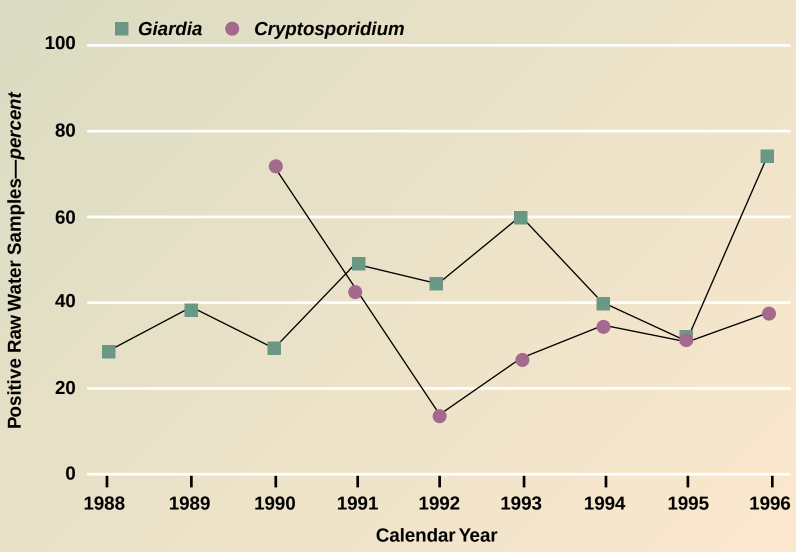


TABLE 1 Total samples collected for Giardia and Cryptosporidium analysis*

Sample Location	Year								
	1988	1989	1990	1991	1992	1993	1994	1995	1996
Raw water	77	56	60	69	64	65	65	54	66
Finished water	77	56	60	69	64	65	69	59	66

*No samples were collected for *Cryptosporidium* analysis in 1988 and 1989; 1990 included 43 samples

FiGURE 6 Annual percentages of Giardia-positive raw water samples collected during filter plant performance evaluations



provide assistance and followup support for the FPPE program as part of their normal duties.

Program improves performance, highlights difficulties

Strong improvement trend seen. Since the FPPE program's inception in 1988, the percentage of acceptable performance ratings has more than doubled, reaching a high of 91 percent in 1996. Figure 3 shows a strong trend of improving filter plant performance in the state. Furthermore, nearly 100 filter plants serving more than 3 million people have been upgraded from unacceptable to acceptable as a result of Pennsylvania's effort to improve water system performance (Figure 4). Water systems have achieved these improvements largely through operational changes and some facility renovations. To foster these changes, the DEP has cooperated with the majority of the filter plants and has implemented several innovative assistance programs. These efforts include the Small Water Systems Outreach Program, the Comprehensive Performance Evaluation Program,[1] and a low-interest loan program through the Pennsylvania Infrastructure Investment Authority (PENNVEST).

In addition to the increase in acceptable performance ratings, Pennsylvania's finished water turbidity levels are dropping. During an FPPE, evaluators determine an average finished water turbidity with the DEP's in-line turbidimeter. Through the years, achieving a turbidity of 0.2 ntu has become more commonplace. In 1988, 60 percent of the evaluated filter plants produced water with turbidities >0.2 ntu. By 1996, only 4 percent of the evaluated plants were providing high-turbidity water (>0.2 ntu) to their customers.

Figure 5 shows a year-by-year bar graph of the finished water turbidities that were >0.2 ntu during FPPEs.

The DEP considers turbidity of <0.1 ntu from each filter to be an optimum level of filter plant performance. At the most, plants (other than those using slow sand or diatomaceous earth technologies) should not produce water >0.2 ntu. These performance criteria are goal-oriented and are necessary to protect consumers against waterborne pathogens. An earlier FPPE study[2] involving 194 evaluations confirmed this turbidity threshold. When the DEP measured effluent turbidity at 0.2 ntu or less, 68 of 114 filter plants (60 percent) were acceptable. At 0.3 ntu or more, though, only 9 of 80 (11 percent) were acceptable.

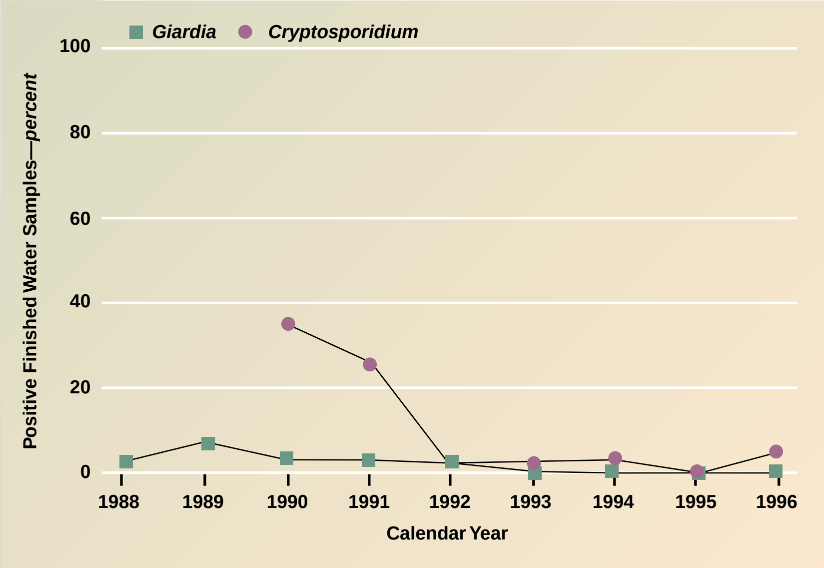
Everett Smeltzer operates a filter flow control valve at the Wrightsville water plant during a filter plant performance evaluation.

No matter how good a water system's performance is, the utility should continuously strive to enhance filter plant performance.

Ten common problems identified. Because the team reevaluated numerous plants, some as many as four times, the total number of FPPEs equaled 506. During the surveys, the evaluators characterized the major problems and compiled results in a database of performance-limiting factors. Beginning with the most commonly cited factor, the following list contains the top 10 problems noted:

- ***Inadequate jar-testing or lack of other coagulant control strategy***. This could involve the operator's ability to prepare stock solutions, calculate chemical dosages, or duplicate full-scale plant performance with jar tests. It might also involve the operator's ability to interpret information from a streaming-current monitor or from historical performance data (e.g., turbidity, pH,) to optimize the plant. This indicates that chemical pretreatment adjustments involve considerable guesswork.
- ***Inadequate rapid mixing process***. This involves the lack of static or mechanical rapid mixers. Although common, this factor may not have a substantial impact on plant performance unless the plant uses a destabilization (low-dosage) coagulation process.
- ***Lack of individual filter effluent monitoring***. This involves the lack of in-line turbidimeters and recorders to determine continuous performance of each filter. This factor limits the operator's ability to understand the effects of filter flow rate changes, proper filter run time between backwashes, or adequate filter-to-waste duration.
- ***Inadequate or lack of a filter-to-waste (rewash) process***. In this case, piping, valves, and appurtenances are not available to initiate filter-to-waste after a backwash, or undersized pipes prevent the filter-to-waste flow rates from matching the normal production rates. Also, the operator either does not use filter-to-waste long enough or chooses not to use it at all. A filter-to-waste process is usually critical for eliminating postbackwash turbidity spikes that may contain protozoa and other pathogens.
- ***Turbidimeters not calibrated***. In-line or benchtop turbidimeters are inaccurate. In some cases, the operator does not understand the calibration procedures. In other situations, the primary standards, glassware, and other items are not available to calibrate the instruments. Turbidimeter accuracy is essential, considering that turbidity is the most common surrogate for determining filter plant performance.
- ***Improper chemical dosages***. This involves the operator's inability to optimize coagulant dosages during changes in raw water quality characteristics. The operator may lack basic understanding of water treatment or lack mathematics skills to calculate chemical dosages. Other problems may include a lack of cali-

FIGURE 7 Annual percentages of *Giardia* and *Cryptosporidium*-positive finished water samples collected during filter plant performance evaluations



bration columns to determine output of the chemical feed pumps or a chemical feeder that is not sized to accommodate the desired range of doses. Proper chemical pretreatment is the most important factor influencing *Giardia* and *Cryptosporidium* removal.[3]

• ***Inadequate operation and maintenance knowledge***. This more general problem involves the operator's knowledge about water treatment chemistry, mathematics skills to calculate flow rates or chemical dosages, operation of benchtop instruments, or maintenance of filter plant equipment. An operator with inadequate knowledge is quite different from one who is unwilling or not motivated to properly control filter plant processes.

• ***Starting up dirty filters***. This problem occurs in plants that do not operate 24 hours a day. In part-time operations, filters are often placed into service even though they have not undergone a backwash. This can lead to on-line turbidity spikes—a dangerous risk indicator of breakthrough if the dirty filter media contain protozoa.

• ***Inadequate process monitoring***. This involves improper measurement and recording of water quality parameters, inadequate monitoring frequency, or insufficient sampling locations. Also, this factor includes the operator's ability to correctly interpret and apply the monitoring results. A poor process monitoring program will prevent the operator from determining whether each major unit process is consistently performing at peak efficiency.

• ***Using filter run time as the only criterion for initiating a filter backwash***. In this case, filters are not equipped with head-loss gauges and in-line turbidimeters, so the operator initiates a wash at a standard frequency (e.g., every 72 h). A filter without head-loss and effluent turbidity data can lead to undetected particle breakthrough at the end of a filter run.

Cryptosporidium and Giardia results provide guidance for improvements. With careful interpretation, the results of *Cryptosporidium* analysis provide another gauge of improving filter plant performance in the state. The number of collected water samples remained between 54 and 77 each year (Table 1). Figure 6 indicates that the annual percentage of raw water samples positive for *Giardia* fluctuated from 27 to 60 percent between 1988 and 1996. Positive *Cryptosporidium* samples fluctuated from 14 to 74 percent between 1990 and 1996. These percentages are slightly lower than the results of other Pennsylvania studies that focused on river sources with large watersheds.[4,5] Conversely, Figure 7 shows that the percentage of finished water samples positive for (presumptive) *Cryptosporidium* dropped dramatically from 35 percent (1990) to less than 5 percent in 1996. Positive identifications of *Cryptosporidium* have remained below 5 percent in the past five calendar years. The percentage of finished water samples positive for *Giardia* has remained less than 7 percent since 1988.

In January 1994, microscopic analysis progressed from a presence–absence *Cryptosporidium* designation to concentrations expressed in oocysts/100 L. In 63 positive raw water samples, *Cryptosporidium* concentrations ranged from 0.035 to 100 oocysts/100 L. *Giardia* concentrations in 49 positive samples ranged from 0.038 to 11.4 cysts/100 L. The geomet-

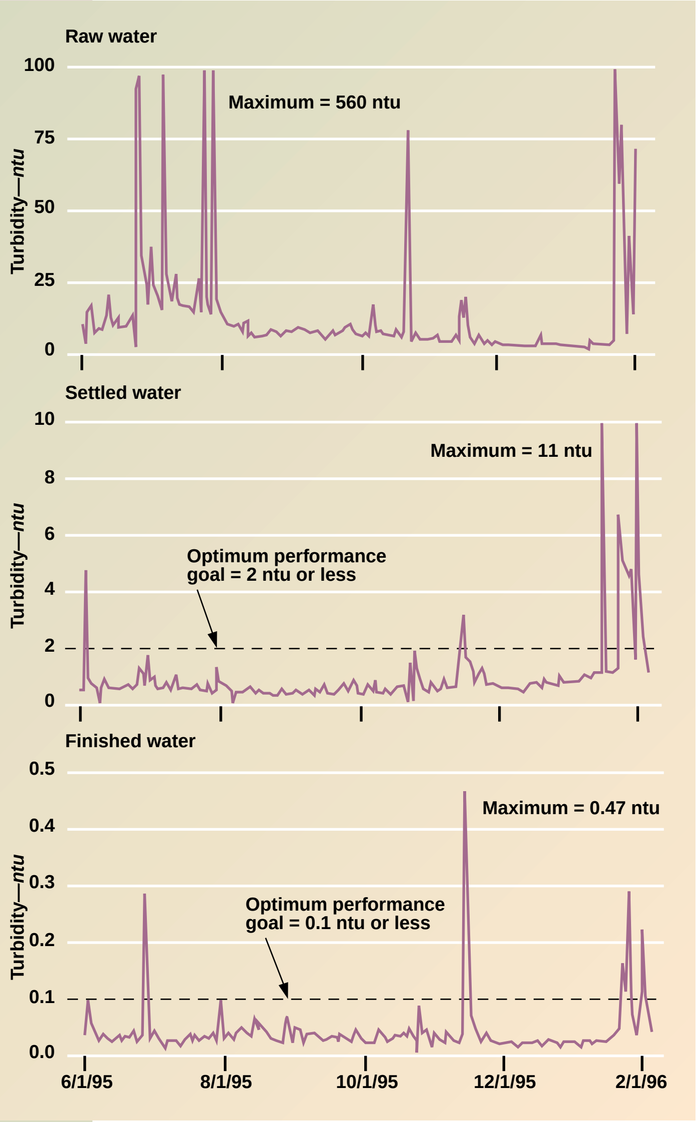
Nearly 100 filter plants serving more than 3 million people have been upgraded from unacceptable to acceptable as a result of Pennsylvania's effort to improve water system performance.

ric means of the positive raw water concentrations for *Cryptosporidium* and *Giardia* were 0.58 and 0.53/100 L, respectively.

Since 1994, laboratory staff identified only five of 194 finished water samples as positive for *Cryptosporidium*. Two of these samples had densities of 0.02 oocysts/100 L, and the other three had concentrations of 0.04, 0.07, and 0.75 oocysts/100 L. Laboratory staff have not identified any *Giardia* cysts in finished water samples for the past three years. These concentrations are lower than in some national studies. Differences in organism densities may relate to the multiple locations from which the samples were taken around the state, the number of source waters with more isolated watersheds, or the sensitivity of the protozoa analysis.[6]

The DEP is well aware of the controversy surrounding protozoa analysis. The uncertainties inherent in *Cryptosporidium* sampling and analysis certainly warrant caution regarding interpretation of the results. The Pennsylvania Departments of Health and Environmental Protection have developed a *Cryptosporidium* action plan[7] and an information package to provide guidance on risks from *Cryptosporidium*. Essentially, the DEP does not expect water systems to produce sterile water. Rather, the Department of Health is undertaking efforts to educate immunocompromised people (e.g., people with AIDS, people receiving chemotherapy for cancer or to prevent rejection of transplanted organs, and those with any other illness that weakens the immune system). These people are susceptible to chronic diarrhea and even death as a result of cryptosporidiosis. They should understand options to further reduce their risk of cryptosporidiosis.

FIGURE 8 Turbidity of raw, settled, and finished water in filter plant A



Particle count information provides valuable tool. The DEP added in-line particle count instrumentation to the FPPE procedure in October 1994. Because of heavy organic loading in most Pennsylvania source waters, the evaluators were concerned about accurate, usable raw water particle counts at the filter plants. Raw water counts can often exceed the upper limit of the instrument or lead to a high coincidence error. However, DEP staff members collected particle count and turbidity profiles of the filter effluent at 85 plants. With use of the 90th percentiles of the data, the particle count information provided an additional valuable tool to determine optimized performance. The most helpful data related to the approximate protozoa particle size ranges of 3 to 18 µm.

For example, at plants with overall ratings of acceptable, the 90th percentiles ranged from 0.11 to 456 particles/mL, with an average of 33/mL. On the other hand, the finished water at plants rated unacceptable contained from 152 to 1,536 particles/mL and averaged 510/mL. Initial assessment of this data suggests a postfiltration count of 50 particles/mL in the 3- to 18-µm size range as the threshold for acceptable performance. If a filter produces water containing more than 50 particles/mL in that size range, the evaluator sees a caution light and pursues the possible reasons for these high particle concentrations. Because optimized performance is a goal, particle concentrations should remain below 10/mL to minimize breakthrough of pathogenic protozoa.

Although counts <50 particles/mL appear to correlate with sound filter plant operation and acceptable ratings from microscopic particulate analysis, particle count technology is still in its infancy in the drinking

Don Greenfield (left) watches Tim Biseli, an operator at the Altoona Horseshoe Curve plant, initiate a filter backwash from the control panel.

water community. It would be difficult to compare results from counters made by different manufacturers and from instruments that use differing technologies and may undergo various calibration practices. The evaluation team's results are based on a consistent use of identical models, comparable sample points, and similar calibration practices, thus supporting the validity of the 10/mL in-house optimization criterion. Utility staff members should establish site-specific criteria because of variations in particle counter models and possibly even sensor-to-sensor dissimilarities. More important, they should determine a stable and consistent baseline performance goal so that any variations will alert operators to possible treatment problems.

Evaluators build database for future. Surface water treatment plants are designed to take a raw water source of variable quality and produce a consistent high-quality finished water. The plants provide multiple treatment processes in a series to remove turbidity, protozoan cysts, and other microorganisms. Each process represents a barrier to prevent the passage of microorganisms through the plant. By providing multiple barriers, a water treatment plant can reduce microbial concentrations if the microorganisms should pass through one process by removing them in the next one. In this way, the well-operated plant will reduce the likelihood of microorganisms passing through the treatment system and surviving in the public supply.

Floods and droughts pose extraordinary challenges to multiple barriers. Drought can lead to difficult-to-treat algae blooms. Floods cause increased farm runoff, combined sewer overflows, and sewage treatment plant failures. These events can cause undesirable raw water quality changes including high turbidity, increased microbiological contamination, and fluctuations in pH and alkalinity. In some cases, changes in raw water quality can persist for four to six months after the event. During the autumn of 1995 and the winter of 1996, weather extremes occurred across Pennsylvania, beginning with drought conditions and followed by heavy snowmelt that led to a winter flood.

All of these problems increased the potential for high concentrations of protozoan cysts in drinking water sources. Accordingly, graphs of yearly turbidity trends can help water system staff members and regulators to gain historical perspective on how these source water variations affect treatment plant performance.

Taking a few pointers from the National Partnership for Safe Water[8] and the Comprehensive Performance Evaluations of the US Environmental Protection Agency (USEPA), the evaluators have recently added a new dimension to FPPEs. The DEP has always assessed the capability of individual unit processes to continuously provide an effective barrier to the passage of microorganisms. Now, evaluators are collecting as much as a year's worth of turbidity data for raw, settled, and finished water. Plotting the maximum values for each day in a graph will show variations in raw water turbidity throughout the year. Corresponding turbidity variations in the sedimentation and filtration processes may or may not show. In this assessment, performance problems become apparent. Settled water turbidity concentrations >2 ntu or filter effluent turbidities >0.1 ntu (excluding postbackwash performance) would probably indicate a lack of optimized performance. The trend graphs also provide an opportunity to demonstrate deteriorating or improving performance of the filter plant over time. In essence, a graphic depiction of turbidity data alone can often motivate operators to improve plant performance.

Figure 8 shows the daily raw, settled, and finished water turbidity that staff members of plant A measured over seven months. The data show that raw water variations in winter led to settled water turbidity levels above the goal of 2 ntu. Finished water turbidity also exceeded the 0.1-ntu performance goal several times. Overall, these graphs indicate that the operators correctly responded to some of the raw water quality fluctuations but allowed others to carry through the filter plant. Consequently, the finished water turbidities demonstrate a need to further optimize treatment and thus strengthen the barrier to the passage of cysts and microorganisms.

To gain further awareness about the usefulness of observing turbidity trends, utility staff members should earnestly consider involvement in a self-assessment program. Renner et al, with assistance from several national experts who attended a workshop sponsored by the AWWA Research Foundation, developed a comprehensive manual[9] that builds on experiences gained through USEPA's Comprehensive Performance Evaluations and the Partnership for Safe Water. The manual, *Plant Optimization Handbook*, provides many of the tools necessary for conducting a self-assessment to improve performance of conventional and direct filtration water treatment plants. By completing a thorough self-assessment process, water utility personnel can determine whether plant performance is adequate to maximize public health protection from microbial contamination of treated water. More important, recent experience shows that utility personnel can take a methodical, cost-effective approach to implementing improvements that will move the treatment plant toward optimum performance.[10]

Conclusion

Pennsylvania's experience indicates that water systems that are aware of weaknesses and expect a higher level of performance will improve their operations and facilities. Considering Pennsylvania's evaluation program and recent cryptosporidiosis outbreaks in the United States, merely meeting the turbidity performance regulations for surface water treatment plants is not good enough. How far, then, should water systems go to ensure adequate public health protection? Should the high-risk population (i.e., immunocompromised individuals) bear the full burden of ensuring that their drinking water is safe? It seems that a collective responsibility—one that involves sharing information among government agencies, the water system, and the public—can lead to reduced risks of waterborne disease outbreaks. In Pennsylvania's experience, working toward optimization has been successful, even to the extent of reducing *Cryptosporidium* in the finished water. Still, much work remains.

A good evaluation program should involve a thorough on-site assessment and should include support information obtained from particle counters, turbidimeters, microscopic particulate analysis, and other tools. The authors have suggested some performance criteria for most types of filter plants. For example, utility staff members should establish a goal of consistently providing finished water of <0.1 ntu from each filter. In Pennsylvania, performance ratings have been acceptable much more often when the finished water remains <0.2 ntu. Alternatively, utilities may decide that finished water particle counts below a certain threshold—perhaps 10 particles/mL in the size ranges corresponding to those of *Giardia* and *Cryptosporidium*—indicate good plant performance, depending on the counter's manufacturer and sensor.

The bottom line is that no matter how good the water system's performance is, utilities should continuously strive to enhance filter plant performance. Thus, the word "optimize" entails a wide range of tasks that involve improvements to operations, design, administration, and maintenance of a water system. Reliability calls for more than just optimization—it means ensuring that the water system facility and staff are capable of handling future challenges, such as unanticipated changes in source water quality.

Pennsylvania's filter plant evaluation program has focused primarily on low-cost improvements to existing facilities rather than on costly construction of new treatment units. Water systems cannot afford to remain comfortable with mediocre performance. The public trust obligates them to achieve—perhaps through a comprehensive self-assessment program—the most efficient and effective means of reducing risks of waterborne disease outbreaks.

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