A Strategy for Optimizing Water Treatment Plant Performance Using Light Scatter Technologies

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Purpose of Research

Two new nephelometers have been developed to help optimize filter performance at water treatment plants. One nephelometer was designed to give simple, accurate, and rapid response to turbidity changes during a backwash cycle. The other nephelometer was designed specifically to monitor filter effluent. During this study the instrumentation was used to monitor the filter effluent for events detected before filtration. The ultimate goal will be to optimize plant performance through identification and subsequent reduction of particle events that occur prior to filtration or during the backwash cycle.

A laser nephelometer and a particle counter will be used together to monitor particulate levels passing through a filter during the filter run. Filter events will be characterized from that data. The backwash turbidity value at termination will be correlated against the filter run performance. Ripening, particulate events, and trends will be investigated and used to interpret the performance of each filter run. The challenge for the water treatment plant operators will be to use these new analytical tools to optimize both backwash and filter performance.

In this study, optimization of the filter run will be defined by the production of a stable effluent stream (characterized by low and consistent turbidity). Particle shedding from the filter into the sample must be minimized for the duration of the run. Turbidity and particle counts will be used to identify particle events and to optimize filter run performance.

The study involves the use of a local water treatment plant that is a member of the Partnership for Safe Drinking Water. The plant's current goal is to not exceed 0.1 NTU in the effluent, even during a backwash event. For the past year, this plant has been heavily involved in the development and testing of a new laser nephelometer. The data collected from that testing was used as a baseline for comparison to data generated in the study.

The study hypothesizes that filter backwash cycles that are consistently monitored to a set turbidity value will correlate to a high performance filter run. If this is indeed true, the process will save the plant time and money. The costs and benefits of using these technologies will be summarized in this study.

Site Profile

The water treatment plant (WTP) where this study was conducted is located near Fort Collins, Colorado. A member of the Partnership for Safe Drinking Water, the plant has the capacity to produce 30 MGD using 12 filters. For the purpose of this study, a single filter was evaluated. This plant's processes are under excellent control but the management and operators are interested in continuous improvement by further optimizing their filter runs.

During this study, the plant undertook an expansion project to increase its production capability to 50 MGD. Also, the raw water source, a reservoir, experienced significant change due to severe draw down. The geographical area supplied by the plant experienced significant drought conditions that required the plant to run at or near capacity for the duration of the study.

Introduction

Particle events are seen as surrogates for the quality of water produced in a WTP. Fewer events indicate a higher filter performance and therefore, better water quality. In this study, particle events detected by either a particle counter or turbidimeter in the effluent stream were examined. Particle spikes were monitored for at two points prior to filtration. We used a standard turbidimeter (1720C) to monitor the water as it exited the sedimentation basin and an OptiQuant™ TSS probe turbidimeter to monitor the water just before application through the filter.

The instruments were strategically positioned in the treatment stream to help determine if spikes in the sedimentation basin travel to the filter. If they do, the goal was to determine if the spikes change before and after filtration. The magnitude and duration of the spikes was also analyzed at different phases of the treatment process.

Both turbidimeters and particle counters were used to monitor the filter effluent in an effort to determine if the instruments are complementary (both identifying the same particle event) or if they detect different events. This comparison of instruments should provide WTP management insight into which instrument technology will help them optimize their filtration management.

During this study, process monitoring was conducted for a total of 66 continuous filter runs on a single filter. A requirement of the study was to not impact the day-to-day operation of the plant and instead to focus on the collection, preparation and analysis of the data. All monitoring was done on a passive basis and the data was analyzed after collection. Plant management can assess final data to determine if events are traceable to operations. A decision can then be made if modifications should or could be considered. In addition, overall plant performance during construction and geographical drought effects can be evaluated.

Three primary goals were set for this study:

1. To demonstrate that the instrumentation used in this study has value as tools for continuous improvement in this DWP.
2. To provide more insight into the WTP processes and the impact, if any, on events as they move through a water treatment process.
3. To determine which technologies are best for the detection of spikes before and after the filter.

Materials and Methods:

a. Instrumentation

Three types of instruments were used for effluent monitoring event detection: a particle counter, a low-level regulatory-approved turbidimeter, and three laser nephelometers. All instruments monitoring the effluent were run in parallel with regular sampling.

- The 1900 WPC particle counter used in the study has size sensitivity down to 2 microns. For consistent and reliable application of the instrument, it was positioned on the effluent side of the filter.
- The regulatory turbidimeter was a Hach 1720D. The 1720D is commonly used in WTPs for regulatory filter effluent monitoring. This instrument meets all instrument design criteria specified by the USEPA method 180.1.
- FilterTrak™ 660 Laser Nephelometers were also used. These instruments are approximately 150 times more sensitive than traditional turbidimeters and will confirm particle events that might otherwise be reported as noise on a traditional low-level turbidimeter. The FT660 measures turbidity in mNTU units (where 1 mNTU = 0.001 NTU).

Above the filter, two types of instruments were used.

- A Hach 1720C owned by the WTP monitors the sample as it leaves the settling basin.
- A new turbidimeter, the OptiQuant TSS, was installed on the settled water immediately above the filter. This instrument is of probe design and utilizes ISO 7027 technology. Characterized by its quick response, the probe turbidimeter is often used for profiling events including the turbidity of backwashes.

Table 1 summarizes the instrumentation used in the study.

All instruments were polled simultaneously at 1-minute intervals and data were logged to a computer using digital data networking protocol to minimize errors in measurement and transcription. Microsoft Excel was used to analyze and graph the data.

Table 1 – Instrumentation Used in the Study

Location	Instrument	Primary Application
Filter Effluent	1900WPC Particle Counter	Counts and profiles particles that are >2µm in size
Filter Effluent	1720D Turbidimeter	Regulatory low-level turbidity
Filter Effluent	FilterTrak 660 SN 408	Low-level spike detection
	FilterTrak 660 SN 314	
	FilterTrak 660 SN 315	
Settled Water	1720C Turbidimeter	Turbidity in the 0.5-5 NTU Range
Applied to Filter	OptiQuant TSS Turbidimeter	Fast Response in 0.3 – 1000 NTU Range

Redundant testing using three FilterTrak 660 Nephelometers was performed to increase confidence in the new technology, to confirm the detection of minor events and to isolate interferences such as bubbles or contamination.

Once installed, all instrumentation was calibrated according to the manufacturer's instructions. After calibration, the instruments were allowed to run continuously from May 6 to July 15, 2000 until the 66 filter runs were completed. At approximately four-day intervals, the data was downloaded and analyzed for particle events and other significant criteria.

b. Particle Events:

Events are characterized as either major or minor. For this study, a major event is a turbidity spike that is greater than 5 mNTU and that lasts longer than 5 minutes. For particle counting, a major event is any sustained count spike that is greater than 2 counts per mL and that lasts longer than 5 minutes. A turbidity minor event is any spike that is between 1 and 5 mNTU, or any change between 1-2 counts per mL above the baseline on a particle counter. These criteria only apply to the filter effluent. The events are summarized in Table 2 below:

Table 2 – Particle Event Characterization in Filter Effluent

Instrument	Major Event	Minor Event
FT660 or 1720D	>5 mNTU above baseline	1-5 mNTU above baseline
1900WPC Particle Counter	>2 cts/mL above baseline	1-2 cts/mL above baseline

To be considered an event, the spike above the baseline must last more than 5 minutes. This way, it is unlikely that a bubble would be identified as an event. Depending on which instrument detects the event, the event profile can be determined. If the event is seen only by the turbidimeter and not by the particle counter, the particles are sub-micron in nature. If the event is seen only by the particle counter, then the particle of that event are greater than 2 µm and exist in very low numbers. If the events are observed on both instruments, it is an indication that the spike is most likely natural in nature after passing through the filter. An example of this distinction is shown in the data section.

Event detection using laser nephelometry technology required simultaneous detection of the particle spike by all three FilterTrak 660s in the study. When all three instruments detected the spike, the presence of the spike was confirmed.

Data

Once the data was collected and plotted, several pieces of information (metrics) were entered into a master matrix. These include the following:

- Run number (sequenced in chronological order)
- Run time: Time from the end of the ripening period to the start of backwash
- Date and time of the filter run
- Day of the week for the respective filter run
- Number of major and minor turbidity events
- Number of major and minor particle counter events
- Number of spikes in the filter influent
- Significant changes in baseline noise
- Baseline trends
- Peak turbidity value during backwash
- Measured turbidity value at backwash

Using this master matrix we were able to quickly identify filter runs that contained events and compare them to filter runs that contained no particle events. From the perspective of this study, a “good” run is one that is free of particle events, trends, or significant baseline noise during the period of time starting at the end of the ripening period and ending at the start of the backwash cycle. In short, the run is stable. Events due to the backwash cycle or within the ripening period were not considered part of the filter run and are not included in the data. Figure 1 shows a “good” filter run, typical of the runs observed over the duration of this study. During this study, 66 percent of the runs were deemed good and had no particle events or trends over these runs.

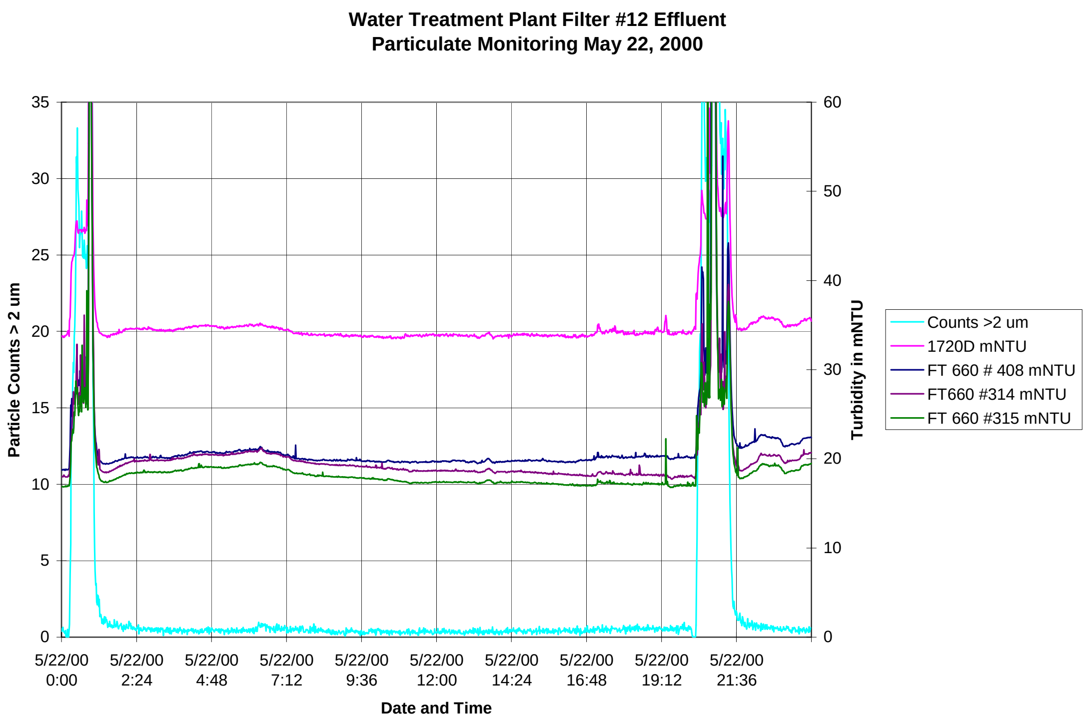

Figure 1

Of the 66 filter runs, a total of 22 showed at least one particle event. These 22 runs were tabulated into a scaled-down matrix that is summarized in Table 3. The runs are ranked according to the number of total events detected starting with the highest number of events. Within this table, five of the runs had a precursor event that was detected in settled water prior to filtration. An asterisk identifies those runs.

Table 3 Filter Runs showing at Least One Particle Event

EFFLUENT										
			Major Filter Events			Minor Filter Events				
Run	**Run Length (hr)**	**Total Number of Events**	**Particle Counter**	**FT660 #315**	**1720D**	**Particle Counter**	**FT660 #315**	**1720D**	**Event Date(s)**	**Backwash Termination Turbidity (NTU)**
21*	24.98	3	3	1	1		2	2	6/1/00	1.74219
54*	24.30	3		1	1	2	2	2	7/5 & 7/6	1.10880
58	19.29	3	1			2	3	3	7/9/00	1.18336
2*	26.8	2	2	2	2				5/8/00	0.99504
5	27.05	2	2				2	2	5/17/00	1.48070
22*	31.55	2	2				2	2	6/2/00	0.81269
49	23.95	2				2	2	2	7/1/00	1.05519
52	20.72	2	1			1	2	2	7/4/00	1.13972
1	20.33	1				1	1	1	5/7/00	1.11836
4	21.23	1				1	1	1	5/16/00	1.17717
12	17.28	1				1	1	1	5/23/00	1.54982
14	22.04	1	1				1	1	5/25/00	1.05917
15*	26.33	1	1				1	1	5/26/00	1.07300
25	22.87	1				1	1	1	6/5/00	1.17753
32	23.19	1				1	1	1	6/13/00	0.94590
34	26.04	1	1				1	1	6/15/00	0.93263
36	27.63	1				1	1	1	6/17/00	0.78922
38	24.79	1	1				1	1	6/19/00	0.69477
44	24.94	1	1				1	1	6/25/00	0.85205
46	35.52	1				1	1	1	6/28/00	0.87059
59	16.53	1				1	1	1	7/10/00	1.05735
63	20.53	1	1	1	1				7/13/00	1.10095

* Runs with an event in the filter influent and in the filter effluent that was detected by the nephelometric turbidimeters 100% of the time and by the particle counter 60% of the time.

Figures 2 and 3 show filter runs that have either particle events or excessive noise (when compared to the criteria of a good filter run). Figure 2 shows that the events (at 6:30, 8:40, and 9:45) are detected by each of the instruments on the effluent stream. However, the last event before backwash (at 9:45) is detected earlier on the turbidimeters than on the particle counter. This gives an indication that the sub-micron particles (detected by the turbidimeters) are precursors to larger particles (detected by the particle counter).

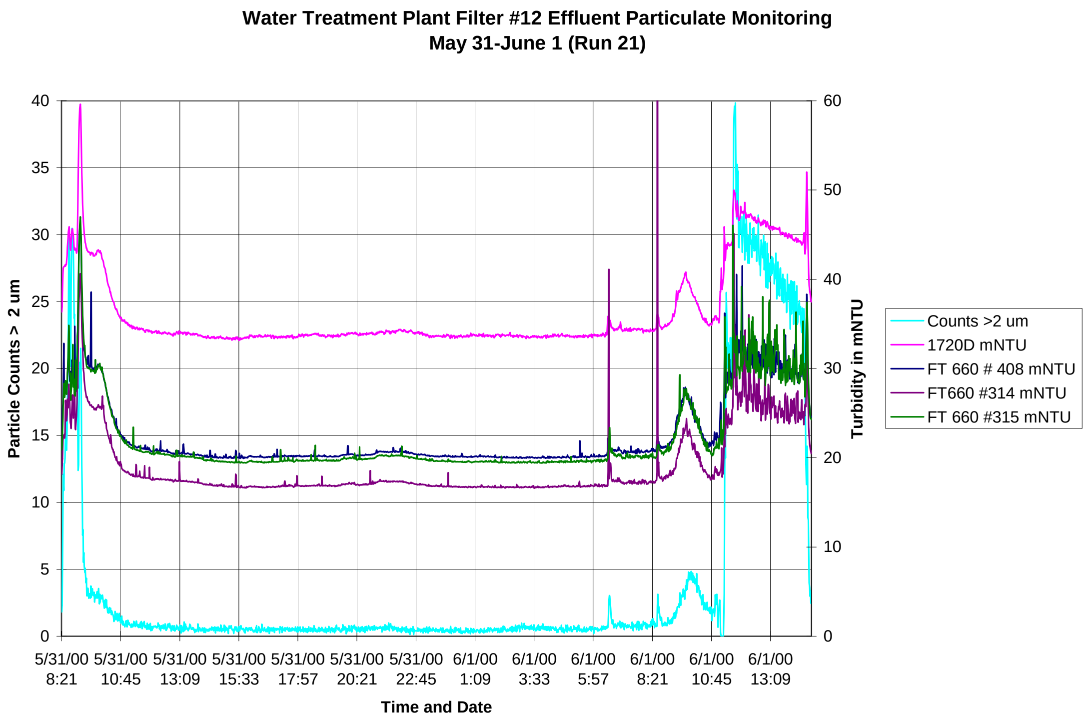

Figure 2

Figure 3 does not distinguish separate events, but the baseline noise is substantial throughout the run and the particle count trends do not follow the turbidity trends. When comparing all the runs in the study, this run stands out due to the high level of noise and lack of complementary data on the instruments.

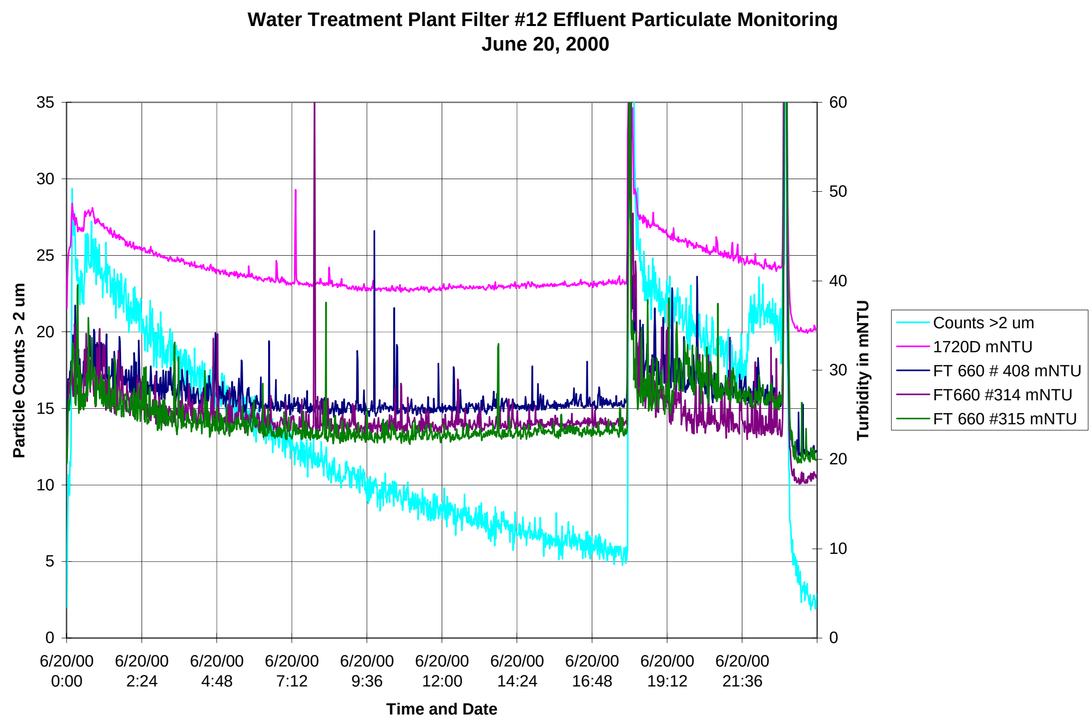

Figure 3

When examining the 22 runs that contained particle events, five of the runs contain influent spikes that can be detected in the effluent as well. In all five cases where the spike is detected above the filter, a similar spike in the effluent is seen within the next couple of minutes. Figure 4 shows that the particle event in the influent appears to be a precursor to the particle event that is immediately observed in the effluent with the turbidity technologies. During this run, the spike (at 13:50) in the settled water immediately above the filter increased from 1.2 to 1.9 NTU, a 0.7 NTU increase. The effluent event increased approximately 0.02 NTU, indicated the filter did remove the majority of this spike. In all five cases, particle spikes that were observed above the filter were easily detected by the laser nephelometer.

Several spikes that were logged at the settled water basin were not detected by the instrumentation downstream from the filter. Only when the SST probe turbidimeter that was positioned immediately above the filter media detected the event, was the particle event also detected in the effluent.

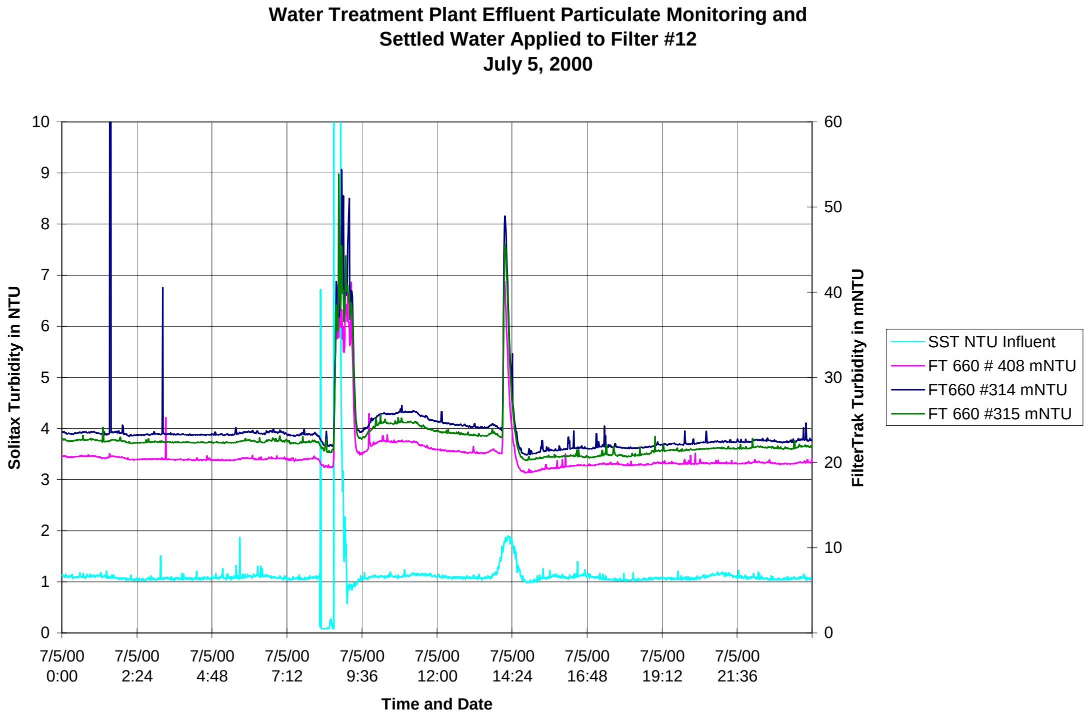

Figure 4

Since an area of the water plant close to the filter under observation was undergoing construction, we were interested in determining if the data could offer a distinction between the days that construction occurred (primarily Monday through Friday) and days with no construction (Saturday and Sunday). Figure 5 shows a plot of filter events versus the day of the week for the 22 runs containing particle events. Based on this plot, it appears that construction had very little impact since particle events were seen every day of the week.

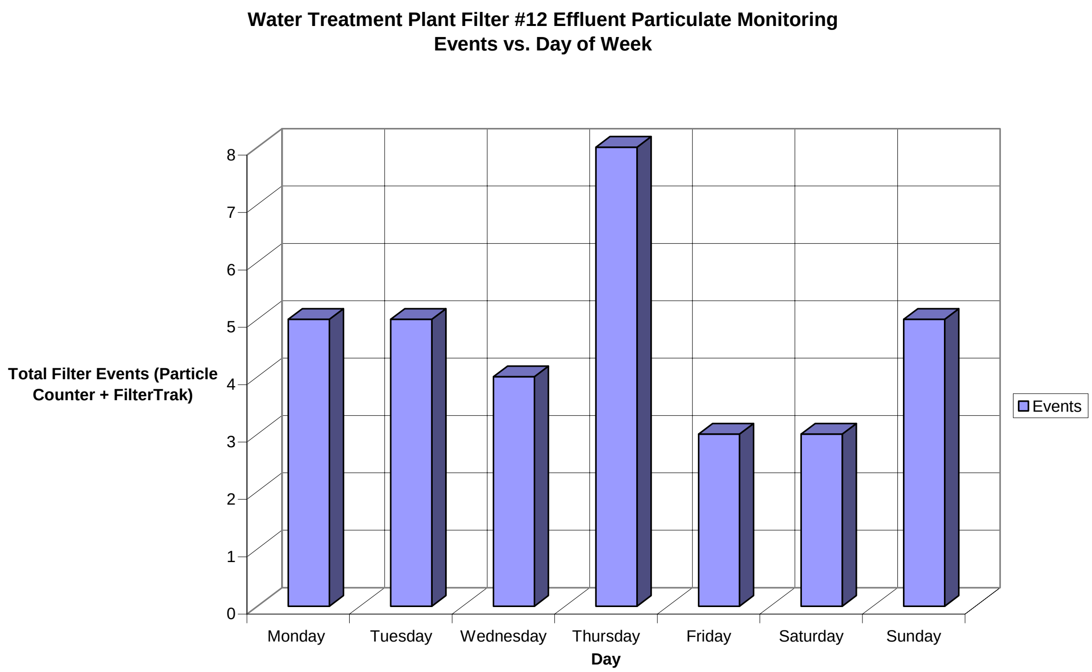

Figure 5

As an interesting aside, we observed an occurrence in the majority of the 66 filter runs in this study. At the beginning of a typical good run, the FilterTrak 660 baseline shows very low noise. The low noise is maintained until the run is between 65 and 75 percent complete. The noise appears to increase dramatically as the run progresses toward termination. Figure 6 shows a typical run in which the three FilterTrak 660 turbidimeters all display the same magnitude of baseline noise throughout the run. For 10 randomly selected "good" filter runs, we looked at the relative standard deviation for the first 75 percent of the run compared to the last 25 percent of the run up to backwash. The baseline relative standard deviation for the last 25 percent of a filter run increased 2.35 times the baseline relative standard deviation over the first 75 percent of the same run.

Also note on Figure 6, there is one particle event that is detected by the turbidimeters, but is missed by the particle counter (at 15:00). This is indicative that the event is primarily sub-micron in nature and is lost in the baseline noise of the particle counter.

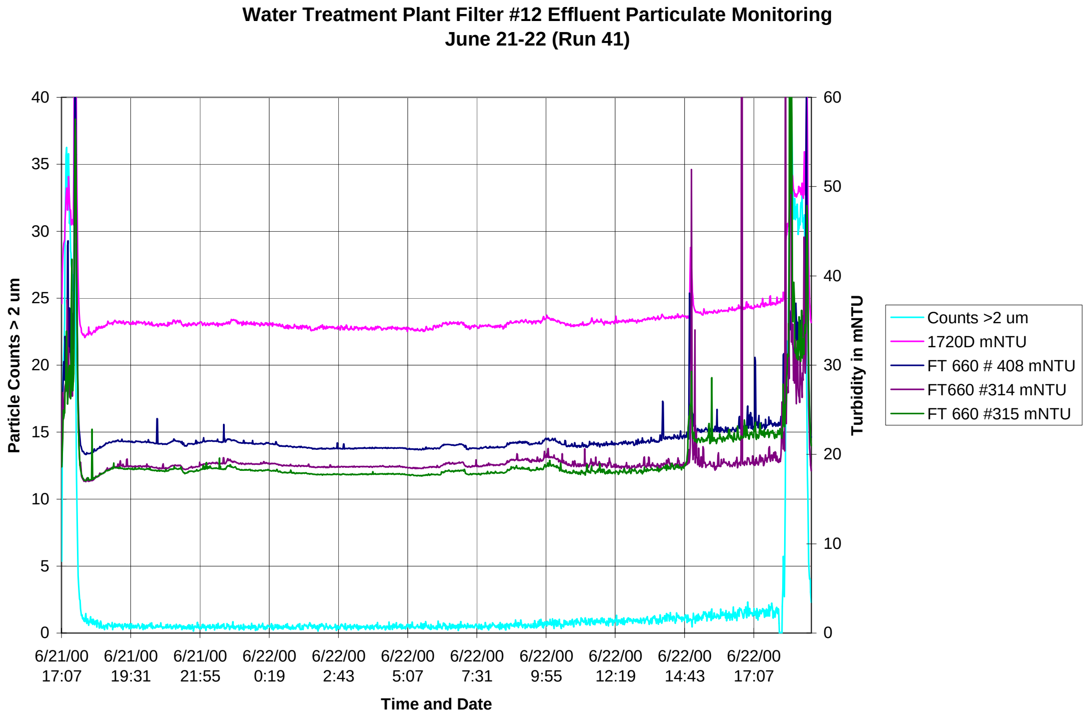

Figure 6

In the large majority of the filter runs logged, the two technologies—turbidity and particle counting—complemented each when detecting events in the filter effluent. However, in a couple of cases, events that were detected by the turbidimeters were totally missed by the particle counter. Figure 7 is the same filter run displayed in Figure 4 but includes the data from the particle counter. This figure shows that the precursor event detected above the filter was seen by the effluent turbidimeters, but was not detected by the effluent particle counter. Because the particle counter missed the event, we can surmise that this event is sub-micron in nature.

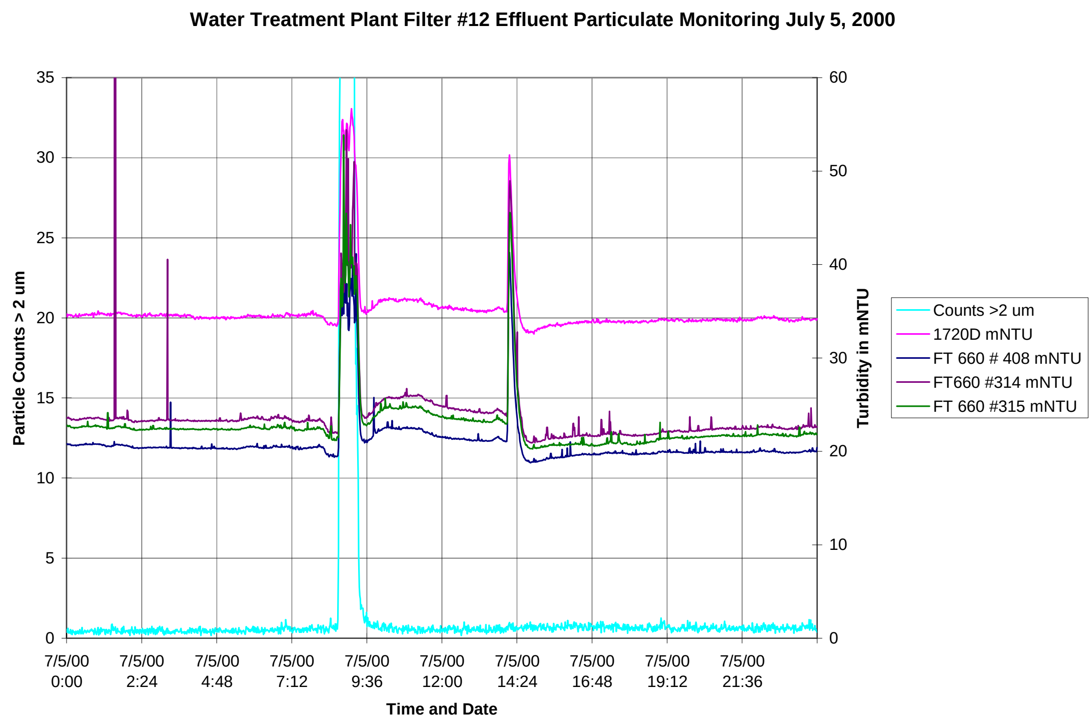

Figure 7

We also looked for correlations between the turbidity value at the termination of backwash and filter events. The turbidity values at backwash termination were in a very narrow range between 0.69 and 1.74 NTU. The author speculates that the tight range of values at backwash termination predicts the overall consistency of the filter runs over time. No correlation was found between these values and particle events. The correlation between the peak turbidity at backwash and subsequent filter events of the proceeding run was also investigated. Again, there was no correlation between these two parameters.

Conclusions

Of the 66 continuous filter runs that comprise this study, 33 percent contained particle events as they were defined at the beginning of this study. Of the 22 runs that contained events, 23 percent appear to have a precursor event that was detected by the OptiQuant TSS probe turbidimeter that was monitoring the pre-filter sample.

The FilterTrak detected the majority of events that the other instrument detected and also detected some events that they missed. In addition, the FT660 baseline's standard deviation increases as the run progresses. This may be a precursor to breakthrough and warrants further investigation.

Events that are detected in the pre-filtered water were also consistently seen by the FT660 and particle counter. All five settled water precursor events were also seen in the effluent. The turbidity of these influent spikes ranged between 0.5 and 2 NTU were reduced significantly as they passed through the filter. The resulting these events in the effluent were very small with turbidity changes ranging between 0.005 and 0.030 NTU (5-30 mNTU) and the process itself was maintained far below the requirements of the Partnership for Safe Drinking Water.

The impact on construction and the seasonal drought in the area did not appear to correlate to the frequency of events. Runs with events did occur in somewhat random order during the 66 runs.

As was discussed earlier, having both a particle counter and a laser nephelometer provides information as to the composition of a particle event. Event detection that is complemented by both instruments indicates a natural distribution of particles roughly following the $1/d^3$ relationship. In these cases, the nephelometer will detect the particles slightly before the particle counter because small particles move more rapidly through a filter. If only the laser nephelometer detects the event, the composition of the particles is most likely sub-micron in nature. If the particle counter alone detects the event, this indicates a non-natural distribution of large (2 µm) particles and may indicate a change in the conditions within the filter or a contamination issue. In all cases, the use of two instruments provides further insight into the particle sizes of respective events.

This WTP filter effluent did not exceed the Partnership turbidity limits throughout the entire study (including backwash runs). However, the instrumentation did show both good, clean filter runs along with runs with definitive particle events. Though it may be challenging, the WTP management can investigate their logs to see if the runs that contained events relate to any changes in the treatment upstream of the filter. This is continuous improvement at its best.

The WTP showcased in this study is, in reality, a best-case scenario. Its processes were optimized for the duration of this study and are under very tight control at all times. However, a WTP that does not have consistent filter runs, or one that often has particle spikes could use this instrumentation to detect, analyze and eventually reduce or eliminate such events. The intent and anticipated use of the study instrumentation goes beyond regulatory requirements and will help plants achieve production of water characterized by high quality and consistency.

We plan to continue monitoring this filter for the benefit of the plant management. Due to problems with the dams on the raw water source, it will be drained significantly throughout the summer and fall of 2000. We will continue to see if changes to the raw water source will have an impact on particle event occurrence at this sample site.

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