Application Note 120

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

Executive Summary

Two new particle detecting technologies have been developed to help optimize filter performance at water treatment plants (WTP). One nephelometer was designed to give simple, accurate, and rapid response to turbidity changes during a backwash cycle and while monitoring the filter effluent. The other nephelometer was designed specifically to monitor filter effluent. During this study, the instrumentation was primarily used to monitor particle events during the WTP process. The ultimate goal is to optimize plant performance by identifying and reducing particle events that occur either before or after final filtration.

Optimization of the filter run was defined as the production of a stable effluent stream (characterized by low and consistent turbidity and low and consistent particle counts). Particle shedding from the filter into the sample was minimal for the duration of the run.

Two new instruments were used in this study, a laser nephelometer and a probe turbidimeter. The laser nephelometer, which is designed to detect very small changes in turbidity, was combined with a particle counter and regulatory turbidimeter on the filter effluent. The probe turbidimeter exhibits quick response and contains an 860-nm infrared light source, making it immune to color interference. The probe was positioned in the influent immediately above the filter. Collectively, this instrument distribution allows for more in-depth profiling of each particle event as it moves through the filter.

The study involved the participation of a local water treatment plant that is a member of the Partnership for Safe Drinking Water. For the past year, this plant has been heavily involved in the development and testing of this laser nephelometer. The data collected from that testing was used as a baseline for comparison to data generated in the study.

Site Profile

The water treatment plant 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. The plant’s current goal is to not exceed 0.1 NTU in the effluent, even during a backwash event. 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 drawdown (draining of the reservoir). 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 often viewed 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, laser nephelometer, or standard regulatory turbidimeter in the effluent stream were examined. Monitoring for particle spikes was performed at two points prior to filtration. A standard turbidimeter (1720C) was used to monitor the water as it exited the sedimentation basin and an OptiQuant™ SST probe turbidimeter was used to monitor the water just before passing through the filter.

The instruments were strategically positioned in the treatment stream to help determine if spikes that were detected leaving the sedimentation basin travel through the filter. If they did travel through the filter, the goal was to determine if the spikes changed before and after filtration. The magnitude and duration of each spike was also analyzed at different phases of the treatment process.

Laser nephelometers, regulatory turbidimeters, and a particle counter were used to monitor the filter effluent in an effort to determine if the instruments are complementary (which instruments identify the same particle event) or if they detect different events. This comparison of instruments provides WTP management insight into which instrument technology will help them optimize their filtration management. In addition, overall plant performance during plant expansion and geographical drought can be evaluated.

During this study, process monitoring was conducted for a total of 66 continuous filter runs on a single filter. The goal was to focus on the collection, preparation, and analysis of the data without impacting the day-to-day plant operation. All monitoring was passive and the data was analyzed after collection.

Four primary goals were set for this study:

1. To evaluate the role of different technologies in filter optimization and continuous improvement in this DWP.

2. To provide more insight into the WTP processes and the impact, if any, on particle events as they move through a water treatment process.

3. To determine which technologies are better suited for the detection of particle spikes before and after the filter.

4. To investigate the relationship between influent spikes and final effluent turbidity and particle counts.

Materials and Methods

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 interpreted as noise on a traditional low-level turbidimeter. The FilterTrak 660 measures turbidity in mNTU units (where 1 mNTU = 0.001 NTU).

Above the filter, two types of instruments were used:

- A Hach 1720C turbidimeter, owned by the WTP, monitored the sample as it left the settling basin.
- A new turbidimeter, the OptiQuant SST, was installed on the settled water immediately above the filter. This probe design instrument utilizes ISO method 7027 design criteria for turbidity monitoring. 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. Figure 1 shows the strategic location of the instruments in this 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.

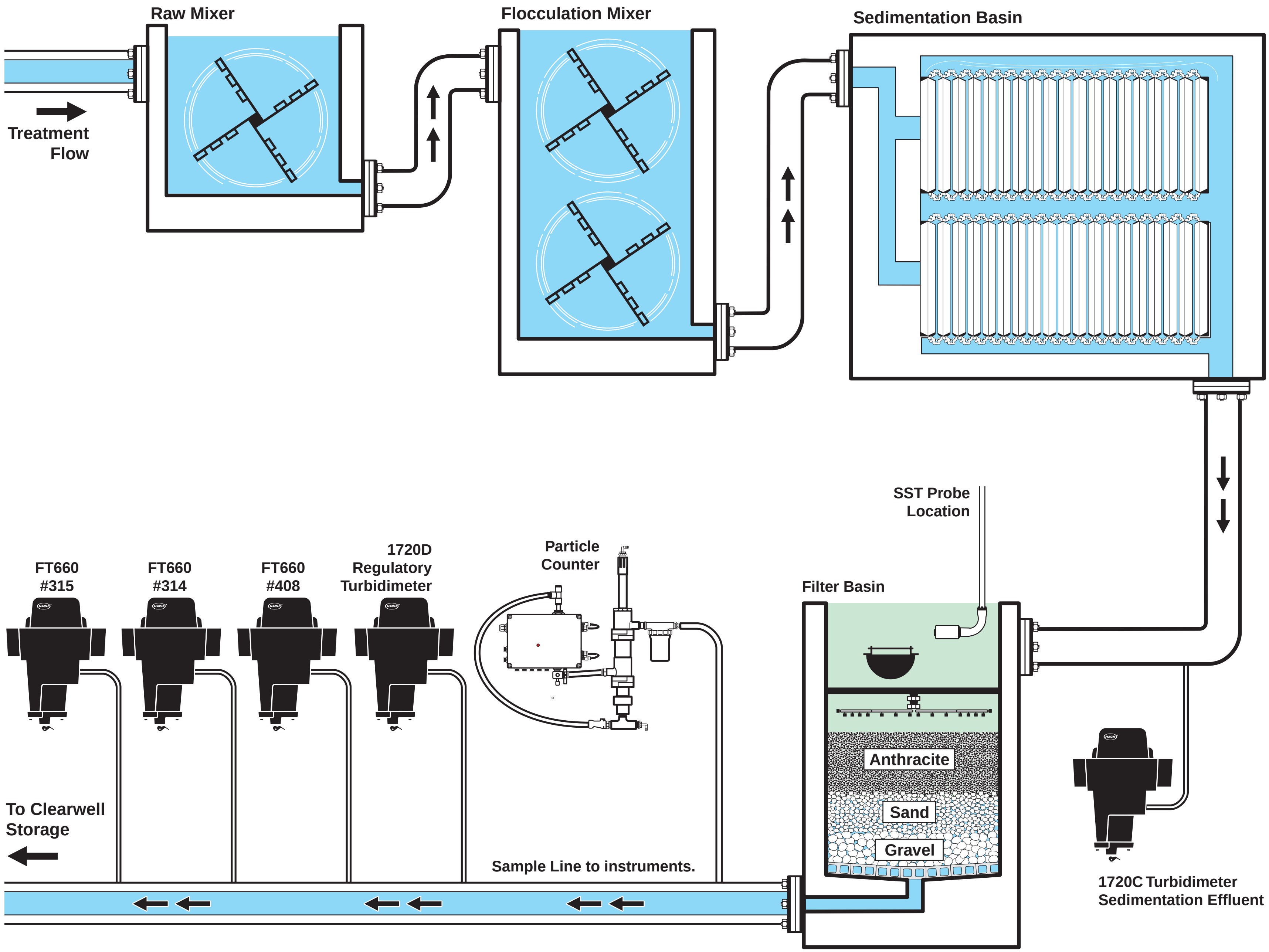
Table 1 Instrumentation Used in the Study

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 FilterTrak 660 SN 314 FilterTrak 660 SN 315	Low-level spike detection
Settled Water	1720C Turbidimeter	Turbidity in the 0.5–5 NTU Range
Applied to Filter	OptiQuant SST 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.

Figure 1 Instrument Location in the Water Treatment Plant



Particle Events:
Events are characterized as either major or minor. For this study, a major event is categorized as 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. Using this criteria ensures that bubbles are not identified as events. 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.

Table 2 Particle Event Characterization in Filter Effluent

Instrument	Major Event	Minor Event
FilterTrak 660 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

***Note:** Natural particle distribution follows a $1/d^3$ relationship with respect to number and size. Each order of magnitude decrease in particle size shows approximately 10^3 more smaller particles.*

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 assumed to be sub-micron. If the event is seen only by the particle counter, then the particles of that event are greater than 2 µm in size and exist in very low numbers. Events that are observed on both instruments indicate that the spike contains a natural size distribution after passing through the filter. An example of this distinction is shown in the data section.

Event detection using laser nephelometer 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

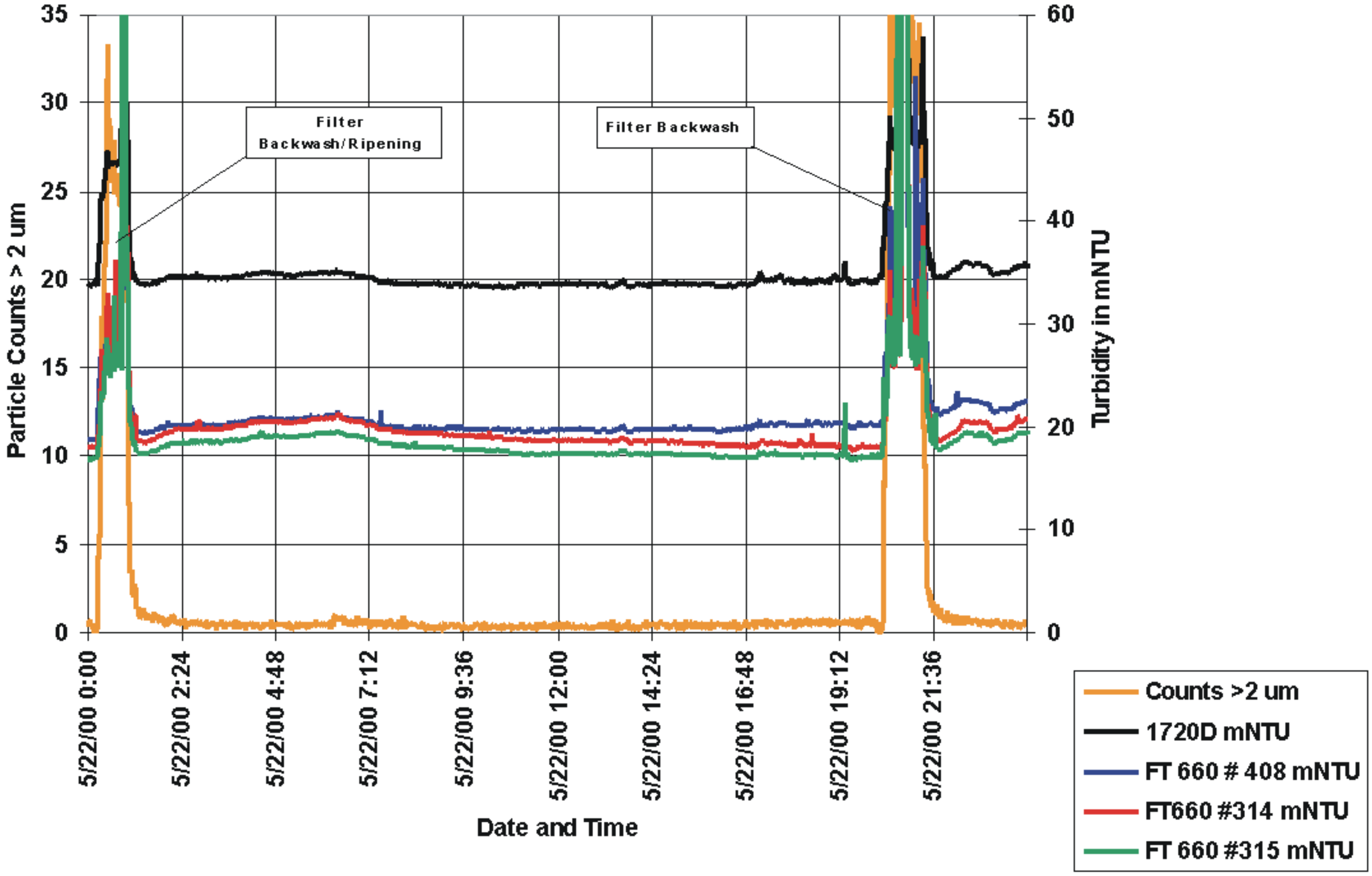
Once the data was collected and plotted, several pieces of information (metrics) were entered into a master matrix. These include the following:

- Run number (sequenced in chronological order)
- Run time: Time from the end of the ripening period to the start of backwash of the filter
- 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 on the influent of the filter
- Measured turbidity value at backwash on the filter effluent stream

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, an ideal 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 2 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.

Filter run termination is primarily determined by time at this water treatment plant. Termination occurs on a regular timed schedule if no breakthrough or loss of head occurs during the prior 20 to 26 hour time frame.

Figure 2 Water Treatment Plant Filter #12 Effluent Particulate Monitoring (05/22/00)



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	000.000
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 were detected by the nephelometric turbidimeters 100% of the time and by the particle counter 60% of the time.

Figure 3 and 4 show filter runs that have either particle events or excessive noise (when compared to the criteria of a good filter run). Figure 3 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 indicates that the sub-micron particles (detected by the turbidimeters) are precursors to larger particles (detected later by the particle counter).

Figure 3 Water Treatment Plant Filter #12 Effluent Particulate Monitoring (05/31/00-06/1/00)

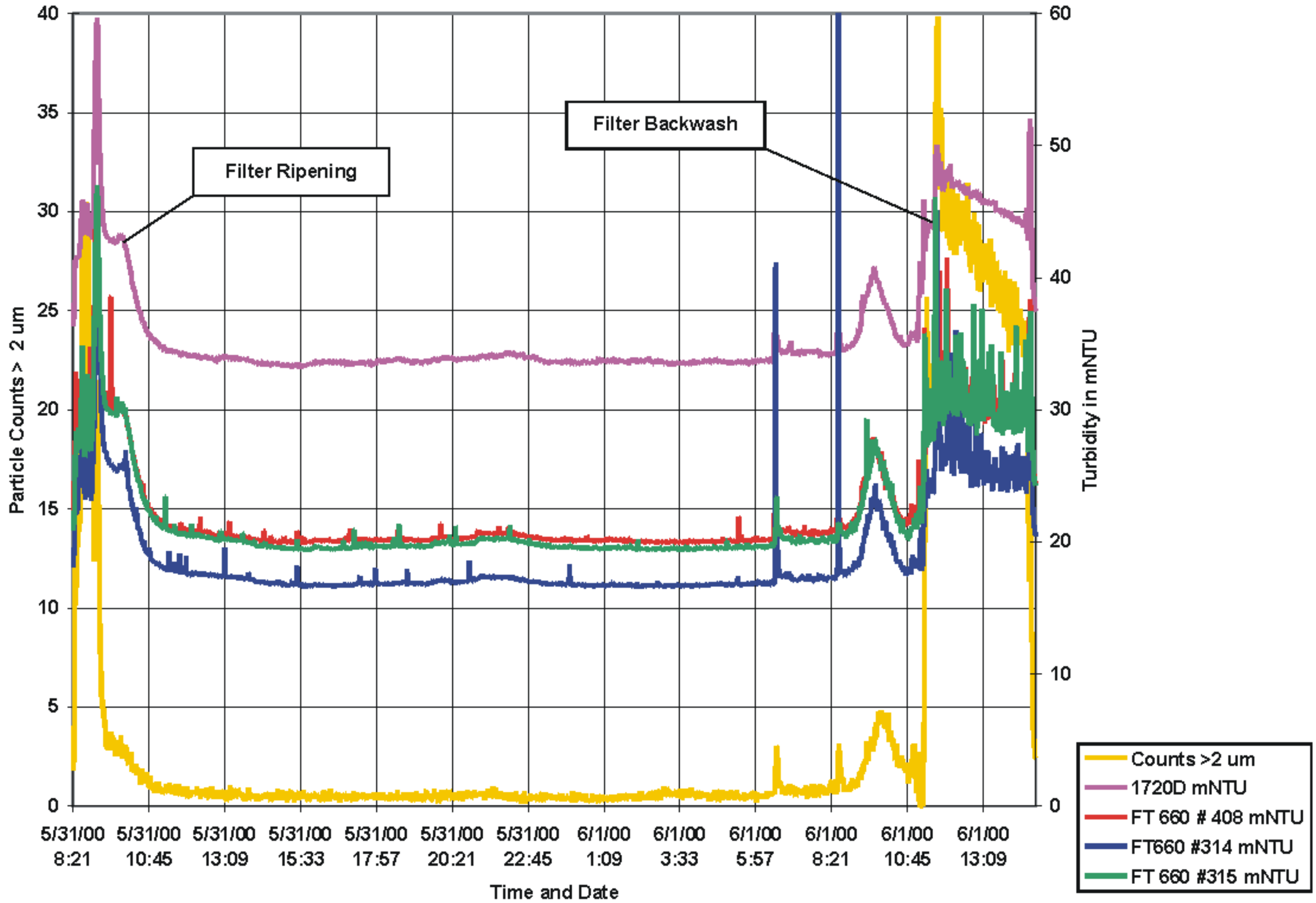
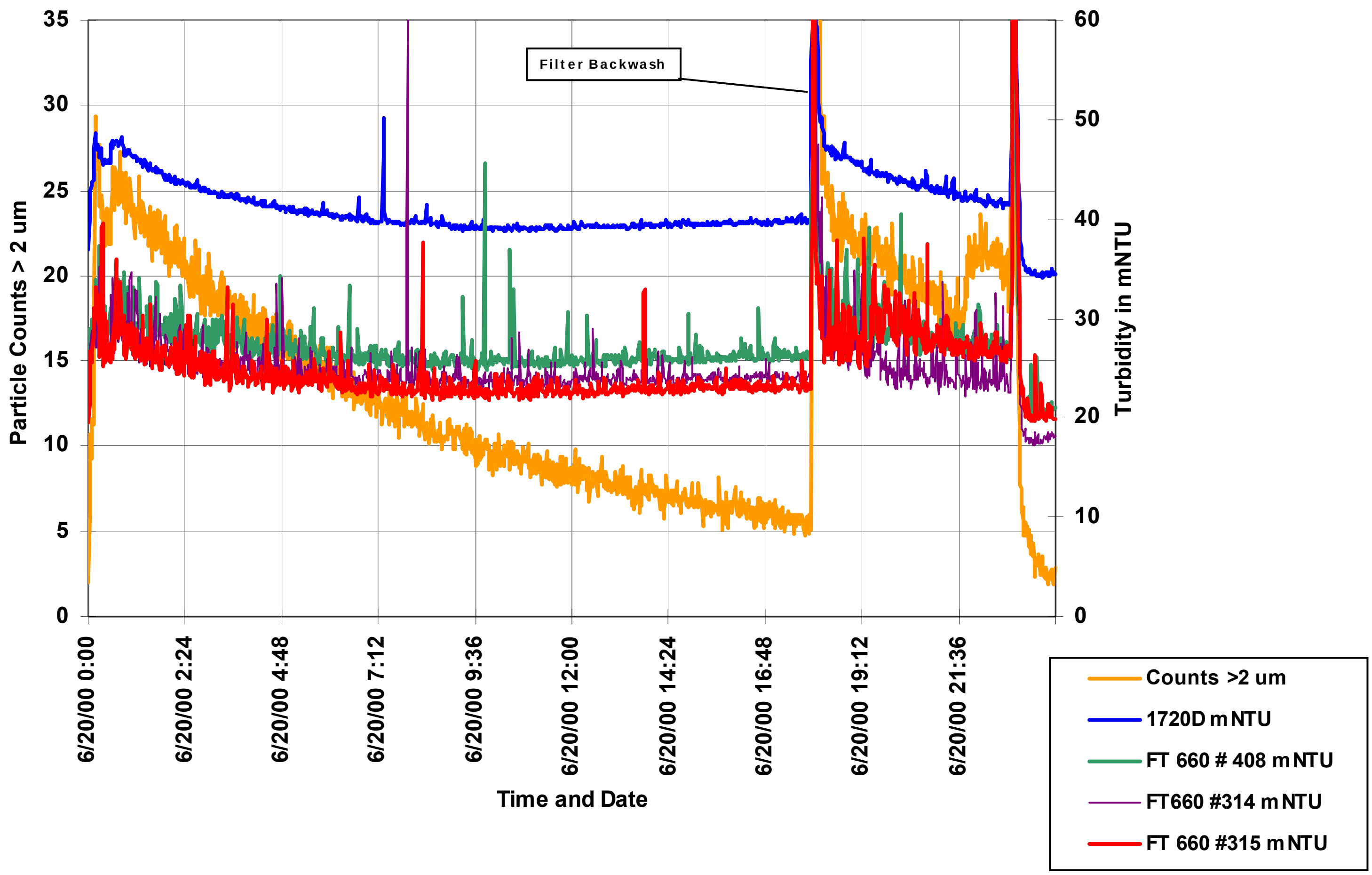


Figure 4 does not distinguish separate events, but the baseline noise is substantial throughout the run and the particle count trends do not follow the turbidity trends. When comparing all the runs in the study, this run stands out due to the high level of noise and lack of complementary data on the instruments. Reviewing the log books may lead the operator to the cause of the noise.

Figure 4 Water Treatment Plant Filter #12 Effluent Particulate Monitoring (06/20/00)



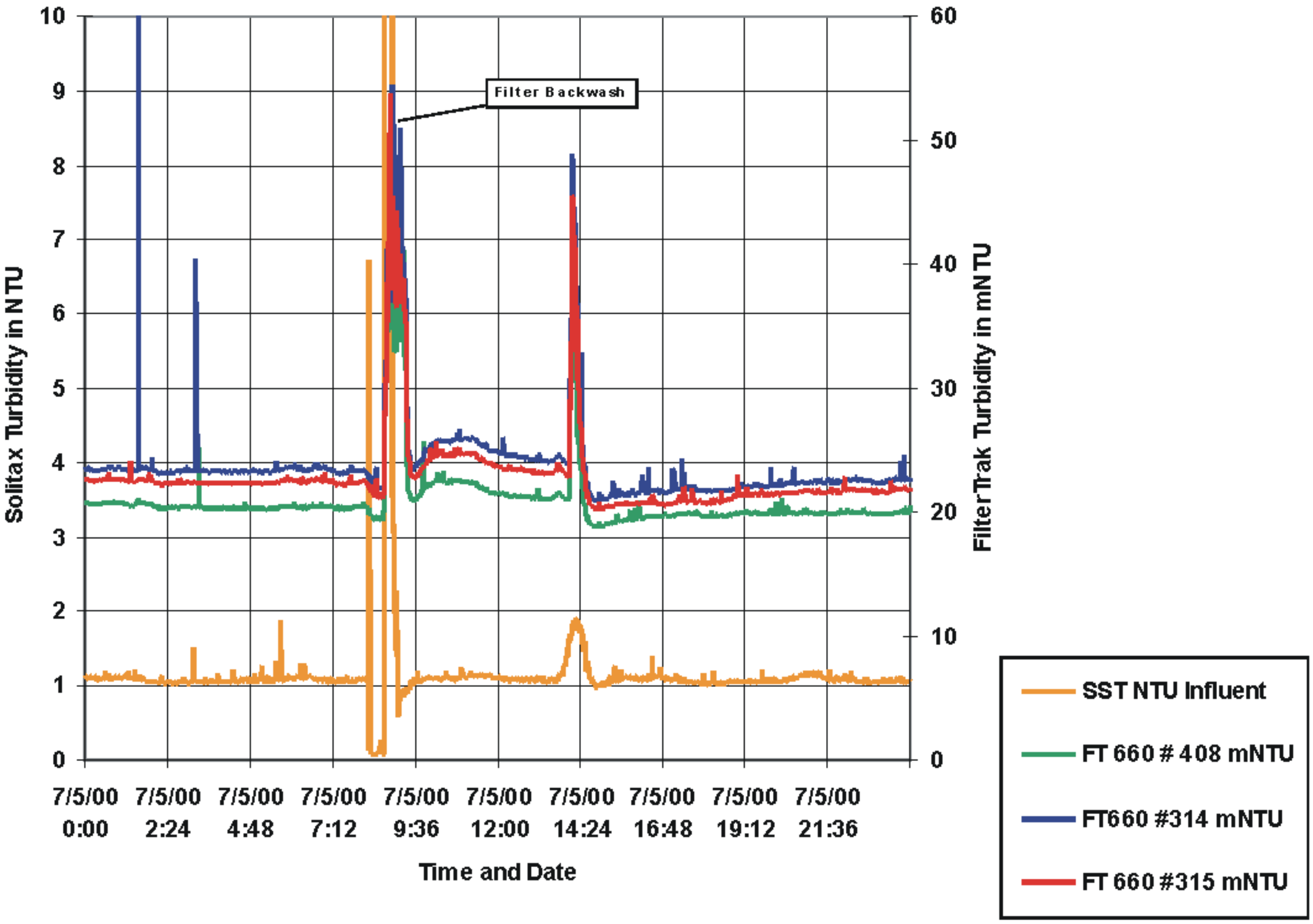
Of the 22 runs that contained particle events, five of the runs contained influent spikes that could be detected in the effluent as well. In all five cases where the spike is detected above the filter, a similar spike in the effluent is seen within the next couple of minutes. Figure 5 shows that the 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, indicating that 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.

Since both the OptiQuant SST and the FilterTrak 660 Nephelometer are calibrated using formazin, the light source differences between the two instruments are minimized. Positioning the instruments on both the influent and the effluent sides of the filter allows log removal calculations to be performed based on the turbidity differential across the filter.

Color interferences in the influent are eliminated by the 860-nm wavelength of the OptiQuant SST Probe Turbidimeter. Color is not an interference in the low turbidity levels of the effluent stream.

Several spikes that were recorded at the settled water basin by the 1720C turbidimeter were not detected by the instrumentation downstream from this sample point. Hydraulic surges are the suspected cause and these events are short-lived. The particle spikes that were investigated in this study were those that are tracked through the filter into the effluent.

Figure 5 Water Treatment Plant Effluent Particulate Monitoring and Settled Water Applied to Filter #12 (07/05/00)



In the majority of the 66 filter runs in this study, an additional occurrence was seen. At the beginning of a typical good run, the FilterTrak 660 baseline showed very low noise. The low noise is maintained until the run is between 65 and 75 percent complete. The noise appeared to increase dramatically as the run progresses toward termination. Figure 6 shows a typical run in which the three FilterTrak 660 Nephelometers all display the same magnitude of baseline noise throughout the run. For 10 randomly selected “good” filter runs (defined as runs without spikes), 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.

It is speculated that large particle detachment from the filter media may be the cause of the increase in background noise as the filter run progresses. If this is true, then monitoring background noise may be another means of predicting breakthrough.

When looking at Figure 6 it is interesting to note that there is one particle event that is detected by the turbidimeters, but is missed by the particle counter (at 15:00). This indicates that the event is primarily sub-micron and is below the detection threshold detection limit of the particle counter.

In the large majority of the filter runs logged, the two technologies—turbidity and particle counting—complemented each other 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 5 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 6   Water Treatment Plant Filter #12 Effluent Particulate Monitoring (06/21/00–6/22/00)

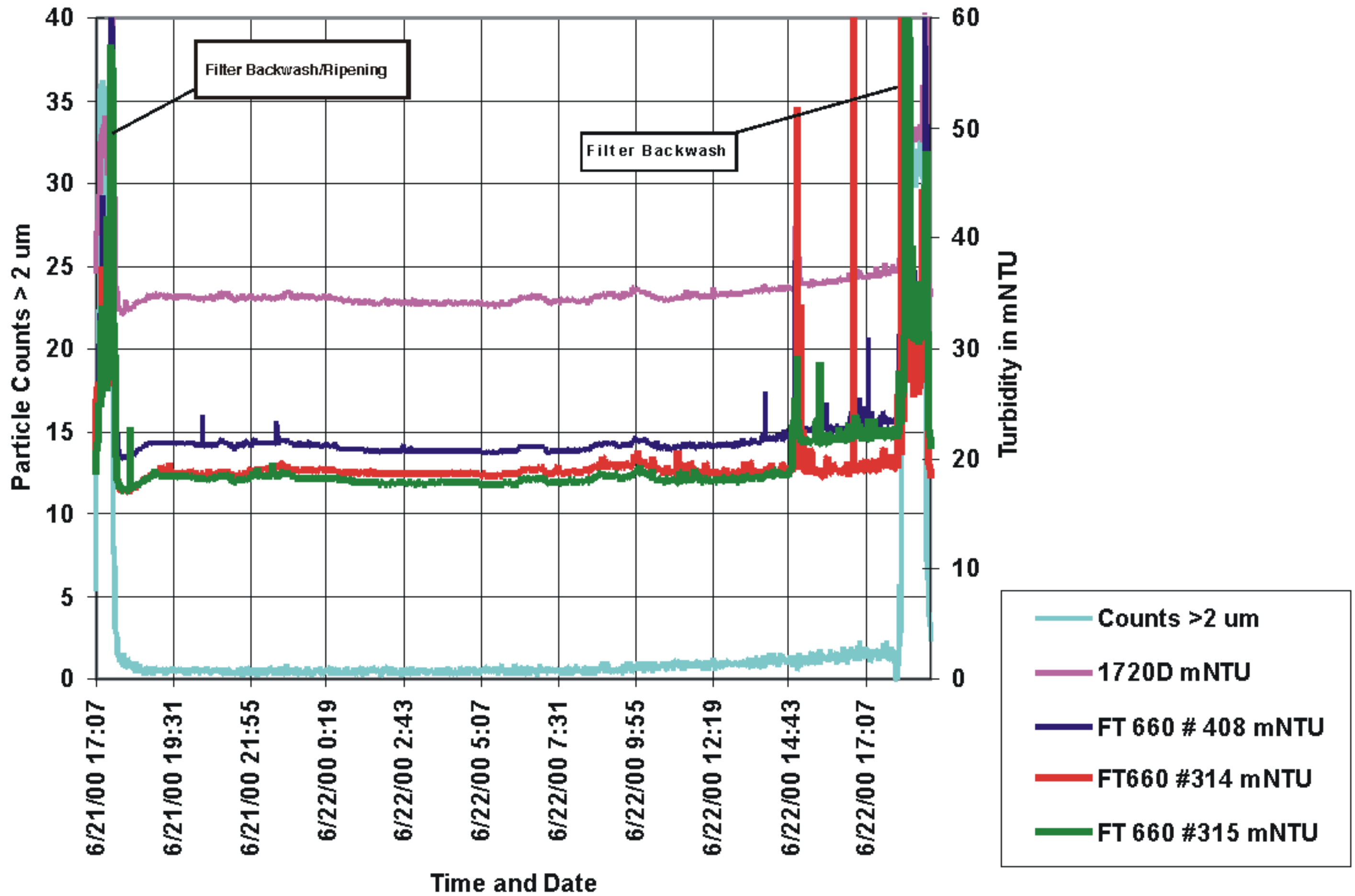
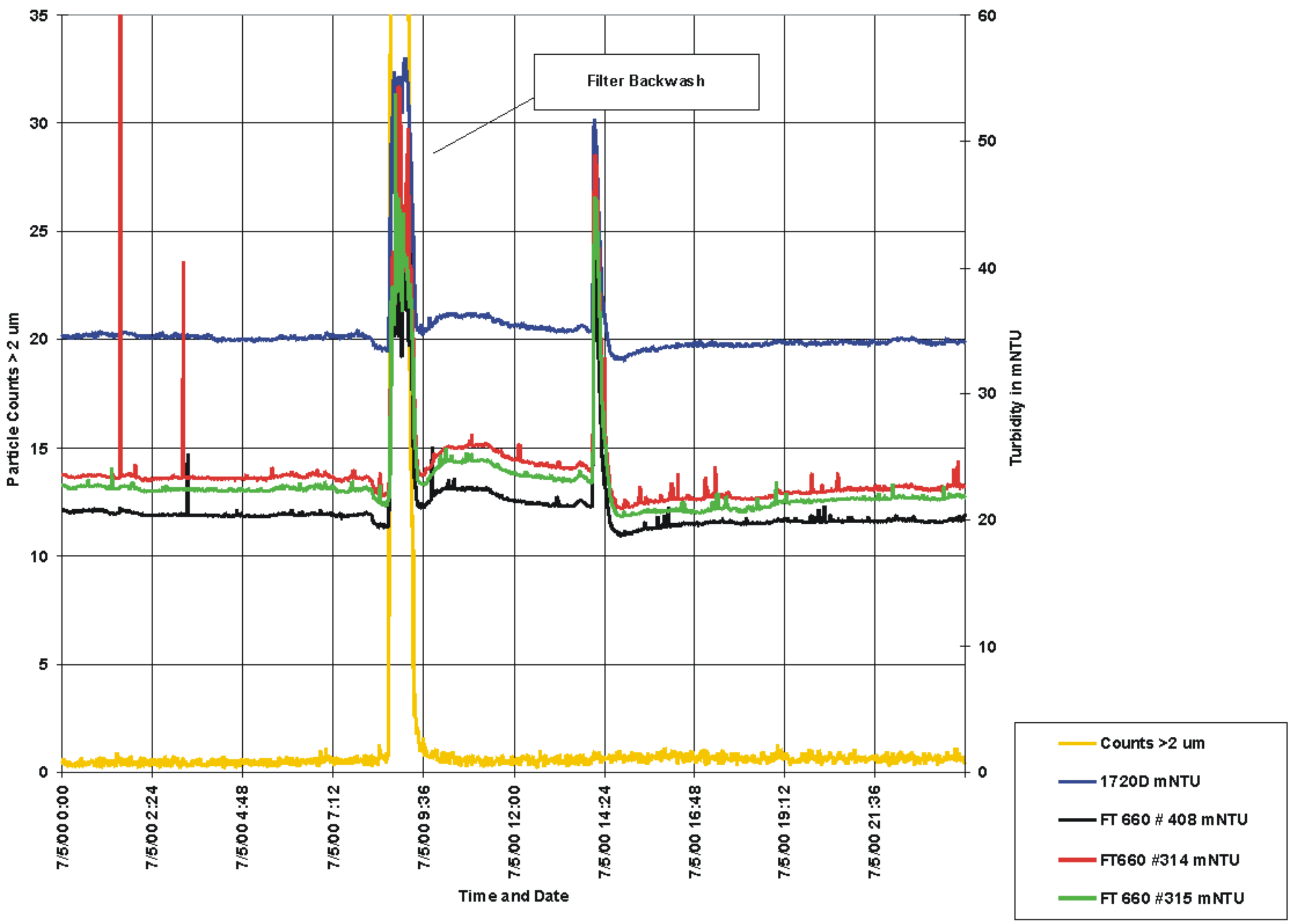


Figure 7 Water Treatment Plant Filter #12 Effluent Particulate Monitoring (07/05/00)



Correlations between the turbidity value at the termination of backwash and filter events were also examined. The turbidity values at backwash termination were in a very narrow range between 0.69 and 1.74 NTU. It can be speculated 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 detected by the OptiQuant SST probe turbidimeter that was monitoring the pre-filter sample.

The FilterTrak 660 detected the majority of events that the other effluent instruments detected and also detected some events that they missed. In addition, the FilterTrak 660 baseline 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 FilterTrak 660 and particle counter. All five settled water precursor events were also seen in the effluent. The turbidity of these influent spikes, which range between 0.5 and 2 NTU, were reduced significantly as they passed through the filter. The resulting events in the effluent were very small with turbidity changes ranging between 0.005 and 0.030 NTU (5-30 mNTU) and the finished water 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 an apparently 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 structural problems on the dams for the raw water source, the source will be drained significantly throughout the summer and fall of 2000. We will continue to see if changes to the raw water source have an impact on particle event occurrence at this sample site.

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