United States Environmental Protection Agency

Generating High-Quality Turbidity Data in Drinking Water Treatment Plants to Support System Optimization and Monitoring

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About this document

This document describes the common turbidimeter setups and associated Supervisory Control and Data Acquisition (SCADA) systems used in drinking water treatment plants. It also identifies “best practices” approaches to help ensure data quality.

Background

Water treatment facility staff use data from continuous reading turbidimeters to determine compliance with drinking water regulatory requirements. These data also support plant process control, including optimization activities. The EPA Area-Wide Optimization Program assists plants in setting and achieving optimization goals. Recent activities of this program have focused on improving data quality, including data collected by online turbidimeters. Some of the best practices identified through the program’s training activities are listed below and addressed in more detail in the sections of this document.

- Ensure representative sampling (e.g., avoid excessively long sample lines that lead to delayed online measurements, choose proper sample locations, ensure proper sample tap installation, ensure appropriate sample pumping). See Section 2 for more information.

- Avoid inappropriate capping of turbidity data captured by plant Supervisory Control and Data Acquisition (SCADA) system (i.e., ensure that the system can capture true spikes). See Section 4.1 for more information.

- Determine the most representative maximum daily individual filter effluent (IFE) and combined filter effluent (CFE) turbidities. See Section 3 for more information.

- Be aware of the impact of turbidimeter settings on signal output. See Section 4 for more information.

- Ensure consistent settings between instruments. See Section 4 for more information.

- Ensure that instrument flow rate is within range recommended by manufacturer, as mentioned in Section 2.

- Adhere to instrument maintenance schedule (e.g., annual change of bulbs, inspection of photo detector, periodic sample line flushing and cleaning or replacement).

- Ensure that historical turbidity data are readily accessible from plant SCADA (e.g., create exportable daily time-stamped turbidity files). See Section 5 for more information.

- Conduct quality control reviews for continuous turbidimeter databases (e.g., ensure that date-time stamps for instruments match the SCADA system record, investigate data sets that show turbidity spikes that are inconsistent with reported plant performance), as mentioned in Section 5.

1. Typical Capability for Continuous Reading Turbidimeters and SCADA Systems in Water Treatment Plants

1.1 Turbidimeter capability:

Continuous reading turbidimeters record results approximately once per second (i.e., real-time data) and usually transfer these data to the plant SCADA through an analog (most common) or digital signal. The real-time data can often be viewed by the operator at multiple locations, including the turbidimeter controller screen and the control room computer monitor (i.e., plant SCADA screen). The ability to access historical turbidity data in SCADA systems varies widely from plant to plant. Access can be very limited (e.g., manually *"scrolling"* back on the SCADA screen to find data of interest) to exceptional (e.g., inputting selected date range and data frequency to produce an electronic report).

Turbidimeter data can also be accessed from the local short-term memory of the turbidimeter through its associated controller. Data stored in the controller can be downloaded to a computer and viewed in a spreadsheet. The data stored locally in a turbidimeter controller are usually limited to approximately six months of 15-minute data.

1.2 Individual Filter Effluent (IFE)/Combined Filter Effluent (CFE) monitoring and recording requirements:

The regulatory requirement for IFE turbidity monitoring recording is at least every 15 minutes (40 C.F.R. § 141.560). The CFE turbidity monitoring recording requirement is at least every four hours (40 C.F.R. § 141.74). The recorded IFE data must be stored for at least three years (40 C.F.R. § 141.571) and the CFE data must be stored for at least five years (40 C.F.R. § 141.33). Individual states may have more stringent requirements for data retention and recording frequency. Turbidity data are usually stored on the SCADA computer, and the file is referred to as the *data log* in this document (sometimes also referred to as the data historian). See Section 5 for a discussion of storing and accessing turbidity data logs.

Federal regulations do not require that the CFE turbidimeter data be logged electronically, but states may require it. State monthly operating reports (MORs) usually require the operator to report the daily 4-hour readings when the plant is in operation. This data can be captured by analyzing grab samples or by a continuous-reading turbidimeter. Many plants have continuous-reading turbidimeters to measure CFE, but some use grab samples for compliance purposes.

2. Turbidimeter Location and Sample Tap Considerations

2.1 Turbidimeter location:

Continuous-reading turbidimeters should be located as close as possible to the sample tap, ideally achieving one minute or less travel time to the turbidimeter, while ensuring the flow rate to the instrument is within the manufacturer's recommendation for optimal instrument operation. This best practice helps to minimize sample detention time and resulting delay in receiving real-time results. Recognizing the balance between minimizing sample detention time and allowing access to turbidimeters for calibration and maintenance, a sample detention time of less than one minute is typically sufficient to promptly capture changes in IFE and CFE performance.

2.2 Sample tap location:

The sample tap location for turbidimeters should be representative of process performance.

- For IFE turbidity samples, the sample collection tap must be located on the filtered water line prior to combining with water lines from other filters (i.e., upstream of the CFE manifold).

- For plants with filter-to-waste (FTW) capability, continuous monitoring during the filter-to-waste period should be representative of the water going to waste. In order to accurately monitor FTW turbidity, the CFE sample tap must be located upstream of the FTW discharge.

- The CFE sample tap must be downstream of the CFE manifold. For the CFE sample to be representative of the performance of the filters, the sample should be taken upstream of the clearwell and any post-filtration pH adjustment. This avoids negative bias from settling in a clearwell or positive bias from precipitation of iron, manganese, or post-floc due to pH adjustment.

3. Turbidity Data Interpretation and Related Instrumentation Support

3.1 Key parameters:

For optimization purposes, operators should make process control decisions based on using the real-time data available on the SCADA monitor or turbidimeter controller. Operators should use these data to evaluate performance during a filter run and during the recovery period following a backwash. Analysis of this information forms the basis for potential process control changes to improve filter performance. Critical data that support the assessment of a water treatment plant relative to optimization goals include:

- Maximum raw water turbidity measured each day that the plant is in operation, based on grab samples or continuous data (whichever is the more frequent reading). Raw water turbidity monitoring frequency for grab samples is plant-specific, based on the variability of the source water, but should be frequent enough to alert operators to changing raw water quality so that treatment adjustments can be made in a timely manner. Continuous instruments should capture data at least every 15 minutes for optimization purposes.

- Maximum daily settled water turbidity from each settling basin or clarifier. Grab samples should be taken at least every four hours for optimization purposes. Continuous instruments should capture data at least every 15 minutes for optimization purposes.

- Maximum IFE turbidity measured each day for every filter, excluding times when filter is out of service, during backwash, and during FTW. Some data loggers associated with plant SCADA have the flexibility to be turned on and off to record only performance data when the filter effluent is going to the clearwell.

- Turbidity data at return-to-service following each filter backwash and the highest turbidity during FTW, if FTW capability is available.

3.2 IFE data source and recording:

To track IFE performance relative to optimization goals, operators should also use real-time continuous data representing filtered water going to the clearwell, excluding data during backwashes and FTW. These data can be entered into a trending spreadsheet such as the Optimization Assessment Spreadsheet (OAS), available at the Area-Wide Optimization Program (AWOP) website: https://www.epa.gov/dwstandardsregulations/optimization-program-drinking-water-systems. Options for selecting a data set to determine the maximum daily IFE turbidity value are described in the table below.

Source of IFE data	Desirability of option
Determine daily maximum manually from SCADA trend line.	This option is the ideal option for determining the maximum daily IFE turbidity for each filter.
Determine maximum from 1-minute readings from data logger.	This option is better than 15-minute readings[2].
Determine maximum from 15-minute readings from data logger.	Appropriate if the return-to-service turbidity post-backwash is determined by some other means such as from the SCADA trend line[1].
Determine maximum from grab samples (collected at least every 15 minutes).	If any of the options above are available, then this is the least desirable option. Turbidity spikes could be missed between sampling intervals.

[1] This option works well if each 15-minute reading represents the maximum turbidity value during the 15-minute period and the return-to-service turbidity is determined from the SCADA trend line.

[2] This option works well if the 1-minute readings represent the maximum turbidity value during the 1- minute period.

For historical records, the plant SCADA should log IFE turbidity data at a frequency of at least once every 15 minutes (maximum value during the period would meet optimization needs). Refer to Section 5.3 for suggested format. These records provide the basis for internal and external assessment of historical plant performance.

3.3 CFE data source and recording:

To track CFE performance relative to the optimization goals, operators should follow an approach similar to that described in Section 3.2, including guidance on determining the maximum daily value. EPA's optimization program recommends fifteen (15)-minute data logging or more frequently. Critical optimization data that support the CFE optimization goal include the highest CFE turbidity value measured each day.

While there is no federal regulatory requirement to record the maximum daily CFE turbidity, there are maximum CFE limits, and reporting requirements and actions, for when CFE turbidity levels exceed 1.0 NTU (see 40 C.F.R. § 141.175 for further information). Recording the maximum daily CFE turbidity supports optimization efforts and some states may require it. Many states require the daily maximum CFE turbidity value to be reported on their MOR.

4. Turbidimeter Settings

4.1 Output span (applicable to analog signals only):

Setting the turbidimeter output span involves configuring the analog 4-20 milliamp (mA) signal for corresponding turbidity values. A minimum span of 0 to at least 5.1 NTU will capture data needed for determining regulatory compliance and for optimization purposes. A span up to 5.1 NTU will accommodate slow sand filter and alternative filtration technologies. Most current turbidimeters have sufficient capability (i.e., ≥ 12-bit processors) to provide the needed data resolution to support this span. This range will also allow the plant and regulatory agency to evaluate the need for (1) a self-assessment, if IFE turbidity readings are above 1.0 NTU in two consecutive measurements in three consecutive months, or (2) a Comprehensive Performance Evaluation (CPE), if IFE turbidity readings are above 2.0 NTU in two consecutive 15-minute interval measurements in two consecutive months, as required by 40 C.F.R. § 141.175.

NOTE: The transmitting device (instrument's controller) and the receiving device (SCADA, PLC, chart recorder, etc.) must be spanned correctly for the data to be accurately recorded in SCADA. The analog output from the controller/transmitter and the analog input to the receiving device must both be calibrated for span independently. Many modern instruments offer the choice of digital or analog outputs and receiving devices may also be digital or analog. It is possible to intermix analog and digital systems. Because of the variety of systems available, a trained instrumentation controls technician may be needed to set up data collection system input and output devices. The system should be checked whenever it is re-spanned to ensure that the signal span in the controller is the same as the signal span in SCADA. For example, if an analog 4 - 20 mA signal is initially set up for a span of 0 - 1 NTU, then the output device (instrument controller) and receiving device must be scaled the same. If the controller is later rescaled to 0 - 5.1 NTU output range, the entire system should once again be checked (ideally by a trained instrumentation controls technician) to assure that every part of the system is appropriately rescaled. In a SCADA system, this will involve reprogramming the receiving device and the HMI (Human-Machine Interface). If an all-digital system is used for data transmission, the process of ensuring the data are spanned correctly throughout the entire system is simpler.

4.2 Signal averaging:

The default on most turbidimeters is to average the last 30 readings (i.e., 30 readings taken at approximately 1-second intervals) and send the resulting average value to the controller and SCADA. The averaged number is displayed on the controller as well. The signal averaging results in one new value being added to, and the oldest value dropped from, the average every second. This tends to even out any irregular variations that may occur in the signal. This variation can be caused by air bubbles or the presence of non-representative particles, such as those caused by scale or corrosion, drifting in and out of the view of the detector. For both compliance and optimization monitoring, the 30-second default associated with some instruments works well and usually does not require adjusting. In some turbidimeter controllers, this feature can be referred to a “speed of response” when coupled with algorithms that minimize positive interference from air bubbles and other anomalies.

4.3 Bubble reject algorithm:

The bubble reject algorithm is a means to minimize the positive interference caused by gas bubbles in the sample (i.e., the bubble interference causes higher turbidity readings). The bubble reject feature in turbidimeters is a statistical algorithm built into the instrument that attempts to adjust for positive interference in discrete measurements. Sometimes this feature can be referred to as the "speed of response" of the turbidimeter, when it is coupled with a signal averaging feature. The values that are deleted by the algorithm occur over a very short time span (seconds) and should not impact the ability of the operator to identify true spikes in their process. The default for most instruments is for the bubble reject algorithm to be turned on. For both compliance and optimization monitoring, using this default setting works well and usually does not require adjustment.

4.4 Loss of signal to the controller:

If the turbidimeter controller loses its signal, the controllers usually have two options for how to respond: (1) "Hold Outputs" (also known as "Error Hold"), or (2) "Transfer Outputs". Controllers are usually preset by the manufacturer to the "Hold Outputs" / *"Error Hold"* mode. In this mode, if the controller does not receive a signal from the turbidimeter, the controller will continue to send the last known value that came from the turbidimeter to SCADA. This default setting can mask the signal loss problem from operators, sometimes for days if the typical filter performance is steady. For compliance and optimization monitoring, the controller "loss of signal" option should be set to *"Transfer Outputs"* mode, when available. In other turbidimeter controllers, this can be referred to as "configuring the error level". This feature generates a user-defined preset value when the signal is lost from the turbidimeter. The preset value should be one that would be immediately recognizable (e.g., 0.0 or 5.0 NTU, or the corresponding mA signal can be set to indicate an error, such as 4.0, 2.0 or 0.0 mA for a 4-20 mA setup). The SCADA system can be designed to initiate an alarm based on that value. The operators would then be immediately aware of the problem and address the situation. Any "loss of signal" data (e.g., 0.0 or 5.0 NTU) could then be excluded from compliance reporting and any optimization analyses. Loss of signal problems should be addressed promptly.

An alternative or complementary approach to resolving a “loss of signal” issue is to design the system to initiate an alarm to the SCADA whenever the turbidity reading does not change over a specific period of time. For example, if the turbidity value identified by three decimal places (e.g., 0.055 NTU) does not change for 15 minutes (a highly unrealistic circumstance if the turbidimeter is functioning properly), an alarm would be triggered by SCADA.

4.5 Calibration and maintenance settings:

Using the *“Hold Outputs” / “Error Hold”* setting during calibration and maintenance activities will typically account for erroneous turbidity spikes that may occur when sample lines are disturbed during these types of activities.

4.6 Calibration verification:

States have different calibration and verification frequency requirements. The manufacturer’s operating instructions should be followed for turbidimeter calibration. Measure standards on the turbidimeter covering the range of interest. If the instrument is already calibrated in standard turbidity units, it is important to verify that the instrument is still reading accurately on a regular basis. At least one standard should be measured within the expected turbidity range during normal usage. Some instruments permit adjustments of sensitivity so that scale values will correspond to turbidities. Surface scratches on solid standards, such as those made of lucite blocks, can cause calibration changes to the instrument. If a pre-calibrated scale is not supplied, calibration curves should be prepared for each range of the instrument. See EPA Method 180.1 for further information.

5. Storing and Accessing Turbidity Data Logs

5.1 General:

The data logs in a SCADA system have the capability of handling long-term data storage needs. Refer to Section 1.2.

5.2 Daily data log elements:

An electronic turbidity data log should be created daily in an easily accessible format (e.g., csv, xlsx). Date, time, and turbidity values should be included for each continuous reading turbidimeter. Turbidity data should be logged at least every 15 minutes to best assess plant performance and support optimization.

Plant operating conditions (i.e., filter-to-clear well, FTW, backwash, out-of-service) should be identified for logged IFE turbidity data. Sorting functionality should be included to allow the operator to review historical data related to a specific plant operating condition (e.g., filter-to-clear well data only).

5.3 Storage and integrity:

Data log files should be stored in a directory easily accessible by the plant operators and backed up routinely (e.g., weekly). To mitigate the effects of equipment failure, the data should be backed up to both onsite servers and a remote drive, such as a portable hard drive. Surge protection should be provided for systems that store the data logs to mitigate the effects of power failures.

Quality control reviews for continuous turbidimeter databases should be conducted on a regular basis to ensure optimal operation and consistency with other collected data. For example:

- Ensure that date-time stamps for instruments match the SCADA system record.
- Investigate data sets that show turbidity spikes that are inconsistent with reported plant performance.

6. SCADA Monitoring

6.1 Trend lines:

The SCADA monitoring system should be programmed to allow operators to create their own trend lines using a flexible turbidity scale and a flexible time scale (e.g., ability to change a scale from 0 - 5 NTU to 0 - 1 NTU).

6.2 Control screens:

The SCADA monitoring system should allow operators flexibility to create plant-specific control screens showing selected trend lines (e.g., selected filter IFE turbidity, filter flow rate, and valve open-closed position for the selected filter in the same view).

7. Summary

A tabular summary of key recommendations is included in Appendix 1.

Appendix 1: Summary of Recommendations for Generating High-Quality Turbidity Data in Water Treatment Plants

Table 1. Turbidimeter and Sample Location Considerations

Critical Data Handling Element	Recommendation	Reference
Continuous turbidimeter location and sample line detention time	As close to sample tap as possible, ideally achieving one minute or less travel time to the turbidimeter.	See Section 2.1.
IFE turbidity sample tap location	Locate on the filtered water line prior to combining with water lines from other filters (i.e., upstream of the CFE manifold) and prior to FTW discharge.	See Section 2.2.
CFE turbidity sample tap location	Locate downstream of the CFE manifold, but upstream of the clearwell and any post-filtration pH adjustment.	See Section 2.2.

Table 2. Data Integrity Considerations for Maximum Daily Values

Critical Data Handling Element	Recommendation	Reference
Daily maximum turbidity values	Determine raw water, individual settled water, IFE, and CFE daily maximums.	Used for optimization and for compliance in some states. See Sections 3.1, 3.2, and 3.3 as well as the applicable sub-sections.

Critical Data Handling Element	Recommendation	Reference
Raw water turbidity data logging frequency	Plant-specific but at least one sample per day. Continuous instruments should capture data at least every 15 minutes for optimization purposes.	See Section 3.1.
Settled water turbidity data logging frequency	At least one sample per day. Continuous instruments should capture data at least every 15 minutes for optimization purposes.	See Section 3.1.
IFE turbidity data logging frequency	Obtain manually from SCADA trend line or 15-minute intervals using the maximum value within each 15-minute interval (with return-to-service value after backwash determined from the SCADA trend line) or 1-minute intervals. Excluding data when the filter is not filtering to the clear well.	Used for optimization. See Sections 3.1 and 3.2.
CFE turbidity data logging frequency	15-minute data logging.	See Section 3.3.

Table 3. Turbidimeter Settings Considerations

Critical Data Handling Element	Recommendation	Reference
Output span	Set span to 0 to at least 5.1 NTU.	See Section 4.1. Not applicable to digital data transfer systems. IMPORTANT: The transmitting device (instrument's controller) and the receiving device (SCADA, PLC, chart recorder, etc.) must both

Critical Data Handling Element	Recommendation	Reference
		be spanned correctly for the data to be accurately recorded in SCADA.
Signal averaging	30 seconds.	See Section 4.2.
Bubble reject	Set to *"On."*	See Section 4.3.
Loss of signal	Set to *"Transfer Outputs",* if feature is available, and/or set alarm based on loss of signal.	See Section 4.4. Set turbidimeter to transfer to a known value to alert operators if signal is lost. Consider designing SCADA alarm to alert on loss of signal.
Calibration settings	Set to *"Hold Outputs."*	See Section 4.5.

Table 4. Turbidity Data Storage Considerations

Critical Data Handling Element	Recommendation	Reference
Accessibility	Locate log files in a directory easily accessible to operators.	See Section 5.3.
Backup	Data logs should be backed up at least routinely (e.g., weekly).	See Section 5.3.