3. TURBIDITY METHODS & MEASUREMENT

3.1 Introduction

The IESWTR requires systems to measure the turbidity of combined filter effluent and individual filter effluent. Because these measurements are used for reporting and compliance purposes (as described in Chapter 2), accurate measurement and strict adherence to approved methods is of paramount importance. The following chapter describes approved methods, analytical issues associated with turbidimeters, quality assurance and quality control issues, and data collection and management.

3.2 Approved Turbidity Methods

Currently, the Agency has approved three methods for the measurement of turbidity as described in §141.74. Systems must utilize turbidimeters which conform to one of the following methods for compliance purposes. If the instrument does not conform, then it may not be used for monitoring under the requirements of the IESWTR. A brief description of each of the methods is found below.

3.2.1 EPA Method 180.1

EPA method 180.1, "Determination of Turbidity by Nephelometry", is found in the Agency's publication, *Methods for Chemical Analysis of Water and Wastes*. The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. Readings, in NTUs, are made in a nephelometer designed according to specifications laid out in the method. A primary standard suspension is used to calibrate the instrument. A secondary standard suspension is used as a daily calibration check and is monitored periodically for deterioration using one of the primary standards. See Appendix B for EPA Method 180.1.

3.2.2 Standard Method 2130B

Standard Method 2130B, found in *Standard Methods* (1995), is similar to EPA Method 180.1. The method is also based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity. Formazin polymer is used as the primary standard reference suspension. See Appendix C for Standard Method 2130B.

3.2.3 Great Lakes Instrument Method 2 (GLI 2)

Great Lakes Instruments Method 2 is an instrument specific, modulated four beam method using a ratiometric algorithm to calculate the turbidity value from the four readings that are produced. The comparison is also based on a comparison of light scattered by the sample under defined conditions with the intensity of the light scattered by the reference suspension. The higher the intensity of the scattered light, the higher the turbidity. Readings in NTUs, are made in a nephelometer designed according to specifications in the method. See Appendix D for Great Lakes Instrument Method 2.

3.3 Turbidimeters

As noted, turbidimeters must conform to one of the three approved methods for measuring turbidity. For regulatory reporting purposes, either an on-line or a benchtop turbidimeter may be used. A system may find it appropriate to utilize on-line turbidimeters to monitor individual filter effluent, while utilizing either a benchtop or on-line turbidimeter for combined filter effluent. If a system chooses to utilize on-line units for monitoring combined filter effluent, they must validate the continuous measurements for accuracy on a regular basis using a protocol approved by the State.

3.3.1 Bench Top Turbidimeters

Bench top units are used exclusively for grab samples and include glass cuvettes for holding the sample. Measurement with bench top units requires strict adherence to the manufacturer's sampling procedure to reduce errors from dirty glassware, air bubbles in the sample, and particle settling. Plant operators should read and be fully familiar with the operation manuals for all bench-top turbidimeters used in the plant. Many maintenance and operational issues are specific to turbidimeter make and model, and instruments are usually supplied with a thorough user's manual.

Bench-top Basics

Although durable, turbidimeters need to be stored and operated in a safe and protected environment. Moisture and dust need to be prevented from entering and accumulating inside turbidimeters. Humidity also needs to be controlled to prevent condensation inside the instrument. Turbidimeters should be located where they will not be exposed to corrosive chemicals or fumes. Chemicals such as chlorine and acids can ruin instrumentation. Finally, turbidimeters should be located in an environment that is temperature controlled, at a consistent temperature between 0°and 50°C.

Generally the instrument should be left on at all times (unless otherwise specified in the user's manual). If any instrument is not left on at all times, it may require a warm-up period before sample analysis.

The length of the sample piping or tubing from the sampling location to the point where the sample is drawn off should be minimized. Long sample lines can lead to problems with biological fouling and scaling which can impact turbidity values. It is best to limit sample

lines to ten feet or less. Long sample lines can also cause confusion due to the lag time as the sample travels through the piping. The longer the lag time, the more difficult it is to correlate turbidity fluctuations to actual process changes that might be occurring.

Sample taps in piping should be located on the sides of pipes. Samples taken from the top or bottom will not accurately represent the turbidity of the water. Samples taken from the bottom will often times contain sediment while samples from the top may contain a greater number of air bubbles. Ideally, sample taps should be angled into the water flow at an angle of 0-45 degrees and extend into the center of the flow channel. Sample taps should be located away from items which disturb flow such as fittings, bends, meters, or pump discharges.

Operation and Maintenance

Preventative and routine maintenance should be carried out according to manufacturers' instructions. Do not make repairs to the instrument unless specified in the instruction manual. Even if a repair can be made, consider sending the unit back to the manufacturer. Keep track of maintenance and repair on a log sheet located next to the unit.

Maintain benchtop instruments in accordance with manufacturer recommendations. Inspect the cleanliness of bulb and lenses daily. Clean lenses, light sources, and other glassware with appropriate materials to avoid scratches and dust accumulation. Avoid the use of chemicals or other materials when cleaning unless instructed by the manufacturer. Do not touch the optical components with bare hands (soft cotton gloves are recommended). Recalibrate the instrument after any significant maintenance or cleaning procedure.

Bench-top turbidimeters, just like most instruments, have an effective service life. Various elements within the instrument can deteriorate over time and with repeated use. Daily usage can result in wear on electronics due to movement and temperature. Microprocessor based electronics are also prone to memory loss during power supply fluctuations. Service personnel can often provide insight on instrument life and can make recommendations for specific maintenance items. Since turbidimeters have become integral parts of a water treatment plant operation and reporting, it is imperative to maintain instruments and budget for replacements.

Replace incandescent turbidimeter lamps annually, or more frequently if recommended by the manufacturer. Recalibrate the instrument whenever optical components (e.g., lamp, lens, photodetector, etc.) of the turbidimeter are replaced or cleaned.

Calibration

Calibration is an essential part of accurate turbidity measurement, and as such, instrument calibration should be verified on a daily basis. Calibration verification can be completed using primary or secondary standards. If verification indicates significant deviation from the standard (true) value (greater than ±10%), thoroughly clean and recalibrate the

instrument using a primary standard. If problems persist the manufacturer should be contacted. At a minimum regardless of calibration results, turbidimeters should be thoroughly cleaned and calibrated with primary standards ***at least quarterly***.

After calibration, performance of the turbidimeter should be verified with a secondary standard. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the operator should use these tools to verify proper calibration and operation. Calibration is discussed in significant detail in Section 3.4.5.

3.3.2 On-Line Turbidimeters

On-line turbidimeters are process instruments which sample a side stream split-off from the treatment process. The sample flows through the on-line instrument for measurement and then wasted to a drain or recycled through the treatment process.

Selection of the flow rate through on-line turbidimeters should be in accordance with manufacturer specifications. The sample flow should be constant without variations due to pressure changes or surges. Installation of a flow control device such as a rotameter on the sample line can eliminate fluctuations in flow rate.

To the extent possible, turbidimeter samples should be obtained directly from the process flow and not pumped to a remote instrument location. Pumped samples can be non-representative of the process flow due to changes in the character of particles caused by the pump or the addition of bubbles due to rapid pressure changes. If pumping is required, the use of peristaltic pumps are desirable, as they have the least amount of impact on particles in the sample.

Several of the on-line turbidimeters available today have various sample chamber sizes. It is important to note that the size of the sampling chamber will affect the instrument response. The path length of the light passing through the sample is inversely proportional to resolution of the instrument. Therefore, the larger the sample size, the more likely that the turbidity reading will be dampened.

Installation

On-line turbidimeters should be installed in accordance with manufacturer instructions. The goal of proper installation is to ensure proper operation, easy access for maintenance and calibration procedures that should be performed, and obtain an accurate, representative and timely sample.

Carefully consider the location of the sample tap. The tap should provide a representative sample of the water being monitored. If an individual filter is being monitored, locate the sample tap as close to the filter as possible. The tap should provide a sample from the centerline of the pipe, as opposed to the bottom or top of the pipe where sediment or air bubbles may interfere with sample integrity. Ideally, the sample will flow by gravity from

the sample tap to the turbidimeter without a sample pump. Sample pumps may have an effect on turbidimeter measurements.

The length of conduit between the sample tap and the instrument should be minimized, to the extent possible. Lengthy sample runs can delay instrument response time and may cause changes in sample quality (i.e., settling of particulate matter, increased opportunity for biological growth). In selecting sample tubing or pipe, the required sample flow rate and pressure should be considered. Sample lines of insufficient diameter may not provide adequate flow to the instrument and may be prone to clogging. Excessively large diameter sample lines will delay the instrument response and may permit settling of particulate matter. Line flushing valves and ports may be necessary depending on the water being sampled. Carefully consider these items when installing an on-line turbidimeter.

A good sample tap location and plumbing arrangement will minimize the potential for bubble formation. Most on-line turbidimeters have the capability to eliminate minor bubble interference through baffles and/or degassing chambers, but if the problem is severe, the turbidity measurements may be affected.

The turbidimeter should be installed in a location that provides easy access for routine maintenance and calibration procedures. It should be protected from direct sunlight, extreme temperatures (<32ºF/0ºC and >104ºF/40ºC), and rapid temperature fluctuations. It should also be firmly mounted so as to avoid vibrations, which may interfere with the accuracy of turbidity measurements.

The turbidimeter drain should provide easy access for flow verification and collection of calibration verification samples. Flow rate and calibration verification samples are important in establishing data validity. Therefore, hard piping the turbidimeter drain without an airgap is not recommended.

Operation and Maintenance

Preventative and routine maintenance should be carried out according to manufacturer's instructions. A regular cleaning schedule is necessary to ensure proper operation of on-line turbidimeters. A weekly inspection is recommended, but this frequency may vary depending on the instrument location and raw water quality. Warm or turbid samples may dictate more frequent cleaning. An instrument mounted in a dusty environment may also require more frequent cleaning. Items to inspect and clean include, but are not limited to, lenses, light sources, sample reservoirs, air bubble traps, and sample lines. Clean lenses, light sources, and other glassware with appropriate materials to avoid scratches and dust accumulation. During maintenance, care needs to be taken not to touch the surface of any bulbs or detectors without proper covering on the fingers. Soft cotton gloves should be worn when changing bulbs or detectors. Recalibrate the instrument after any significant maintenance or cleaning procedure.

On-line turbidimeters, just like most instruments, have an effective service life. Various elements within the instrument can deteriorate over time and with repeated use. Daily

usage can result in wear on electronics due to movement and temperature. Microprocessor based electronics are also prone to memory loss during power supply fluctuations. Many on-line units with unsealed sensor electronics are vulnerable to damage by outside contamination and splashing. Service personnel can often provide insight on instrument life and can make recommendations for specific maintenance items. Since turbidimeters have become integral parts of a water treatment plant operation and reporting, it is imperative to maintain instruments and budget for replacements.

Incandescent turbidimeter lamps should be replaced annually or more frequently if recommended by the manufacturer. The instrument should be recalibrated whenever optical components (e.g., lamp, lens, photodetectors, etc.) of the turbidimeter are replaced.

Systems should consider verifying sample flow rates on a weekly basis. Flow rates should be within a range specified by the manufacturer.

Calibration

EPA recommends that on-line turbidimeters have calibration verified on a weekly basis, if being utilized for combined filter effluent monitoring. Less frequent verification may be more appropriate for turbidimeters monitoring individual filter turbidity, but EPA recommends verification be conducted with a frequency of **at least** once per month.

Calibration verification can be completed using primary standards, secondary standards, or by comparison to a properly calibrated turbidimeter. If verification indicates significant deviation from the standard (true) value (greater than ±10%), the instrument should be thoroughly cleaned and recalibrated using a primary standard. If problems persist, the manufacturer should be contacted. Regardless of calibration results, turbidimeters should be thoroughly cleaned and calibrated with primary standards ***at least quarterly***.

EPA does not recommend calibrating on-line instruments by comparison with a bench-top turbidimeter. It has been determined that this procedure is likely to introduce unacceptable levels of error into the calibration.

After calibration, verify instrument performance with a secondary standard or by comparison with another properly calibrated instrument. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the operator should use these tools to verify proper calibration and operation. For additional information on calibration see Section 3.4.5.

3.4 Quality Assurance/Quality Control

Although using proper techniques and equipment is an important part of conducting proper turbidity measurements, it is imperative that operators are aware of factors in the processes which may lead to poor quality data. Such factors include poor lab techniques, calculation mistakes, malfunctioning or poorly functioning instrumentation, and out-of-date and deteriorated chemicals. Development of a Quality Assurance and Quality

Control (QA/QC) Program ensures that lapses do not occur which allow inaccurate measurements or erroneous reporting. Systems may want to establish plans to provide assurance that measurements are being made accurately and consistently.

3.4.1 Quality Assurance Organization and Responsibilities

A good QA/QC plan provides clear organization and defines who is responsible for each of the aspects laid out in the plan and what their responsibilities are. This section should include a list of the positions (by title) that have responsibilities and what those responsibilities are. The appropriate training or skills necessary for each of the positions listed should also be included.

3.4.2 Quality Assurance Objectives

The objectives of the Quality Assurance Program need to be laid out and understood by the staff members. Objectives should be succinct, and clear. SOPs should be developed with input from staff, enabling them to effectively conduct work activities in compliance with applicable requirements. Systems may wish to include one primary objective, followed by a number of goals which all relate to the objective. An example might look like the following:

The primary objective of the Quality Assurance Program is to ensure that turbidity measurements are accurate and consistent. Based on this, the goals of the Quality Assurance Program at a generic water treatment plant are the following:

- To adhere to proper sampling techniques as set forth in the Standard Operating Procedures.
- To maintain and operate all turbidimeters at the plant properly in accordance with manufacturer instructions and Standard Operating Procedures.
- To perform calibration of instruments on a routine and as-necessary basis.
- To communicate and report all, malfunctions, abnormalities, or problems which may compromise the ability to accurately and consistently measure turbidity.

3.4.3 Standard Operating Procedures

Standard Operating Procedures (SOPs) are a way to ensure that activities are accomplished in a consistent manner, and that each activity is understood by all involved. SOPs should be kept as simple as possible in order to ensure that each operator is consistent in undertaking the task at hand. The title of the procedure should be clear, concise, and descriptive of the equipment, process, or activity. Systems should consider adopting SOPs for any of the following activities:

- Cleaning turbidimeters
- Creating Formazin Standards

- Calibrating Turbidimeters
- Referencing Index Samples

Instructional steps should be concise and precise, using the following guidelines:

- Steps should contain only one action.
- Commands should be written with an action verb at the beginning.
- Limits/and or tolerances for operating parameters should be specific values and consistent with the accuracy of the instrumentation. Procedures should not include mental arithmetic.
- **"Cautions"** should be used to attract attention to information that is essential to safe performance.
- **"Notes"** should be used to call attention to supplemental information. Notes present information that assists the user in making decisions or improving task performance.
- Documentation methods should be incorporated as part of the procedure including what data needs to be recorded, if the individual needs to sign or date data, etc.

After developing an SOP, the author(s) should consider the following questions:

- Can the procedure be performed in the sequence it is written?
- Can the user locate and identify all equipment referred to in the procedure?
- Can the user perform the procedure without needing to obtain direct assistance or additional information from persons not specified by the procedure?
- Are words, phrases, abbreviations, or acronyms that have special or unique meaning to the procedure adequately defined?
- Is there a need for special controls on data collection and recordkeeping?

After completing the SOP it should be tested to the extent possible. It is also a good idea to ask a technical reviewer to verify the accuracy of the procedure. SOPs should be reviewed at least once every 2 years to determine if the procedure and requirements are still accurate.

The following is a simplified example of an SOP written for the development of Formazin.

Creating a 4000 NTU Formazin Stock Suspension

1. Dissolve 1.000 g of ACD grade hydrazine sulfate, N_2H_4 H_2SO_4 in ultra filtered deionized water and dilute to 100 mL in a Class A, 100 mL volumetric flask.
2. Dissolve 10.00 g of analytical grade hexamethylenetetramine, $(CH_2)_6N_4$, in ultra filtered deionized water and dilute to 100 mL in a Class A, 100 mL volumetric flask.
3. Combine the equal volumes of the hydrazine sulfate solution and the hexamethylenetetramine solution into a clean, dry flask and mix.
4. Let the mixture stand for 48 hours at 24-26 ºC.
5. Store the suspension in a bottle that filters ultraviolet light.

3.4.4 Sampling Strategy and Procedures

The procedure for conducting sampling should be laid out clearly and concisely, preferably in SOPs (discussed in Section 3.4.3). It should include information such as sampling location and frequency, collection methods, sample handling, and any logistical considerations or safety precautions which are necessary. Adherence to proper techniques is an important step in minimizing the effects of instrument variables and other interferences (Sadar, 1996). Measurements will be more accurate, precise, and repeatable if operators follow and incorporate the techniques listed in this section.

All turbidimeter manufacturers emphasize proper techniques and include detailed instructions in their literature. Water treatment plant operators responsible for conducting turbidity measurements are urged to review these instructions and incorporate them into their SOPs. Specific instruction for securing samples and measuring turbidity will differ for the various instrument manufacturers and models, but there are certain universally accepted techniques that should be utilized when conducting measurements. The following paragraphs highlight some of these techniques.

Handling of Cuvettes/Sample Tubes

Sample cells must be handled with absolute care to avoid contamination or damage, such as marks and scratches, which might change the optical characteristics of the glass. Scratches, fingerprints, and water droplets on the sample cell or inside the light chamber can cause stray light interference leading to inaccurate results. Cells can be acid washed periodically and coated with a special silicone oil to fill small scratches and mask the imperfections in the glass. Since the silicone oil required for this application should have the same refractive characteristics as glass, it is recommended that the oil be obtained from the instrument manufacturer. Care should be taken to not apply excessive oil that could attract dirt or contaminate the sample chamber in the instrument. Once the oil has been applied to the cell, the excess oil should be removed with a lint-free cloth. The result

should be a sample cell surface with a dry appearance, but with all imperfections filled with oil. Sample cells should always be handled at the top of the cell or by the cap to avoid fingerprints or smudges. After a cell has been filled with a sample and capped, the outside surface should be wiped with a clean, lint-free absorbent cloth until it is dry. Store cells in an inverted position on clean surfaces to reduce contamination by dirt or dust or store capped and filled with low turbidity water.

Orientation and Matching of Sample Cells

Since imperfections in the sample cell glass can influence light scattering, the cell should be inserted in the turbidimeter with the same orientation each time it is used. At the Philadelphia Water Department, new cells are indexed and are not allowed to vary by more than 0.01 NTUs. Philadelphia reports that as many as one quarter of the cells are never used due to imperfections in sample cells (Burlingame, 1998).

Matched sample cells are required to minimize the effects of optical variation among cells. If possible, it is better to use a single sample cell for all measurements to minimize the variability due to cell-to-cell imperfections. Once the orientation of a cell has been established, the operator should always use the same orientation when placing the sample cell into the instrument. Techniques for matching and indexing are provided below.

Indexing Cells (Steps 1-2) Matching Cells (Steps 1-3)

Step 1. Pour ultra-pure dilution water into a sample cell (several cells if performing matching) that has been cleaned according to the techniques described previously in this section.

Step 2. Select sample cell, and place it into the turbidimeter. Rotate the cell within the instrument until the display reads the lowest value. Record the reading. Using a marker or pen, place a mark on the top of the sample cells neck. **Do not put the mark on the cap.** Use this mark to align sample cells each time a measurement is made.

Step 3. Select another sample cell, place it into the turbidimeter and rotate the cell slightly until the reading matches that of the first sample cell (within 0.01 NTUs). Using a marker or pen, place a mark on the top of the sample cells neck. If unable to match the readings select a different sample cell. Repeat the process until the appropriate number of cells have been matched.

Degassing of the Sample

Water samples almost always contain substantial amounts of entrained gases that can be released during turbidity measurement. Bubbles are either generated during the filling of a sample container, occur due to temperature fluctuations resulting in a reduced solubility of the gas in a liquid, or are due to chemical and/or biological processes. Bubbles within a

sample act much like particles and can scatter light resulting in an incorrect measurement. Many on-line turbidimeters contain apparatuses inside the instrument that serve to trap, collect, and vent air bubbles. Usually these consist of baffled entries or membranous chambers. Some vendors also manufacture add-on units which can be placed in the sample line before the on-line turbidimeter. There are several other options for removing bubbles from water (degassing) to reduce the effect they have on measurements. The most commonly used methods include, addition of a surfactant, application of a partial vacuum, and use of an ultrasonic bath.

Addition of a surfactant compound to a water sample lowers the surface tension of the water and allows entrained gases to readily escape. There are a variety of surfactants used in turbidity measurements today. Because of the variety in chemical composition, it is difficult to provide guidance for their use. It is important to note that some surfactants may have constituents which serve as a coagulant and cause particles to aggregate and settle out. Other chemicals might contain constituents with an ionic charge that cause particles to rise to the surface. The use of surfactants is more appropriate for measurement of highly turbid waters such as raw water. The most appropriate instrument-specific advice regarding the use of surfactants can be obtained by contacting the instrument manufacturer.

Application of a partial vacuum to a sample lowers the partial pressure above the liquid surface and allows entrained gases to escape. Partial vacuums can be created by a simple syringe or by use of a vacuum pump. Some instrument manufacturers and suppliers provide pre-made vacuum kits that include syringes for degassing samples. The most common arrangement is the use of a syringe and a stopper sized for the opening of the sample cell or test tube.

The use of an ultrasonic bath creates vibrations in the sample to facilitate the escape of gases. Ultrasonics is a specialty field/science that utilizes an inaudible spectrum of sound frequencies ranging from about 20,000 cycles per second to 100,000 cycles per second. Ultrasonic baths are used for thoroughly cleaning supplies in the medical, electronic, and metals industries. When high frequency sound waves are passed through a cleaning fluid, such as water with suitable detergent additive, many millions of microscopic bubbles form and then rapidly collapse. The bubbles are the result of the stretch and compress phases of the sound waves within the fluid, a process known as cavitation. Ultrasonic devices may be most effective in severe turbidity conditions or with viscous samples, however if used for degassing samples, samples should be sonified **for no more than 1 to 2 seconds**. Sonification can change particle size ranges, affecting a turbidimeters response if improperly utilized (Burlingame, 1998).

Timeliness of Sample

Samples should be measured expeditiously after being secured to prevent changes in particle characteristics due to temperature and settling. Temperature can affect particles by changing their behavior or creating new particles if precipitates are created. Dilution water may dissolve particles or change their characteristics (Sadar, 1996). Operators are

encouraged to draw samples only when turbidimeters are ready to be operated. Do not draw a sample and allow it to sit while the instrument warms up or is being readied.

Other Important Sampling Techniques

- Samples should not be violently agitated as particles can be broken apart or air may be entrained into the fluid. Gentle agitation such as swirling the sample cell is advisable to reduce particle settling.
- Sample cells should be used only with the instruments for which they were intended. Do not mix and match.
- Perform a visual observation of the sample cell every time a measurement is made. Verify that there are no visible bubbles in the sample and the cell is clean and free of scratches.
- Samples entering the turbidimeters should be at the same temperature as the process flow samples. Changes in temperature can cause precipitation of soluble compounds and affect readings.
- Sample cells should be evaluated with a low turbidity water (after cleaning) to determine if cells remain matched. If the evaluation determines that a cell is corrupted, discard the cell. Systems should consider conducting this evaluation weekly.
- When in doubt, throw it out - If you have a question as to whether a sample cell is too scratched or stained get rid of it.

3.4.5 Calibration

Turbidimeters, like all instrumentation, need to be calibrated periodically to ensure that they are working properly and provide true and accurate readings.

> ***Calibration should always be conducted according to manufacturer instructions.***

Determine the appropriate technical requirements for calibration based on the following

- Manufacturer
- Model name and/or number
- Parameters to be calibrated
- Range to be calibrated
- Acceptance criteria
- Mandatory calibration procedures or standards
- Required calibration program

After calibration, performance of the turbidimeter should be verified with a secondary standard. If the instrument has internal electronic diagnostics designed to assist in determining proper calibration, the operator should use these tools to verify proper calibration and operation.

Calibration Standards

A calibration standard must be used to conduct a calibration. Standards are materials with a known value which, when placed in the instrument, should be used to adjust the instrument to read the known value.

There are a variety of standards on the market today which are used to calibrate turbidimeters. They are most often characterized as Primary, Secondary, or Alternative standards. Standard Methods describes Primary Standards as a standard which is prepared by the user from traceable raw materials, using precise methodologies and under controlled environmental conditions. (Standard Methods, 1995) Standard Methods defines Secondary Standards as those standards a manufacturer (or an independent testing organization) has certified to give instrument calibration results equivalent (within certain limits) to results obtained when an instrument is calibrated with a primary standard.

Standard Methods and EPA differ in their definitions of each of these standards. EPA recognizes the following three Standards for approved use in the calibration of turbidimeters.

- FORMAZIN (user prepared and commercially produced)
- AMCO-AEPA-1® MICROSPHERES
- STABLCAL® (STABILIZED FORMAZIN)

Users need to realize that some instruments have been designed and calibrated on specific primary standard(s) listed above. For optimal results, users should contact the manufacturer of the instrument to determine the recommended primary standard to be used for calibration.

Additionally, EPA recognizes Secondary Standards for use in monitoring the day-to-day accuracy of turbidimeters by checking the calibration. This check is used to determine if calibration with a Primary Standard is necessary. Secondary Standards are used to check whether an instrument produces measurements within acceptable limits around a nominal value (typically 10%). Examples of *SECONDARY STANDARDS* include:

- GELEX®
- GLASS/CERAMIC CUBES
- MANUFACTURER PROVIDED INSTRUMENT SPECIFIC SECONDARY STANDARDS

The need to reconcile the definitions and differences among Primary and Secondary Standards will be a continuing issue. It has been recognized that the standards need to be unbiased, easy to use, safe, available for a range of turbidities, and reproducible. Future efforts of the Agency, in concert with other organizations and manufacturers, will focus on ensuring the most appropriate, variation-free, and technologically feasible standards are available and used for calibration of turbidimeters.

Conducting the Calibration

All reputable turbidimeters have been factory-calibrated before leaving the manufacturer. As described previously, turbidimeters, like most instrumentation, tend to lose accuracy over time due to a variety of factors, making periodic calibration very important to maintain accurate measurements. The most important point to remember is:

Calibration should always be conducted according to manufacturer instructions.

Manufacturers differ in the steps to conduct a calibration, but the following points are applicable to all calibrations.

- Standards should be checked to ensure they have not expired. Never pour a standard back into its original container.
- Care should be taken when preparing Formazin. If a spill occurs, clean up immediately according to the Material Safety Data Sheets (MSDSs) provided with your chemicals. Make sure to inspect the tube/cuvette for scratches and chips prior to pouring the solution in.
- Check to make sure the tube/cuvette is lined up properly according to the indexing. Be sure not to scratch the tube when inserting, and ensure that the tube/cuvette is free of dust, smudges, and scratches.
- When obtaining the reading, write the value legibly onto a form similar to the one found in Figure 3-1. Make sure to record the date of the calibration, the individual conducting the calibration, the value, and any peculiar situations or deviations from normal calibration procedures (e.g., switch to a new lot of Formazin, switch in standards, use of a new tube/cuvette, etc.) These measurements will allow for an understanding of whether the performance of a turbidimeter is in question. For example, if for 6 months a turbidimeter reads approximately 20.152 when calibrated using polystyrene beads and one morning it reads 25.768, this could be an indication that the bulb in the turbidimeter has a problem. Conversely, if the standard in use was switched that morning, the resulting change might be due to change in standards.
- Conduct the calibration the same way each time. Variations in how the calibration is conducted could yield inaccurate measurements.
- It is extremely important that individuals who conduct the calibration have been trained to do so. Systems should consider creating Standard Operating Procedures to be read, learned, and followed by operators at the plant.

Frequency of Calibration

EPA recommends that the calibration of units be verified daily with secondary standard and recalibration occur at least quarterly with primary standards. Specific calibration procedures should be developed for each individual instrument location. Listed below are several guidelines for selecting calibration frequencies and procedures:

- Select a frequency for checking instrument calibration with secondary standards and for full re-calibration of instrument with primary standards .
- Establish the acceptable deviation from the primary standard during secondary verifications. Readings in excess of the deviation should trigger immediate re-calibration of the instrument. ($\pm$10% is recommended by EPA)
- Choose a time of day when full attention can be devoted to the calibration. Calibration at the end of a shift or right before a break can often lead to mistakes and sources of error. A calibration time should be established when operators are fully alert and focused on completing the task.
- Identify and schedule in advance the dates for full turbidimeter calibration on the plant calendar or work scheduling chart.
- Make preparations and maintain adequate supplies to prevent delays in the calibration schedule. It is important to keep an appropriate stock of standards. Due to the limited shelf-life of various standards, the age of the stored standards should be monitored so they can be replaced or reformulated as needed.
- Assign calibration duties to a select group of individuals, and make it one of their standard activities. Train all appropriate individuals/operators in conducting a calibration in the event that one of the regular individuals is not available.
- Create a Standard Operating Procedure for conducting a calibration and post next to the turbidimeter.

3.4.6 Data Screening, Validation, and Reporting

The methods for data screening, validation, and reporting should be detailed to ensure that measurements are recorded calculated and reported correctly. These methods should be designed to meet the Quality Assurance Objectives. Again, the development and implementation of SOPs will facilitate those goals.

CALIBRATION CHECKLIST

Month_____

Year _____

Date	Initials	Value	Standard	Comments

Figure 3-1. Calibration Checklist

3.4.7 Performance and System Audits

Performance and system audits should be conducted periodically to determine the accuracy of the total measurement system(s) or component parts thereof. Performance audits may include review of documentation and log books for legibility and completeness. The systems audit consists of evaluation of all components of the sampling and measurement systems to determine their proper selection and use. This audit includes a careful evaluation of both field and laboratory quality control procedures and can include verification of written procedures and analyst(s) understanding, verification and documentation of procedures, as well as adherence to any SOPs.

3.4.8 Preventative Maintenance

Preventive maintenance should be conducted on all instrumentation. The maintenance program consists of scheduled (preventive) and non-scheduled maintenance procedures. All maintenance performed and the results of calibrations should be documented. Maintenance procedures and schedules for equipment used should be available to the appropriate staff. Adherence to maintenance schedules and procedures may be

investigated during a systems audit. A preventive maintenance schedule recommended by the respective manufacturers should be followed for each instrument. This preventive maintenance will include regular battery checks and maintenance of a sufficient stock spare parts and supplies. Manufacturers' procedures identify the schedule for servicing critical items to minimize downtime of the measurement system.

3.5 Data Collection and Management

The final steps in turbidity measurement deal with the collection of data and management of collected data. The advent of the personal computer revolution has provided much needed assistance to tasks that were once time consuming, although automation still requires operators who are skilled and trained in the use of sometimes sophisticated equipment. This section describes the several methods available to systems for the collection of data and provides a brief description of the management of that data.

Data obtained from Supervisory Control and Data Acquisitions (SCADAs), data recorders, or strip charts should be verified on a weekly basis by comparing the turbidimeter reading with the data recording device reading. If verification indicates greater than ±10% deviation, the electronic signal should be recalibrated according to manufacturer instructions.

3.5.1 Data Collection Methods

Acquisition of data from turbidimeters is an important step in the turbidity measurement process. With the individual filter turbidity requirements, systems will be required to continuously monitor each filter. Each of the methods discussed below are typically used for on-line turbidimeters. Readings using benchtop units are typically recorded by hand or entered into a PC without the use of the data collection equipment listed below. Systems may have experience using these methods in monitoring other water quality parameters.

Strip Recorders and Circular Chart Recorders

Strip Chart and Circular Chart Recorders are a relatively established technique for recording data. The units are set to obtain a reading at a timed interval. A pen records the reading on paper at the interval. As additional readings are taken, the pen moves back and forth (or up and down in the case of a circular recorder) recording the values that are being monitored.

Newer models include digital readouts as well as the capability to transfer data to data loggers or other data acquisition systems. The greatest disadvantages to using chart recorders is the difficulty in incorporating data into electronic format and archiving such data. Recorders also require the purchasing of replacement pens and charts.

Data Loggers

Data Loggers are "black boxes" which store data which is received from input channels. The box records the data in memory which can then be downloaded at a future time. Data loggers consist of two distinct components: hardware and software.

Hardware

The units themselves typically consist of a device containing solid state memory encased in a plastic weatherproof enclosure. Units have a varying number of inputs that can be either analog (records actual numbers) or digital (records a series of 0s and 1s), as well as an output to download data. Systems most often are battery powered, but some can be connected to existing power supplies. Nearly all systems contain lithium or other batteries to keep memory active in the event of a power failure.

Software

Two software components are important to data loggers/acquisition devices. First, specialized software is necessary to configure the logging unit. This configuration specifies the unit frequency at which to obtain turbidity readings. The second part of the software is used to retrieve the data from the logger and import it into a usable format on a PC. Most companies offer integrated packages that allow users to import the data and immediately plot and graph the data to depict trends or produce reports. Data should be downloaded at regular intervals, as data loggers cannot store data indefinitely.

Several methods exist to transfer data from the logger into the PC. Data acquisition systems are often equipped to be compatible with telemetry to upload data to PCs via telephone, cellular telephone, or radio. Alternatively, either a laptop or palmtop can be connected to the unit to download information, or the data logger can be brought into the office where the PC is located and plugged into one of the input/output ports on the PC. The better method could necessitate utilizing a second data logger to take the place of the first logger when it is being downloaded. Systems may wish to schedule downloads to occur at times when a filter may not be in operation (when off-line or being backwashed).

SCADA

SCADA systems are devices used for industrial measurement and control. They consist of a central host (base unit), one or more field gathering and control units (remotes), and a collection of standard and/or custom software used to monitor and control remotely located field data elements. The base unit and the remote units are linked via telemetry, and the base unit receives data and provides instructions as specified in the software. SCADA systems at treatment plants are also often times referred to as Distributed Control Systems (DCS). DCSs function the same as SCADA systems except that field gathering and control units are located in a more confined area and communications may be via a local area network (LAN) as opposed to remote telemetry.

SCADA systems can take inputs from a variety of sources and instruments. These systems collect and display the data produced by a variety of instruments so that the plant

operator can monitor the entire treatment process from one location. SCADA systems are typically used for a variety of functions at a water treatment plant including flow control, pH and temperature monitoring, automated disinfection dosing, and a host of other functions. Control may be automatic or initiated by operator commands. The inclusion of continuous turbidity monitoring could be incorporated into the regime of items being measured and controlled by a SCADA/DCS system at a treatment plant.

SCADA systems can also be used to log and store data for recording purposes. Signals sent from remote instruments located on the plant site are interpreted at the base unit. This unit provides the logic to interpret all of the different signals and display real-time measurements. The central unit can be programmed to automatically transfer historical data to other storage media such as a tape drive or Zip-drive.

3.5.2 Data Management

There are two distinct objectives to management of turbidity data: (1) Regulatory Compliance, and (2) Checking Process Control and Treatment Plant Optimization. The turbidity reporting and monitoring requirements set forth in Chapter 2 establish the types of data which must be collected and the analysis which must be done to meet the requirements of the rule. In order to meet these requirements, operators must understand three areas of data management:

- Data Format;
- Data Storage; and
- Data Analysis.

Format

Storage of the data in a usable format is the first step to effective data management. Operators should have the ability to download data from their acquisition equipment into a usable and manageable format. Data is typically placed in one of many different formats such as Excel, Access, dBASE, and Lotus 123. Data should be converted into a format that can be used by the facility. Many systems currently utilize software such as those listed above. The key to selecting a format is the ease at which the data can be viewed, manipulated, and or converted. Certain software packages allow users to create reports, tables, or graphs based on the data.

Storage

Storage of the data is the next step in effective data management. Maintaining these data points for future analysis may pose a problem due to the amount of disk space required. Systems should consider the use of Zip-Drives or tape-drives for storage of data. Hard drives can be used to store data while manipulating or evaluating. Tape and Zip-Drive backups are also recommended due to the possibility of a PC crashing.

Interpreting and Analyzing Data

Data Analysis is the last step in effective data management. Systems are encouraged to utilize the Data Collection Spreadsheets and Macros developed for the Partnership for Safe Water. A description of the Partnership for Safe Water is found in Chapter 4.

Spreadsheets were prepared for the Partnership for Safe Water to assist utility partners in collecting performance data. The spreadsheets were developed to capture turbidity data from raw water, sedimentation basin effluent and filter effluent, but can be used to measure repetitive data of any kind, from any point in the process for up to 365 days. Macros have been written to generate frequency distributions on a monthly and annual basis, to help evaluate trends and summarize large amounts of data. Graphics capabilities of the spreadsheets are also built in to automatically plot trend charts and frequency distributions. There are also capabilities for generating summaries of the data to report as background information. Other data summaries within the capabilities of each spreadsheet software version could be generated as well. A disk containing the software along with guidance for using the software is found in the Composite Correction Program Handbook published by EPA.

The software provided with many of the data acquisition systems, which can be custom designed for SCADA/DCS systems, also allow operators to trend and analyze data. Easy-to-use software provides clear graphics for operators to evaluate. Typically, data can be exported to various spreadsheets or database programs for later analysis. Software is typically interactive, with the ability to change colors, and graph sizes.

Systems should analyze turbidity data to check process control and treatment plant optimization. Systems may wish to evaluate backwash turbidity spikes for individual filters, how storm events affect the filtration capabilities, or the effect of various chemical dosages on filtered effluent. Analysis could be undertaken to compare different filters within a system or the effect of different flow rates. Chapter 5 provides information on conducting a Filter Self Assessment and analysis which systems may wish to implement.

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