Designation: D7512 – 09 (Reapproved 2015)

Standard Guide for
Monitoring of Suspended-Sediment Concentration in Open Channel Flow Using Optical Instrumentation[1]

This standard is issued under the fixed designation D7512; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the equipment and basic procedures for installation, operation, and calibration of optical equipment as a surrogate for the continuous determination of suspended-sediment concentration (SSC) in open channel flow.

1.2 This guide emphasizes general principles for the application of optical measurements to be used to estimate suspended-sediment concentration (SSC) in water. Only in a few instances are step-by-step instructions given. Continuous monitoring is a field-based operation, methods and equipment are usually modified to suit local conditions. The modification process depends upon the operator skill and judgment.

1.3 This guide covers the use of the output from an optical instrument, such as turbidity and suspended-solids meters, to record data that can be correlated with suspended-sediment concentration. It does not cover the process of collecting data for continuous turbidity record, which would require additional calibration of the turbidity readings to the mean turbidity of the measurement cross section. For the purposes of this method it is assumed that the dependent variable will be mean cross-sectional suspended-sediment concentration data.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D3977 Test Methods for Determining Sediment Concentration in Water Samples

D4411 Guide for Sampling Fluvial Sediment in Motion

D7315 Test Method for Determination of Turbidity Above 1 Turbidity Unit (TU) in Static Mode

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration drift, n*—the error that is the result of drift in the sensor reading from the last time the sensor was calibrated, and is determined by the difference between cleaned-sensor readings in calibration standards and the true, temperature-compensated value of the calibration standards.

3.1.2 *continuous, adj*—refers to a time series of unit values that are close enough in time to simulate a continuous record.

3.1.2.1 *Discussion*—Generally, in studies of open-channel flow, 15-minute intervals are used and are adequate to estimated continuous record. However, the time interval maybe as little as a minute or as great as an hour.

3.1.3 *fouling, n*—the error that can result from a variety of sources (such as biological growth on the sonde and covering of the probe with sediment), and is determined by the difference between sensor measurements in the environment before and after the sensors are cleaned.

3.1.4 *sonde, n*—part of the monitoring equipment that contains the measurement sensors.

3.1.4.1 *Discussion*—A sonde may be either a single parameter sensor or a combination of different sensors of different parameters.

4. Summary of Guide

4.1 This guide covers the equipment and basic procedures for installation, operation, and calibration of optical equipment as a surrogate for the continuous or near continuous determination of SSC in open channel flow.

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[1] This practice is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

Current edition approved Jan. 15, 2015. Published February 2015. Originally approved in 2009. Last previous edition approved in 2009 as D7512 – 09. DOI: 10.1520/D7512-09R15.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4.2 This guide emphasizes general principles for one particular application of optical measurements in water. This guide covers the use of nephelometers and backscatter type turbidity meters to record data that can be correlated with SSC.

5. Significance and Use

5.1 This guide is general and intended as a planning guide. To satisfactorily monitor a specific site, an investigator must sometimes design specific installation structures or modify those given in this guide to meet the requirements of the site in question. Because of the dynamic nature of the sediment transport process, the extent to which characteristics such as mass concentration and particle-size distribution are accurately represented in the monitoring program depends on the type of equipment used and method of collection of the SSC samples used to calibrate the optical readings. Sediment concentration is highly variable in both time and space. Numerous samples must be collected and analyzed with proper equipment and standardized methods for the rating of the optical equipment at a particular site (see Guide D4411 and Practice D3977).

5.2 All optical equipment have an upper limit for valid readings, beyond which the meter will not read properly, commonly referred to as "blacking out." If upper range of SSC are expected to cause optical instrument black out, then some other means should be devised, such as automatic pumping samplers, to collect samples during this period. See Edwards and Glysson (**1**)[3] and Glysson (**2**) for information on collection of suspended sediment samples using pumping samplers. It should be noted that other technologies, such as lasers and acoustic dopplers, are also being used to monitor SSC continuously.

5.3 The user of this guide should realize that because different technologies and different models of the same technology of turbidity meters can produce significantly different outputs for the same environmental sample, only one manufacturer and model of the turbidity meter can be used to develop the relationship between the SSC and turbidity readings at a site. If a different manufacturer or a different model type of turbidity meter is used, a new relationship will need to be develop for the site.

6. Apparatus

6.1 In general, three types of configurations of installations of monitors can be used: *(1)* the flow-through monitoring system, *(2)* the in-situ monitoring system, and *(3)* the self contained, combined sensor and recording system.

6.2 Optical instruments such as photoelectric nephelometer (best used for lower levels of SSC) and backscatter sensors (best used for higher levels of SSC) provide the basis for this method. For more information concerning the advantages and disadvantages of each, see Test Method D7315. As they become available, other sensors may be used.

6.2.1 The Alliance for Coastal Techniologies (ACT) did an in-situ evaluation of different nephelometer technologist. Users of this guide may be interested in the results of this study which can be found online.[4]

6.3 Before selecting the type of meter to be used, the operator needs to review the site requirements in order to ensure selection of the proper instrumentation. Things to consider, but are not limited to, are: the instruments ability to survive the study site environment, the degree of fouling that may take place, and the range of readings likely to be encountered at the site.

6.4 If a flow-through or in-situ monitoring device is used, a recording system must be installed. The recording system must have enough storage capacity to store all data recorded between site service visits. See manufacturer's advice on which recording devices will work best for the type of monitor being used.

6.5 Remote access and near real-time transmission of data from the site to the office can be very important in meeting the objectives of the monitoring station. Remote access and the near real-time transmittal of the recorded data take other equipment (such as a data collection platform (DCP), and transmittal antenna) in addition to the optical sensor. A DCP performs the same fundamental function as a basic data recorder (BDR). They both collect data from attached sensors on a timed interval and store the results. The difference is the BDR retains the data until it is retrieved manually, while the DCP has the ability to transmit the collected data to another location. Since data is transferred elsewhere for storage shortly after collection, a DCP may have less memory than a BDR. The data may be transmitted via telephone modem, line-of-site radio link or satellite. It is beyond the scope of this guide to discuss how to instrument a site for remote data transmission and no single reference on how to do this is available for reference here. The user is encouraged to visit the U.S. Geological Survey's Hydrologic Instrumentation Facility website[5] for information on equipment needs and used by the USGS.

6.6 The installation of an automatic pumping sampler, especially in remote areas, will allow samples to be collected that can be used to relate the optical reading to the suspended-sediment concentration in the stream and also address the blackout periods discussed in 5.2. Detailed information concerning the installation and operation of pumping samplers is beyond the scope of this guide. See Edwards and Glysson (**1**) and Glysson (**2**) for more information on the use of automatic pumping samplers.

7. Site Selection

7.1 The procedure for establishing a sampling location should emphasize the quest for a stream-data site. A stream-data site is as a cross section displaying relatively stable hydrologic characteristics and uniform depths over a wide

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[4] Available from http://www.act-us.info/evaluation.php.

[5] Available from http://water.usgs.gov/hif.

range of stream discharges, from which representative sediment data can be obtained and related to a stage-discharge rating and optical readings from the site. This is an idealized concept because the perfect site is rare at best. Therefore, it is necessary to note the limitations of the most suitable site available and build a program to minimize the disadvantages and maximize the advantages.

7.2 Sites that may be affected by backwater conditions should be avoided whenever possible. Backwater condition is a transient condition that occurs when water is backed up or retarded in a stream by tides or from inflow from another stream. Backwater affects both stage-discharge and velocity-discharge relationships. Therefore, a given discharge may have varying stage and mean stream velocity and thus have varying sediment transport rates.

7.3 A sediment-measuring site located downstream from the confluence of two streams may require extra sediment measurements due to incomplete mixing of the flows from the tributaries. Moving the sampling location far enough downstream to ensure adequate mixing of the tributary flows should be investigated.

7.4 Because sediment samples must be obtained more frequently during high flows, and it is imperative that a site be selected where obtaining data during these times are feasible. Particular attention should be given to the ease of access to the water-stage recorder and to a usable bridge or cable during high flows, many of which occur at night. Sites accessible only by poorly maintained backroads or trails should be avoided.

7.5 The average monitoring site will consist of a shelter to house and protect the equipment and some means for either bringing water to the meters or conduits that will allow the meter to be placed in the flow zone of the channel. The shelter should be located to minimize the distance between the stream and the meters, and at a high enough elevation to protect the equipment during flooding events. Some instruments may need AC power and therefore the proximity to power lines is important.

7.6 For additional information and discussion on the selection of a site for the collection of surface water and sediment data see Edwards and Glysson (**1**), Wagner et al. (**3**), and Rantz et al. (**4**).

8. Installation of Equipment

8.1 Placement of sensor in cross section of the stream: The primary consider when placing an optical meter, sensor, or water intake (collectively referred in this section as "sampling point.") in the streamflow at a cross section is that only one point in the flow is being sampled. Therefore, to yield reliable and representative data, the sampling point should be placed at the point where the concentration approximates the mean SSC for the cross section for the full range of flows. SSC data may have to be collected from several verticals in the cross section to help define where the mean SSC values is most likely to accrue (see (**1**)). This is an idealistic concept and the mean cross-section concentration almost never exists at the same point under varying streamflow conditions. It is even less likely that specific guidelines for locating a sampling point under given stream conditions at one stage would produce the same sampling point location relative to the flow conditions at a different stage. Therefore, generalized guidelines (modified from (**1**)) are outlined here and should be considered on a case-by-case basis when selecting a sampling point.

8.1.1 Select a stable cross section of reasonably uniform depth and width to maximize the stability of the relationship between sediment concentration at a point and the mean sediment concentration in the cross section. This guideline is of primary importance in the decision to use an optical meter in a given situation; if a reasonably stable relation between the sample-point reading and mean cross-section concentration cannot be attained by the following outlined steps, the meter should not be installed and an alternate location considered.

8.1.2 Consider only the part of the vertical that could be sampled using a standard U.S. depth- or point-integrating suspended-sediment sampler, excluding the unsampled zone, because data collected with a depth- or point-integrating sampler will be used to calibrate the optical meter. See Guide D4411 and Edwards and Glysson (**1**) for information on the unsampled zone, proper procedures, and equipment to collect samples for SSC analysis.

8.1.3 Determine, if possible, the depth of the point of mean sediment concentration in each vertical for each size class of particles finer than 0.250 mm, from a series of carefully collected point integrated samples. See Edwards and Glysson (**1**) for information on the collection of point samples and Guy (**5**) for procedures for determining particle size of sediment samples.

8.1.4 Determine, if possible, the mean depth of occurrence of the mean sediment concentration in each vertical for all particles finer than 0.250 mm.

8.1.5 Use the mean depth of occurrence of the mean sediment concentration in the cross section as a reference depth for placement of the sampling point.

8.1.6 Adjust the depth location of the sampling point to avoid interference by dune migration (which may bury the probe) or contamination by bed material.

8.1.7 Adjust the depth location of the sampling point to ensure submergence at all times.

8.1.8 Locate the sampling point laterally in the flow at a distance far enough from the bank to eliminate any possible bank effects such as inflow of overland flow for the banks and localized increased SSC do to bank erosion.

8.1.9 Place the sampling point in a zone of high velocity and turbulence to improve sediment distribution by mixing and reduce possible deposition on or near the sampling point.

8.2 *Flow Thru*—The flow-through monitoring system has a pump to convey water from the stream to a tank inside a shelter that contains the monitoring sensor or sonde (Fig. 1). Typical pumps require 120-volt alternating current (AC) and deliver about 10 gallons of water per minute. If access to AC power is not a problem, then other site considerations become important (Table 1); the advantages and disadvantages of the flow-through monitoring system must be compared to the data objectives.

8.3 *In-Situ*—The sensors in the in-situ monitoring system are placed at the measuring point in the stream cross section

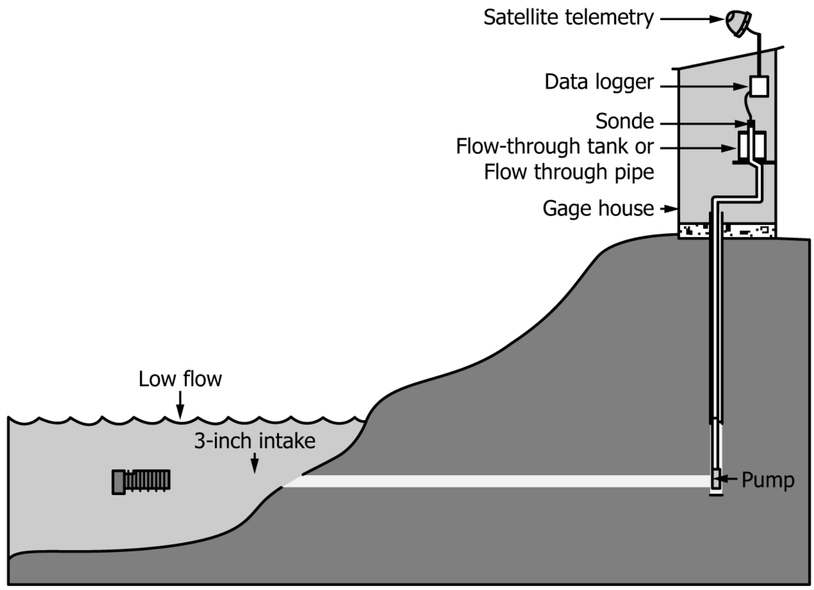

FIG. 1 Typical Flow-Through Water-Quality Monitoring Station (Modified from (3))

TABLE 1 Principle Advantages and Disadvantages of Flow-Through Monitoring Systems

Advantages	Disadvantages
Unit can be coupled with chlorinators to reduce fouling.	120-volt AC power source is needed.
Sensor systems can be secured in vandal-proof shelters.	Higher installation costs are incurred.
Calibration can be performed in the shelter.	Pumps tend to clog in streams with algal fouling or high sediment loads.
Can help eliminate interferences caused by ambient light and bubbles.	Electrical shock protection is required.
	Pumps may be damaged by corrosive waters.
	Pump maintenance is required.
	Pumping may cause changes in water-sediment concentration and particle size distribution.

(Fig. 2). Cables run from the sensors to the recording equipment that is housed in a shelter. The primary advantage of this configuration is that no power is needed to pump water (Table 2). Direct current, 12-volt batteries easily meet the power requirements of the sensors and recording equipment. In-situ water-quality monitoring systems can be installed at remote locations where AC power is not available, but the advantages and disadvantages of the in-situ monitoring system also must be considered.

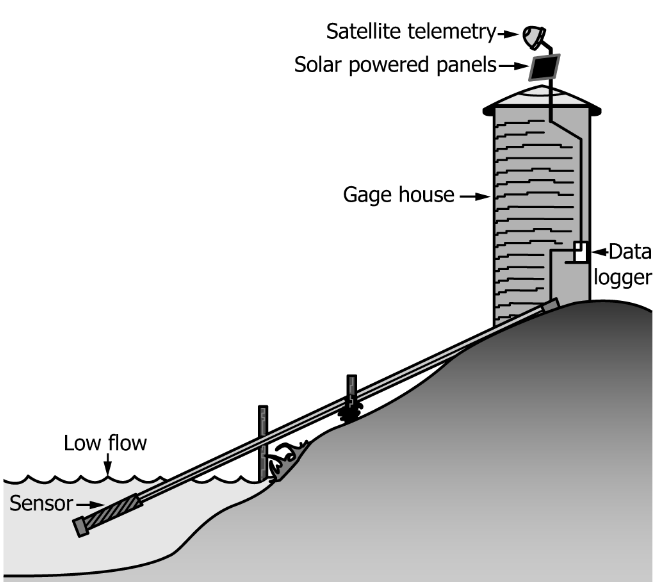

FIG. 2 Typical In-Situ Water-Quality Monitoring Station (Modified from (3))

8.4 *Self-Contained*—The third water-quality monitoring system is a combined sensor and recording sonde that is self-contained, requires no external power, and reduces exposure to vandalism. Power is supplied by conventional batteries located in a sealed compartment, and sensor data are stored within the sonde on nonvolatile, flash-memory, recording devices (Fig. 3). The advantages and disadvantages of the self-contained sensor and recording system must be considered (Table 3).

8.5 *Placement of Recorders in Relation to Sensor*—Recorders should be placed as close to the sensor as possible, but at a high enough elevation to protect it from being inundated by high water. The recorder should be placed in a secure structure to protect it from the environment and from possible vandalism.

9. Operation of Meters

9.1 *Maintenance*—The operation of a sediment monitoring station is intended to produce the greatest amount of correctable field record that can be verified. The general operational categories include maintenance of the station and equipment;

TABLE 2 Principle Advantages and Disadvantages of In-Situ Monitoring Systems

Advantages	Disadvantages
No power is needed to pump water.	Sensors are susceptible to vandalism.
Remote locations are possible.	The water flow cannot be treated to reduce fouling.
Smaller shelters can be used.	In shallow bank installations, the proper location of sensors in the cross section is difficult.
Pumping maintenance is not required.	Servicing sensors during flooding can be difficult.
Freeze protection is provided to the sensors.	Sensors are susceptible to debris at high flows and chemical and biological fouling.
Electrical hazards are reduced.	Shifting channels may cause movement of the equipment.
No pumping therefore no lift limit.	Sensors may be susceptible to interferences for light and surface reflections or bubbles.

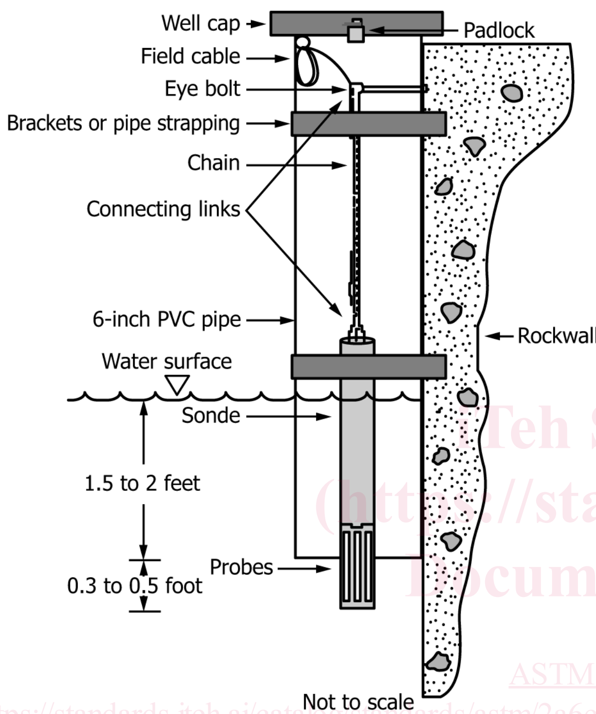

FIG. 3 Typical Self-Contained Water-Quality Monitoring Sensor and Recording System (Modified from (3))

inspection and recording of sensor readings; cleaning, calibration, and troubleshooting of sensors and recording equipment; cross section measurements; and accurate record keeping. Optical sensors are prone to fouling. Maintenance frequency is generally governed by the fouling rate of the sensors, and this rate varies by sensor type, hydrologic environment, and season. The use of wiper or shutter mechanisms on modern optical instruments has decreased the fouling problem significantly. For stations with critical data-quality objectives, service intervals may be weekly or more often. Monitoring sites with nutrient-enriched waters and moderate to high temperatures may require service intervals as frequently as every third day. In cases of severe environmental fouling or remote locations, the use of an observer for servicing the water-quality monitor should be considered. In addition to fouling problems, physical disruptions (such as pump failure, recording equipment malfunction, sedimentation, electrical disruption, debris, ice, or vandalism) also may require additional site visits. The service needs of sediment monitoring stations equipped with telemetry, or some other form of real time remote connection, can be recognized quickly.

9.1.1 In addition to the maintenance/servicing instructions recommended by the manufacturer, the general maintenance functions at a water-quality monitoring station include:

9.1.1.1 Daily review of sensor function for sites equipped with telemetry

9.1.1.2 Inspection of the site for signs of physical disruption

9.1.1.3 Inspection of sensor(s) for fouling, corrosion, or damage

9.1.1.4 Battery (or power) check

9.1.1.5 Time check

9.1.1.6 Routine sensor cleaning and servicing

9.1.1.7 Calibration (if needed)

9.1.1.8 Downloading of data

9.2 *Sensor Inspection*—The purposes of the sensor inspection are to provide an ending point for the interval of optical meter record since the last service visit, a beginning point for the next interval of record, and verification that the sensor is working properly. This is accomplished by recording the initial sensor readings, servicing the sensors, recording the cleaned sensor readings, performing a calibration check of sensors by using appropriate standards, and if the readings of the monitoring sensor are outside the range of acceptable differences (see 9.3.2), recalibrating the sensor. A final environmental sensor reading is required after the calibration check or after recalibration. The difference between the initial sensor reading and the cleaned sensor reading is the sensor error as a result of fouling; the difference between the calibration-check reading and calibrated-sensor reading, if necessary, is a result of drift. All information related to the sensor inspection must be recorded on a field form or in a field notebook. Contact the manufacturer if any unexpected condition with the monitoring sensor is detected.

9.2.1 The initial sensor readings (before cleaning) of the monitoring equipment are taken before removing the monitor sonde for servicing. This initial sensor reading becomes the ending point of the data record since the last servicing.

9.2.2 Upon removal from the water, the monitoring sonde is inspected for signs of chemical precipitates, stains, siltation, or aquatic growth. Readings are then taken on standards appropriate for the optical meter being used and the readings recorded, and that represent the estimated range the meter had read since the last visit. At a minimum, a high and low standard must be checked. These observations are recorded in the field

TABLE 3 Principle Advantages and Disadvantages of the Self-Contained Monitoring System

Advantages	Disadvantages
Location options are flexible.	Data are available only during site visits.
The monitor can be protected better from vandalism.	Equipment status checks are required.
Electrical hazards are nonexistent.	Servicing sensors and recovering data can be difficult.
No power is needed to pump water.	Sensors are susceptible to debris and high flow.
Pump maintenance is not needed.	Shifting channels may cause movement of the equipment.
No pumping therefore no lift limit.	Status of the equipment can be checked only while servicing.
	If batteries die, data maybe lost.

notes before cleaning. A field calibration check is then performed on the meter (see 9.3). See manufacturer's recommendations for cautions and or additional checks that should be performed.

9.2.3 The sonde is then cleaned according to the manufacturer's specifications. Readings using the same level standards are made and recorded after the cleaning. The cleaned, and if necessary recalibrated (see 9.3), sonde is then returned to the stream. Observed difference between the initial sensor reading and the cleaned sensor reading is a result of fouling (chemical precipitates, stains, siltation, or aquatic growth).

9.3 *Field Calibration of Meters:*

9.3.1 Field inspection or calibration of the optical sensor is made by using Formazin or other approved primary standards and following the manufacturer's calibration instructions as described by Wilde and Gibs (**6**). Turbidity standards with various ranges are commercially available, and most sensor manufacturers recommend either Formazin, stabilized formazin (StablCal), or styrenedivinylbenzene (AMCO Clear), standards for calibrating turbidity sensors. Formazin-based standards can be diluted by using a dilution formula; however, unless high accuracy techniques are used, errors may be introduced during the dilution process, thus reducing the accuracy of the standard solution. Turbidity-free water, used in the preparation of standards, dilution, and rinsing, is prepared as described by Wilde and Gibs (**6**) and is also commercially available.

9.3.2 Sensors should first be inspected for damage, ensuring that the optical surfaces of the sensor are in good condition. Before placing the turbidity sensor in a calibration standard, the sensor should be cleaned, rinsed three times with turbidity-free water, and carefully dried. If the readings are unusually high or erratic during the sensor inspection, entrained air bubbles and or sediment build-up may be present on the optic sensor and needs to be removed. If the sensor readings exceed the calibration criteria during the inspection process, the sensor must be calibrated by following the manufacturer's instructions. Wagner (**3**) defines the calibration criteria for optical meters to be that recalibration is needed if the differences between the record monitor reading and the another field meter reading differ by more than ±0.5 turbidity units or ±5 % of the measured value, whichever is greater.

9.3.3 Three-point calibration is recommended for most applications where a wide range of turbidity values is expected. One point of any calibration should be turbidity free water. If only a 2-point calibration is possible then a mid-point calibration standard value should be reported to ensure linearity of readings.

9.4 *Operation of Meters and Retrieval of Recorded Data:*

9.4.1 The objective of having the meter placed in the stream is to obtain near continuous data that can be correlated with samples of SSC for the site being monitored. The record made at the site may not be an accurate record of the parameter being recorded, such as turbidity, but must reflect a consistent relationship between the parameter being recorded and the stream's SSC.

9.4.2 Certain steps should be taken each time the installation is serviced. Table 4, modified from Wagner (**3**), outlines the steps that should be performed each time the equipment is serviced.

9.4.3 The steps outlined in Table 4 are adequate for servicing optical monitors most of the time, but during periods of rapid stage changes (leading to rapidly changing SSC) it may be necessary to alter these steps. Wagner (**3**) defines rapidly changing as changes that exceed the calibration criteria. Table 5 outlines the servicing steps that should be followed during rapidly changing conditions.

9.4.4 *Field Forms*—Accurate and complete field notes and instrument logs are essential for the converting of optical records to SSC. The following are the minimum field-note required items for optical monitors (modified form Wagner (**3**)):

9.4.4.1 Station name and if one has been assigned, the station number,

9.4.4.2 Name(s) of data collector(s),

TABLE 4 Standard Protocol for the Operation and Maintenance of an Optical Monitor (modified from Wagner (3))

1. Conduct site inspection
 a. Record monitor readings, time, and monitor conditions
 b. With an other field meter of the same manufacturer and model as the field monitor, observe and record readings and time near the sensor(s)

2. Remove sensor from the monitoring location

3. Clean sensor

4. Return sensor to the monitoring location
 a. Record monitor readings and time
 b. Using the other field meter, observe and record readings near the sensor(s) to determine if stream conditions have changed during the cleaning processes.

5. Remove sensor a second time, rinse thoroughly, and check calibration
 a. Record calibration-check values
 b. Recalibrate if necessary

6. Return sensor to monitoring location
 a. Record monitor readings and time
 b. Using the another field meter, observe and record readings near the sensor(s)