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Quality Assurance Methods for Continuous Rainfall, Run--off, and Turbidity Data

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For

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Introduction

Provision C.8.e. of the Municipal Regional Stormwater Permit (MRP) (SFRWRCB, 2009) requires Permittees to perform monitoring in selected tributaries sufficient to determine loads or concentrations of pollutants of concern (POC) mainly during storm flow. To address these requirements, a Multi-Year-Plan (MYP) was written and is being updated annually by (BASMAA, 2011; BASMAA, 2012; BASMAA, 2013) that provides a comprehensive plan for activities that will be implemented over the next 5-10 years to provide information and comply with the MRP. The MYP provides rationale and generally describes the locations, sampling methods, and analytes for POC loads monitoring. In addition to a combination of manual and automated water sampling techniques employed for collecting samples for laboratory analysis of water quality constituents, a continuous monitoring approach of short time interval (15 minutes or less) measurement of rainfall, channel flow stage, and turbidity has been adopted. The purpose of this short document is to outline the methods for quality assurance for all short time interval (functionally continuous) rainfall, stage, and turbidity data collected in relation to POC concentration and loads monitoring in compliance with MRP Provision C.8.e.

Definitions

Rainfall: The depth of net accumulated precipitation reaching the land surface. Rainfall data is measured in units of decimal inches or points (1/100 of an inch). For example, a 5 min interval reading of 0.07 inches is equivalent to 7 points in 5 min. Rainfall data is collected at the STLS POC loads monitoring locations with an electronic tipping bucket rain gauge and logged on site using an electronic data logger that is periodically downloaded to laptop computer.

Stage: The elevation of the water surface in a flood control channel, stormdrain, drainage line, creek, or river relative to a defined stationary benchmark elevation (datum). Stage data is usually measured in feet and decimal fractions of feet (for example 5.32 feet would be 5 feet and 32/100 of a foot). Stage data is collected at the STLS POC loads monitoring locations with an electronic vented pressure transducer and logged on site using an electronic data logger that is periodically downloaded to laptop computer. At USGS monitoring locations, equipment may differ between sites and to STLS deployed equipment and quality assurance and data publishing will be completed by USGS.

Turbidity: A measure of the optical properties of water in relation to light scattering caused by "cloudiness" primarily associated with suspension of particles most of which are less than 62.5 µm in size and, for most creeks in the Bay Area, virtually always less than 250 µm (USGS data). Additional cloudiness factors include organic matter, phytoplankton, other microscopic organisms, organic acids, and dyes. Turbidity is usually measured in nephelometric turbidity units (NTU) but can also be measured as Formazin Nephelometric Units (FNU). Turbidity is measured using a nephelometer with a light detector setup in relation to a light beam (can be either side scatter or back scatter). The instrument takes a reading at a set time interval by pulsing light for a given period and recording the average amount of light detected. More light reaches the detector if there are lots of small particles scattering the source beam than if there are few. How much light is reflected for a given amount of particulates in the water column is dependent upon the properties of the nephelometer as well as the properties of the particles (shape, color, and reflectivity), therefore, a relationship between turbidity and other water quality measures such as suspended sediment concentration or pollutant concentration is watershed specific, sampling location specific, and instrument specific. Turbidity data is collected at the STLS POC loads monitoring locations with an electronic turbidity probe attached to an articulating boom in the thalweg of the channel and logged on site using an electronic data logger that is periodically downloaded to laptop computer. Quality assurance and data publishing will be completed by USGS for monitoring sites they are collaborating on. Two instrument models (a FTS – DTS 12 and a Campbell Scientific OBS 500) with differing optical properties and measurement ranges have been deployed in relation to likely maximum observable turbidity at each site.

Table 1. Turbidity instrument specifications and reporting units.

Instrument	Detector geometry	Light wavelength	Useful range and accuracy
FTS DTS-12	Measures 90° side scatter.	780 nm	0-399 FNU ±2% of reading 400-1,600 FNU ±4% of reading
CS OBS-500	Dual Probe: 90° side scatter (better at measuring lower turbidity) and backscatter (better at measuring high turbidity).	850 nm	0-4000 FNU/FBU/FNRU[1] ±2% of reading or 0.5 Turbidity Units (whichever is greater)

Intended data uses

Each of the STLS POC loads monitoring watersheds provides a unique spatially defined landscape unit inside which a complex mosaic of natural and anthropogenic processes and activities operate and culminate in the transmission of water, sediments, and pollutants, mostly under the influence of gravity, past the downstream measurement point (the POC loads monitoring station) and ultimately to the Bay. A monitoring design that includes short time interval (continuous) measurement of rainfall, stage, and turbidity provide data that has high utility for accurately describing many of the watershed and channel processes that account for the temporal variability of POC concentrations and loads especially during storms when variability and flux is greatest. Such data can also be utilized to understand processes during dry weather flows or under managed flow conditions such as reservoir release or legal or illegal water extraction or discharge.

In relation to MRP Provision C.8.e., the Water Board has grouped POCs into two subgroups: 1) those requiring improved information to support the computation of storm specific and wet season loads estimates (suspended sediments, polychlorinated biphenyls (PCB), total and methyl mercury, total organic carbon, nitrate, total phosphorus, and phosphate), and 2) those requiring improved information for characterization of concentrations in relation to watershed factors such as rainfall and flow conditions, pollutant sources, land uses, and toxicity (hardness, total and dissolved copper, total and dissolved selenium, polycyclic aromatic hydrocarbon (PAH), polybrominated diphenyl ether (PBDE), carbaryl, fipronil, and pyrethroids). Continuous data on rainfall, stage, and turbidity is being collected to directly support generation of information about the character and loads of these POCs.

[1] See "U.S. Geological Survey Implements New Turbidity Data-Reporting Procedures" for detailed description of turbidity units. Available online at: http://water.usgs.gov/owq/turbidity/TurbidityInfoSheet.pdf

Short time interval rainfall data: Rainfall data provides important ancillary information used in a variety of ways during the process of interpreting the causes of fluctuations of turbidity and POC concentrations, and for computing suspended sediment and POC loads. Specifically rainfall data is used to:

- determine if stage during a given time period is associated with storm conditions, reservoir release, legal or illegal water extraction or discharge, or natural processes such as fluctuation in the water demands of riparian vegetation or changes in the groundwater channel interactions,
- check storm specific or wet season rainfall run-off relations against a conceptual model of the portion of rainfall that should end up as run-off (storm specific or seasonal runoff coefficient),
- determine the relative proportion of run-off derived from urban versus non-urban sources; during small storms and dry years urban sources often dominate when rainfall is completely soaked up in agricultural and open space portions of the watershed,
- identify causes of turbidity fluctuations (e.g. due to storm conditions, reservoir release, legal or illegal water extraction or discharge).

Short time interval stage data: In relation to suspended sediment and POC loads computations, stage data is the primary data set used to:

- determine the flow of water through a flood control channel, stormdrain, drainage line, creek, or river cross-section. This is achieved by applying a rating relationship (the term used to describe the relationship between stage and cross-sectional discharge) either determined through field measurements of velocity at a wide variety of stages or by Manning's formula,
- determine the likely source of flow among possible sources including storm induced rainfall-runoff processes, reservoir release, legal or illegal water extraction or discharge, or other natural processes such as groundwater relaxation or variations in riparian demand. This is done through assessing the shape/slope of the time-stage relationship,
- indicate point sources or groundwater sources that are diluted during high flow conditions, which results in inverse correlations between water quality parameters and flow conditions.

Short time interval turbidity data: In relation to suspended sediment and POC loads computations, turbidity data is an additional primary data set used to:

- estimate continuous concentrations of suspended sediment or hydrophobic pollutants such as mercury and PCBs at the time interval of the turbidity measurements. Such estimates are generated by using turbidity surrogate regression (the term used to describe the application of the equation generated by regressing the target water quality constituent against turbidity). The resulting regression equation is applied to the continuous turbidity data set to compute concentration. Loads are then computed by multiplying the concentration estimate by the flow estimate,
- indicate spatial source heterogeneity through differences in particle ratios (indicated by turbidity) on the rising stage versus the falling stage of the hydrograph; for example, the rising

stage often indicates near-field or urban sources whereas the falling stage often represents far-field or sources distributed across the whole watershed.

Importantly, turbidity data collected in relation to MRP Provision C.8.e. and POC loads monitoring is not intended for making comparisons between sampling locations. Specifically, two instrument models (a FTS – DTS 12 (usable range 0-~1600 FNU) and a Campbell Scientific OBS 500 (usable range (0-4000 NTU)) with differing optical properties have been deployed in relation to likely maximum turbidity at each site. There is no attempt to perform any calibration and quality control between instruments or sampling locations. The data will be used solely for developing site-specific relationships with suspended sediment concentrations and the concentrations of each POC.

Data verification

Data verification is the process by which the completeness of the records are checked and documented, and any obvious instrumentation problems are identified and corrected. This process is done throughout the season by a field staff scientist and in a final step at the end of the season by the data management team.

Throughout the season, field staff is responsible for data verification checks after data is downloaded during site visits. Upon return to the office and prior to sending to the data management team, the field staff reviews the data and completes the data transmission record. The data transmission record (form located in Appendix B) documents the basic review process required to assess whether the data is complete and whether the sensors appear to be functioning correctly. Through completing the data transmission record, scientists must plot the data to visually, note if the data appears reasonable and whether the three continuous records (stage, turbidity, and rainfall) corroborate one another (e.g. does stage rise in relation to rainfall and does turbidity rise and fall in relation to stage?). Field staff email the data management team the field log for the site visit (Appendix A), the raw downloaded data, the manipulated data (if any immediate corrections are made), and the data transmission record.

Data verification is also performed by the data management team at the end of the field season and includes an assessment of the completeness of the entire season record. Data management (DM) should provide the site lead with a table summarizing the period of record for each gauge and any data gaps in the records. The field staff should then verify that these periods align with the monitoring period.

Data validation and correction

Data validation is the process of assessing the quality of the data, and documenting that quality according to validation criteria. In instances where the validation process indicates that corrections can and should be made to the data, the appropriate correction methods are applied along with the appropriate qualifiers noting these corrections.

Precision, instrument calibration drift, instrument fouling, and missing data due to instrument malfunction or poor/problematic installation are the main concerns in relation to the measurement and logging of continuous rainfall, stage, and turbidity data. Data representativeness and completeness are additional quality measures for continuous data. Representativeness is a qualitative term that expresses if the rainfall, stage, and turbidity data represent a characteristic of a population for a given sampling location, and primarily addresses whether the instrument is able to measure the full range of conditions at the site, and whether the recording interval provides a detailed enough description of the conditions. Completeness refers to the proportion of valid data obtained, and may indicate the percentage of valid raw data, the percentage of corrected or estimated data, and the percentage of missing and/or rejected data. These issues are discussed below systematically for each type of data, along with the appropriate correction methods, flags, and validation criteria.

Data Validation, Corrections, and Flags – Rainfall: Continuous rainfall data is validated by comparison to one or more nearby rainfall gauges as well as by comparison to the discharge data record. Due to micro-climatic differences and depending on proximity of the comparison gauges, rainfall will not exactly align between gauges. But assuming relatively close proximity and no extreme orographic differences, nearby rainfall gauges should have similar enough records to help identify periods of missing record (flagged as such), and to possibly allow for estimation of missing records (flagged as such). While not all discharges in a creek/drainage system are associated with storm events, the discharge record should help to identify periods of likely storms. The suggested QA procedure involves the following steps:

1) Review field notes and ensure the events in which the rain gauge was manually tipped are zero'd out.
2) Calculate site-specific magnitude-frequency-duration curves based on NOAA regional data or Rantz (1971) and compare estimated statistics to maximum recorded rainfall per monitoring interval (5- or 15-minute) to determine if that amount is reasonable.
3) Compare monthly rainfall totals to two nearby gauges. Calculate the percent difference between monthly totals. Identify months in which data may be inaccurate. Record percent differences in a table.
4) Rainfall data may be missing from a record if the connection with the datalogger is bad or during times when the tipping bucket has become stuck from dirt, bird excrement or for other reasons. Plot the rainfall and discharge record, looking for periods of discharge with no rainfall to identify periods of likely missing record. Is there any other likely reason for discharge during non-storm events? Do the potential missing rainfall records occur during months identified in Step 3 as having greater percent difference between the monitoring site rain gauge and the nearby rain gauge? For periods of likely missing data, apply the flag "MD".
5) If there are nearby gauges that have records on an hourly or shorter time interval, it may be possible to estimate the missing period of record. The simplest method would be to develop a regression equation between one or more nearby gauges with the monitoring site record for comparison. To minimize scatter in the relationship due to temporal differences caused by location differences of the gauges, the regression should use a daily or weekly summation of rain at each gauge. The equation resulting from the best relationship between the site and a nearby gauge can then be used to calculate the missing period at the monitoring site. Any

attempted regression should include a minimum of 6 months of data and show a correlation coefficient of 0.8 or better (corresponds to “good” and/or “excellent” precision criteria). Exceptions to this may be made based on using best professional judgment if there are fewer points in the equation but these points are predominantly during the rainy season in combination with a stronger correlation coefficient. If the regression meets these criteria, the resulting equation should be applied to estimate the rainfall during periods of missing record, and these portions of the record should be flagged as estimated data with an “EST”.

6) Evaluate the dataset in relation to the validation criteria (Table 3) and report on each the accuracy through calibration, the accuracy in relation to other nearby gauges, the precision of the repeat volume tests at the beginning of the season, dataset representativeness relative to logging interval and estimated data interval, and finally on completeness of the dataset.

Table 2. Rainfall record QA flags.

Flag	Flag Name	Flag Description
NM	Not Measured	Gauge not operating during this time.
MD	Missing Data	Gauge likely not operating correctly during this time and, as determined in comparison to other nearby gauges and presence of discharge with no presence of rainfall.
EST	Estimated	Data is estimated based on application of regression equation with nearby rain gauges.

Data Validation, Corrections, and Flags – Stage: The stage measurements using the Campbell Scientific CS450 Submersible Pressure Transducer should generally be accurate. Infrequently there may be gaps in the data due to poor wiring connection to the datalogger. Also infrequently, the vent tube may become kinked or plugged, which will prevent the proper adjustment for atmospheric pressure and will cause the water level changes to include the cyclic fluctuation from atmospheric pressure.

At each site, an offset correction should be applied to the continuous record so that stage is reflective of the stage at the location of velocity measurements. The offset is the difference in height between the mounted location of the pressure transducer and the bottom of the bed in the thalweg of the channel at the velocity measurement location. This height difference should be ascertained through field survey and verified through comparison of the continuous record to the manual stage measurements made at the sampling location throughout the season. The offset is a constant and should be consistent, and this consistent difference should equal the offset determined by survey. The offset is then applied to the automated/continuous stage record. Proper field notes should indicate if manual stage measurement is likely to be inaccurate (e.g. due to boom obstruction of flow at the manual measurement location).

After application of the offset, the QA review procedure involves the following steps:

1) Identify maximum recorded stage per monitoring interval (5- or 15-minute) and determine if that amount is reasonable based on knowledge of storm events and top of bank heights.

2) Review field logs for any notes on pressure transducer burial. If this occurred, review data to see if a constant correction factor can be applied for the period the sensor was buried. If so correct and flag, and if not, reject and flag.
3) Plot the continuous stage readings and review record looking for missing periods, rapid spikes/dips, and periods of cyclical fluctuation that would indicate a plugged vent tube. Flag the data appropriately.
4) In the unlikely event of a spike/dip for unknown reasons, or in the event of a few skipped records, the record may be estimated by interpolation. Flag the data appropriately.
5) Evaluate the dataset in relation to the validation criteria (Table 3) and report on each the accuracy through calibration, the accuracy in relation to comparison with manual measurements, the precision of repeat measurements of the same stage immediately following calibration, the representativeness of the dataset relative to logging interval, and finally on completeness of the dataset. If appropriate, correct dataset for calibration drift. Ensure drift correction improves regression with manual field measurements. If the drift correction worsens the relationship with manual measurement, investigate reasons why and correct data accordingly.

Table 4. Stage record QA flags.

Flag	Flag Name	Flag Description
NM	Not Measured	Sensor not operating during this time.
MD	Missing Data	Sensor not operating during this time for unknown reasons but likely due to poor wire connection to datalogger.
REJ	Reject Data	Sensor not operating correctly during this time likely due to a plugged vent tube.
FOUL_REJ	Fouling and Data Rejected	Fouling due to sensor burial and data could not be corrected.
FOUL_EST	Fouling and Data Estimated	Fouling due to sensor burial and data is estimated.
EST	Estimated	Data is estimated by interpolation.

Correction for Calibration Drift (Stage and Turbidity)

Calibration drift error is the result of an electronic drift in the sensor reading from the last time the sensor was calibrated and is determined by the difference between cleaned-sensor readings in standard solutions or buffers and the true, temperature-compensated value of the standard solution or buffer. Calibration drift is assumed to occur at a constant rate during the service interval. If the calibration drift error exceeds the data-correction criteria (Table 3), a correction is required. The calibration drift correction equals the calibration drift error and is computed as follows:

$$C_d = E_d = V_s - V_c$$

where

C_d = calibration drift correction,
E_d = calibration drift error,
V_s = value of a calibration standard solution Or buffer of known quality, and,
V_c = sensor reading in the calibration standard solution.

The correction should be applied as a linear interpolation over the correction interval (i.e. as a two-point variable data correction), beginning with a zero-correction at the start of the period and a full correction at the end of the period, as done for the fouling correction.

Table 3. Data validation criteria for continuous records of precipitation, stage, and turbidity.

Parameter	Accuracy at Calibration			Accuracy of Comparison		
Qualifier	**Excellent**	**Inaccuracy/Drift Noted but within Tolerance:**	**Correct for Drift If % Error at time of Calibration:**	**Excellent**	**Good**	**Poor**
Precipitation	±1%	1-3%	NA	Regression between site gauge and nearby gauges have r^2>90% and normal distribution of residuals	Regression between site gauge and nearby gauges have r^2=80-90% and normal distribution of residuals	Regression between site gauge and nearby gauges have r^2<80% and normal distribution of residuals
Stage	±0.1%	<±3%	≥ ±3%	Regression between sensor and manual measurement data with r^2>90% and normal distribution of residuals; ≥3 manually collected stage measurements in each quartile of the stage range	Regression between sensor and manual measurement data with r^2=80-90% and normal distribution of residuals; 2 manually collected stage measurements in each quartile of the stage range	Regression between sensor and manual measurement data with r^2<80%; ≤1 manually collected stage measurements in each quartile of the stage range
Turbidity	0.5 turbidity units or ±5% of reading (whichever is greater)	<±10%	≥ ±10%	Regression between field probe and Hach2100P data with r^2>90% and normal distribution of residuals; ≥3 manually collected turbidity measurements in each quartile of the range	Regression between field probe and Hach2100P data with r^2=80-90% and normal distribution of residuals; 2 manually collected turbidity measurements in each quartile of the range	Regression between field probe and Hach2100P data with r^2<80%; ≤1 manually collected turbidity measurements in each quartile of the range

Parameter	Repeatability (Precision)		
Qualifier	**Excellent**	**Good**	**Poor**
Precipitation[1]	RSDs of 5 replicate tests of low volume and 5 replicate tests of high volume ≤5%	RSDs of 5 replicate tests of low volume and 5 replicate tests of high volume ≤10%	RSDs of 5 replicate tests of low volume and 5 replicate tests of high volume >10%
Stage[2]	RSDs of 10 replicates at low reference stage and 10 replicates at high reference stage ≤1%	RSDs of 10 replicates at low reference stage and 10 replicates at high reference stage ≤3%	RSDs of 10 replicates at low reference stage and 10 replicates at high reference stage >3%
Turbidity[3]	RSDs of 10 replicates using low NTU standard and 10 replicates using high NTU standard ≤5%	RSDs of 10 replicates using low NTU standard and 10 replicates using high NTU standard 5-10%	RSDs of 10 replicates using low NTU standard and 10 replicates using high NTU standard >10%

[1]This replicate testing should be performed at the beginning or end of season immediately following calibration and using known volumes.
[2]This replicate testing should be performed at the beginning or end of season immediately following calibration and using known stages (e.g. by placing sensor in a bucket of water of known depth).
[3]This replicate testing should be performed at the beginning or end of season immediately following calibration and using known standard turbidity references.

Parameter	Representativeness of the population			Confidence in corrections		
Qualifier	**Excellent**	**Good**	**Poor**	**Excellent**	**Good**	**Poor**
Precipitation	Site gauge and estimated data on same time interval as turbidity and stage	> 75% Site gauge and estimated data on same time interval as turbidity and stage, and remaining data on interval not ≤4x stage/turbidity interval	< 75% Site gauge and estimated data on same time interval as turbidity and stage, or remaining data on interval >4x stage/turbidity interval	<1% of records requiring correction and clear evidence for method used to fill data gaps.	>90% data records validated and remaining records could be estimated by regression with a nearby gauge with a linear relationship of r^2>80%	<90% data records validated or remaining records could not be estimated by regression with a nearby gauge with a linear relationship of r^2>80%
Stage	Data is plausible; <1% of records have change between consecutive readings >15%	Data is plausible; <5% of records have change between consecutive readings >15%	Data is plausible; >5% of records have change between consecutive readings >15%	<1% of records requiring correction and clear evidence for method used to fill data gaps.	>90% data records validated and clear trend or gradient providing clear evidence for method used to fill data gaps.	<90% data records validated and/or poor trend or gradient providing low confidence for selecting a method to fill data gaps.
Turbidity	For <1% of records, change between consecutive readings ≥ 20 NTU absolute change and ≥15%relative change from preceding; and for <0.5% of records, change between consecutive readings ≥ 20 NTU absolute change and ≥50%relative change from preceding record	For 1-4% of records, change between consecutive readings ≥ 20 NTU absolute change and ≥15%relative change from preceding; and for 0.5-1% of records, change between consecutive readings ≥ 20 NTU absolute change and ≥50%relative change from preceding record	For >4% of records, change between consecutive readings ≥ 20 NTU absolute change and ≥15%relative change from preceding; and for >1% of records, change between consecutive readings ≥ 20 NTU absolute change and ≥50%relative change from preceding record	<1% of records requiring correction and clear evidence for method used to fill data gaps.	>90% data records validated and clear trend or gradient providing clear evidence for method used to fill data gaps.	<90% data records validated and/or poor trend or gradient providing low confidence for selecting a method to fill data gaps.

Correction for Fouling (Turbidity)

Sensor-fouling error can result from a variety of sources and is determined by the difference between sensor measurements in the environment before and after the sensor is cleaned. The fouling correction, in percent, is determined by the following equation:

$$\%C_f = 100 * \frac{(M_a - M_b) - (F_s - F_s)}{M_b}$$

where

C_f = fouling correction, in percent,
M_a = monitor reading after the sensor is cleaned,
M_b = monitor reading before the sensor is cleaned,
F_s = field meter reading at the start of servicing,
F_e = field meter reading at the end of servicing.

The field meter readings in the above equation ensure that any differences in measurement due to changing environmental conditions are discounted from the fouling correction. The field meter reading portion of the equation may be ignored if the cleaning occurred during stable environmental conditions, for example on maintenance visits during low-flow conditions.

The correction should be applied as a two-point variable correction using linear interpolation over the correction interval (i.e. as a two-point variable data correction). This is done by applying a zero correction at the start of the fouling period (either at the time of the previous cleaning if fouling is believed to have occurred at a constant rate since then, or at a particular moment within the interval if environmental conditions can be identified that likely initiated the

Data Validation, Corrections, and Flags – Turbidity: Turbidity is the most challenging of the three datasets to QA/QC due to the potentially real rapid changes in turbidity during a storm, the potential variability of turbidity in the cross section of the creek, frequent opportunities for debris to accumulate near the sensor, the potential for fouling, and the potential for the sensor to read the bottom of the creek bed during low flows. Unlike with rain, there are no nearby gauges to compare against. In addition, given instrument specific optical properties, comparisons with other instruments are relative. With these challenges in mind, we employ the following the QA procedures:

Plot the turbidity record with discharge. Flag periods of fluctuating turbidity in which discharge isat base-flow or no-flow. Flag periods in which turbidity record is missing during a storm event. Flag periods in which the sensor is recording at its maximum, and whether this is due to high turbidity during a storm event or the wiper blade parking on the lens (for DTS-12 sensor).

1) De-spike the data using interpolation (flagging appropriately). Using best professional judgment, determine through assessment of the data how large temporal gaps may be estimated (i.e., the minimum duration of real excursions or peaks above measurement noise) using this method, and only fill in gaps this time interval or smaller.
2) Correct for fouling. Fouling is caused by build-up on the optical lens of the sensor. Both sensor types used in this study have anti-fouling mechanisms (DTS-12 has a wiper blade, the OBS-500 has a shutter/wiper and biocide) but it is possible for these mechanisms to fail. Field visit logs should indicate when build-up of algae or debris around or on the turbidity sensor was observed. Particularly if this condition was documented, but in all cases when a site visit involved cleaning of the sensor, the QA officer should look at the before- and after-cleaning records. A fouling correction factor should be applied if the correction is ≥ ±5% using the method applied in the call-out box on page 8 of this methods report. If cleaning occurs during changing environmental conditions, manual measurements can be collected in parallel and evaluated using the Hach 2100P turbidimeter in order to discount the differences due to truly changing conditions. The correction is assumed to apply at a constant rate to the entire record since the previous cleaning. However, if there are certain environmental conditions that can be identified as significant fouling events, then these events could also mark the beginning of the fouling correction period.
3) Assess the data during periods of low-flow to identify periods in which the sensor is likely reading the bottom of the bed. Note: the OBS-500 back-scatter sensor “sees” in clear water out to about 20 inches, while the side-scatter sensor “sees” about 2 inches out to the side. The DTS-12 sensor “sees” approximately 4 inches out and 2 inches to the side. The likelihood that the sensor is reading the bottom of the bed would be indicated by high turbidity readings during flows low enough that the OBS-500 sensor is less than 20 inches or the DTS-12 sensor is less than 4 inches from the bed. DTS-12 sensor readings of the bed should be rejected. For readings in which the OBS-500 was seeing the bed, experiment with using only the side-scatter readings and use these where side-scatter readings are more reasonable. During intervals in which both the side-scatter and ratiometric readings are really high, the data should be rejected.

4) Instrument precision should be determined through duplicate measurements (same time and position in the water column) made in parallel with measurements using a calibrated Hach 2100 P field-portable turbidity meter. Given turbidity is not an absolute measure, precision is determined through the consistency of the relationship developed from multiple measurements using the two instruments as determined by regression. The precision is then expressed as a %bias against the reference or perhaps a qualified bias against best professional judgment (likely bias high or low).
5) Calibration drift is assessed at the time of calibration, which should be done at a minimum of once/year. Results of any calibration drift should be recorded and minimally included as a statement of the bias.
6) Evaluate the dataset in relation to the validation criteria (Table 3) and report on each the accuracy through calibration, the accuracy in relation to comparison with manual measurements, the precision of repeat measurements immediately following calibration using standard turbidity references, dataset representativeness relative to logging interval, and finally on completeness of the dataset.
7) After all data corrections have been made, re-plot the data along with stage to verify that data look reasonable and no errors were made during the correction process.

Table 5. Turbidity record QA flags.

Flag	Flag Name	Flag Description
NM	Not Measured	Sensor not operating during this time.
DMT	Discharge Missing Turbidity	Discharge indicating a storm flow but lacking turbidity data.
TMD	Turbidity Missing Discharge	Turbidity fluctuations present in the absence of storm flows.
REJ_BED	Rejected, Seeing Bed	Reject data due to sensor reading the bottom of the bed.
SS	Side Scatter	Side scatter measurement used in place of ratiometric data due to sensor reading the bottom of the bed.
>MAX_ST	Exceeds Instrument Maximum, Storm	Record is above the maximum and due to high turbidity during storm flow.
>MAX_PARK	Exceeds Instrument Maximum, Wiper Parking	Record is above the maximum and due to the wiper blade parking on the lens.
COR_FOUL	Fouling Correction	Fouling correction applied during this period.
COR_DRIFT	Calibration Drift Correction	Calibration drift correction applied during this period.
EST	Estimated	Data point is estimated by interpolation.

QA/QC'd Data Deliverables and Formatting

Data that is QA/QC'd should be in a continuous format in the time interval the data was recorded on (either 5- or 15-minute intervals). Three columns will be added in the QA process: Rain_Flag, Stage_Flag, and Turbidity_Flag. Into these columns, the appropriate flags should be placed for each corresponding data record. The continuous QA'd data should either be within an Access or Excel database structure.

References

Anderson, C.W., 2004, Turbidity (version 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, section 6.7, 64 p. http://water.usgs.gov/owq/FieldManual/Chapter6/6.7_contents.html

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Appendix A: Field Log Form

Watershed Stormwater Monitoring - Field Log		
GENERAL INFORMATION:		
Site Name:	Team leader's name:	
Date:	Time of arrival:	Time of departure:
Additional field personnel:		
Purpose of visit (check all that apply):	☐ Storm monitoring ☐ Maintenance	☐ Special inspection

INSPECTION CHECKLIST (pre-storm and maintenance visits):

Were the ISCOs cleaned?	*☐ Yes for ISCO# 1 2 (circle if cleaned) ☐ No*
Was the Teflon intake tubing been inserted?	*☐ Yes for ISCO# 1 2 3 (circle if inserted) ☐ No*
Is the tubing free of kinks and are joints well connected?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Is the distributor arm tubing extended just to the end of the arm?	*☐ Yes ☐ No ☐ See comments*
Are the 12-volt batteries fully charged?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Is the solar panel charging the batteries?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Are the instruments powered and operational?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Are the equipment desiccant packs/cartridges OK?	*☐ OK ☐ Replaced ☐ See comments*
Has the pressure transducer (stage offset) been checked and reset if necessary?	*☐ Checked ☐ Reset ☐ Not applicable ☐ See comments for stage offset details*
Has the CR1000 sampling program been enabled?	
Have sample trigger values (turbidity & flow) been enabled?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Have the ISCO sample volumes been calibrated?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Are bottles installed, aligned, packed with ice and lids removed?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Are the ISCOs programmed and turned on?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Is the sampling boom free of obstructions?	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Is the turbidity sensor clean and free of obstructions?	*☐ Yes ☐ Cleared ☐ Not applicable ☐ See comments*
Does the turbidity and stage data seem reasonable?	*☐ Yes ☐ Cleaned ☐ Not applicable ☐ See comments*
Are the data logger clock and sampling watches aligned, in	*☐ Yes ☐ No ☐ Not applicable ☐ See comments*
Standard Time and Military Time?	*☐ Yes ☐ No ☐ See comments (show timing offset below)*

COMMENTS / ACTION TAKEN (continue on back of page if needed):

____

(Team Leader's Signature)

Appendix B: Data Transmission Form

Information for the Data Management Team		
	Name of DataFile	
	Monitoring Site	
	Agency/organization/firm	
	Storm #, or "non-storm event"	
	Period Start (Date Time)	
	Period End (Date Time)	
	Samples Collected (Y/N)	
	Number of Sips in Toxicity Composite	
	Number of Sips in Pyrethroid Composite	
	Staff member who QA'd the data	

Information for interpretation of the data	
"X" where appropriate	
	A comment field was added after the last column in the spreadsheet (in csv file) and all appropriate/relevant comments have been added.
	Is actual sip time different from sip trigger time? If so, update the CSV file with actual sip times (actual sip times are captured by each individual ISCO sampler). Any changes to the sip routine were applied so that the sampling routine is accurately reflected in the corresponding columns.
	The beginning of the downloaded immediately continues on from the previous download e.g. there are no data gaps and no duplicated data records
	The ending of the downloaded data matches the date and time of the download.
	There are no gaps in the data.
	Any sips recorded in the file that are not part of the current storm have been deleted.
	The turbidity data was plotted and there are no glaring spikes.
OR	
	The turbidity data was plotted and there are obvious spikes or low readings that are possibly not real. If data look suspect, each group must validate that the instrument is working properly and resolve any issues.
	The stage data was plotted and there are no glaring spikes.
OR	
	The stage data was plotted and there are obvious spikes or low readings that are possibly not real. If data look suspect, each group must validate that the instrument is working properly and resolve any issues.
	The turbidity and stage data were plotted together and generally follow one another during periods of rainfall (e.g. both values rise during a storm; no need to comment on hysteresis).
OR	
	The turbidity and stage data were plotted together and do not generally follow one another during periods of rainfall (e.g. values rise or fall independently from one another during a storm such that something seems off with the data).
	The rainfall data have been reviewed.
	A local copy of the raw (uncorrected) .dat file has been saved to a local file.
	A corrected version of the file has been saved as a .csv to a local file.
Describe any issues noted with the data such as changes made from the raw datalogger file, and/or sample specific comments that could affect the interpretation of the data. WARNING: these comments are not added in to the database with the data file but should still be noted to assist in later interpretation.	

Checklist for data submission:	
	Raw .dat file
	Corrected .csv file
	Scanned sampling and field log sheets
	This QA log

Thank you!

SFEI staff will directly upload the .csv file into an Access Database that includes the SFEI Data Management Team-generated queries designed to transfer the raw data from the existing format into SWAMP to populate the COC/EDD database.