Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedure for Monitoring Total Dissolved Gas in Freshwater

Version 1.0

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Any reference to specific equipment, manufacturer, or supplies is for descriptive purposes only and does not constitute an endorsement of a particular product or service by the author or by the Department of Ecology.

Although Ecology follows the SOP in most instances, there may be instances in which Ecology uses an alternative methodology, procedure, or process.

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)
05/7/10	1.0	Recertified	All	Kammin

Environmental Assessment Program

Standard Operating Procedure for Monitoring Total Dissolved Gas in Freshwater

1.0 Purpose and Scope

1.1 This document is the Environmental Assessment Program (EAP) Water Quality Studies Unit Standard Operating Procedure (SOP) for Monitoring Total Dissolved Gas (TDG) in Freshwater.

2.0 Applicability

2.1 This SOP should be followed for all monitoring of TDG in freshwater. It includes procedures for spot measurements and long-term continuous monitoring of TDG pressure, and the measurement of barometric pressure data to allow calculations of TDG as percent of saturation.

3.0 Definitions

3.1 Total Dissolved Gas: the amount of gases, typically the constituents of air, dissolved in water. Usually measured as pressure (e.g. mm Hg) or percent of saturation relative to ambient barometric pressure.

3.2 Compensation Depth: the depth in a water column at which the total dissolved gas pressure is equal to the hydrostatic pressure. As a rule of thumb, this corresponds to roughly 1 meter for every 10 percent of saturation above 100%.

3.3 Aerated Zone: the area below a dam's spill, waterfall, or other plunging stream of water where bubbles are entrained in the water column and TDG is crossing the air-water interface of the bubbles either into or out of solution.

4.0 Personnel Qualifications/Responsibilities

4.1 Training in the use of Hydrolab® equipment, including the Standard Operating Procedures for use of Hydrolab® equipment.
4.2 Trained in safety procedures for work on or over the water.

5.0 Equipment, Reagents, and Supplies

5.1 Equipment

5.1.1 A Hydrolab® meter fitted with a TDG sensor.
5.1.2 Spare membrane for TDG sensor
5.1.3 Calibration kit with NIST pressure sensor, bulb hand air pump, fittings and tubes, modified calibration cap, and tools.
5.1.4 Laboratory barometer
5.1.5 Portable digital barometer (optional)

5.2 Supplies

5.2.1 Selzer water (USGS standard is Schweppe's Club Soda)

6.0 Summary of Procedure

6.1 Overview

6.1.1 TDG, simply stated, is air dissolved in water. The dynamics of TDG are governed by gas laws such as Henry's Law and Boyle's Law (Colt, 1984) Supersaturated TDG is most commonly caused by air forced into solution by hydrostatic pressures when a stream of water with entrained air bubbles plunges to depth.

6.1.2 TDG levels can also be affected by a variety of environmental conditions:

6.1.2.1 Primary biological productivity, which changes dissolved oxygen levels, since DO is one component of TDG.

6.1.2.2 Changing water temperatures, which directly change TDG pressures and percent saturation in accordance with gas laws.

6.1.2.3 High winds, and shallow, turbulent flow can increase the rate of gas exchange. Supersaturated TDG is constantly seeking equilibrium with the atmosphere through the air-water interface, but under calm conditions with laminar flow and deep water (such as in reservoir with little wind), that exchange is very slow. A vigorous set of rapids or cascades can allow a rapid return of supersaturated waters to equilibrium.

6.1.2.4 Changes in barometric pressure change TDG levels relative to the standards, since TDG water quality criteria are expressed in terms of percent of saturation relative to ambient barometric pressure. This also means that evaluation of criteria requires measurement or estimation of the absolute barometric pressure at the location being monitored.

6.1.2.5 All TDG monitoring is conducted by field measurements with specialized meters. Various manufacturers provide TDG meters, but all use diffusion membrane methods equivalent to Standard Method 2810 (APHA *et al.*, 1998). Ecology owns several Hydrolab® meters outfitted with TDG sensors. Other meter models are sold by Common Sensing (the original developer of TDG meters) and In-Situ (who bought Alpha Designs, the source of replacement TDG membranes for the Hydrolab® meters). Prior to development of field measurement methods, dissolved gas was measured in the laboratory using a blood gas analyzer, but this method is now rarely used.

Figure 1. TDG sensor and membrane

6.1.2.6 The basic principle behind TDG monitoring is that dissolved gas diffuses through thin silastic tubing wound around a base, and the pressure exerted through the membrane is measured by a pressure sensor. The pressure sensors are quite robust and accuracy is quite stable (they reportedly are the same as those used in automobile engines for emission control). The membrane, however, is delicate and usually the source of any monitoring challenges. Membranes need to be intact, dry inside, and clean. This requires some attention to equipment maintenance and handling.

6.1.2.7 Good TDG measurements require three elements unique to the method: proper meter placement, diligent care of the membrane, and patience:

6.1.2.7.1 For proper functioning of the membrane, meters need to be placed below the compensation depth and outside any aerated zones. Membranes placed in shallow supersaturated water or in bubbly conditions may produce inaccurate readings. Because monitoring often occurs during high flow periods, rapid water velocities, high turbulence, and dynamic water elevations create challenging deployment logistics.

6.1.2.7.2 Periodic cleaning and calibration will help insure membranes are performing properly. During continuous monitoring deployment, maintenance about every two weeks is optimal, but monthly maintenance is adequate.

6.1.2.7.3 Membranes can take 15-20 minutes to equilibrate to changing conditions, so plenty of time needs to be allowed for calibration and for properly equilibrated spot measurements. Bring a book, a laptop to check email, a radio or music player, or just enjoy the scenery!

6.1.2.8 Like all environmental monitoring, a Quality Assurance Project Plan should be developed for TDG monitoring. Examples developed by Ecology are cited in the References (Ecology 2002; 2003; 2004). Ecology's TDG data quality procedures are modeled on the methods developed by the U.S. Geological Survery (Tanner and Johnston, 2001).

6.2 Calibration

6.2.1 Calibration procedures follow the outline provided in Section A.1. of Appendix A. Other parameters measured by the Hydrolab® meter should also be calibrated, especially temperature and dissolved oxygen because of their close relationship to TDG pressure. See the SOPs for Hydrolab® use for instructions on these parameters.

6.2.2 Calibrate the pressure sensor without membrane

6.2.2.1 Take a meter reading with pressure sensor open to ambient air, and compare to the barometric pressure (BP) using the laboratory standard barometer.

6.2.2.2 Attach the fitting to the pressure sensor that connects through tubing and a tee fitting to the NIST pressure gage and the bulb.

6.2.2.3 Pump up the pressure on the bulb until the NIST meter shows 100 mm Hg and record the meter reading and lab BP+100. Repeat for +200 and +300 mm Hg.

6.2.2.4 If any readings are greater than 2 mm Hg different from the lab BP standard, calibrate the meter at ambient BP and ambient BP+200.

6.2.3 Test Hydrolab® meter with dry membrane

6.2.3.1 Attach the dry TDG membrane, then put on a calibration cup with the special cap with tubing.

6.2.3.2 Record a meter reading with the chamber open to ambient BP.

6.2.3.3 Add 200 mm Hg pressure to the chamber (make sure all seals are tight!) and record meter reading. Readings should agree within 2 mm Hg.

6.2.4 Test Hydrolab® meter in Club Soda

6.2.4.1 Remove the calibration cup and put the sensor guard on the meter.

6.2.4.2 Place the probe in a beaker and fill with Club Soda. Watch the readings and record the high reading. TDG should rise from ambient to over 1000 mm Hg (for fresh soda) in about 40 to 60 seconds, and then start to drop.

6.2.4.3 Remove the probe from the Club Soda. Watch the readings and record the low reading. TDG should drop to slightly below ambient BP (effect of evaporation on the membrane) in about 1 to 3 minutes, then begin to rise.

6.2.4.4 If the TDG readings in Club Soda rise or fall too quickly or too slowly, or if the readings don't rise as high as expected or don't fall below ambient, replace the TDG membrane and repeat 6.22 and 6.23. (This is why it's always good to have a spare membrane or two!)

6.2.4.5 The problem membrane can be washed in distilled water, dried thoroughly (at least 24 hours) and then retested. Moisture inside the membrane will cause problems. Membranes can also develop tiny splits or pinholes, in which case they need to be refurbished (rewound with new silastic tubing).

6.2.4.6 If the TDG meter and membrane passes all tests, it is ready to go. Dry the membrane and visually inspect for flaws or internal moisture. Remove the sensor guard and replace calibration cup for transport. TDG membranes are best stored dry when not in use.

6.3 Barometric pressure measurement methods

6.3.1 Obtaining BP measurements that coincide with your TDG pressure readings can be problematic. Ideally a continuous data-logging barometer would be installed adjacent to the deployment location, but Ecology has not found the high cost to be justified by the limited need, and several alternative methods should work adequately.

6.3.2 For spot measurements, the meter itself can work as a barometer. Remove the membrane at the monitoring location and take a reading with only the pressure sensor. The disadvantage of this method is that any handling of the membrane increases the chance of membrane damage.

6.3.3 A hand-held digital barometer of acceptable accuracy serves well for spot readings. (The Quality Assurance Project Plan should specify MQOs for barometer readings.) EAP has some analog (aneroid) barometers, but they have been found to be very sensitive to temperature changes and often provide inaccurate readings in field conditions. Barometer readings can be checked with paired readings with the meter and laboratory barometer during calibration.

6.3.4 For continuous deployment, a meteorological station in the vicinity is needed which records continuous BP. BP tends not to vary on fine spatial scales (within a mile or two), but on regional scales significant differences can occur, especially when BP is dynamic such as during an approaching low front. Ideally you should visit the meteorological station during field surveys and take a spot BP reading on-site for paired comparison. Spot BP readings at the deployment site can then be compared to the meteorological station data, and a regression developed to predict BP at the deployment site from the meteorological station time series. BP varies linearly with altitude, so a first-order linear regression usually works well.

6.4 Spot measurements

6.4.1 The trick to taking spot TDG measurements is to get the meter below the compensation depth and keep it there long enough for a stable reading. The main approaches to accomplish this are:

6.4.1.1 Find a quiet spot where the water is connected to the river but currents are slow, such as an eddy or below an obstruction.

6.4.1.2 Take readings while drifting in a boat.

6.4.1.3 Attach a heavy weight on a short cable with the meter at the end of a rope. Ecology has a cable and weight for this purpose.

6.4.2 Modify the attached form A-3 in Appendix A for the spot readings you plan to collect. When you reach the site, take a BP reading, then lower the meter into the water to an appropriate depth. Monitor the TDG readings until they are stable (less than 1 mm Hg change in 2 minutes). Check the depth to make sure the meter is below the compensation depth (divide the BP by 10, then allow 1 meter for each increment of BP/10 that the TDG reading is above the BP). Record your reading (electronically and in the field book).

6.5 Continuous monitoring deployment

6.5.1 Continuous deployment requires the selection of a location that meets several criteria:

6.5.1.1 Accessible for maintenance;
6.5.1.2 In a representative location;
6.5.1.3 Below the compensation depth for all flows and water surface elevations
6.5.1.4 Will stay in place during high flows; and
6.5.1.5 Protected from damage from debris or movement of the meter itself

6.5.2 A number of approaches have been used around the state. A few are listed here:

Figure 2. TDG continuous monitoring deployment with a PVC pipe mounted from a bulkhead.

6.5.2.1 Install a PVC pipe on a dock, bulkhead, abutment, or other permanent structure, so the meter is 5 meters below low water and the top is accessible from the structure. This is the most ideal kind of deployment for easy access and dependable readings. It is best if the site has secure access.

6.5.2.2 Install a PVC pipe along the river bottom with the end anchored in the channel and the top accessible on the shore. It's challenging to find a location for this kind of deployment where the end is deep enough and won't wash away and the top is in a secure location

6.5.2.3 Put the meter in a protective PVC case and attach to an anchor, which is lowered from a boat or dock. This works best in low velocities, with an anchor heavy enough to stay in place or attached to a structure. An anchor made of a piece of flat steel tends to stay put better than a concrete anchor. At higher velocities you don't want the anchor to move or the meter to bang on the bottom. You could build a custom anchor with a clamp or attached housing for the meter. An alternative to attaching the meter directly to the anchor is to put the meter on a small buoy that is pulled below the surface but keeps the meter off the bottom. The usual security problems exist for buoy deployments in areas with public access.

Figure 3. Anchor and PVC housing deployed from a dock for continuous TDG monitoring.

6.5.2.4 If you have the time, funds, and aptitude to rig a custom deployment, you could rig a cable out to an anchor and then suspend the meter in a housing that hangs from the cable on pulleys. To deploy or retrieve the meter you put tension on the cable and then lower or raise the meter with a second rope.

6.5.3 When you first deploy the meter, take a second meter and take a paired reading before deployment. At intervals of 2-4 weeks, bring a second calibrated meter, take a paired reading, and then swap the meters. If you have another meter for spot readings, a three-way replicate reading is even better. If an extra meter is unavailable, the meter can be retrieved, milked for data, recalibrated, and redeployed in the field. Form A-3 can be adapted to guide this field work and record data.

6.6 Post-calibration and maintenance

6.6.1 Post-calibration follows most of the same steps as calibration (Section 6.2). Form A-2 is provided in Appendix A to guide post-calibration.

6.6.2 After post-calibration, the TDG membrane should be removed, the solid cap placed on the pressure sensor, and the membrane allowed to dry thoroughly. The TDG membrane should then be stored in a sealed container with a moisture absorbent packet.

6.6.3 Damaged TDG membranes can be refurbished for about half the cost of buying an entirely new membrane. Sometimes a membrane that is functioning poorly will work fine after being cleaned and thoroughly dried, so this is worth trying before paying for refurbishment.

7.0 Records Management

7.1 The standardized recording sheets provided in Appendix A should be modified as appropriate for the specific needs of the project and used for calibration and field QA procedures. Care should be taken to record times, barometric pressures, field conditions and other relevant information at frequent intervals.

8.0 Quality Control and Quality Assurance

8.1 QA/QC procedures are described in the procedures above, and will be addressed thoroughly on a project-by-project basis in the QAPP for the project. See References for examples of TDG QAPPs.

9.0 Safety

9.1 All appropriate safety procedures to the installation method employed should be followed for working off of docks, bridges, or boats, and for deploying and retrieving remote moorings with buoy and anchors.

9.2 Installation of mounted tubes or other deployment should follow safety procedures for use of tools and work over water.

9.3 For further field health and safety measures refer to the Environmental Assessment Program (EAP) Safety Manual .

10.0 References

10.1 APHA, AWWA, and WEF, 1998. Standard Methods for the Examination of Waste and Wastewater. 20th Edition. American Public Health Association, American Water Works Association, and Water Environment Federation. Washington, D.C.

10.2 Colt, J., 1984. Computation of Dissolved Gas Concentrations in Water as Functions of Temperature, Salinity, and Pressure. American Fisheries Society Special Publication 14.

10.3 Ecology, 2002. Quality Assurance Project Plan, Mid Columbia and Snake Rivers Total Dissolved Gas Total Maximum Daily Load Field Monitoring. Pub. No. 02-03-067, Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA.

10.4 Ecology, 2003. Quality Assurance Project Plan, Spokane River Total Dissolved Gas Total Maximum Daily Load Evaluation. Pub. No. 03-03-102, Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/0303102.html.

10.5 Ecology, 2004. Quality Assurance Project Plan, Pend Oreille River Total Dissolved Gas Total Maximum Daily Load Study. Publication No. 04-03-107. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/0403107.html

10.6 Tanner, D.Q. and M.W. Johnston, 2001. Data-Collection Methods, Quality-Assurance Data, and Site Considerations for Total Dissolved Gas Monitoring, Lower Columbia River, Oregon and Washington, 2000. Water-Resources Investigations Report 01–4005, U.S. Geological Survey, Portland, OR.

Appendix A

Laboratory and Field Data Sheets

A.1. HYDROLAB CALIBRATION PROCEDURES (To be done prior to survey)

Hyrolab #______________ Lab barometer ID ___________
TDG sensor #___________ Date barometer last calib. ___________
Survey location _______ Today's date ___________
Survey Date _________ Checked by ___________

1. CALIBRATE TDG WITH DIGITAL PRESSURE GAUGE (MEMBRANE OFF).

Lab BP ________ mm Hydrolab ambient pressure ________ mm Time __________
Baro+100mm: expected/measured ________ /________
Baro+200mm: expected/ measured ________ /________
Baro+300mm: expected/ measured ________ /________

If any readings are >2 mm off, do a 2-point calibration at BP and BP+200 mm and note below.
Calibration BP: calibrated/measured ________ /________
BP+200mm: calibrated/ measured ________ /________

2. INSTALL DRY MEMBRANE AND TEST HYDROLAB WITH PRESSURE GAGE AND CHAMBER.

Lab BP + 200mm = ______ mm
Before applying 200 mm pressure Hydrolab pressure ________ mm Time _______
After applying pressure Hydrolab pressure ________ mm Time _______

3. INSTALL SENSOR GUARD AND TEST HYDROLAB WITH CLUB SODA.

Before soda test Hydrolab pressure ________ mm * Time _______
High pressure, soda test Hydrolab pressure ________ mm Time _______
Low pressure, after soda test Hydrolab pressure ________ mm Time _______

4. CHECK MEMBRANE FOR INTERNAL MOISTURE AFTER THE OUTSIDE HAS HAD TIME TO DRY.

A.2. HYDROLAB TDG POST-CALIBRATION PROCEDURES (To be done at the conclusion of a survey.)

Today's date ___________ Checked by ___________

1. TEST LOW CALIBRATION WITH MEMBRANE ATTACHED.

Lab BP _________ mm Hydrolab Pressure ________ mm Time _______

2. TEST HYDROLAB WITH DIGITAL PRESSURE GAGE AND PRESSURE CHAMBER.

Lab BP + 200mm = ______ mm
Before applying 200 mm pressure Hydrolab pressure ________ mm Time _______
After applying pressure Hydrolab pressure ________ mm Time _______

3. TEST HYDROLAB WITH CLUB SODA.

Before soda test Hydrolab pressure ________ mm Time _______
High pressure, soda test Hydrolab pressure ________ mm Time _______
Low pressure, after soda test Hydrolab pressure ________ mm Time _______

(If the unit does not perform well on #1-3 above, re-evaluate the corresponding site record.)

Remove TDG membrane, clean the membrane, air dry, store with desiccator.
Allow TDG sensor to air dry for at least 24 hours.

A.3. HYDROLAB TDG FIELD INSPECTION/CALIBRATION SHEET

Deployment/Retrieval Procedures

Project: ___________ Date: ___________ Personnel: __________________________________

Weather: ______________________________ Air temperature: ______ °C

Observed river conditions (flow, spill, etc.): ____

Barometer ID ____________ Date last cal.__________ Survey meter #:________

1. Spot reading at:_______________________________. Start time:_____; Site conditions:______________________

BP:______; Depth:_____; TDG:______; DO:____; pH:_____; Cond:______; Temp:______;

2. Paired readings at deployment site:_____________________________. Site conditions:_____________________

Start time:________ Bar Press:____________

Meter #:___; Time:___; Depth:_____; TDG:______; DO:____; pH:_____; Cond:______; Temp:______;

Meter #:___; Time:___; Depth:_____; TDG:______; DO:____; pH:_____; Cond:______; Temp:______;

After a minimum of 15 minutes, if both Hydrolab readings have not changed 1 mm./2 min, or if meters are changing but difference is constant:

___________ mm (DS#____) - ____________ mm (DS#____) = ___________ mm Time: ________

IF Difference is > 10 mm, do A and B

A. Test both Datasondes with club soda:

DS#____ ; TDG:___________ mm Time: ________

DS#____; TDG:___________ mm Time: ________

B. Test both Datasondes with pressure gage and chamber:

DS#____: ambient___________ mm; plus 200mm__________ mm Time: ________

DS#____: ambient___________ mm; plus 200mm__________ mm Time: ________

IF DATASONDE FAILS EITHER TEST, REPLACE MEMBRANE AND RETEST, OR DO NOT USE.

Old meter retrieval time:_____, new meter deployment time:_____. End time:_______ BP:___________

3. Spot reading at:______________________________. Start time:_____; Site conditions:_______________________

BP:______; Depth:_____; TDG:______; DO:____; pH:_____; Cond:______; Temp:______

4. Spot reading at:______________________________. Start time:_____; Site conditions:_______________________

BP:______; Depth:_____; TDG:______; DO:____; pH:_____; Cond:______; Temp:______