Operation Manual

HydroCycle Phosphate Sensor

Single analyte wet chemistry sensor with RS-232 Interface

support@wetlabs.com | service@wetlabs.com | Tel: +1 541 929 5650

Table of Contents

Table of Contents

Table of Contents

Section 1   Product overview

The HydroCycle-PO_4 is based on US EPA standard methods and uses the manufacturer's precision fluidics with state-of-the-art optics for accurate nutrient monitoring. The sensor is designed for unattended data collection and includes pre-mixed on-board reagent cartridges and calibration standards, which give users quality data.

The manufacturer-supplied software lets the user set up the sensor, calibrate the sensor with the check standard, and download collected data. Users can also plot data in real time, or from downloaded data.

1.1 Description of nutrient units

Nutrient units express the amount of something, usually moles or mass, relative to the volume it is in. Many researchers and scientists use micromoles per liter (µM), a unit that is independent of mass and useful for stoichiometric calculations.

Most freshwater monitoring programs and many researchers use units of milligrams per liter. This unit is almost always expressed as milligrams of relevant atoms per liter—for example, milligrams of phosphorus (P) per liter, rather than milligrams of phosphate per liter. Although phosphate (PO_4) is the most prevalent form of phosphorus, this unit is frequently used as a means of easily keeping track of total phosphorus loading. Because milligrams per liter is a mass-based unit and the mass of P and PO_4 are different, this difference is very important to prevent mistakes. Milligrams per liter is also typically referred to as parts per million (ppm), the mass of P relative to the mass of water.

The HydroCycle-PO_4 sensor measures soluble reactive phosphate and shows units in micromolar (µM) or milligrams of phosphorus per liter (mgP/L). The sensor also shows units in milligrams phosphate per liter (mg/L or mgPO_4/L). MgPO_4/L is not commonly used in environmental analysis. Standards, such as the Hach® 0.5 mg/L standard, are sometimes expressed in this unit.

Section 2   Specifications

2.1 Mechanical

Rated depth	200 m
Weight in air	7.6 kg (w/reagents)
Weight in water	0.36 kg
Height (w/handle)	56 cm
Diameter	18 cm
Temperature range, operation	0–35 °C

2.1.1 Bulkhead connectors

2.1.1.1 Standard bulkhead connector

Contact	Function	MCBH-6-MP connector
1	Ground	
2	RS232 RX	
3	External wake	
4	Voltage in	
5	RS232 TX	
6	Analog 1	
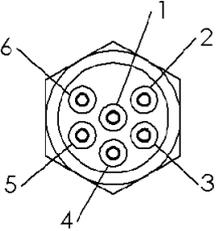
2.1.1.2 8-contact connector

Contact	Function	MCBH-8-MP connector
1	Voltage in	
2	Ground	
3	No connect	
4	Bi-directional SDI-12	
5	RS232 TX	
6	RS232 RX	
7	No connect	
8	No connect	
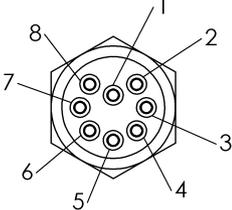
2.2 Electrical

	Main port (6-pin)	SDI-12 port (8-pin)
Input	10.5–18.0 V	
Current draw, operation	115 mA avg, 3 A max	125 mA avg, 3 A max
Current draw, low power	< 0.25 mA	< 1 mA
Power dissipation	1.15 W avg, 12 W max, ~0.034 AH (1.6 kJ)/normal operation; ~0.056 AH (2.5 kJ)/spiked operation	
Communication interface	RS232	SDI-12 and RS232
Baud rate	19200	1200 (SDI-12) or 19200 (RS232)

Specifications

Data storage	1 GB compact flash card type II
External "wake" high voltage	3.5–20.0 V
External "wake" low voltage	0.0–3.3 V

2.3 Optical

Wavelength	870 nm
Pathlength	5 cm
Linearity	> 95% R^2

2.4 Analytical

Detection limit, three standard deviations of 18 MOhm water	less than or equal to 0.075 µM less than or equal to 0.0023 mg/L PO_4-P
Quantification limit, ten standard deviations of 18 MOhm water	less than or equal to 0.025 µM less than or equal to 0.0077 mg/L PO_4-P
Range, nominal	0–10 µM 0–0.3 mg/L PO_4-P ***Note:** A higher range of 0–40 µM, 0–1.2 mg/L PO_4-P is possible but outside specifications.*
Number of runs per reagent set	greater than or equal to 1000 runs for CSF=2 greater than or equal to 1500 for CSF=6
Sampling rate	Standard operation: 15 min./sample Spiked operation: 35 min./sample
Reagent life	Refer to the "Best by" date on the cartridge (5 months from manufacture)
Filter pore size	5–10 µM (7.5 µM average)
Filter material	Ultra-High-Molecular-Weight Polyethylene

Section 3   Sensor setup

3.1 Assemble the sensor

> ⚠ **CAUTION**
>
> Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

The sensor comes in two boxes. One is a fiberboard box with the reagent cartridges. The second is a ruggedized plastic case with the sensor and spare parts.

1. Remove the sensor and the spare parts kit from the plastic case.
2. Remove the cartridges from the fiberboard box.

Figure 1 Sensor cartridges

3. Set the sensor on its side to remove the seven screws that attach the protective sleeve to the sensor.
4. Remove the seven Phillips screws on the sleeve. Keep the screws.

Figure 2 Screws removed from protective sleeve

5. Hold the bottom of the sensor and put it vertical to slide the protective sleeve off.
6. Look at the sensor. One side has the intake tubing to the sample port, marked with "C," and calibration tubing. The other side has reagent tubing.

Figure 3 Reagent tubing

Sensor setup

Cartridge color	Location on sensor	Description
Blue	C	phosphate standard
Yellow	R1	ascorbic reagent
Red	R2	mixed molybdate reagent

7. Remove the reagent cartridges from the box and unwrap each cartridge.
   Note that the cartridges are indexed so each one will only fit in one place on the sensor.
8. Remove, rinse, and save the yellow caps.

Figure 4 Protective cap for connectors

9. Make sure that the connectors are clean and free of debris.
10. Install the blue calibration cartridge first. Hold it above the upper housing, above the intake ports.
11. Slide the cartridge onto the guide pins until it "clicks" into place.
    If the cartridge does not "click" into place, lift it off of the guide pins and slide it onto the coupler on the sensor again with one hand on the connector and one hand on top of the cartridge above the connector.
12. Verify that the cartridge is installed correctly: gently pull up on the cartridge base.

Figure 5 Blue cartridge on guide pins
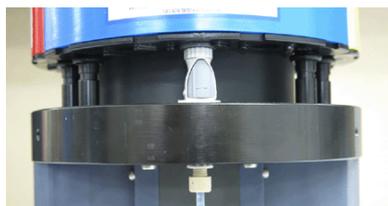
13. Install the yellow and then the red cartridge.

Figure 6 Install cartridges on guide pins

Figure 7 Cartridges installed

The cartridges are installed correctly if they cannot be gently lifted off of their bases.

3.2 Install the software

Download the Cycle Host installation program from the *Software* tab on the Cycle Host product page on the manufacturer's web site. The user must have "administrator" privileges set up on the PC on which the software is installed.

1. Start the Installer. Push **Yes** to the **User Account Control** pop-up window to let the program make changes to the PC.
2. Push **Next** from the **Setup** window on the Installer.
3. Read and agree to the License Agreement.
4. Push **Next**.
5. Select the **Start Menu** folder where the program shortcuts will be made.
   The manufacturer recommends that the user use the default location. Select a different location if more than one version of the software is installed on the same PC.
6. Push **Install**.
7. Optional: Put a check in the box to create a desktop shortcut to the software.
8. Push **Finish** to install the software on the PC.

3.3 Prime the sensor

Note: Use a vacuum only to prime the sensor. Do not use pressure.

It is only necessary to vacuum-prime the reagent tubing of the sensor on the initial set up, after the sensor has been shipped, or for troubleshooting.

3.3.1 Prepare to prime the sensor

The sensor comes with de-ionized (DI) water in all of the fluid passages. The user must prime the sensor before it is turned on to move the reagents and the phosphate standard into the fluid paths.

Table 1 Equipment needed to prime the sensor

User-supplied	Manufacturer-supplied
One container for waste water from the sensor	50 mL syringe
Regulated power supply	Test cable
PC	¼" outside diameter (OD) tubing, < 1 m in length

1. Unwind the exhaust tubing from the top of the sensor.
2. Put one end of the exhaust tubing in an empty container.
3. Connect the manufacturer-supplied test cable to the sensor, a power supply that can provide 3 amps, and the PC. The user will need a serial-to-USB adapter cable.
4. If necessary, start the software.

3.3.2 Prime sensor with vacuum

1. Attach the Luer-lock adapter to the supplied syringe.
2. Attach the syringe with the adapter to the outlet of the 1/16" ID sensor effluent tubing that comes out of the top end flange.
3. Under the *Settings* tab, put a check in the "Cal" box and set the calibration pump to operate for 100 pump cycles.

Pump Controls

S Cal R1 R2

Pump: ☐   ☑   ☐   ☐

Num Pumps: 100

Run Pump(s)   Stop
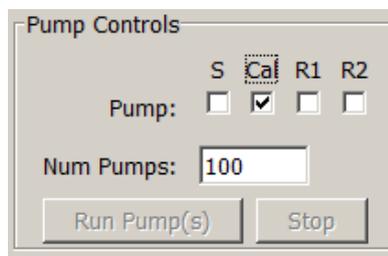
4. Push **Run Pump(s)**.

5. While the pump operates, pull a light vacuum, approximately 1/5 (10 mL) of the full travel of the plunger.

6. After the pump operates for 100 cycles, make sure that the reagent tubing that connects the cartridges and the inlet barbs does not have any air bubbles.
Look at the tubing from the reagent cartridges to the manifold.

    • If bubbles are present, do steps 4 and 5 again.
    • If bubbles are small, it may not be possible to remove them.

7. Do steps 3–5 with the pumps at R1 and R2.

8. Disconnect the tubing from the syringe.

9. Put the end of the tubing into an empty receptacle.

10. Flush the inlet tubing or get a new length to connect to the sample barb.

11. Fill a clean beaker with approximately 150 mL of clean water and put the other end of the tubing from the sample barb into the beaker.

12. Use a syringe to fill the tube with water.

13. Disconnect the syringe and pinch the tubing so that the water stays in the tubing.

14. Connect the tubing that is filled with water onto the sample port.

15. Connect the tube to the "S" barb.

16. Connect the blue sample tubing onto the sample barb.

17. Go to the *Settings* tab and push **Flush**.
The "Sample" fluid opening primes.

3.4 Prepare sensor for deployment

⚠ C A U T I O N
Do not drop the sensor. It can be damaged, which is not covered by warranty. If the sensor is dropped, the user may be injured, and, if reagent cartridges are installed, hazardous reagent chemicals may spill.

1. Use the software to make sure that the sensor is in a low power ("sleep") mode.

2. Disconnect the test cable from the sensor, the power supply, and the PC.

3. Wind the exhaust tubing at the top of the sensor.

4. Make sure to align the indentations of the protective sleeve with the eye bolts, then slide the protective sleeve over the sensor.

Figure 8 Eye bolts with exhaust tubing

5. Put the sensor on its side, hold the eye bolts, and align the screw holes for the sensor and the protective sleeve.
   Note that the protective sleeve is longer than the sensor. The screws cannot be installed when the sensor is vertical.

6. Install the seven Phillips screws again.

7. If necessary, start the software.

8. Make sure that the sensor is connected to the PC and a power supply, and is in standby mode.

9. Go to the **Tools** menu.

10. Select the *Deployment Wizard*.

11. The **Cycle Deployment Wizard** window opens.

12. Select "Autonomous - Standalone with no external controller."

13. Push **Next.**

14. Enter the name of a directory in which to store the collected data.
    Note that the name can have only 8 characters.

15. Push **Next.** The **Priming and Sampling Start Date and Time** window appears.

16. Make sure that there is **not** a check in the "Skip Prime Cycle" check box.
    The sensor does a priming cycle.

17. Select the date to start the first sample on the **Sampling Start Date and Time** calendar.

18. Enter the time to start the first sample at the <u>Sample Start Time</u> variable box.

19. Select the date to start the first priming cycle on the **Priming Start Date and Time** calendar.

20. Enter the time to start the first sample minus 30 minutes in the <u>Prime Start Time</u> variable box.
Make sure that the sensor is deployed 45–60 minutes before the first sample so that there is time for the priming cycle to operate in-situ.

21. Enter the total samples for the deployment in the variable box next to <u>Number of Samples</u>.

22. Enter the sample interval in the variable box area next to **Sample Interval.**

23. Keep the default of 6 in the <u>Cal Frequency</u> variable box. This is the manufacturer's recommended frequency.

24. Push **Next.**
A summary of the configuration shows.
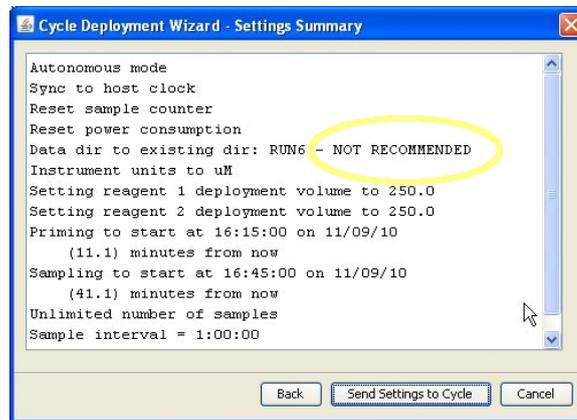
25. Push **Send Settings to Cycle.**
If the user selects a configuration that will have a negative effect on the operation of the sensor, a window shows.

26. Push **Yes.**

27. Push **Yes** at the next window to make a configuration report.
Configuration values will still be sent to the sensor if the user does not want a report and pushes **No.**

28. Enter a name and location to store the report. Use **.txt** or **.log** as the filename extension.

29. Push **Save.**

30. Push **Finish**, then **Yes** to make a results report.
The results report records the new values and the previous values.

The sensor goes into a low power mode.

31. Disconnect the sensor from the power supply.

Section 4 Deployment

4.1 Modes of operation

The sensor has six modes of operation. Both raw and engineering units for each sample are stored in the sensor's memory.

- **Host-controlled mode**. The sensor is connected to a PC and is controlled and monitored by the sensor software. The user can look at the data output of the sensor and other status indicators in this mode.
- **Autonomous mode**. The sensor operates by itself. *Deployment example*: the sensor is installed on a mooring that has no controller or data logger. The power is supplied by a battery pack.
- **Asynchronous slave mode**. The sensor is connected to a master controller. At certain intervals, the controller pulls the most recent data from the sensor. The sensor collects data on its pre-determined schedule, independent of the controller. The controller supplies power to the sensor. *Deployment example*: the sensor is installed on a mooring with a system controller that is set to collect and send the collected data to a shore-side database at regular intervals. Other sensors on the mooring turn on for 2 minutes of every 15. The HydroCycle-PO$_4$ collects data once per hour.
- **Synchronous slave mode**. The sample rate of the sensor is synchronized with the controller. The sensor collects data when signalled by the controller. The controller supplies continuous power to the sensor. *Deployment example*: the sensor is installed on a mooring with a system controller that is set to collect and send the collected data to a shore-side database in real-time.
- **SDI-12 mode**. The sensor operates in the synchronous slave mode through the SDI-12 port. Note that the sensor takes longer than the 999 specification to complete a measurement. When a sample is started through the SDI-12, the sensor immediately sends the data from the previous sample and starts a new sample. This data will be available the next time a sample is started.
- **Commanded mode**. The sensor is connected to the controller and is under the control of the controller. This mode has the most control over the sensor, and also needs the most work to use.

4.2 Set up for deployment

⚠ CAUTION

Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

⚠ CAUTION

The waste solution from the sensor cartridges is Hazardous Waste. Follow the applicable regulations to discard the solution.

Note the effects of temperature on the operation time of the sensor. The time to complete reactions increases at lower temperatures. The sensor will do a rinse when the reaction is complete and the KCO (default) is enabled. To do a fixed-time run of 19 min. (or 35 min. with a calibration spike), set the KCO to 2000. Refer to the section on Operation commands on page 53 for details.

- The sensor can be deployed as a single sensor or part of a larger system. Deployment options include—

  - Attached to fenceposts in a stream
  - Attached to a deployment cage
  - Installed in a well flushed pipe
  - Installed in a pumped tank system

- Hung under a dock with a length of rope.
- **Do not** use the handle to attach the sensor for a deployment.
- Attach the sensor to a structure such as a mounting bracket. Make sure to have a backup attachment for safety.

- Use braided line rope, not twisted nylon, to support the cables.
- Operate the sensor no more than ± 15 degrees off-vertical.
- The manufacturer recommends full submersion of the sensor. The sensor can operate in less water as long as the intake filters on the bottom of the sensor are submerged. If they are not, the sensor cannot flush air bubbles, which can result in poor data quality.
- Prevent the reagent cartridges from freezing and use a sun shade to keep the cartridge temperatures below 35 °C.
- Make sure that the waste tubing does not have kinks in it when the sensor is deployed. Use the manufacturer-supplied tubing that is 5 ft. long with a 1/16" inside diameter (ID) for waste. A longer tube or smaller ID can cause an increase in back-pressure and the sensor will not operate correctly.
- Operate the sensor at least 10 cm above the bottom of a body of water. This allows for circulation around the intake filters.
- Make sure that the electrical cables have no tension.

Replace any questionable hardware that is less expensive than the data from the sensor. Make sure screws, screw eyes, brackets, ropes, straps, O-rings, etc. are in good condition. Replacement parts are available from the manufacturer or a marine supply store.

The sensor effluent exits through the outlet tubing. Make sure that the effluent flows freely and does not go onto the sensor or its mounting. The effluent contains antimony and molybdenum and has a pH of < 2. Refer to the SDS that comes with the reagent cartridges for specific information. Contact the manufacturer for waste containment solutions.

4.2.1 SDI-12 operation

All sensors that have an 8-contact connector can operate on an SDI-12 network. SDI-12 version 1.3 is supported. Refer to the SDI-12 Version 1.3 specification at http://www.sdi-12.org for details.

Required equipment

1. Sensor with both 6- and 8-contact connectors
2. PC with software installed
3. SDI-12 recorder
4. Power supply
5. 6-contact test cable
6. 8-contact SDI-12 cable

Cable compatibility
Users that have a SUNA sensor SDI-12 cable can use that cable with the HydroCycle-PO_4 sensor. Note that—

- The HydroCycle-PO_4 sensor is not compatible with the SUNA V2 USB programming cable.
- The HydroCycle-PO_4 SDI-12 cable is not compatible with the Cycle SDI-12 cable and vice versa.

Verify that the SDI-12 cable operates with the sensor:

1. The manufacturer recommends that the user connect only the 8-contact SDI-12 cable.
2. Send an "al!" command. The sensor sends its serial number and the firmware and software that are installed. Refer to SDI-12 commands on page 61 for details.

Power requirements and sample setups

- The sensor must have a minimum of 10.5 VDC at 3 amps.
- The decrease in voltage over 30 m of 18-gauge cable is approximately 3.3 V.
- Use a standalone power supply if the SDI-12 recorder cannot supply 3 amps.
- Connect the negative terminal of a standalone power supply to the ground terminal of the recorder.
- Do not connect the positive terminal of a standalone power supply to any terminal on the recorder.
- Make sure to add the power requirements of any SDI-12-capable sensor to the total current requirement.

Example setup 1

	Equipment	Power requirement
sensor	HydroCycle-PO_4	3 amps, 10.5 VDC

cable length	60 m (200 ft)	6.6 VDC (200 x 3.3)
cable gauge	18	
power supply	SDI-12 recorder that supplies 12 VDC at 0.5 amps	**3 amps at 17.1 VDC**

Example setup 2

	Equipment	Power requirement
sensor	HydroCycle-PO$_4$	3 amps, 10.5 VDC
sensor	SUNA	1 amp, 12–18 VDC
cable length	30 m (100 ft)	4.4 VDC
cable gauge	18	
power supply	SDI-12 recorder that supplies 12 VDC at 0.5 amps	**4 amps at 14.9 VDC**

Note: Set the HydroCycle-PO$_4$ and SUNA to different SDI-12 addresses. Change the HydroCycle-PO$_4$ from its default of 0 to 1 before deployment.

4.2.2 SDI-12 deployment

1. Connect the SDI-12 cable to the 8-contact connector on the sensor.
2. Connect the other end of the SDI-12 cable to the SDI recorder and a 12V power source. The power supply must supply a minimum of 3 amps.
3. Configure the SDI recorder to send "aM!" or "aC" commands at the chosen frequency.
   These will start measurements on a preset schedule.

   - The sensor will ignore the "aM!" and "aC!" commands if a prime sequence is scheduled but not complete. The sensor should be primed before it starts to collect data.
   - The SDI-12 recorder controls when to collect data. The sensor controls whether the data measurement is spiked or normal.
   - Schedule the "aM!" or "aC" commands at an interval longer than 35 minutes: spiked measurements take up to 35 minutes.
   - The sensor will show the data from the previous sample and will start a new sample when the user sends an "aM!" or "aC!" command.

4.3 Deployment procedures

⚠ CAUTION

Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

The user makes the decision about which mode of operation to use, then does the steps below to deploy the sensor.

1. Install new cartridges on the sensor if necessary. Refer to the sections on Assemble the sensor on page 9, Prepare to prime the sensor on page 11, and Prepare sensor for deployment on page 12 for details.
2. Connect the sensor to a 12V, 30-watt power supply and PC with the manufacturer-supplied cable.
   The user needs a serial-to-USB adapter for the supplied cable to connect the sensor to the PC.
3. Start the software and choose the applicable serial port.
4. Turn on the power supply to the sensor.

5. Push **Get Settings** to make sure that the software and the sensor have communication.
6. Select the **Tools** menu, then *Deployment Wizard*.
7. Choose the mode in which to operate the sensor.

   • For SDI-12 mode: choose the "synchronous slave mode" in the *Deployment Wizard*.

8. Push **Next**.
9. Complete the steps in the *Deployment Wizard*.

   a. Choose the prime and sample start times that give sufficient time to deploy the mooring.
   b. Push **Finish**.
   c. Push **Yes** to put the sensor into a low-power mode.

10. Make sure that the sensor is in a low power mode.
11. Disconnect the sensor from the test cable and PC.

4.3.1 Prime filters for deployment

1. Disconnect the blue sample tubing from the sample port and inject 60 mL of DI water into the blue sample tubing and into the filter. If there is any resistance when water is injected into the filter, verify that the filter is fully installed. Refer to step 9 in Change sensor filters on page 42.

Figure 9 Prime filters
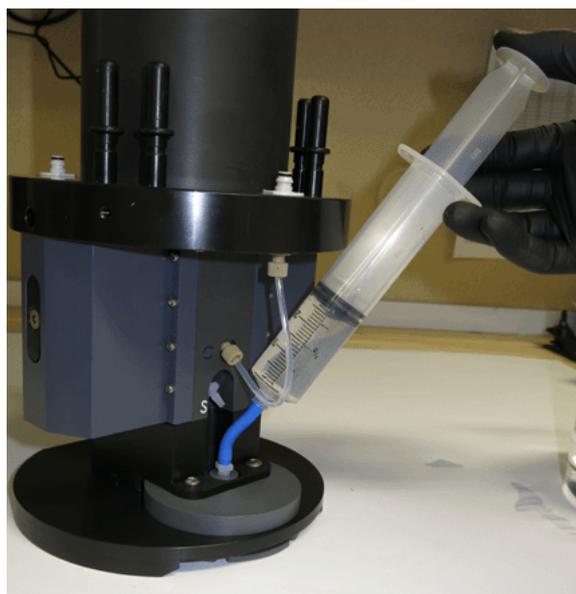
Make sure that there is no air in the sensor (refer to Prime the sensor on page 11 for details).

2. Connect the blue sample tubing onto the sample barb.
3. If possible, keep the sensor in a bucket in approximately 20 cm of water while the sensor travels to the deployment site.
4. Put the bucket of water with the sensor in it in the water at the deployment site. This will keep air from getting into the sensor.
5. Make sure that the waste tubing on the top of the sensor has no blockages or kinks.

Note that if it is necessary to get saved data from the sensor during a deployment, make sure to complete the procedure between data collection cycles. For example, if the sensor is set up to collect data for one ½ hour every 2 hours, the user has 1½ hours to

get data: after the ½-hour data collection cycle is complete and before the next data collection cycle.

4.4 Complete the deployment

> **⚠ C A U T I O N**
>
> Do data transfers away from harsh environments such as strong electric fields or electrostatic discharge (ESD) sources. ESD sources may temporarily disrupt data transfer. If this occurs, move the sensor away from the ESD source. Turn the power off and then on and continue operation.

> **⚠ C A U T I O N**
>
> If the sensor receives an ESD it can go into an unresponsive mode. It will pull approximately 0.25 A and the autonomous sampling schedule may be lost. Turn the power off for 30 seconds and then on again. This will start communication again. The user may need to set a new sampling schedule.

Make sure that the sensor does not continue to operate when it is removed from a deployment. Stop data collection before the sensor is pulled from the water and before power is supplied again. If data collection is not stopped before power is supplied to the sensor again, it can start operation and pull air in. Also, do not let the reagent cartridges become empty or the pumps can make air bubbles.

Stop the sensor if necessary and do a flush if the sensor is not already in a low power "sleep" mode.

The manufacturer recommends that the user retrieve the sensor in a bucket that has approximately 20 cm of water in it so that the sensor stays submerged for travel.

1. For the SDI-12 mode of operation: stop the SDI-12 recorder.
   This will stop the SDI-12 but not the sensor.
2. Turn the power off to the sensor, and then back on to stop any active samples.
   The sensor will save the last sample even when the power is turned off.
3. For SDI-12 mode of operation: Send an "aR!" command.
   The sensor will send the data values from the previous sample.
4. Disconnect the cable from the sensor.
5. Remove the sensor from the mooring.
6. Connect the sensor to the host PC and power supply with the test cable.
7. Turn on the sensor.
8. Go to the *Files* tab, then push **Refresh Directory Listing** to save the "summary.txt" file and any other desired files from the current data sub-directory.

Section 5   Optional in-laboratory performance analysis

> ### ⚠ CAUTION
> The waste solution from the sensor cartridges is Hazardous Waste. Follow the applicable regulations to discard the solution.

> ### ⚠ CAUTION
> Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

- To make an analysis of the sensor's performance, make sure the sensor is primed and that the collected data is stable.
- Use deionized (DI) or tap water and operate the sensor overnight to make sure that the data collected by the sensor is stable.
  Note: DI and tap water can contain measurable phosphate.
- Make sure the sensor does not run out of solution to sample or it will pull in air. A 500 mL bottle (approximately 30 mL/run) will be enough solution for approximately 10 sample cycles ($csf=1). This will make a little more than 500 mL of waste. Make sure the waste container is large enough for this volume.
- Use ultrapure, Millipore™, or equivalent 18 MOhm water to prepare the check standards and the blanks. Use de-gassed water for better results: let the water sit in a beaker for one hour. If there are bubbles after that period, de-gas the water.
- To bypass the filters, the water must be filtered to better than 10 μm.

5.1 Setup for in-laboratory performance analysis

1. Make sure that the sensor is connected to the PC and a power supply, and is in standby mode.
2. Make sure to have 1 L of clean water, with no particles over 10μm.
3. If necessary, start the software.
4. Go to the *Settings* tab and push **Get Settings**.
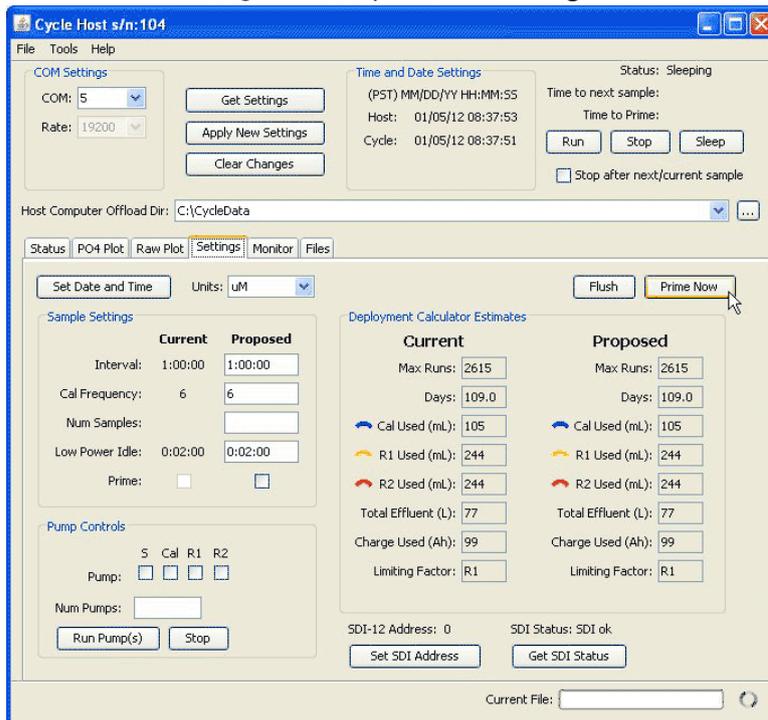
5. Set the "Interval" to 15 minutes (00:15:00) or as necessary for an overnight test.
6. Set the "Cal Frequency" to 1.

7. Set the "Num Samples" to approximately 20 for an overnight test.

8. Click on any area within the window so that the software accepts the values from the steps above.

9. Check the <u>Deployment Calculator</u> in the *Status* tab to make sure there is enough reagent (> 50 mL) in the cartridges for an overnight test.

10. Push **Apply New Settings**.
    The yellow highlights go away.

11. Go to the *Files* tab.

12. Make a folder for stabilization or laboratory sample collection (for example, "Stable" or "Lab1"). Note that the file name is limited to 8 characters.

13. Push **Run**.
    A new **Choose Run Option** window shows.

14. Push **Set Start Data and Time** to select when the sensor starts to prime and operate. It takes approximately 12.5 minutes to prime the sensor.

5.2   Operation sequence

The graph and the table below describe the sensor operation during each period of a cycle of data collection.

Figure 10 Graph of output periods
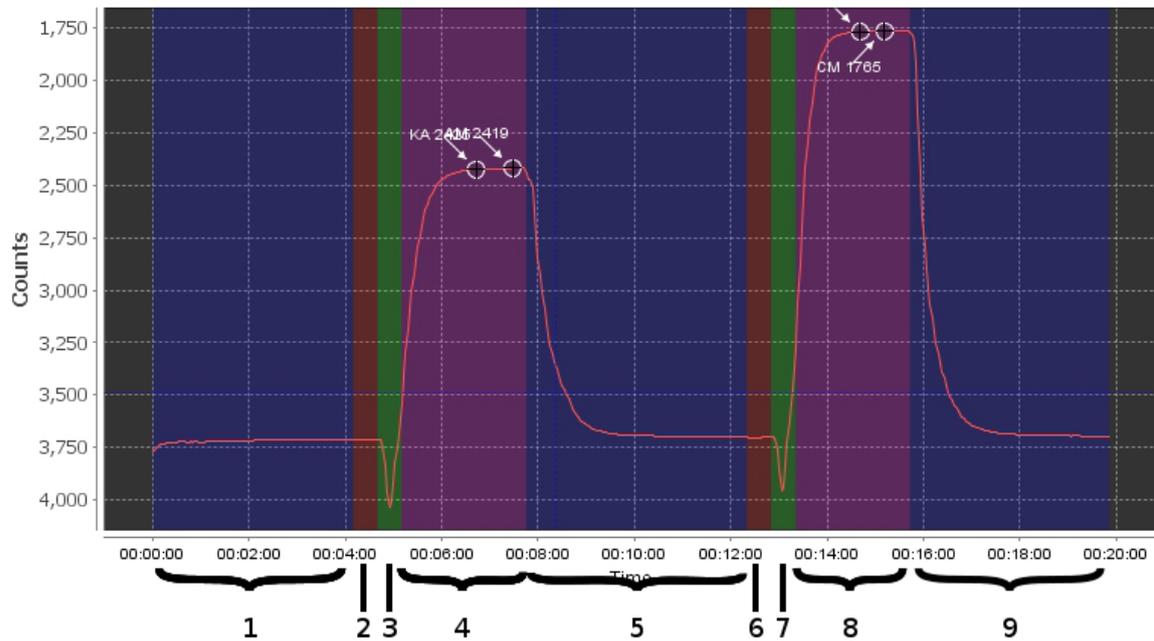
1	Blue	Pre-analysis flush period. The sample pump operates. Referred to as the "baseline."
2	Red	Ambient read period. Used for 100% transmittance without any absorption from phosphate reaction. No pumps operate.
3	Green	Sample mix period. The sample pump and both reagent pumps operate.
4	Purple	Sample read period. No pumps operate. The reaction curve color develops. Counts decrease until complete. The white circle and number show the signal used as the sample transmission.
5	Blue	Post-analysis flush period. The sample pump operates. Output counts spike then increase to approximately the baseline value.
6	Red	Spike ambient output period. No pumps operate.
7	Green	Spike mix period. The sample pump, both reagent pumps, and the calibration standard pump operates. A known amount of phosphate is added to the sample.
8	Purple	Spiked sample read period. No pumps operate. Signal output counts decrease because there is more phosphate added to the sample. This means more color develops and the transmission is lower.
9	Blue	Final flush period. The sample pump operates. As with the other flush periods, the output returns to a baseline value.

5.3   In-laboratory sensor stability analysis

1. Select the *Raw Plot* tab to see the data.
2. Look at the data after 19 operation cycles to see if the data is stable.

Optional in-laboratory performance analysis

Figure 11 Example of unstable data
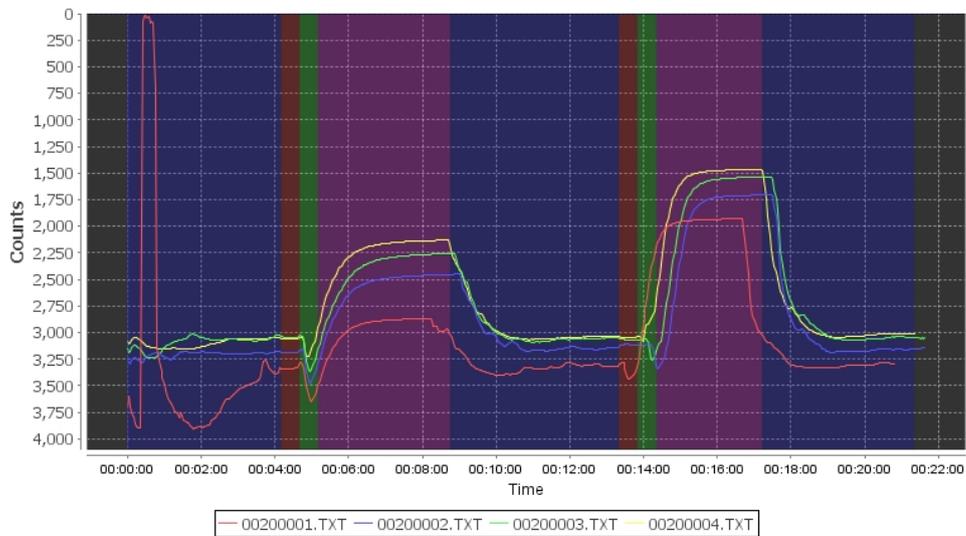
3. If the data is stable, go to the next section.
4. If the data is not stable, refer to Prepare to prime the sensor on page 11 and do the steps again to make sure the sensor is set up correctly and has not pulled in any air, which will give data that is not accurate.

Figure 12 Example of bubbles in the sample line
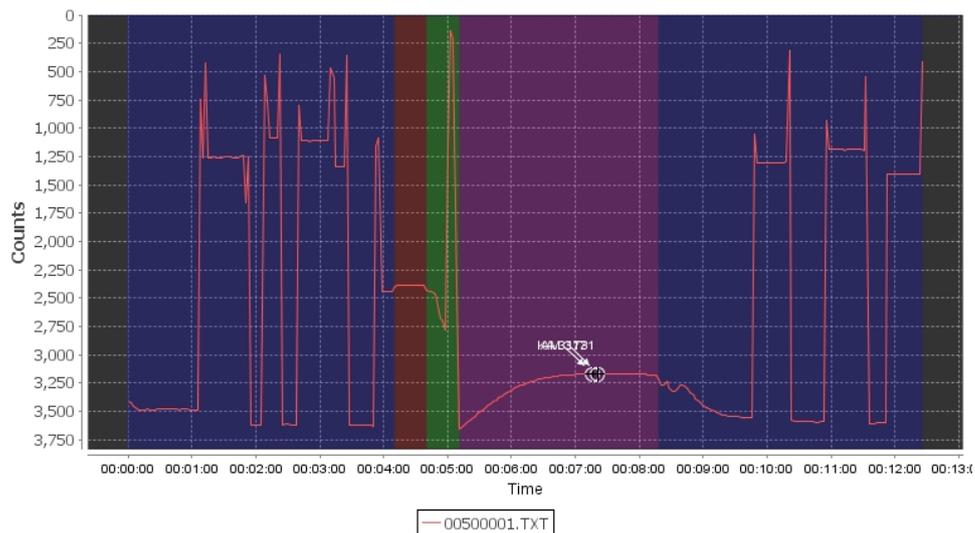
Figure 13 Example of shifting baseline
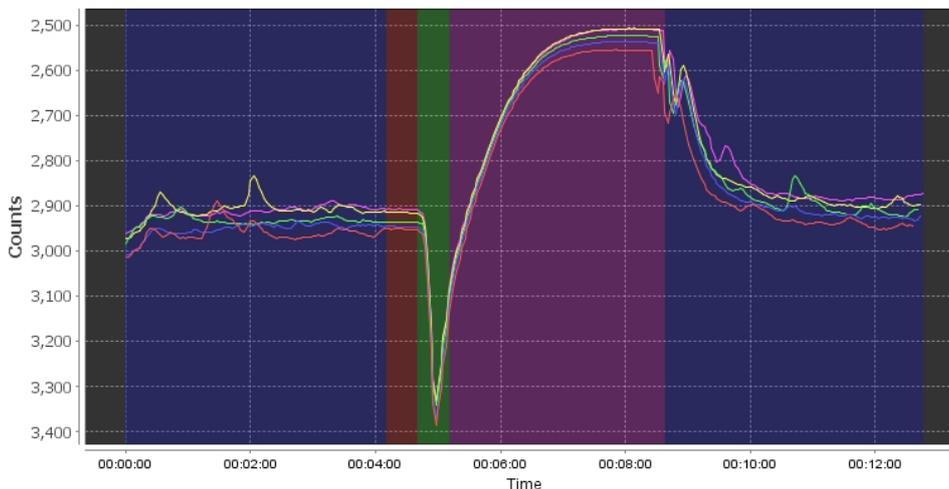
5.3.1 Use of water tanks for in-laboratory performance analysis

When the sensor operates in a laboratory water tank, temperature changes or a decrease in water flow can cause air bubbles to form. The manufacturer recommends that the user operates a pump to circulate the water that crosses the sensor intake areas to prevent the collection of air bubbles.

Data output values may change because of adsorption or primary production of a water tank. The manufacturer recommends that the user validates the water in the tank.

5.4 NIST check standards for in-laboratory performance analysis

The manufacturer uses a 5.3 µM NIST-traceable check standard that is used after calibration and before servicing to check the sensor's calibration. The user can make an analysis of the calibration of the sensor and validate any lab-prepared standards. Contact the manufacturer to purchase the 5.3 µM NIST-traceable check standard (P/N HXA-ZX0001) used by the manufacturer.

5.5 Solutions for in-laboratory performance analysis

Change to a new solution to analyze with the sensor.

1. Disconnect the sample inlet tube from the "S" barb.
2. Let the solution drain into the sample reservoir.
3. Flush the inside and the outside of the tube with clean water. The manufacturer recommends de-gassed 18 MOhm.
4. Shake to dry.
5. Refer to the steps in Prepare to prime the sensor on page 11 and be careful to not make more bubbles in the intake tube.
   Degassing sample can minimize the formation of bubbles.

Optional in-laboratory performance analysis

Section 6   Data analysis

This section describes how the sensor calculates phosphate and how to interpret the quality of the data.

6.1 Files tab

Use the software to get the data that is saved in the sensor.

1. Start the software if necessary.
2. Select the *Files* tab.

3. Push **Refresh Root Directory Listing**.
   The files saved in the sensor will show in the *Files* tab.
4. Enter the file directory, or folder, on the PC to save the data from the sensor, or create a new folder.
5. Push **Offload Selected File(s)/Dir** to move a copy of the data from the sensor to the PC.
   The user can save only one directory at a time, but it is possible to select several files at the same time to save to the PC.
6. Monitor the data saved to the PC.
   Look at the "Current File" area at the bottom of the software window.

6.2 Blank run example

A clean sensor will usually have a decrease in counts as it is conditioned. When the user calibrates the sensor, there is a shift in ambient read counts from run to run, or a slight shift in the pre- and post-analysis rinse baseline of 50–100 counts.

Figure 14 Good quality blank run with spike
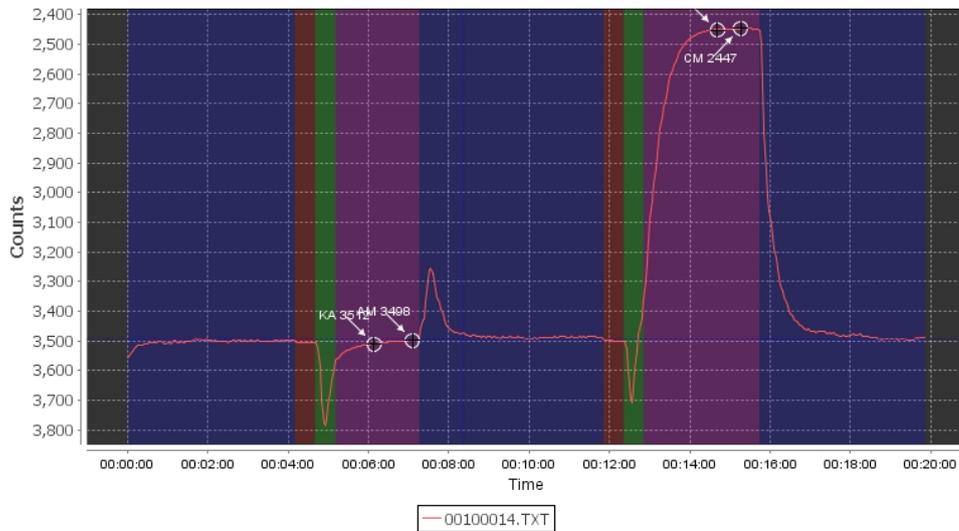
6.3 Good quality calibration data

Data such as the seven overlaid lines below shows good data. The lines show flat, stable flush periods, downward spike during mixing, no signs of bubbles, and all seven lines agree.

Figure 15 Good quality calibration output with spike
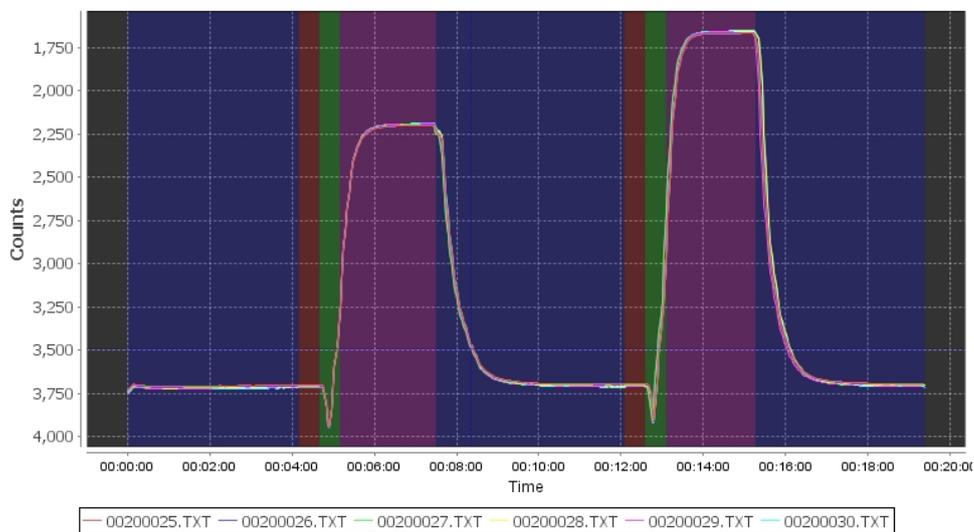
6.4 Bad data

The raw data graph below is an example of bad data caused by bubbles.

Figure 16 Bad data output from bubbles
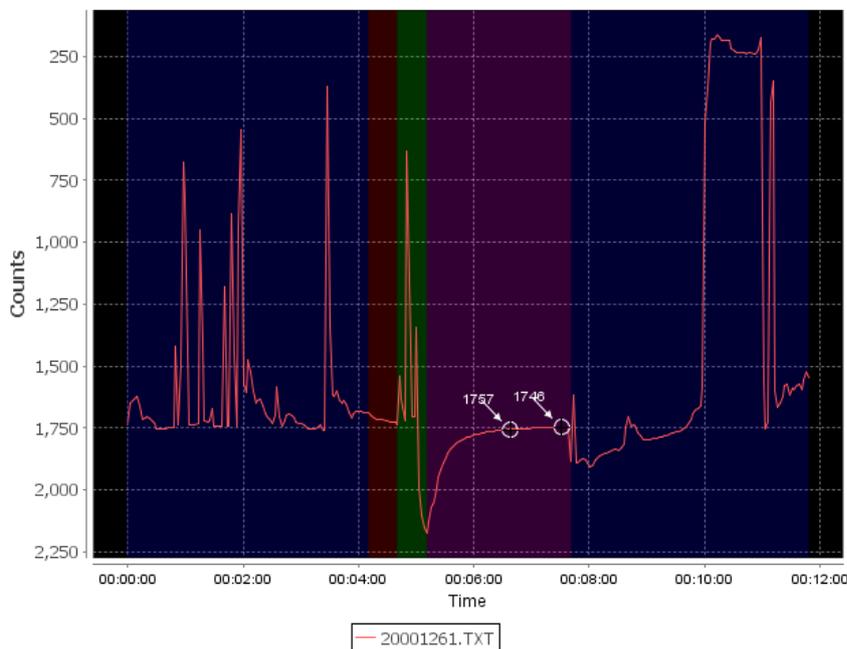
6.5 Data QC

Select the *QC Plot* tab to make an analysis of the quality of the data collected by the sensor. Use the software to open and look at the data in a number of files. There are algorithms in the software that let the user examine elements of the collected data as "good," "bad," "suspect," or "not evaluated." Refer to QC example and explanation of default thresholds on page 83 for details about these algorithms.

6.5.1 Open data files for analysis

The user can select a number of data files for analysis. Note that the more files that are selected, the more time it takes the software to process the data. The manufacturer recommends that the user selects no more than 2000 files at one time.

1. If necessary, start the software.
2. Go to the **File** menu, then *Load File(s)*.

    a. Select the directories or files to look at.
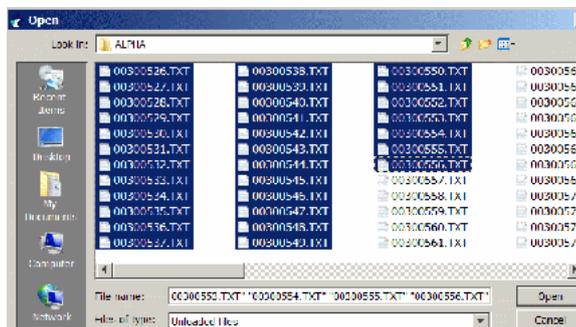
    b. Select the type of file to open in the software at "Files of Type." The default is "Unloaded Raw Files."

Files that have not already been opened during the current session of software show. Files that have already been opened for the software do not show.

c. If necessary, select another file type to open in the software.

- "All Files" opens all of the files in a selected directory. The software does not apply any filters.
- "Raw Cycle Files" are all files that have the format "sssnnnnn.txt " where "sss" is the serial number of the sensor, and "nnnnn" is the file number of the collected data.
- "Non-suspect Files" are any files that do not have "_SUS" before the file type. When the software does not fully save a file from the sensor, it will save that file as "sssnnnnn_SUS.txt" and this option will stop them from being opened for data analysis.

3. Push **Open**.
The **Raw Data Plot** window opens and shows the selected graph.
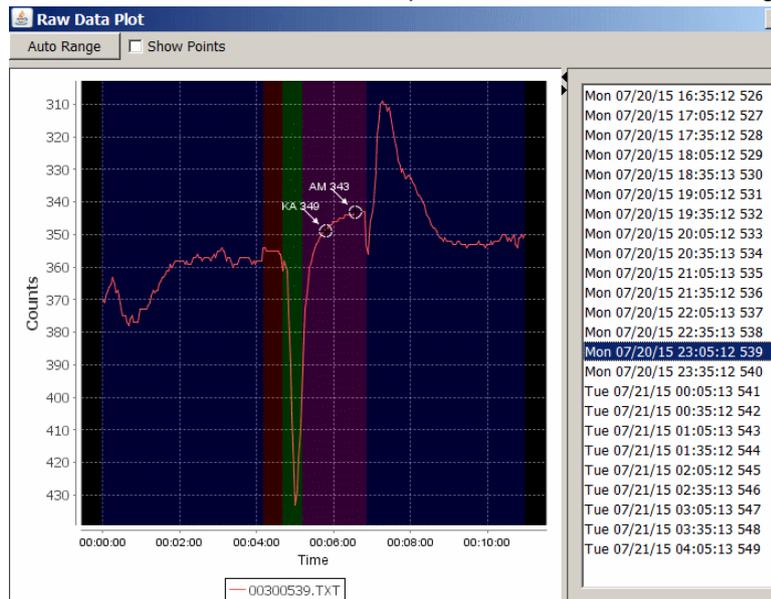
A pop-up window shows while the files are loaded for analysis. To stop the selected files from being loaded, push **Cancel**. The operation of the software can be slow if a large number of files are loaded for analysis. The manufacturer recommends that the user selects no more than 2000 files at one time.

4. To erase files from the analysis, select the file to erase, then right-click and select "Remove Selected" or type Ctrl-R on a selected file.

5. Look at the summary graph in the *QC Plot* tab of the software. Each of the files that were selected to offload shows as a green, yellow, or red dot.

🟢	"Good." The file has no suspect or bad test parameters.
🟡	"Suspect." The file has one or more test parameters that are suspect.
🔴	"Bad." The file has one or more test parameters that are bad.
🔵	"Not evaluated, missing data." The data is saved for analysis, but the related raw data file has not yet been read for analysis.

The blue dashed line shows which graph displays in the **Raw Data Plot** window.
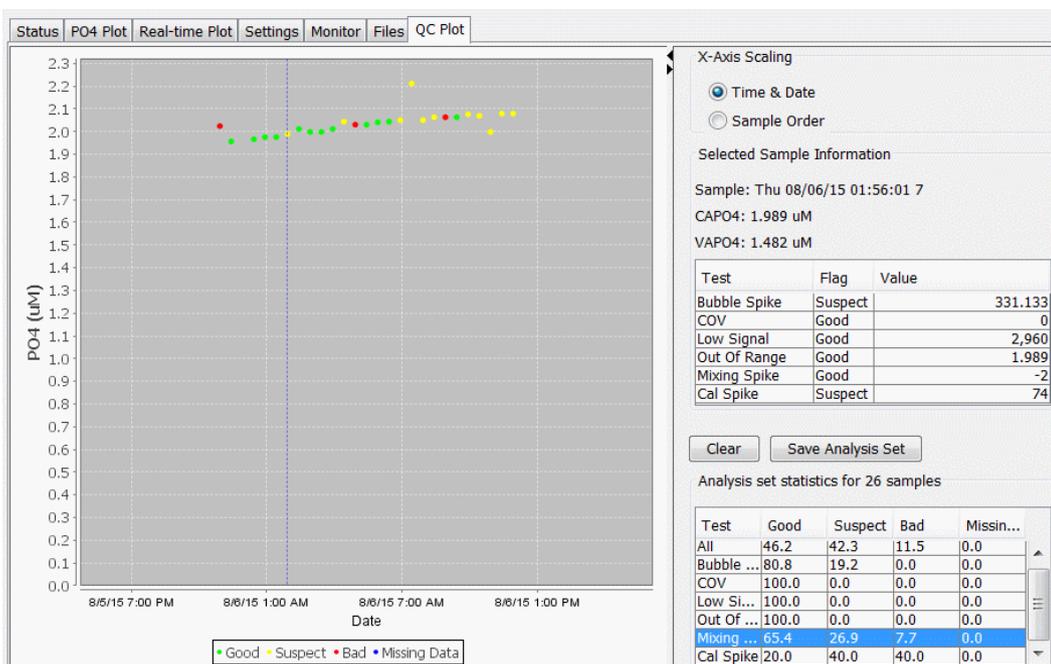
- • Select "Time and Date" to see data files by date.
- • Select "Sample Order" to see data files that are still ordered by date, but are equally spaced.

6.5.2 Examine flag levels

Use the "Test," "Flag," and "Value" information from the table in the "Selected Sample Information" area to examine which test values have resulted in data quality flags.

Flag	Description
Good=1	The data has passed critical real-time quality control tests and is deemed sufficient.
Not evaluated, missing data=2, 9	Data is missing, so there is nothing for the QC test. Used as a placeholder.
Suspect =3	The data is suspect or of "high interest" to data suppliers and users and is flagged as suspect so that users look carefully at the data.
Bad=4	The data has failed one or more critical real-time QC checks. If the data is disseminated at all, it is easy to tell that it is not acceptable.

The user may need to change the threshold test values that cause the flags if:

- • a data value has a "Good" flag but the data point in the *Raw Data Plot* looks suspect.
- • a data value has a "Suspect" or "Bad" flag but the data point in the **Raw Data Plot** looks satisfactory, or grab samples usually agree.

Refer to QC example and explanation of default thresholds on page 83 for a description of thresholds.

1. If necessary, open the files to examine. Refer to the previous section Open data files for analysis on page 29 for details.
2. Look at the summary graph in the *QC Plot* tab.
3. Select one of the dots in the graph to open a data file in the **Raw Data Plot** window.
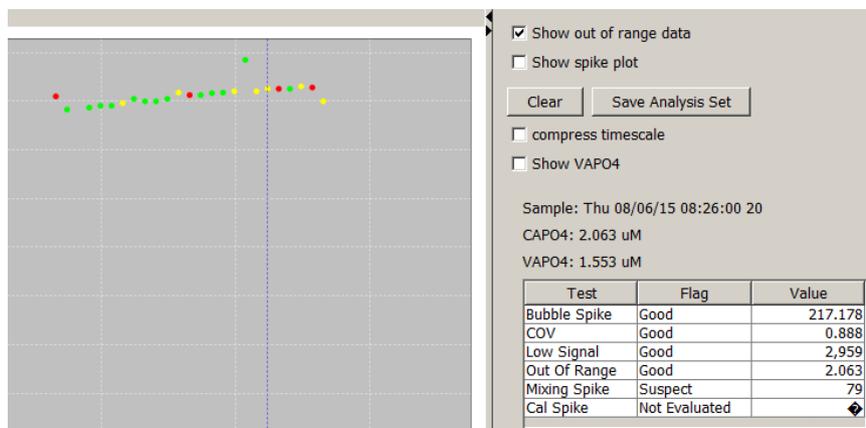
4. Look at the "Test," "Flag," and "Value" information.
   In the example above, the "Mixing Spike" shows a "Suspect" "Value" of 79.

5. Look at the data in the **Raw Data Plot** window.

   Note the spike in the "Mixing" period (green background).

6. Put the cursor in the graph above and to the left of the spike. Drag the pointer diagonally down and to the right to zoom in on the spike.
   The spike is from approximately 2960 to 2880, a distance of 79 counts. It shows as "Suspect" in the "Mixing Spike" row of the table in the *QC Plot* tab.
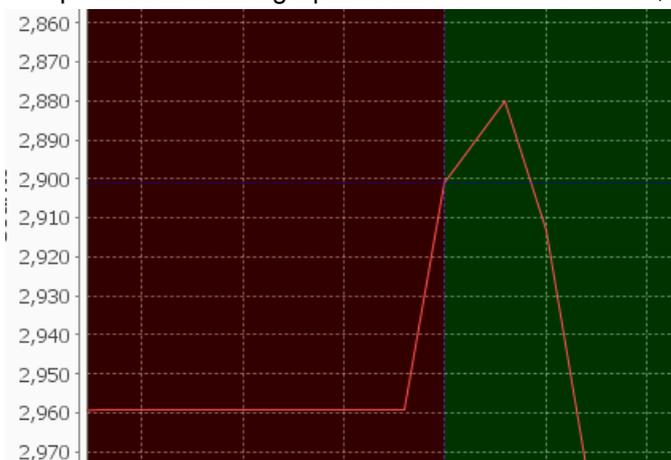
7. Push **Auto Range** in the **Raw Data Plot** window to change the plot back to the default scale, or drag the pointer from the lower right to the upper left (the opposite direction from step 6) to return the graph to the default view.

8. The user can remove outlier data values from the QC Plot so that they are not included in the "Analysis-Set" text file and the scaling of the data graphing is better.

   - Go to the **Tools** menu, then *Remove Selected Analysis Sample*. Any file that is selected in the **Raw Data Plot** window is removed.
   - To remove a data value, make sure that the data point is selected with the blue dashed line in the *QC Plot* tab.
   - Select the file name in the **Raw Data Plot** window.
   - Right-click (or enter "Ctrl-R"), then select "Remove Selected."

9. Go to **Tools**, then *Options*, or enter Alt-O, to open the **Cycle Host Options** window.

The user can look at and change the values in this window. Push **Reset to Defaults** to return to the manufacturer-set values.
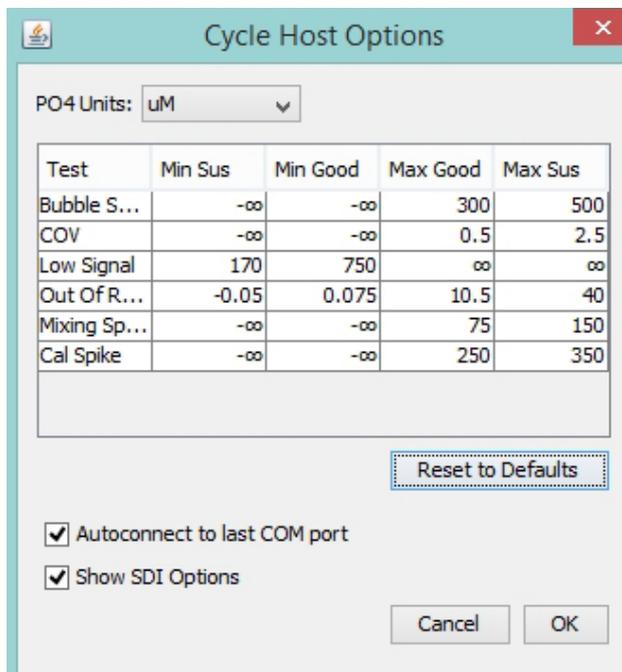
The ranges of values for "Good," "Suspect," or "Bad" are given in the table below.

Value (output from sensor)	**Flag**
Value < Min Sus	Bad
Min Sus <= *Value* < Min Good	Suspect
Min Good <= *Value* <= Max Good	Good
Max Good < *Value* <= Max Suspect	Suspect
Value > Max Sus	Bad

6.5.3 File format of analysis set summary

Line	Description
1	Version of the software that made the summary file, local date and time of the PC when the file was saved.
2	Reserved.
3	Delimiter for QC test settings in the file.
4	Lists the tab-delimited headings for the QC threshold settings below:
5–10	Lists each value of the QC tests, followed by the values that were used for the minimum good, maximum good, and maximum suspect thresholds when the file was saved. When opened in MS Excel®, cells that have "infinity" values show as "#NAME?" Ignore these values.
11	Lists the other QC test settings that were used when the analysis set was saved.
12	Headings for the analysis summary. The headings come after five tab characters so that the columns align with the samples that follow.
13	Number of samples evaluated for each QC test in the summary.
14–17	Percentage of each flag (good, suspect, bad, or missing data) for the overall flag and each QC test.
18	Individual samples in the QC analysis set. See below for list of headings.
19–end	The data for each sample in the data set for the heading in line 18.

Values for headings on line 18:

1. Date, MM/DD/YYYY
2. Time, HH:MM:SS
3. Run number
4. CAPO4 (µM)
5. VAPO4 (µM)
6. Overall QC level
7. QC bubble spike flag
8. QC COV flag
9. QC low signal flag
10. QC out of range flag
11. QC mixing spike flag
12. QC calibration spike flag
13. QC bubble spike test
14. QC COV test
15. QC low signal test
16. QC out of range test
17. QC mixing spike test
18. QC calibration spike test
19. VAS
20. State
21. Flush1
22. Ambient minimum
23. Flush2
24. Calibration minimum
25. Raw file location on PC

6.6 Sensor response to changes in temperature and nutrient concentration

Temperature changes have an effect on the pump volume and the LED intensity of the sensor, such as when the sensor is taken from the laboratory into the field, or vice-versa.

* If the temperature change is less than 1 °C/15 minutes, the sensor operates within specification (error < ±0.05 µM).
* If the change is more than 1 °C/15 minutes, the sensor may operate out of specification.

Laboratory tests found that for a 2.6 µM standard and a 1.5 °C/hour change, the CAPO4 values co-varied less than 0.05 µM. For a 6 hour period and a 10 °C decrease in temperature, the CAPO4 values decreased 0.2 µg/P/L (0.005 µM) per degree decrease in temperature. The PO_4 decrease lagged the decrease in temperature by 1–4 hours (lag is non-linear as temperature equilibrates.)

Make sure that the sensor is flushed thoroughly after the optics are cleaned with either bleach or Micro-90, because it is possible that there will be a phosphate bias in some subsequent samples.

In most conditions, environmental concentrations do not change quickly, and any carryover from the previous sample is negligible, but it is possible that a large phosphate spike followed by a return to the baseline can cause a carryover bias in the next sample. For example, a 0.46 mgP/L (15 µM) spike of phosphate followed by phosphate-free water within 10 minutes can cause an approximately 10% carryover in the next sample, and approximately 1.5% in the second sample.

Ideally, the sample and the sensor are at the same temperature. Data quality was suspect in an experiment in which the sample and the sensor were different by 25 °C.

6.7 Guide to sediments tested

The manufacturer has done tests with the HydroCycle-PO$_4$ and the Cycle-PO$_4$ with a filter upgrade in high-sediment conditions and compared the results with the Cycle PO$_4$ without the filter upgrade. The tests were done in a tank with the sediments suspended by use of a propeller pump circulation system to maximize the suspension of particles.

The sediments that were tested came from deposits at the sources listed below:

- IHSS Elliot Silt Loam
- Maumee River, Walterville OH
- Missouri River, Herman MO
- Rio Grande River, Albuquerque NM

Field tests were done in the Rio Grande, Maumee, and Illinois Rivers and in Great Bay, Yaquina Bay, and Delaware Bay, among other waters.

Although units of NTU are used to describe the sediment loads as a way to compare the tests and extrapolate the performance of the sensors under certain field conditions, NTU is not sufficient because particle size has a large effect on how well the filters function. Thus, the manufacturer recommends that users think about the type of sediment as well as turbidity for a given application.

Manufacturer's note on tests: the output of the HydroCycle-PO$_4$ showed good quality data for approximately 100 samples in 200 NTU Elliot Silt Loam sediment and approximately 90 samples in 100 NTU Missouri sediment. In general, the filter life was good, but may be shorter in fine sediment. The data quality of the sensor was good for 80 cycles of operation in a mixture of test sediments of 600 NTU.

In a 500 NTU mixture of the test sediments, the output quality of the HydroCycle-PO$_4$ filters was a 3 NTU filtrate compared to the Cycle filtrate of 250 NTU. The lower the value of the filtrate, the higher the quality of the phosphate measurement.

The HydroCycle-PO$_4$ can continue to give good data for a few, short-lived (days) sediment events, but may require that the user change the filters for sustained, high-frequency, or small-particle events.

Section 7   Maintenance

> ⚠ **CAUTION**
>
> Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

> ⚠ **CAUTION**
>
> Do not drop the sensor. It can be damaged, which is not covered by warranty. If the sensor is dropped, the user may be injured, and, if reagent cartridges are installed, hazardous reagent chemicals may spill.

Replace the reagent cartridges and intake filters on the sensor approximately every 1000–1500 samples, and clean the optics flow path. Change the battery core of the battery pack if that is the power source for the sensor. (The BPA-50 supplies power for approximately 1000 samples.)

The sensor is calibrated to output a reactive phosphate concentration in user-defined units of µM, mg/L, or mgP/L. The sensor will operate for approximately ten 1000–1500-sample deployments, or 12–18 months between service and re-calibration by the manufacturer.

1. Put the sensor on its side and use a Phillips screwdriver to remove the seven screws that attach the protective cover to the sensor.

Figure 17 Protective cover removed

2. Support the bottom of the sensor and lift into a vertical position.
3. Pull the sleeve up and off the sensor. Keep the sleeve and the screws.

7.1 Clean macro-fouling

Wash and scrape clean any macro-fouling from the sensor to keep it in good condition. Do not wash with a pressure-washer. Remove any anti-fouling tape before the sensor is sent to the manufacturer for service.

7.2 Clean sensor flow paths with cleaning solution

> ⚠ **CAUTION**
>
> Do not operate the sensor with Micro-90® in it. It can damage the sensor.

> ⚠ **CAUTION**
>
> Make sure all of the Micro-90® is flushed out of the sensor.

Clean the flow paths between each deployment with a 2% cleaning solution of Micro-90® or Liqui-Nox® to keep the optics clean from the products of chemical reactions, which can cause a decrease in sensitivity. Both solutions are available from various scientific supply companies.

1. Make sure that the sensor is connected to a power supply and a PC with the software installed. If necessary, start the software.

2. Unwind the exhaust tubing from the top of the sensor and put one end into a beaker (for waste).

3. Connect a syringe to a 25 cm length of 1/8" inside diameter (ID) Tygon® tubing and put the end of the tubing in a beaker with cleaning solution.

4. Pull a minimum of 10 mL of 2% cleaning solution into the syringe.

5. Place the sensor vertical and remove the blue tubing from the barb on the manifold that connects the filter to the sensor.

Figure 18 Disconnect sample tubing

6. Disconnect the syringe and pinch the tubing so that the cleaning solution stays in the tubing.

7. Connect the tubing that is filled with cleaning solution onto the sample port.

Figure 19 Connect tubing to cleaning solution
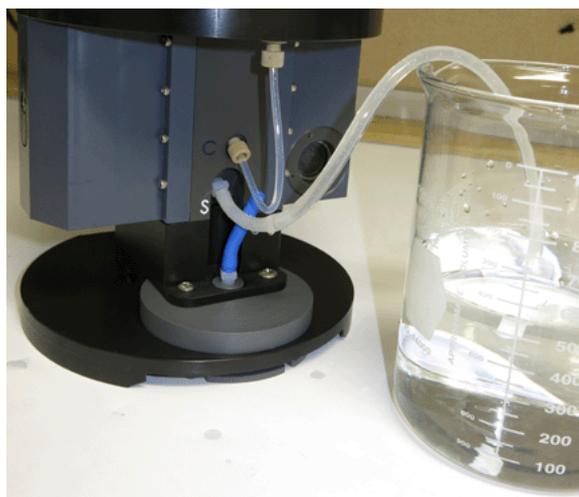
8. Go to the *Settings* tab of the software and push **Flush.**
    The sensor takes 5 minutes to fill with the cleaning solution.

9. Let the solution soak in the sensor for approximately ½ hour to 1 hour.

7.2.1 Flush cleaning solution from flow path

1. Flush the inlet tubing or get a new length to connect to the sample barb.
2. Fill a clean beaker with approximately 150 mL of clean water and put the other end of the tubing from the sample barb into the beaker.
3. Use a syringe to fill the tube with water.
4. Disconnect the syringe and pinch the tubing so that the water stays in the tubing.
5. Connect the tubing that is filled with water onto the sample port.
6. Connect the tube to the "S" barb.
7. Connect the syringe with the Luer-lock to the 1/16" barb adapter, and then to the effluent tube.
8. Put the inlet tubing back in the beaker for 2 seconds to let approximately 2 cm of water into the tubing.
9. Do the two steps above three times, until the tube is filled with air and water.
10. Go to the *Settings* tab of the software and push **Extended** in the **Flushing Options** pop-up window.
    The "Flush Timer" counts down to 0 to make sure that the sensor is thoroughly flushed clean. The flush takes approximately 21 minutes.
11. When the flush is complete, remove the inlet tubing and connect the blue tubing from the filter to the sample barb again.

Note: Any time the blue sample tubing is disconnected, it is necessary to prime the filters before deployment. Refer to Prime filters for deployment on page 19 for details on this procedure.

7.3 Clean flow paths with bleach solution

⚠ W A R N I N G

Bleach is caustic. Wear nitrile gloves and safety glasses and work in a well ventilated area to use bleach.

⚠ W A R N I N G

Never mix bleach with ammonia. It can make dangerous gasses.

⚠ W A R N I N G

Obey the safe handling and disposal instructions on the bleach containers.

⚠ C A U T I O N

Do not mix bleach with water > 1 PSU salinity or let bleach into a sensor that has not been flushed with clean, fresh (< 1 PSU) water.

⚠ C A U T I O N

Do not make a measurement with the sensor while there is bleach in it. It can damage the sensor.

N O T I C E

Do not pre-dilute bleach. It will go bad. Only use bleach well before the expiration date on the container.

It may be necessary to clean the optics with a bleach solution if the data output of the sensor does not increase to greater than approximately 2500 counts after it is cleaned with the Micro-90® solution.

Table 2 Bleach dilutions

Description	Dilution
Clorox® Pro Results (concentrated outdoor)	9:1
Clorox® Ultra	2:1
Regular	none

A 9:1 dilution is 9 parts water to 1 part bleach. For a 40 mL beaker, the solution is 4 mL of outdoor bleach, 36 mL of water.

1. Make sure that the sensor has been flushed with clean, salt-free water that is filtered to better than 10 microns.
2. Do the procedures in the section on Clean sensor flow paths with cleaning solution on page 37 but use bleach, not Micro-90®.
3. When the bleach flush procedure is complete, make sure to thoroughly rinse the flow paths with clean water.

7.3.1 Flush the flow path

1. Flush the inlet tubing or get a new length to connect to the sample barb.
2. Fill a clean beaker with approximately 150 mL of clean water and put the other end of the tubing from the sample barb into the beaker.
3. Go to the *Settings* tab of the software and push **Extended** in the **Flushing Options** pop-up window.
   The "Flush Timer" counts down to 0 to make sure that the sensor is thoroughly flushed clean. The flush takes approximately 21 minutes.
4. When the flush is complete, remove the inlet tubing and connect the blue tubing from the filter to the sample barb again.

Note: Any time the blue sample tubing is disconnected, it is necessary to prime the filters before deployment. Refer to Prime filters for deployment *on page 19 for details on this procedure.*

7.4 Do a check on flush1

The manufacturer recommends that the user do a check of the clean water counts after the sensor has been cleaned with Micro-90®, bleach, or both. High concentrations of phosphate and the characteristics of sediment may make it necessary to clean the sensor several times to get a good clean water count value. The sensor should be free of bubbles. Use distilled or 18 MOhm-ultrapure water filtered to 10 µm to do a check of the clean water counts.

There are two ways to get the clean water count value.

- In the laboratory: operate the sensor for several cycles and look at the flush1 values in the summary file of the software.
- In the field: use the software to start a cycle of data collection. Make sure that the baseline is stable, and record the count value. Stop the sensor before it begins to pump reagents (after approximately 2 minutes), so that the clean water count value comes from the initial flush cycle of operation.

Sensors should not be deployed if the clean water count value is less that 2000. It is best if the clean water count value is > 3000. It may be necessary to clean the sensor with Micro-90® and bleach multiple times.

7.5   Optional: do a test of the check standard

Do a test with a check standard to make sure that the sensor operates within calibration specifications.

1. Make sure that the sensor is connected to a power supply and a PC with the software installed. If necessary, start the software

2. Unwind the exhaust tubing from the top of the sensor and put one end into a beaker for waste.

3. Connect a syringe to a 25 cm length of 1/8" inside diameter (ID) blue tubing and put the end of the tubing into the beaker with the check standard.

4. Pull a minimum of 10 mL of the standard into the syringe.

5. Put the sensor vertical and remove the blue tubing that connects the filter to the sensor.

Figure 20 Disconnect blue tubing
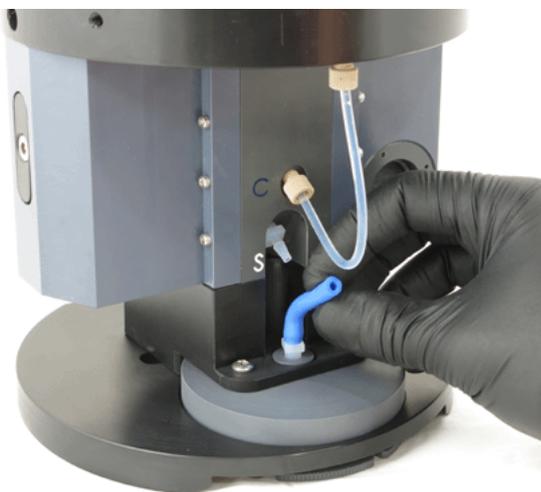
6. Disconnect the syringe and pinch the tubing so that the check standard stays in the tubing.

7. Carefully connect the tubing to the sample barb and keep the tubing pinched to keep the check standard in the tubing.

8. Verify the *Settings* tab in the software is set to 1 sample and a Cal Frequency of 1.

9. Push **Run**, and then **Run Now**.

10. The test of the check standard is complete.

Note: Any time the blue sample tubing is disconnected, it is necessary to prime the filters before deployment. Refer to Prime filters for deployment *on page 19 for details on this procedure.*

7.5.1   Flush the flow path

1. Flush the inlet tubing or get a new length to connect to the sample barb.

2. Fill a clean beaker with approximately 150 mL of clean water and put the other end of the tubing from the sample barb into the beaker.

3. Go to the *Settings* tab of the software and push **Extended** in the **Flushing Options** pop-up window.
    The "Flush Timer" counts down to 0 to make sure that the sensor is thoroughly flushed clean. The flush takes approximately 21 minutes.

4. When the flush is complete, remove the inlet tubing and connect the blue tubing from the filter to the sample barb again.

> *Note: Any time the blue sample tubing is disconnected, it is necessary to prime the filters before deployment. Refer to* Prime filters for deployment *on page 19 for details on this procedure.*

7.6 Change sensor filters

> # *NOTICE*
>
> Wear gloves to decrease the risk of filter contamination. Hand lotions and soap can contain significant quantities of phosphate.

The filter life is approximately 1500 samples, but if there are bubble flags in the data QC, the filters should be replaced more frequently.

1. Put the sensor on its side.
   The filter retainer assembly has the following parts from top to bottom:

   - plastic filter
   - O-ring spacer
   - copper screen

2. Unscrew the filter retainer disk and remove from the sensor.

Figure 21 Remove filter retainer disk

3. Use the rectangular tool supplied by the manufacturer to loosen the retainer disk if the retainer is difficult to remove.

Figure 22 Tool to remove filter retainer disk
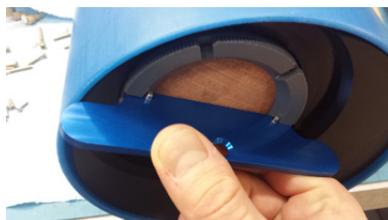
4. Remove and discard the filter disk.
   If the filter does not come out with the retaining ring (shown below as transparent for clarity), carefully remove it from the base of the sensor.
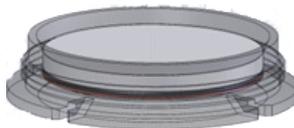
5. Clean the O-ring spacer and copper screen and install the copper screen and then the O-ring spacer into the retaining ring. If the spacer and the copper screen are too fouled to clean, replace them.
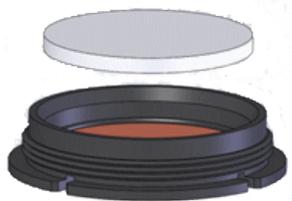
6. Use distilled water and lint-free wipes to clean the O-ring, the O-ring spacer, and the copper screen:

    •   If water is not sufficient, use isopropyl alcohol.
    •   Rinse with distilled water, wipe dry.
    •   Make sure there is no debris or fibers on the parts from the wipe.
    •   Replace any part that cannot be cleaned of debris or fouling.

7. Install the new filter disk in the retaining ring on top of the O-ring spacer. If the plastic filter has only one smooth face, verify that the smooth face is pointed away from the copper screen.

8. Verify that the O-ring in the base of the sensor is clean. If necessary, clean this O-ring.

    •   Make sure that there are no scratches, nicks, or debris on the O-ring. It must be perfectly clean and not damaged. Replace the O-ring if there is any question.

Figure 23 O-ring in sensor

9. Install the retaining ring with the new filter into the base of the sensor. Tighten by hand until the retainer stops firmly ("bottomed out"). To make sure the assembly is "bottomed out," use the rectangular tool to tighten the assembly no more than 1/8 of a turn past hand-tight.

Figure 24 Install retaining ring
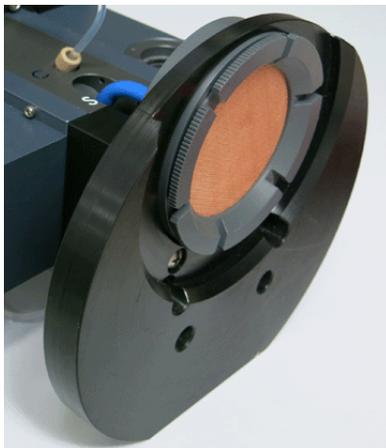
10. Verify that the retaining ring is above, or higher than, the bottom of the sensor.

Figure 25 Height of retaining ring
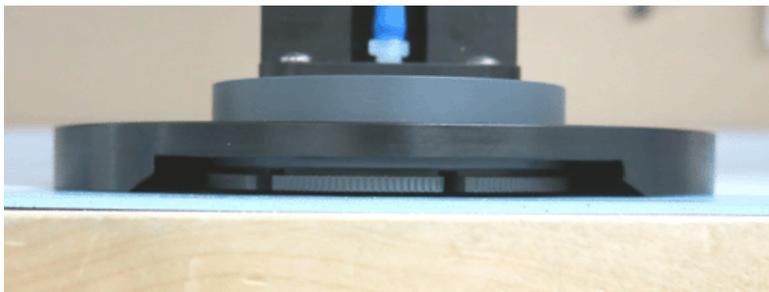
Note: Any time the blue sample tubing is disconnected, it is necessary to prime the filters before deployment. Refer to Prime filters for deployment *on page 19 for details on this procedure.*

7.7 Replace reagent cartridges

> ⚠️ **C A U T I O N**
>
> Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

1. Remove the blue calibration cartridge first. Press the connector button on the bottom of the cartridge to release it.

2. Slide the cartridge up and off the guide pins.

3. Pull the cartridge away from the housing and set the cartridge aside.

4. Remove the yellow and then the red cartridges.
Note: If new cartridges will not be installed immediately, or the sensor will be shipped or stored, install the protective yellow caps on the connectors.

Figure 26 Protective cap installed

5. Install new cartridges. Refer to the section on Assemble the sensor on page 9 for details on this procedure.

6. Make sure that the sensor is set up to do an automatic prime in-situ before it is deployed again.

7.8 Bulkhead connector maintenance

⚠ **CAUTION**

Do not use WD-40® or petroleum-based lubricants on bulkhead connectors. It will cause damage to the rubber.

Damaged connectors can cause a loss of data and additional costs for service.

Damaged connectors can cause damage to the sensor and make it unserviceable.

Examine, clean, and lubricate bulkhead connectors at regular intervals. Connectors that are not lubricated increase the damage to the rubber that seals the connector contacts. The incorrect lubricant will cause the bulkhead connector to fail.

1. Apply isopropyl alcohol (IPA) as a spray or with a nylon brush or lint-free swab or wipes to clean the contacts.

2. Flush with additional IPA.

3. Shake the socket ends and wipe the pins of the connectors to remove the IPA.

4. Blow air into the sockets and on the pins to make sure they are dry.

5. Use a flashlight and a magnifying glass to look for:

Cracks, scratches, or other damage on the rubber pins or in the sockets.		
Any corrosion.		

Separation of the rubber from the pins.	
Swelled or bulging rubber pins.	

6. Use a finger to put a small quantity (approximately 1 cm in diameter) of approved silicone grease on the socket end of the connector and push as much of the lubricant as possible into each socket. Approved silicone greases:

   • Dow Corning Molykote® III Compound (DC III)
   • Dow Corning High Vacuum Grease® (DC 976 V)
   • Dow Corning 4 Electrical Insulating Compound® (DC 4)
   • Dow Corning Molykote 44 High Temperature Grease (DC 44)
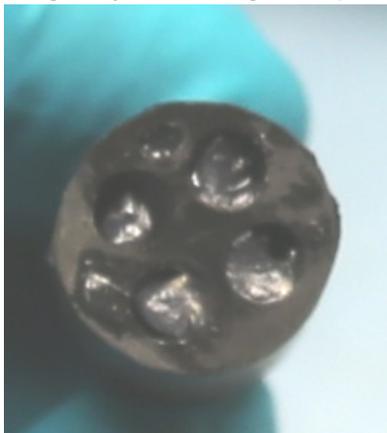
7. Connect the connectors.
8. Use a lint-free wipe to clean any unwanted lubricant from the sides of the connectors.

7.9 Sensor storage

⚠ **C A U T I O N**

Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

⚠ **C A U T I O N**

The red reagent cartridge contains corrosive and toxic chemicals. Refer to the SDS sheet for details.

Always flush all of the reagents out of the sensor. Push **Flush** in the *Settings* tab to do this procedure.

7.9.1 Short-term storage

Short-term storage is several days to several weeks. Make sure that the sensor is clean and has been flushed before it is put into storage. Store the sensor and the reagent cartridges at room temperature.

1. Clean any biofouling from the protective sleeve.
2. Keep the cartridges installed on the sensor.
3. Wind the outlet tubing around the eye bolts.

7.9.2 Long-term storage

Long-term storage is several weeks to months. Make sure that the sensor is clean and has been flushed before it is put into storage.

1. Clean any biofouling from the protective sleeve.
2. Attach an approximately 15 cm long section of 1/8" ID blue tubing to the quick-disconnect inline coupling.
   These two parts are in the manufacturer-supplied spare parts kit.
3. Put the other end of the tubing in an empty beaker.
4. Attach the tubing with the quick-disconnect coupling to an empty or nearly empty red reagent cartridge.
   Any fluid in the cartridge drains into the beaker.
5. Fill a syringe with DI water and fill the cartridge with the water.
6. Disconnect the coupling body from the cartridge.
7. Shake the cartridge.
8. Connect the cartridge to the sensor again and drain the DI water into a beaker.
9. Do steps 5–8 two more times.
10. Do steps 3–9 for the yellow and the blue cartridges.
11. Install the cartridges on the sensor.
12. Turn the sensor on.
13. At the *Settings* tab, type 200 in the "number of pumps" area to do a check on R1, R2, and Cal pumps.
14. Do the steps above for the yellow and blue cartridges.
    Keep the flow passages filled with DI water.
15. Push **Run Pump(s).**
16. Clean and flush the sensor.
17. Wrap the outlet tubing around the eye bolts.
18. Disconnect and store the reagent cartridges in a chemical refrigerator at 2–8 °C.
    Make sure that the reagents do not freeze, or they may leak and fail. Make sure that the cartridges are at room temperature before they are installed on the sensor.
19. Install the yellow caps on the connectors.

Figure 27 Yellow protective cap

20. Lubricate the bulkhead connectors.
21. Attach the protective dummy plugs and lock collars.
22. Attach the protective sleeve to the sensor.
23. Put the sensor in its case for safe storage.

7.10 Send sensor/reagent cartridges back to manufacturer

> **⚠ CAUTION**
>
> Wear Personal Protective Equipment (PPE) to remove or replace cartridges. PPE includes a lab coat or smock, gloves, safety glasses.

For service or repair:

1. Clean fouling or dirt off of the sensor.
2. Make sure that the sensor has been flushed with clean water.
3. Remove the cartridges from the sensor.
4. Put the sensor in a plastic bag.
5. Put the sensor in its original shipping case.
6. Put the cartridges in a box that is large enough to have 5 cm of protective packaging. Multiple cartridges can be packaged together.

To recycle cartridges:

1. Remove the cartridges from the sensor.
2. Put the cartridges in a box that is large enough to have 5 cm of protective packaging around each cartridge. Multiple cartridges can be packaged together.

Section 8   Command-line commands

The user can send command-line commands as an alternative to the manufacturer-supplied software to communicate with the sensor. Refer to the information below for details about how to use the commands.

Commands are limited to 160 characters, which includes the $.

Command characters are case-insensitive. Characters are converted to uppercase by the sensor, but are shown as they are entered.

- Commands start with an ASCII $ character (0x24) and end with an ASCII carriage return <CR> character (0x0d).
- The command designator follows the $.
- Command designators are usually 3 or 4 characters.
- One or more arguments follow the command designator.
- Arguments can be separated by a space (0x20), a tab, (0x09), or a comma (0x2c).
- If a command does not need an argument, a <CR> line terminator follows the designator.
- Non-printing ASCII characters that occur before the $ that starts a command are ignored and not shown.
- More than one command can go on a single line if separated by semi-colons (0x3b).
- The commands operate until there are more than 160 characters per line, or there is an error.

Use the backspace character (0x08) to remove characters from the end of the command. The command interpreter will show the backspace and send a space (0x20) and a backspace (0x08) character to "delete" the removed character.

Set up the command interpreter with the SPR command. The default is "enabled," which shows the PO4> command prompt when it is ready to accept commands.

The sensor shows the success or failure of user-issued commands and ends with <CR><LF> characters.

- Invalid commands will show "Bad command or file name."
- Invalid parameters, or arguments, will show "invalid argument(s)."
- A command that cannot be accepted while the sensor is collecting a sample will show "Not available while sample running."

8.1 Configuration commands

CAS	Constant A-Star value (manufacturer's scale factor)
Description	Get the constant a* value
Argument 1	none
Response	Constant a* value to two decimal places

CLK or TIME	Get/set the sensor's internal clock or date
Description	Get/set the sensor's internal clock or date
Argument 1	New time in hh:mm:ss (24-hour clock) or the new date (mm/dd/yy) if both the date and time are set.
Argument 2	New time in hh:mm:ss (24-hour clock) if both the date and time are being set.
Response	The current or new date and time in mm/dd/yy hh:mm:ss format. The hours are in a 24-hour format. The date and time are separated by a tab character, (0x09), not by a space.

Command-line commands

CNT	Sample counter
Description	Get/set the current or most recent sample number. This is the number used in the raw file naming format. When the sample counter is set, the next sample run is the newly set count plus 1. Set this value to 0 at the start of each deployment.
Argument 1	New count value for the number of data samples completed. Must be followed by a /S switch to change the count. Set to one less than the number of the next sample.
Response	The current or new sample counter.

CSF	Cal spike frequency
Description	Get/set the frequency that a calibration spike is done. The default is 6.
Argument 1	New frequency. The next data sample after this command will do a calibration sequence. Allowed values are 1 to 32767. If a data sample is being collected, the new value will not change it.
Response	The current or new calibration frequency followed by the number of data samples before the next cal spike. The two values are separated by a space character (0x20). A value of zero for the number of data samples before the next calibration spike means that the next sample will run a calibration spike.

DCA	Deployment cartridge amounts
Description	Get/set the quantity of chemicals in the sensor at the start of a deployment.
Argument 1	Calibration standard in mL.
Argument 2	Quantity of reagent 1 in mL.
Argument 3	Quantity of reagent 2 in mL.
Argument 4	/S safety flag
Response	The current or new cartridge quantities to three decimals in milliliters at the start of a deployment. The values are separated by a space character (0x20).

DSD	Data subdirectory
Description	Get/set the subdirectory used to save data.
Argument 1	Name of the subdirectory without the root directory (e.g. C:\). Only subdirectories of the root directory are allowed. Subdirectory names can be no longer than 8 characters. Only a–z and 0–9 are permitted.
Response	The message "resets" when the command is completed.

DSI	Device specific information
Description	Get device-specific pump volumes, the optical pathlength, the PO_4 offset, and the scale factor.
Argument 1	Ambient (sample) pump volume in µL.
Argument 2	Pump volume of the calibration standard in µL.
Argument 3	Pump volume of reagent 1 in µL.
Argument 4	Pump volume of reagent 2 in µL.
Argument 5	PO_4 offset in µM.
Argument 6	Calibration offset in µL.
Argument 7	Cell pathlength in cm.
Response	The current value. The arguments in this table show in order from argument 1 to argument 7, separated by space characters (0x20). The pump volumes and pathlength show to two decimal places. The offsets show to four decimal places.

EUF	Engineering units format
Description	Get/set the units to use for engineering units output.
Argument 1	Units to use. 0 = microMolar (µM). 1 = milligrams of phosphate per liter (mg/L). 2 = mg of atoms of phosphorus per liter measured in the form of reactive phosphate (mgP/L).
Response	The new or current values as "µM," "mg/L," or "mgP/L."

IDT	Idle timeout
Description	Get/set the communication idle time in seconds. If no communication is received within this time period while a data sample is not running, the sensor goes back to a low power "sleep" state.
Argument 1	New communication idle timeout in seconds. The range is 5 to 4924.
Response	The new or current idle timeout in seconds.

INT	Sampling interval
Description	Get/set the time period between data samples, referenced from one start time to the next.
Argument 1	Interval in seconds or minutes:seconds or hours:minutes:seconds. If 0, the sensor will collect one data sample and then stop.
Response	The new or current sample interval as hh:mm:seconds.

NOS	Number of samples
Description	Get/set the number of data samples (includes the current data sample) to collect before the sensor stops.
Argument 1	Number of data samples to collect. The default is -1, which sets no limit to the number of data samples.
Response	The new or current number of data samples to collect.

OPD	Output period
Description	Get/set the data output interval. Use with an SDO setting of 0 to specify how often a data sample is sent from the sensor. The default is 5. This value also specifies how often the raw signal data is written to the raw data files.
Argument 1	New output interval. The old version of data output shows every *n*th LED cycle.
Response	The new or current period of output.

QCA	Auxiliary on-board QC settings
Description	Get/set the auxiliary on-board QC settings.
Argument 1	Mixing spike window in seconds.
Argument 2	Bubble spike detection delay in seconds.
Argument 3	Bubble spike threshold.
Argument 4	Standard deviation value used in the bubble spike detection.
Argument 5	Difference value used in the bubble spike detection.

QCT	On-board QC threshold settings
Description	Get/set the on-board QC threshold settings.
Argument 1	Decimal code of the individual QC test or set or get, where: 0=Bubble Spike, 1=COV, 2=Low Signal, 3=Out of Range, 4=Mixing Spike and 5=Cal Spike.
Argument 2	Minimum Suspect threshold value.

Argument 3	Minimum Good threshold value.
Argument 4	Maximum Good threshold value.
Argument 5	Maximum Suspect threshold value.
No arguments will show the settings for all of the on-board thresholds.	

SDA	SDI-12 address
Description	Get/set the SDI-12 bus address for the sensor.
Argument 1	New SDI-12 sensor bus address as an integer from 0–9.
Response	The current or new address. This will also show an address change that was sent via the SDI-12 bus.

SDO	Output mode
Description	Get/set the format of the data that is output. The default mode of 0 is the same as the old data output format with final engineering units added at the end of each sequence. Modes 1 and 2 are for use by the manufacturer. Mode 3 shows only the engineering units of data at the end of a data sequence. Mode 4 shows no engineering units data.
Argument 1	Mode of operation to use.
Response	The current or new mode of operation.

SPR	Set prompt
Description	Turn the command prompt of PO4 on or off.
Argument 1	1 = turn on command prompt, 2 = turn off command prompt.
Response	The current or new command prompt shows as either "on" or "off." When the prompt is turned off, there is no prompt after a response. When the prompt is turned on, there is a PO4 prompt after a response.

STO	Store configuration to flash
Description	Saves the current configuration values to a non-volatile flash memory. This command automatically executes when a low input power fault happens, before the sensor enters a low power state, or when the user exits to PicoDOS.
Argument 1	None
Response	The message "written" on a complete command.

SUD	Start time and date
Description	Get/set the time and date for the first or next data collection sample or for a scheduled pump priming cycle. No arguments returns the date and time for the next scheduled data collection sample or none. If NOS is 0, it will automatically be set to -1.
Argument 1	Start date as m/d/y (optional) or /P to show the date and time (or none) of the scheduled pump priming cycle.
Argument 2	Start time (h:m:s) or 0 to stop data collection.
Argument 3	/P to apply the preceding time or date and time to the pump priming cycle start time.
Response	The current or new mode of operation.

UPC	UPS count
Description	Get the number of UPS cycles.
Argument 1	None
Response	The number of UPS cycles that have happened from low-power faults.

WKM	External wake mode
Description	Get/set the operation when an external wake signal happens on pin 1. The default = 0 brings the sensor out of a low power mode. Mode 1: starts a data collection (sample) sequence. Mode 2: sensor to show the most recent data collected.
Argument 1	Wake-up mode.
Response	The new or current wake mode. 0 = off. 1 = start on wake signal. 2 = show the most recently completed sample (GLSO) on the wake signal.

8.2 Operation commands

FLT	Fault status
Description	Shows any fault conditions.
Argument 1	none
Response	A four-character hexidecimal value that shows the fault status. The value 0000 shows that there are no faults.

Table 3 Fault conditions

Bit field	Fault
0x0001	Invalid values at startup. The default values are used.
0x0002	The values used at startup were not saved. Some values may not be in effect.
0x0004	Invalid operational values at startup. The default values are used.
0x0008	The operational values used at startup were not saved. Some values may not be in effect.
0x0010	The saved data subdirectory did not exist at startup and could not be made.
0x0020	Communication to the gas gauge controller was not made.
0x0040	SYS.QPBCS is not set correctly.
0x0080	File Create Error
0x0100	Past Due Start Time
0x0200	Low Power Fault Detected

GLSO	Get last sample output
Description	Get the data for the most recently completed or ended sequence of data collected.
Argument 1	none
Response	The most recently completed or ended sample collection sequence followed by two pair of <CR><LF> characters. Refer to Engineering units output on page 71 for details.

KCO	Operate pumps to flush
Description	After a user-specified number of counts (2/second) the reaction is complete and the analytical signal is selected before the sensor flushes.
Argument 1	Positive integer for cycles at 2 Hz.
Response	The pumps operate for a user-specified number of cycles. The manufacturer recommends 120.

LSS	Last shutdown state
Description	Get the status of the last shutdown.

Argument 1	none
Response	The message "ok" if the shutdown was via the "XIT" command or "power failure" if the last shutdown was from a power fault.

ONT	Run time/Power consumption
Description	Get/set the total "on" time for the sensor. This number is usually reset when a new battery is connected.
Argument 1	New "on" time, in seconds.
Argument 2	/S = safety flag.
Response	The current/new "on" time, in h:mm:ss. The hours field is from 1 to 10 characters.

PRI	Prime
Description	Do the priming sequence immediately.
Argument 1	1 = starts the priming sequence. 0 = starts the flush process while the priming sequence occurs.
Response	The status of the priming sequence. The message "on" or "off" will show if no arguments are made. The message "priming" shows if priming is started.

RUN	Run
Description	Start a new data sample sequence now. If NOS is 0, it will automatically set to -1.
Argument 1	/P = start a priming sequence.
Response	The message "Running" shows if a data sample sequence is started. The message "Priming" shows if a priming sequence is started.

SDS	SDI-12 status
Description	Get the status of the SDI-12 interface board.
Argument 1	none
Response	VER:n.n c enabled|disabled. n.n = the interface3 board version number. c = the code that shows the status of operation, and either enabled or disabled to show if the board is on or off. 0–8 = the board is being started, or there is a problem. 9 = the board is OK but does not have power from the SDI-12 bus. 10 = there is no SDI-12 interface board, or it is not in communication. 11 = the board is OK and has power from the SDI-12 bus.

SLP	Sleep
Description	Put the sensor in a low power "sleep" mode for a specified time, until a specified time, or indefinitely. Use the serial port or the external wake signal to put the sensor in a "ready" mode. Some characters are baud rate-dependent and cannot be used to "wake" the sensor. The character that is used to "wake" the sensor is not buffered for input. The manufacturer recommends that the user does an RS232 break of at least 500 ms to "wake" the sensor.
Argument 1	Number of seconds to be in a low power state. No argument = stay in low power until the next data sample time occurs.
Response	The message "Sleeping <CR><LF>" shows. When argument 1 is used, or if the sensor is going to collect a data sample, the message "for n seconds <CR><LF>" shows, where "n" is the smaller of the value of the commanded interval or the time to the next data sample.

STP	Stop
Description	Cancel a sample sequence and flush the sensor, or stop immediately. If the flush occurs, NOS goes down, as though a whole sample was completed. If a sample is not being collected, the SUD and SUD /P move to 0 and the NOS value does not change.
Argument 1	no argument = the flush sequence occurs. /I = the sample sequence stops. The NOS does not change, as though the sample sequence did not occur.
Response	"Stopped" shows if there was no sample sequence. "Flushing" shows if the user made the command without the /I argument. "Stopping" shows if the user made the command with the /I argument.

TPC	Total pump counts
Description	Get the total number of pump actions by any or all of the pumps in the sensor. The pump counter is reset when a new pump is installed.
Argument 1	none
Response	Shows the counts for the ambient (sample) pump, the calibration pump (blue), the reagent 1 pump, (yellow), and the reagent 2 pump (red) separated by spaces. These are the total counts over the life of the pumps. The pump life is 20,000,000 counts.

TTS	Time to next sample start
Description	Get the time until the start of the next scheduled sample sequence.
Argument 1	none
Response	Shows the time in h:mm:ss until the next sample starts. Shows a 0 if a sample is being collected, or -1 if a sample is stopped.

VOL	Volumes pumped/Deployment pump counts
Description	Get/set the volumes for all the pumps in the sensor for this deployment. An optional argument is /R /S = resets all four pump volumes to 0.00.
Argument 1	Ambient volume from the pump in µL.
Argument 2	Calibration standard from the pump in µL.
Argument 3	Reagent 1 from the pump in µL.
Argument 4	Reagent 2 from the pump in µL.
Argument 5	/S = safety flag
Response	The current or new volumes in µL to three decimal places in the order above. The values are separated by a space.

XIT | EXIT	Exit
Description	Stop the firmware application and go to PicoDOS. Scheduled samples are stopped. (Same as SUD 0).
Argument 1	none
Response	None from the sensor application. The PicoDOS start message shows at the current baud rate after several seconds.

8.3 File commands

CPY	Copy
Description	Copy a file to a new filename or location on the flash drive. "Wildcards" (* and ?) are permitted. Note that if a destination file already exists, it will be overwritten.
Argument 1	The file or files to be copied.
Argument 2	The destination of the copied file or files.
Argument 3	An optional /V command to verify the new file or files.
Response	The names of the source files, followed by <CR><LF> as they are copied. After the last file is copied, an additional <CR><LF> shows, followed by "n files(s) copied" where "n" is the number of files copied. The message is padded with spaces so that the number field is always eight characters wide and ends with two <CR><LF>.

DEL	Delete
Description	Erase the specified file or files from the flash drive. "Wildcards" (* and ?) are permitted.
Argument 1	The file or files to be erased.
Response	"n" file(s) erased. n = the number of files erased. The response ends with two <CR><LF>.

DIR	Dir
Description	Get a list of the files in the directory. "Wildcards" (* and ?) are permitted. The "*" character = any group of one or more alphanumeric characters. The "?" = any single alphanumeric character.
Argument 1	The directory to list, or /D for the "current" directory.
Argument 2	The optional filename pattern to list. For example, "*.txt"
Response	A list of the directory with the specified filters. If a data file is being collected, it will show on the last line, separated by a space from the preceding "Active file."

GET	Get file
Description	Get the specified file or files. "Wildcards" (* and ?) are permitted. The file move is stopped with an RS232 break signal of 500 ms or longer. This is followed by the "checksum" for the characters that were sent before the sensor got the break signal.
Argument 1	The files to be moved.
Response	All of the specified files will be moved. A header line comes before each file. The header line has the filename, the number of the file being moved, from 1 to "n", the total number of files moved, the file size in bytes, and the number of bytes that need to be moved. This information is separated by a space. The whole file is moved and is followed by the CRC-32 "checksum" of eight hexidecimal characters. Data being collected will stop while the file is moved. The data output stream pauses for the internal requirements of the sensor.

REN	Rename
Description	Change the name of a specified file on the flash drive.
Argument 1	Path and the file to change.
Argument 2	New path and the file name.
Response	<CR><LF>. "Not found error" = the file does not exist. "Rename error" = the file exists or there was another error.

RMD	Remove directory
Description	Erase the specified sub-directory if it is empty. Note that an open subdirectory cannot be erased even if it is empty. Use the DSD command to change the data sub-directory first.
Argument 1	Path to the empty directory to erase.
Response	"Dir Removed"= directory is erased. "error code" = directory does not exist. "Dir not empty error" = directory is not empty.

TYPE	Type
Description	Shows the specified files from the serial port. There is no data verification or way to see the end of a file. "Wildcards" (* and ?) are permitted.
Argument 1	Files to show.
Response	Directory, then filename, separated by a \ character, then <CR><LF>.

8.4 Miscellaneous commands

DAC	Set DAC output
Description	Set the level of output of the Digital-to-Analog converter to a specified level.
Argument 1	The 12-bit value shows in hexidecimal format from 0–fff.
Response	The new DAC level of output.

Table 4 Common DAC output voltages

Value	Approximate output voltage
0	0.00
333	1.00
400	1.25
666	2.0
800	2.5
999	3.0
c00	3.75
ccc	4.00
fff	5.00

DEV	Device type
Description	Get the device-type and serial number of the sensor.
Argument 1	none
Response	The device-type and the serial number of the sensor separated by a space. "PO4" = device-type. "nnn" = three-characters, where "n" is a number fro 0–9.

H	HELP	Help
Description	Show the available commands.
Argument 1	none
Response	See table below.

Command-line commands

Table 5 Summary of Commands

Type of command			
C = Configuration	O = Operation	F = File	M = Miscellaneous

Type of command	Command	Description	Type of command	Command	Description
C	$CAS	const a*	C	$CCS	calibration concentration
C	$CLK	get/set date and time	C	$CNT	sample counter
F	$CPY	source destination	C	$CSF	calibration frequency
M	$DAC	set dac output	C	$DAT	get/set date and time
C	$DCA	get/set cartridge volumes	F	$DCS	default config
F	$DEL	file	M	$DEV	get device type
F	$DIR	/D for data dir	C	$DSD	data subdir
C	$DSI	device config	C	$EUF	get/set units format
O	$FLT	get fault status	F	$GET	get file(s)
O	$GLSO	get last output	C	$IDT	idle timeout
C	$INT	sample interval	O	$KCO	operate pumps to flush
O	$LSS	last shutdown state			
C	$NOS	number of samples	O	$ONT	show on time
C	$OPD	output period	O	$PMP	operate pumps
M	$PRI	priming state	C	$RAT	get/set baud rate
F	$REN	rename file	F	$RMD	remove empty dir
O	$RUN	run sample	C	$SDA	SDI-12 bus address
C	$SDO	output format	O	$SDS	SDI-12 status
O	$SLP	low power sleep	C	$SPR	prompt on/off
C	$STO	store config info	O	$STP	stop sample
C	$SUD	start time/date	O	$TPC	get total pump counts
O	$TTS	time til start	F	$TYPE	"print" or "display" file(s)
C	$UPC	get ups count	M	$VIN	get input voltage
O	$VOL	get volumes pumped	M	$VSN	show version info
O	$WKM	get/set wake mode	O	$XIT	exit to PicoDOS

PMP	Operate pump(s)
Description	Operate the specified pumps for a specified number of cycles. Files are not made and data is not collected. Use the STP/I command to stop a PMP command.
Argument 1	None to get the number of pump cycles left. Use a decimal code to select which pumps to operate. Set a bit position to 1 to start the pump. Refer to the table below to see the codes for the pumps to be operated.

Response	The number of pump cycles left. "Pumping Done" = pump operation is complete.
Argument 2	The number of cycles left to operate.
Response	The number of pump cycles left. "Pumping Done" = pump operation is complete.

Code	Amb	Cal	R1	R2	Code	Amb	Cal	R1	R2
0	no	no	no	no	**8**	no	no	no	yes
1	yes	no	no	no	**9**	yes	no	no	yes
2	no	yes	no	no	**10**	no	yes	no	yes
3	yes	yes	no	no	**11**	yes	yes	no	yes
4	no	no	yes	no	**12**	no	no	yes	yes
5	yes	no	yes	no	**13**	yes	no	yes	yes
6	no	yes	yes	no	**14**	no	yes	yes	yes
7	yes	yes	yes	no	**15**	yes	yes	yes	yes

VIN	Input voltage
Description	Get the input voltage to the sensor in volts.
Argument 1	none
Response	The input voltage to the sensor shows to two decimal places. It shows approximately 0.2 V lower than the voltage supplied to the sensor.

VSN	Version
Description	Get the firmware version in the sensor.
Argument 1	none
Response	The firmware version. "n.nn" where "n" is a digit from 0–9.

Section 9 SDI-12 commands

The sensor supports all basic SDI-12 commands. Refer to the SDI-12 specification at www.sdi-12.org for details of the command protocol. The SDI-12 interface has been tested with the SDI-12 Verifier from NR Systems Inc. (http://www.sdi-12-verifier.com) with up to 1000 ft. of 24-gauge cable for communication (NOT power). For any command not described below, the sensor will respond according to the SDI-12 v1.3 specification.

The sensor takes longer than the 999 specification to complete a measurement. When a sample is started through the SDI-12, the sensor immediately sends the data from the previous sample and starts a new sample. This data will be available the next time a sample is started.

Definitions

- a = SDI-12 address of the sensor.
- <CRC> = 3-character Cyclic Redundancy Check.
- <CR> = Carriage Return character.
- <LF> = Line Feed character.

Example: a sensor set to address 0, serial number 104, firmware version 1.05.

The SDI-12 recorder sends 0I!

The sensor sends 013WET LABS CYCLEPO4____104___1.05<CR><LF>

Table 6 SDI-12 data format in response to an aM! or aMC! command

Index	Description	Format
1	Run number	ddddd
2	PO$_4$ concentration Note that -99999 shows as the PO$_4$ concentration (index 4) if an unrealistic PO$_4$ value is determined (a "nan" in the summary file). This happens when a sequence is stopped early or the calculation gives an undefined result.	d.dddd OR dd.ddd
3	Overall QC flag	d 1 = Good 2 = Not evaluated 3 = Suspect 4 = Bad
4	VAP04 concentration	dd.ddd
5	Part 1 of the combined QC flags in the order of bubble spike, COV, low signal. Each decimal is 1, 2, 3, or 4 as in the overall QC flag description.	ddd
6	Part 2 of the combined QC flags in the order of out of range, mixing spike, calibration spike. Each decimal is 1, 2, 3, or 4 as in the overall QC flag description. Units of PO$_4$ concentration follow the decimal.	ddd.u 0 = specifies microMolar (µM) 1 = specifies milligrams phosphate per liter (mg/L) 2 = specifies mg of atoms phosphorus per liter measured in the form of reactive phosphate (mgP/L)

7	Low power fault counter	ddddd
8	Voltage in	dd.d
9	Flush1 average	dddd.d

.

Table 7 SDI-12 data format in response to an aC! or aCC! command

Index	Description	Format
1	Run number	ddddd
2	PO_4 concentration. The value -9999 shows as the PO_4 concentration (index 4) if there is an unrealistic PO_4 value (a "NAN" in the summary file). This happens when a sequence is stopped early or the calculation gives and undefined result.	d.dddd or dd.ddd
3	Overall QC flag	d 1 = Good 2 = Not evaluated 3 = Suspect 4 = Bad
4	$VAPO_4$ concentration	dd.ddd
5	Part 1 of the combined QC flags in the order of bubble spike, COV, low signal. Each decimal is 1, 2, 3, or 4 as in the overall QC flag description.	ddd
6	Part 2 of the combined QC flags in the order of out of range, mixing spike, calibration spike. Each decimal is 1, 2, 3, or 4 as in the overall QC flag description. Units of PO_4 concentration follow the decimal.	ddd.u 0 = specifies microMolar (μM) 1 = specifies milligrams phosphate per liter (mg/L) 2 = specifies mg of atoms phosphorus per liter measured in the form of reactive phosphate (mgP/L)
7	Low power fault counter	ddddd
8	Voltage in	dd.d
9	Flush1 average	dddd.d
10	Last sample status	d
11	Variable a-Star (VAS)	dd.ddd
12	Bubble spike value	ddddd
13	COV value	dd.d
14	Low signal value	ddddd
15	OOR value	dd.ddd
16	Mix value	ddd
17	Cal value	ddd
18	Ambient minimum counts	dddd
19	Flush2 average	dddd.d
20	Cal minimum counts	dddd
21	Number of remaining samples	dddd
22	Sample date	YYYY
23	Sample date	MM.DD
24	Sample time	HH.MM

.

Acknowledge Active = a!

Acknowledge Active = a!	
Response	a<CR><LF>
Purpose	verifies the SDI-12 address
Example	address = 0
	recorder sends 0!
	sensor sends 0<CR><LF>

.

Address query = ?!

Address query = ?!	
Response	a<CR><LF>
Purpose	shows the sensor's SDI-12 address
Example	address = 0
	recorder sends ?!
	sensor sends 0<CR><LF>

.

Change address = aAb!

Change address = aAb!	
Response	b<CR><LF>
Purpose	changes the sensor's SDI-12 address to "b". The default address is 0.
Example	address = 0
	recorder sends 0A1!
	sensor sends 1<CR><LF>
	address now = 1

.

Send identification = aI!

Send identification = aI!	
Response	allccccccccmmmmmmvvv_ssssss_fffffff<CR><LF>
	a = sensor address
	ll (lowercase "L") = 2-character SDI-12 version. For example, "13" for version 1.3
	cccccccc = 8-character manufacturer identification. For example, "WET LABS"
	mmmmmm = 6-character sensor model. For example, "_CYCLE"
	vvv = 3-character sensor version. For example, "PO4"
	_ssssss = up to 6-character serial number field. Includes leading space
	_fffffff = up to 7-character firmware version field. Includes leading space
Example	address = 0. serial number = 104. The firmware version is 1.05

	recorder sends 0I!
	sensor sends 013WET LABS CYCLEPO4___104___1.05<CR><LF>

.

Start Measurement = aM!

Start Measurement = aM! Start Measurement and Request CRC (aMC!)	
Response	atttnn<CR><LF>
Purpose	starts a measurement
Notes	a = address = (0–9)
	ttt = measurement time in seconds. The sensor always sends 000.
	nn = 09. The number of measurement values the sensor makes and returns after subsequent Send Data commands.
	If a scheduled prime sequence is pending or in operation, the sensor will ignore the Start Measurement and Start Measurement and Request CRC commands. If the sensor is in a low power "sleep" state, this command puts the sensor into a power state to start a measurement.

The sensor takes longer than the 999 specification up to 1800 seconds (30 minutes) to complete a measurement. The SDI-12 specification allows measurement times from 000 to 999. The sensor uses a "save and forward" technique to work around this limitation. The sensor always sends the measurement time as 000 seconds. The most recent measurement is saved in the SDI-12 queue. If the SDI-12 recorder sends a Start Measurement command and subsequent Send Data command, the sensor sends the results from the previous measurement. If there is no saved data, the sensor sends a null response (a <CR><LF>). The data recorder or data processor program needs to handle these values appropriately.

The sensor has the same response to Start Measurement and Request CRC except that it appends a 3-byte CRC to the data when it responds to the Send Data command.	
Example	address = 0
	recorder sends 0M!
	sensor sends 00009<CR><LF>
	recorder sends 0MC!
	sensor sends 00009<CR><LF>

Refer to the Send Data command for examples of the commands that come after either the aM! or aMC!

Start Concurrent Measurement = aC!
Start Concurrent Measurement and Request CRC (aCC!)

Start Concurrent Measurement = aC! Start Concurrent Measurement and Request CRC (aCC!)	
Response	atttnn<CR><LF>
Purpose	starts a measurement
Notes	a = address = (0–9)
	ttt = measurement time in seconds. The sensor always sends 000.

	nn = 24. The number of measurements the sensor will make and return after subsequent Send Data commands.
	If a scheduled prime sequence is pending or in operation, the sensor will ignore the Start Measurement and Start Measurement and Request CRC commands. If the sensor is in a low power "sleep" state, this command puts the sensor into a powered state to start a measurement.

Example	address = 0
	recorder sends 0C!
	sensor sends 00024<CR><LF>
	recorder sends 0CC!
	sensor sends 00024<CR><LF>

Send Data commands that come after either the aM! or aMC! commands:

Send Data = aD0!–aD1!

Send Data = aD0!–aD1!	
Response	a<values><CR><LF> or a<values><CRC><CR><LF>
Purpose	sends data to the SDI-12 recorder
Notes	aD0! after aM!
	35 characters are allowed. For the sensor the response is the first 6 values in the SDI-12 data format in response to an aM! Command table. There is not space in the 35-character field for 9 values. If a subsequent aD1! command is sent the sensor will send the remaining three values, VAP04 concentration, combined QC flag field, and low power fault counter.
	aD0! after aC!
	75 characters are allowed. For the sensor the response is the first 13 values. There is space in the 75-character field for 13 values. The recorder needs to send an aD1! command to get the remaining 10 values.
	Sends a group of data to the controller after a measurement or verification command. The response depends on the previous measurement command and if the sensor has data in the buffer from a previous measurement. Refer to the two cases below.

.

aD0! and aD1! after aM! or aMC!

aD0! and aD1! after an aM! or aMC! command (Assume the sensor is set to address 0.)	
Example 1	address = 0
values from the previous measurement:	
run number	00092
PO_4 concentration	05.340
Overall QC flag	1
$VAP0_4$ Concentration	05.437
Combined flags (bubble, COV, low signal)	111
Combined flags, (OoR, mix, cal) and units of PO_4 concentration	112.0

LPF counter	00000
Voltage in	11.8
Flush1 average	3453.4

	recorder sends 0MC!
	sensor sends 00009<CR><LF>
	recorder sends 0D0!
	sensor sends 0+00092+05.340+1+05.437+111+112.0Hur<CR><LF>
	recorder sends 0D1!
	sensor sends 0+00000+11.8+3453.4B^b<CR><LF>

.

aD0! and D1! after aC! or aCC!

aD0! and a D1! after an aC! or aCC! command	
Example	address = 0
values from the previous measurement:	
run number	00093
PO$_4$ concentration	05.345
overall QC flag	1
VA PO$_4$ concentration	05.488
combined flags (bubble, COV, low signal)	111
combined flags (OoR, mix, cal) and units of PO$_4$ concentration	112.0
LPF counter	00002
voltage in	11.6
flush1 average	3636.5
last sample status	9
variable AStar	4.626
bubble spike value	00000
COV value	0.00

low signal value	03636
OoR value	05.345
mix value	002
cal value	001
ambient minimum	1165
flush2average	3627.7
cal min counts	0959
number of remaining samples	0000
date	2015
date	12.21
time	06.26

	recorder sends 0CC!
	sensor sends 00024<CR><LF>
	recorder sends 0D0!

	sensor sends 0+0093+05.345+1+05.488+111+112.0+00002+11.6+3636.5+9+4.626+00000+0.00Hur<CR><LF>
	recorder sends 0D1!
	sensor sends 0+03636+05.345+002+001+1165+3627.7+0959+0000+2015+12.21+06.26Hur<CR><LF>

.

R0! after aC! or aCC!

aR0! after an aC! or aCC! command	
Example	address = 0
values from the previous measurement:	
run number	00093
PO$_4$ concentration	05.345
overall QC flag	1
VA PO$_4$ concentration	05.488
combined flags (bubble, COV, low signal)	111
combined flags (OoR, mix, cal) and units of PO$_4$ concentration	112.0
LPF counter	00002
voltage in	11.6
flush1 average	3636.5
last sample status	9
variable AStar	4.626
bubble spike value	00000
COV value	0.00

.

R1! after aC! or aCC!

low signal value	03636
OoR value	05.345
mix value	002
cal value	001
ambient minimum	1165
flush2average	3627.7
cal min counts	0959
number of remaining samples	0000
date	2015
date	12.21
time	06.26

	recorder sends 0CC!
	recorder sends 0R0!
	sensor sends 0+0093+05.345+1+05.488+111+112.0+00002+11.6+3636.5+9+4.626+00000+0.00Hur<CR><LF>

	recorder sends 0R1!
	sensor sends 0+03636+05.345+002+001+1165+3627.7+0959+0000+2015+12.21+06.26Hur\<CR\>\<LF\>

.

Continuous Measurement = aR0! or aR1!
Continuous Measurement and Request CRC (a RC0! or aRC1!)

Continuous Measurement = aR0! or aR1! Continuous Measurement and Request CRC (aRC0! or aRC1!)	
Response	a\<values\>\<CR\>\<LF\> or a\<values\>\<CRC\>\<CR\>\<LF\>
	If no measurement data is available, the sensor sends a null response (a\<CR\>\<LF\>). If the sensor has buffered data from a previous measurement, it sends 13 or 10 values. The format is the same as aD0! and D1! after an aC! or aCC! command.

.

Additional Continuous Measurements = aR2!–aR9!
Additional Continuous Measurements and Request CRC (aRC2!–aRC9!)

Additional Continuous Measurements = aR2!–aR9! Additional Continuous Measurements and Request CRC (aRC2!–aRC9!)	
Response	The sensor does not support additional continuous measurements. It always sends a\<CR\>\<LF\> for all of these commands.

.

Stop Measurement = aX_STOP! or aX_CLEAR!

Stop Measurement = aX_STOP! or aX_CLEAR!	
Response	aSTOPPED\<CR\>\<LF\> or aCLEARED\<CR\>\<LF\>
Notes	Stops the current measurement, then turns the pumps on to flush the sensor. If aX_STOP! or aX_CLEAR! is sent while the sensor is not taking a measurement, the sensor does nothing and no flush sequence is started. If the sensor is in a low power "sleep" state, this command puts the sensor into a higher power state for the interval specified in the $IDT command.

Example	address = 0
	recorder sends 0X_STOP!
	sensor sends 0STOPPED\<CR\>\<LF\>
	The measurement stops and a flush sequence starts. If the sensor is in a low power "sleep" state this command puts the sensor into a higher power state for the interval specified in the $IDT command.

.

Stop Measurement Immediately = aX_STOPI!

Stop Measurement Immediately = aX_STOPI! ("I" is the letter i)	
Response	aSTOPPED\<CR\>\<LF\>
Notes	Stops the current measurement immediately and does not do a flush. If the sensor is in a low power "sleep" state, this command puts the sensor into a higher power state for the interval specified in the $IDT command.

.

Simple Flush = aX_FLUSH!

Simple Flush = aX_FLUSH!	
Response	aFLUSH = Y: the sensor starts a flush that takes approximately 4.2 minutes. If the sensor is taking a measurement or priming, it stops that sequence and goes directly to the flush sequence.

.

Sleep = aX_SLEEP!

Sleep = aX_SLEEP!	
Response	SLEEP=N<CR><LF> if the sensor is taking a measurement, priming, or flushing. The sensor does nothing.
	SLEEP=Y<CR><LF> if the sensor is not taking a measurement, priming, or flushing. The sensor goes to a low power, "sleep" mode.

.

Prime = aX_PRIME!

Prime = aX_PRIME!	
Response	PRIME<CR><LF>
	PRIME=N<CR><LF> if the sensor is taking a measurement or is priming. The sensor does nothing.
	PRIME=Y<CR><LF> if the sensor is not taking a measurement. The sensor begins a priming sequence.
Notes	Sends PRIME=Y<CR><LF> and starts a prime sequence. If a measurement is currently under way, the prime sequence will not start correctly. Use the Get Prime Status command to verify that a prime sequence started correctly.

.

Prime = aX_PRIME?!

Prime = aX_PRIME?!	
Response	PRIME=N<CR><LF> if the sensor is not priming.
	PRIME=Y<CR><LF>if the sensor is priming.

Section 10   Output formats

10.1 Engineering units output

Table 8 Data output format

Field	Description
yyyy	Date, year
mm.dd	Date, month and day
hh:mm	Time, hours and minutes
Run	Run counter. Increases in increments of one for each sample sequence. Use CNT command to set the run number.
CAPO4	Phosphate value calculated by the sensor (default: µM). Collected data shows to 3 decimal places for µM and 4 for mg/L and mgP/L. The data value may also be **nan**, **-inf**, or **+inf**, then the designator.
Units	µM, mg/L, mgP/L
VAPO4	Variable a*-based phosphate calculated by the sensor, then a space, then the unit designator. The data format is the same as CAPO4.
Units	Designation for CAPO4 value.
V in	Input voltage at the end of the sample.
Refer to Examine flag levels *on page 31 for details on the flag fields below.*	
QC flag	Overall QC flag for the sample. It shows the worst case of all six QC tests.
Bubble flag	QC flag code for the bubble spike test.
COV flag	QC flag code for the coefficient of variation test.
Low sig flag	QC flag code for the low signal test.
OoR flag	QC flag code for the out of range test.
Mixing flag	QC flag code for the mixing spike test.
Cal flag	QC flag code for the calibration spike test.
Bubble value	Value from the bubble spike test. It may also be **nan**, **-inf**, or **+inf**.
COV value	Value from the coefficient of variation test. It may also be **nan**, **-inf**, or **+inf**.
Low sig value	Value from the low signal test. It may also be **nan**, **-inf**, or **+inf**.
OOR value	Value from the out of range test. It may also be **nan**, **-inf**, or **+inf**.
Mixing value	Value from the mixing spike test. It may also be **nan**, **-inf**, or **+inf**.
Cal value	Value from the calibration spike test. It may also be **nan**, **-inf**, or **+inf**.
VAS	The variable a* value to three decimal places. Used to calculate VAPO4. It may also be **nan**, **-inf**, or **+inf**
State	The last step reached in the sample sequence.
Flush1	The mean value of the last 10 transmittance signal counts in the ambient flush (Step = 1) part of a sample sequence.
Amb Min	The mean value of the 6 transmittance signal counts that triggered the knee slope threshold reaction (Step = 3) part of a sample sequence.
Flush2	The mean value of the last 10 transmittance signal counts in the ambient flush (Step = 6) part of a sample sequence.
Cal Min	The mean value of the 6 transmittance signal counts that triggered the knee slope threshold reaction (Step = 8) part of a sample sequence.
Remaining	The number of samples left, as set by the NOS command.

Table 9 Phosphate units

Command	Designator	Description
$EUF 0	µM	Micro-molar phosphate concentration
$EUF 1	mg/L	Milligrams per liter of reactive phosphate
$EUF 2	mgP/L	Milligrams of atoms phosphorus per liter measured in the form of reactive phosphate

Table 10 Step values

Index	Step	Index	Step
0	Initial flush	5	Mid flush 2
1	Ambient read 1	6	Ambient read 2
2	Mix ambient	7	Mix spiked
3	Ambient PO_4 read	8	Spiked PO_4 read
4	Mid flush 1	9	End flush

A normal run completes in index level 4. A spiked run completes in index level 9.

10.2 Raw transmittance output

Table 11 Raw transmittance fields

Field	Description
mm/dd/yy	The sample date
hh:mm:ss	The sample time
signal	The transmittance signal counts (0–4095)
run	The run counter. Increases in increments of one for each sample sequence.
step	An index counter that shows the current step in the sample sequence. Refer to the step values above.
code	A legacy code number that shows which pumps are in operation.
counts	An increment counter that shows the number of transmittance measurements left in the current step of the sample sequence.
vin	The voltage of the power supply to the sensor to two decimal places.

10.3 Summary file format

The summary files have information for all the samples in each of the sensor's sub-directories.

After the header line there are one or more lines of data collected. This ends with a <LF>(0x0a) character. Refer to the Engineering units output on page 71 for details.

```
Date     Time     Run    CAPO4     Units     VAPO4     Units     Vin     Overall Flag     Bubble Flag     COV
Flag     Low Sig Flag     OOR Flag     Mixing Flag     Cal Flag     Bubble Value     COV Value     Low Sig
Value     OOR Value     Mixing Value     Cal Value     VAS     State     Flush1     Amb
Min     Flush2     Cal Min     Remaining
```

10.4 Raw file format

The raw sample text files have four header lines that come before the raw transmittance measurements. After the header lines are one or more lines of raw transmittance measurements. The format is shown below.

10.4.1 Raw file format header for status

```
ver:v.vv av=a.aa cv=cc.cc r1v=yy.yy r2v=rr.rr zo=z.zzzz co=o.oooo cas=ss.ss
st=t.ttt cc=10.53 ups=u flt=ffff<lf> fe=e  fc=i
```

Field	Description
ver.v.vv	The firmware revision number under which the file was collected.
av=a.aa	The pump volume saved by the sensor for the ambient pump volume in μL.
cv=cc.cc	The pump volume saved by the sensor for the calibration pump volume in μL.
r1v=yy.yy	The pump volume saved by the sensor for the R1 reagent pump volume in μL.
r2v=rr.rr	The pump volume saved by the sensor for the R2 reagent pump volume in μL.
zo=z.zzzz	The zero offset saved by the sensor in μM.
co=o.oooo	The calibration pump volume offset saved by the sensor in μL.
cas=ss.ss	The constant a* value saved by the sensor.
st=t.ttt	The slope threshold, which is usually negative, saved by the sensor.
cc=10.53	The calibration standard concentration saved by the sensor.
ups=u	The UPS counter saved by the sensor. It increases in increments of one each time the power is removed from the sensor when the sensor is not in a low power mode.
flt=ffff	A four-character hexadecimal code that shows fault conditions within the sensor. A value of 0000 shows that no faults are detected.
fe=e	An error code reported when the user tried to open the raw file. This value is 0 if there were no errors.
fc=i	A regularly updated count of the non-zero fe values.

10.4.2 Raw file format header for auxiliary settings

The settings below are for a reserved time zone offset value and the auxiliary on-board QC threshold settings.

```
tzo:0.0 mix secs:12 spike secs:120 spike threshold:500.0 stdev threshold:20.00 spike
diff:3.000
```

10.4.3 Raw file format header for QC thresholds

These are the settings for the on-board QC thresholds in the order of Minimum Suspect, Minimum Good, Maximum Good, Maximum Suspect. The decimal before the : (colon) for each set are the codes for each of the QC tests, where:

- 0=Bubble Spike
- 1=COV
- 2=Low Signal
- 3=Out of Range
- 4=Mixing Spike
- 5=Cal Spike

```
0:-inf -inf 300.000 500.000 1:-inf -inf 0.500 2.500 2:170.000 750.000 inf inf 3:-0.050
0.075 10.500 40.000 4:-inf -inf 75.000 150.000 5:-inf -inf 250.000 350.000
```

Refer to the QCT table in for details.

10.4.4 Raw file format header for sensor data

The final header line gives column heading for the raw transmittance data with in the file. Refer to for details.

```
Date    Time    Signal    Run    Step    Code    Counts    V in
```

Section 11   Reference

11.1 Communication setup

Use the software to set up the COM port. It may be necessary to use an RS232-USB converter if the PC does not have an RS232 connector.

- Select the appropriate communication port from the drop-down menu, or
- Enter the port number in the variable box.
- Go to the **Tools** menu, then select *Options* to turn off the auto-connect option.

The manufacturer recommends that the user keep the default baud rate of 19200.

The software looks for available communication ports on the PC and makes those available to the user. The port defaults to "None" the first time the software is used. Thereafter, the software will try to connect to the last port used.

Note: There is a known issue with the serial port drivers on some PCs using the Windows® 7 operating system. The user must close the software to make an opened COM port available again.

11.2 File and tools menus

Table 12 File menu commands

Item	Shortcut	Description
Exit	Ctrl+Q	Exits the software.
Explore Offload Dir	Ctrl+E	Opens the directory of files that shows the files in the "Host Computer Offload Dir" area as Windows® Explorer files that can be opened with a text editor.
Load File(s)	Ctrl+O	Lets the user select the data files to compare in the *QC Plot* tab and in the **Raw Data Plot** window.
Save Analysis Set	Ctrl+S	Saves a user-named summary file of the most current QC analysis in a .txt format. The user can replace a current file or add to it and can save data from different directories, deployments, and sensors.

Table 13 Tools menu commands

Item	Shortcut	Description
Deployment Wizard	Ctrl+D	Opens the "Deployment Wizard."
Get Settings	Ctrl+G	Gets the settings that are saved in the sensor.
View Analysis Plot	Ctrl+Shift+A	Shows or hides the **Raw Data Plot** window.
Options	Alt+O	Opens a new window with user-selectable options for QC analysis of data.
Remove Selected Analysis Sample	Ctrl+R	Removes a selected sample from the list in the **Raw Data Plot** window. The user can also right-click to "Remove Selected" on a file or files in the list.
Clear Analysis Samples	—	Immediately erases all of the files from the list in the **Raw Data Plot** window. The user can also push Clear in the *QC Plot* tab.
Restore Instrument Settings	—	Use this only if the settings in the sensor are erased. The user needs a device file from the manufacturer.
Set PO4 Plot Cursor Color	—	Change the color of the cursor on the *PO4 Plot* tab.
Set QC Plot Cursor Color	—	Change the color of the cursor on the *QC Plot* tab.

11.3 Operation values

Change the parameters to collect data in the sensor.
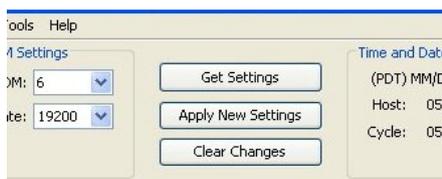
1. Push **Get Settings** to get the operation values stored in the sensor, unless the Deployment Wizard will be used right away.
   The host will get the operation values from the sensor.
2. Push **Apply New Settings** to send new values to the sensor.
   The area around the buttons is yellow until the new values are sent to the sensor.
3. Push **Clear Settings** to make sure there are no active changes.

11.4 Date and time setup

Go to the *Deployment Wizard* tab and push **Set Date and Time**. The software synchronizes the date and time in the sensor from the PC when it sends deployment settings. The user can also use the Control Panel of the PC to do this.

11.5 Modes of operation
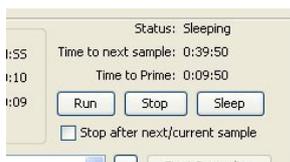
The sensor operates in one of five modes.

Mode ("Status")	Description
Unknown	The PC has not yet received any information from the sensor.
Sleeping	The sensor is in a low power mode.
Idle	The sensor is not in operation and has not yet automatically gone to a low power mode. If the sensor does not receive a command within 2 minutes, the default idle time, it will go to low power.
Running	The sensor is in data collection mode or in a flush mode.
Pumping	The pumps are in operation.

The manufacturer recommends that the user use the **Run**, **Stop**, and **Sleep** buttons in the laboratory. Use the *Deployment Wizard* for field deployments.

11.5.1 Operation options

Operate the sensor or set a time for the sensor to operate with the **Choose Run Option** window.

Option	Action
Set Start Time/Date	Select the start times and dates to set up and operate the sensor.
Run Now	The sensor starts to operate.
Cancel	The window closes.

11.5.2 Stop options

The user has two options to stop the sensor.

Options	Action
Stop and Flush	Stops the sensor and starts a flush sequence of approximately 5 minutes. Do this at the end of a sample sequence.
Stop Now	Stops the sensor. The manufacturer recommends this only if the user starts a new sample sequence soon after the sensor is stopped.
Continue	Closes the window. The sample sequence does not stop.

11.5.3 Low power option

Put the sensor into a low power mode from a standby mode before power is removed.

11.6 Data file storage

Choose the folder on the PC in which to store the data collected by the sensor.

Store the data from the sensor on the PC. There are two options:

- Enter the file path.
- Browse to find the folder.

If this is a new folder, another window lets the user make sure of the selection and makes the folder. The software stores this file path to use when the next software session starts.

11.7 Software tabs

11.7.1 Status tab

The *Status* tab shows the estimated volumes of reagents in each of the sensor's cartridges. Note that the volume of reagent is not measured but is estimated based on the number of pump counts. Make sure to use the Deployment Wizard in the software to set the volume to 250 mL when new cartridges are installed, or the reagent values will not be correct.

Push **Get Settings** or **Refresh** to get information on the cartridge volumes.
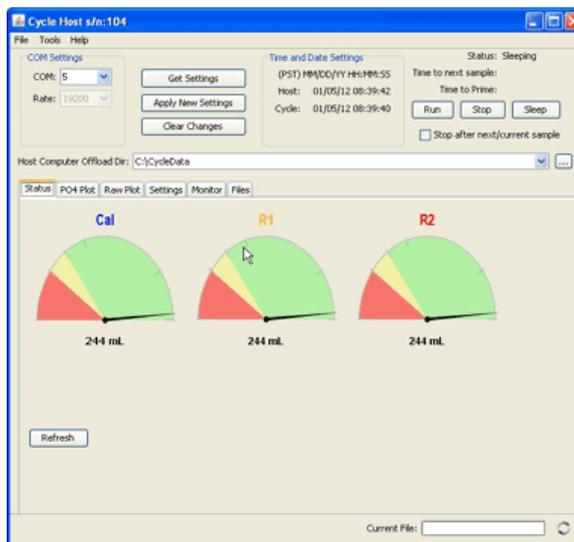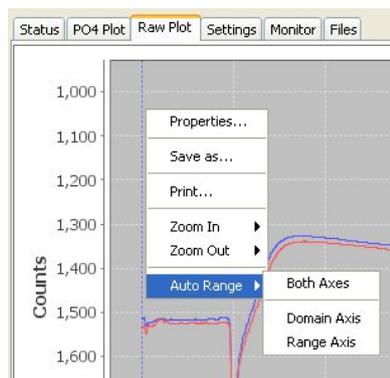
The circular icon at the bottom right of the software window is animated when the COM port is open.

11.7.2 Plot tabs

Monitor the collected data in counts from the sensor in the *Raw Plot* tab, and collected data in µM, mg/L, or mgP/L in the *PO₄ Plot* tab.

Right-click in the plot window to select how to look at the data.

- Select *Domain Axis* to see the time.
- Select *Range Axis* to see the phosphate concentration.

The user can change the background and label color and other aspects of the *PO4 Plot* and *Raw Plot* tabs. Right-click inside the plot area and select *Properties*, then *Plot* tab, then *Appearance*. Push **Select...** next to the "Background Paint" slide bar to select a different background color for the plot area.

11.7.2.1 PO₄ plot tab

Look at the data as the concentration of phosphate in selected units. Refer to Table 9 on page 72 in the Output formats section for more information.
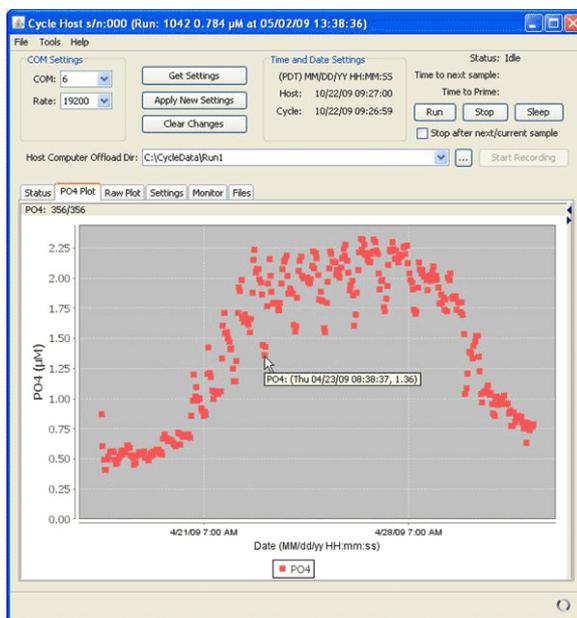
The user can also look at stored data in this window. Refer to "Replay Selected Files" in the *Files* tab.

11.7.2.1.1 PO₄ plot controls

Open the plot controls part of the *PO₄ Plot* tab to look at PO₄ data and whether it is in the range selected. Go the to the **Tools** menu then select *Options,* then *Max PO4 Plot Threshold (µM)* to enter this value.

Other controls the user can select:

- Look at and clear data points in the plot area.

- Look at out-of-range data.
- Look at the number of data points plotted compared to the total data points received. This is the counter on the upper left corner of the *Plot* tab.

Note: If the sensor cannot calculate a phosphate concentration, the output will be NAN (not a number). All NANs are counted as the total number of data points received. No NANs are counted as valid data.
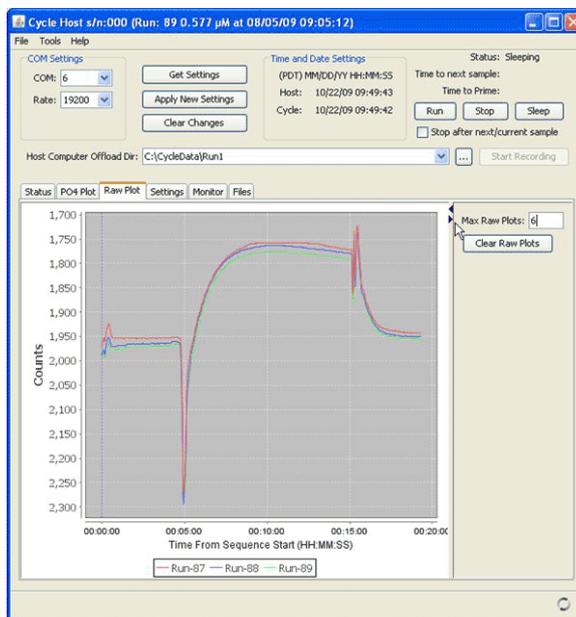
11.7.2.2 Raw data plot tab

Look at the data in this tab as a quality control tool. The raw data (in counts) is proportional to transmittance.
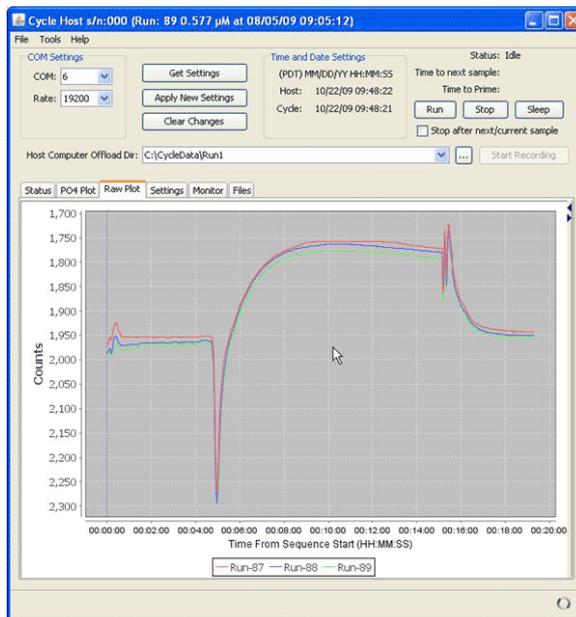
11.7.2.2.1 Raw plot controls

Control the number of plots to show in the Raw Plot tab, and erase all plots from this tab. Note that the default maximum number of raw plots is 6. The manufacturer recommends a limit of 10 plots.

11.7.3 Settings tab

11.7.3.1 Sample collection schedule

The user makes decisions about the values for the sensor to use in the <u>Sample Settings</u> area of the *Settings* tab. The user can also use the *Deployment Wizard* from the **Tools** menu to automatically set these values.

1. Push **Set Date and Time** to adjust the sensor to the same time as the host PC.
2. Enter the type of units in which to save data.
3. Enter the interval for the sensor to sample. The format for this is hours:minutes:seconds. The sensor can take up to 15 minutes to complete a sample sequence and 35 minutes for a spiked run. If the interval is very small, the sensor will apparently collect data continuously. To take a sample once every other day, for example, set the interval to 48:00:00.
   Note the effects of temperature on the operation time of the sensor. The time to complete reactions increases at lower temperatures. The sensor will do a rinse when the reaction is complete and the KCO (default) is enabled. To do a fixed-time run of 19 min. (or 35 min. with a cal spike), set the KCO to 2000.
4. Enter how frequently the sensor will do a calibration spike after an ambient sample. Change this value to 6 so that the rest of the sequences to not do the "cal spike."
5. Select the number of sample sequences or the start date and time. The number of samples can be set from 1 to 32767. A value of -1 or a blank will set the sensor to do sample sequences as long as it has power.
6. Select how long the sensor will stay at full power draw. The default is 2 minutes. The sensor then goes to a low power mode until the next sample sequence starts.
   Note: The sensor may not go to full power if this is set to a value of less than 3 seconds.
7. Put a check in the "Prime:" checkbox to show the effects of a prime cycle on the deployment calculator.
8. Push **Apply New Settings** when the selected values have been entered into the *Proposed* variable boxes.

To turn off the spike, set the "Cal Frequency:" in the *Settings* tab to 2000. The spike will show on the first run and not again until the 2000th cycle of operation.

11.7.3.2 Deployment calculator

The deployment calculator shows an estimate of how long the sensor can operate with the "Current" and "Proposed" settings.

If the software shows an estimate that one of the reagents will be used up before the proposed number of samples is completed, that reagent ("Cal," 'R1," or "R2") will show as the limiting factor. Otherwise "NUM" will show and the limiting factor is the number of samples ("Num Samples").

11.7.3.3 Pump controls

Use the pump control boxes to select a pump to operate. Enter the number of times to operate each of the pumps that are selected in the variable boxes, and push **Run Pump(s)** to start the pump sequence.

To see how many pump operations are left in the current sequence, go to the bottom of the *Monitor* tab and type **$PMP** then push **Send**.

11.7.3.4 SDI-12 controls

Sensors that have an SDI-12 interface have an additional 8-contact bulkhead connector. The default address is 0. The user can change this address in the host software, or at the "set address" command through the SDI-12 port.

The sensor does not need to be connected to an SDI-12 bus to change the address.
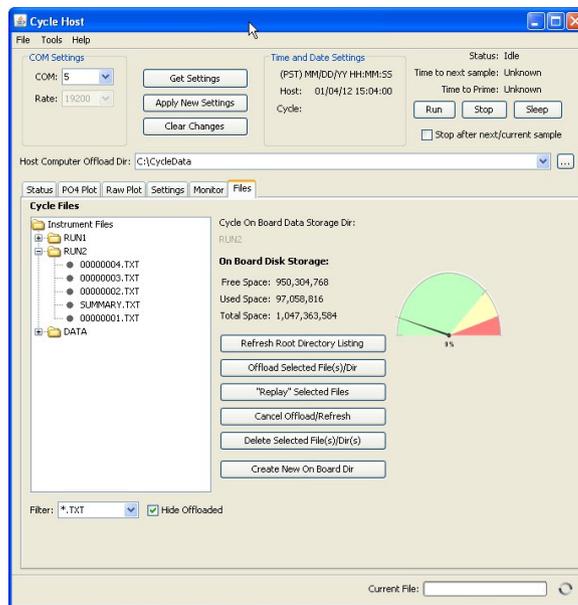
11.7.4 Monitor tab

This tab is generally used for troubleshooting.

Use the *Monitor* tab to look at the serial data that goes between the host PC and the sensor. Copy and save the serial data in the window to another program for evaluation.

11.7.5 Files tab

Use the software to get the data that is saved in the sensor.

1. Start the software if necessary.
2. Select the *Files* tab.

3. Push **Refresh Root Directory Listing**.
   The files saved in the sensor will show in the *Files* tab.

4. Enter the file directory, or folder, on the PC to save the data from the sensor, or create a new folder.

5. Push **Offload Selected File(s)/Dir** to move a copy of the data from the sensor to the PC.
   The user can save only one directory at a time, but it is possible to select several files at the same time to save to the PC.

6. Monitor the data saved to the PC.
   Look at the "Current File" area at the bottom of the software window.

11.7.6 QC plot tab

Refer to Examine flag levels on page 31 in the **Operation** section for more details about the analysis of data that the user can do in the *QC Plot* tab. Other functions are given in this section.
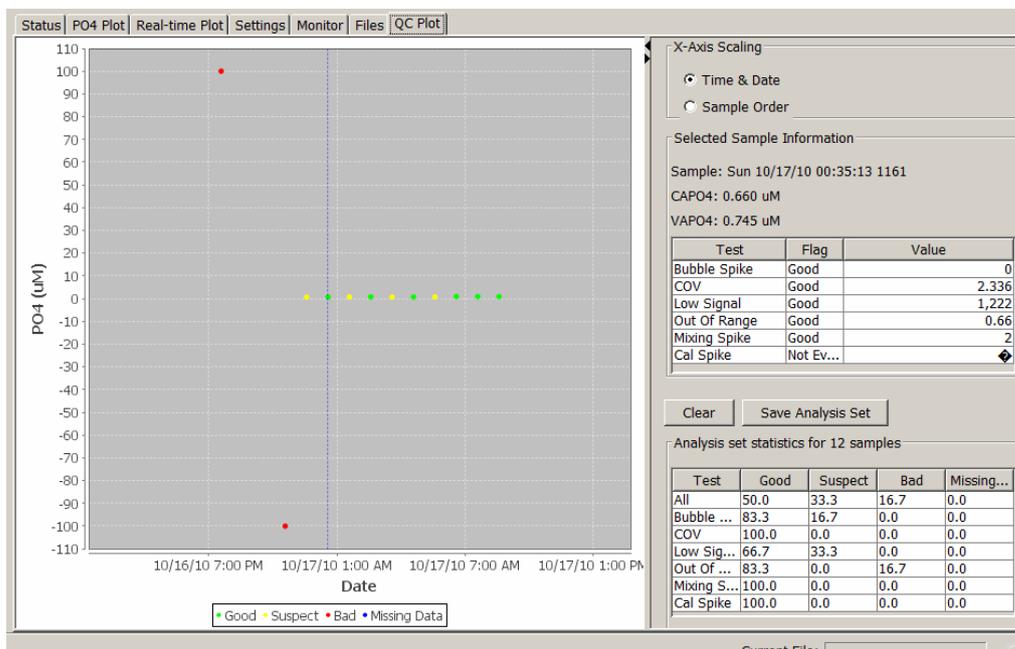
X-axis scaling

- "Time and Date": The data is automatically scaled to show all of the data files that the user has selected to show in the **Raw Data Plot** window.
- "Sample Order": The data shows by sample number, which agrees with the sample number shown in the list of user-selected data files in the **Raw Data Plot** window.

Selected sample information

- "Sample:" The day, date, time, and the sample number of the total number of samples of data collected by the sensor.
- "CAPO4:" The phosphate value in µM that is calculated by the software.
- "VAPO4:" The sensor-calculated spike PO_4 values in the summary graph. The VAPO4 values show as squares. VAPO4 is a "standard addition."
- Summary table for specific sample. Shows the name of the test and the status and value of the data collected.

Sample: Wed 08/05/15 22:55:59 1

CAPO4: 2.024 uM

VAPO4: 1.350 uM

Test	Flag	Value
Bubble Spike	Good	75.186
COV	Good	0
Low Signal	Good	2,954
Out Of Range	Good	2.024
Mixing Spike	Bad	250
Cal Spike	Bad	441

- **Clear**—Push to erase the files that were loaded by the software that show in the right side of the **Raw Data Plot** window.
- **Save Analysis Set**—Push to save the data files that are loaded in the **Raw Data Plot** window. By default, the file is saved in a .txt format in the same directory as the data. As an alternative, the user can save the file to another location on the PC.

Analysis set statistics for "nnn" samples

The software calculates the average value for each "Test" value of the data that the user saved for analysis. In the table below, for example, the software made an analysis of 26 data files and shows the percentage of the data that was loaded that agrees with a given flag.

Analysis set statistics for 26 samples

Test	Good	Suspect	Bad	Missing...
All	46.2	42.3	11.5	0.0
Bubble ...	80.8	19.2	0.0	0.0
COV	100.0	0.0	0.0	0.0
Low Sig...	100.0	0.0	0.0	0.0
Out Of ...	100.0	0.0	0.0	0.0
Mixing S...	65.4	26.9	7.7	0.0
Cal Spike	20.0	40.0	40.0	0.0

11.7.6.1 QC example and explanation of default thresholds

Go to the **Tools** menu, then select *Options*, or type "Alt-O" to open the **Options** window. The values in this table are the upper and lower limits for good, suspect, and bad data.
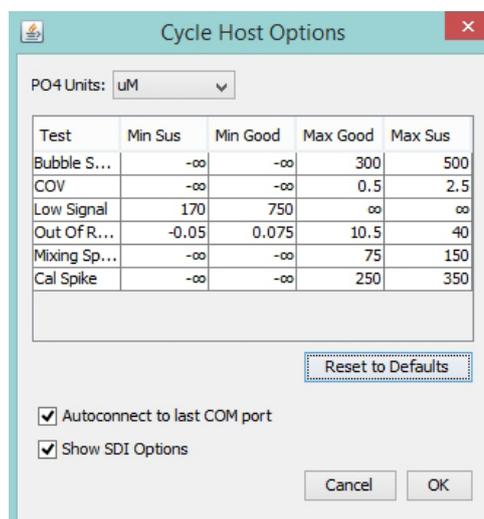
Definitions of tests

Bubble spike—the software calculates the transmittance data while the pump operates and looks for spikes that are an indication of bubbles. The software then shows a cumulative value of spikes in the sample.

- Good: less than or equal to 300 counts
- Suspect: greater than 300 and less than or equal to 500 counts
- Bad: above 500 counts

Coefficient of variation (COV)—the software calculates the statistical coefficient of variation of the last ten values of transmittance data at the end of the initial flush period in the sample sequence. The values show as a percentage. Any change in the optics, usually caused by nano-micro bubbles in the baseline, can cause the data in this period to be "non-flat." The user may change this value if, for example, the flush1 data agrees with grab samples, to a maximum good of 5.5% and maximum suspect of 10%.

- Good: less than or equal to 0.5%
- Suspect: greater than 0.5% and les than or equal to 2.5%
- Bad: above 2.5%

Out of range—The software monitors if the data that is output is in a reasonable range. The detection limit of the sensor is approximately 0.075 µM (0.002 mgP/L). Data that is collected near the detection limit can scatter at approximately 0 and users have collected good data that is below the detection limit, so the manufacturer permits negative values to -0.05 µM (-0.0015 mgP/L). Values that are lower than that are "bad." The user may change this value, for example, to make all negative data "bad" (change Min Sus to 0) or to accept data that is above the Max Good of 10.5 µM (change Max Good to 20).

- Good: 0.075–10.5 µM (0.002–0.31 mgP/L) (inclusive)
- Suspect: -0.05 to less than 0.075 µM; greater than 10.5–40 µM (0.31–1.2 mgP/L) (often linear)
- Bad: less than -0.05 µM; over 40 µM (-0.0015–1.2 mgP/L) (the detector receives very little light, so phosphate cannot be measured.)

Low signal—the software calculates the mean raw count values of the transmittance data values at the end of the initial flush period in the sample sequence. The sensor uses a ratio of "light through-pure-sample" to "light that passes through the sample with reagent" to measure ambient water. If there is not sufficient light, the detector calculates phosphate at a lower precision. Loss of light can be due to stained or fouled windows or data with high absorption/scattering in the analytical wavelength (880 nm). At 720 counts approximately 20% of the full intensity gets to the detector.

- Good: 720 counts and more
- Suspect: 170 to less than 720 counts
- Bad: below 170 counts

Mixing spike and calibration spike—A spike while the sensor does the mix or calibration operation is an indication that there are bubbles in the tubing. The height of the spike is frequently related to the level of interference from bubbles. The user may change this value if, for example, the mixing spike data agrees with grab samples to a maximum of approximately 200 counts.

- *Mixing*—
- Good: less than or equal to 75 counts
- Suspect: greater than 75–150 counts
- Bad: above 150 counts

- *Calibration*—
- Good: less than or equal to 75 counts
- Suspect: greater than 250–350 counts
- Bad: above 350 counts

Table 14 Example threshold application

Test	Flag	Value from sensor	Description
Bubble spike	Suspect	355.826	over Max Good of 300 but less than Max Suspect of 500 counts.
COV	Good	0	between Min Good of -infinity and Max Good of 0.5%.
Low signal	Good	2,954	between Min Good of 720 and Max Good of infinite counts.
Out of range	Good	2.024	between Min Good of 0.075 and Max Good of 10.5 µM.
Mixing spike	Bad	250	over Max Suspect of 150 counts (refer to graph above)
Cal spike	Bad	441	over Max Suspect 350 counts (refer to graph above)

Reference

Section 12   General information

Revised editions of this user manual are on the manufacturer's website.

12.1 Warranty

This sensor is warranted against defects in materials and workmanship for one year from the date of purchase. The warranty is void if the manufacturer finds the sensor was abused or neglected beyond the normal wear and tear of deployment.

12.2 Service and support

The manufacturer recommends that sensors be sent back to the manufacturer annually to be cleaned, calibrated, and for standard maintenance.
Refer to the website for FAQs and technical notes, or contact the manufacturer for support at:

support@sea-birdcoastal.com

Do the steps below to send a sensor back to the manufacturer.

1. Contact the manufacturer for a Return Merchandise Authorization (RMA).
    Note: The manufacturer is not responsible for damage to the sensor during return shipment.
2. Remove all anti-fouling treatment from the sensor before sending it back to the manufacturer.
    Note: The manufacturer will not accept sensors that have been treated with anti-fouling compounds for service or repair. This includes tri-butyl tin, marine anti-fouling paint, ablative coatings, etc.
3. Use the sensor's original ruggedized shipping case to send the sensor back to the manufacturer.
4. Write the RMA number on the outside of the shipping case and on the packing list.
5. Use 3rd-day air to ship the sensor back to the manufacturer. Do not use ground shipping.
6. The manufacturer will supply all replacement parts and labor and pay to send the sensor back to the user via 3rd-day air shipping.

12.2.1 HydroCycle-PO$_4$ service options

The manufacturer recommends that the user sends the sensor back to the manufacturer every 12–18 months for evaluation and calibration or standard service.

Standard service includes evaluation, parts replacement as necessary, and calibration. The manufacturer will:

*   Clean the sensor
*   Replace external tubing and fittings
*   Test the current draw and communication
*   Verify the pump use against the expected pump life
*   Clean the internal fluid pathways so that clean water gives > 80% transmission (3000 counts)
*   Make an analysis of the NIST-traceable check standard (0.164 mP/L ±8%)
*   Tune the volume of the pumps to the optimum level. (Pump volumes can change up to 15% with typical use, which causes an error of a few percent in PO$_4$ measurement.)
*   Make an analysis of the blank and a 0.82 mgP/L standard (±0.8%, std dev < 0.001 mP/L).
*   Calibrate the sensor, which gives new calibration coefficients, pump volumes, and device file.
*   Do a test deployment to make an analysis of the 0.82 mgP/L traceable check standard.

Standard service includes evaluation, calibration, repair. Repair can include replacement of the pump, electronics, internal fluidics, optical and mechanical components, bulkhead connectors, etc. in cases of misused equipment (serious physical damage, no filter at the intake, for example) replacement parts will be quoted at an additional price.

Note: The pumps in the sensor will operate for approximately 20,000,000 counts. The manufacturer replaces pumps when the total pump count is approximately 19,000,000. The user can enter $TPC in the Monitor tab of the software to find the total pump counts. The manufacturer recommends that the sample pump is replaced every 14 deployments (approximately 1500 runs).

12.3 Waste electrical and electronic equipment

Electrical equipment that is marked with this symbol may not be disposed of in European public disposal systems. In conformity with EU Directive 2002/96/EC, European electrical equipment users must return old or end-of-life equipment to the manufacturer for disposal at no charge to the user. To recycle, please contact the manufacturer for instructions on how to return end-of-life equipment, manufacturer-supplied electrical accessories, and auxiliary items for proper disposal.

Sea-Bird Coastal
13431 NE 20th Street
Bellevue WA 98005 U.S.A.
sales (425) 401-7653
support (425) 401-7654
support@sea-birdcoastal.com
www.sea-birdcoastal.com