Product Manual

Sensor

# CS511

## Dissolved Oxygen Sensor

**Revision: 5/18**



RELIABLE SINCE 1974 MONITORING

CAMPBELL SCIENTIFIC

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RMA#_____
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DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC**. FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

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General

- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations, such as those of the FAA in the USA.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 20 feet, or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

# *Table of Contents*

*PDF viewers: These page numbers refer to the printed version of this document. Use the PDF reader bookmarks tab for links to specific sections.*



***Appendices***



***Figures***

## Tables



## CRBasic Examples

# CS511 Dissolved Oxygen Sensor

## 1. Introduction

The CS511 is a rugged, low-maintenance sensor that is manufactured by Sensorex. It consists of a self-polarizing galvanic cell that generates a millivolt signal proportional to the amount of oxygen present in the measured medium (typically water).

**NOTE** This manual provides information only for CRBasic dataloggers. For retired Edlog datalogger support, see a retired manual at *www.campbellsci.com\old-manuals*. Also refer to a retired manual if the CS511 was purchased before June 2008 and for information on using the retired PT4-L Agitator.

## 2. Precautions

- READ AND UNDERSTAND the *Safety* section at the front of this manual.
- The CS511 is a precision instrument. Please handle it with care.
- Because the CS511 is shipped dry, electrolyte needs to be added before using the sensor (Section 7.1, *Getting Sensor Ready to Use* *(p. 6)*).
- Letting the CS511 dry in the field shortens the life of the membrane and sensor.
- The sensor should be stored dry and empty. Therefore, empty the electrolyte, rinse the sensor, and remove the membrane.
- Replace the membrane and recalibrate the sensor before redeploying the CS511 after it has been stored out of water or dried up in the field.

## 3. Initial Inspection

- Upon receipt of the CS511, inspect the packaging and contents for damage. File damage claims with the shipping company.
- Immediately check package contents against the shipping documentation (see Section 3.1, *Shipping Kit* *(p. 1)*). Contact Campbell Scientific about any discrepancies.
- The model number and cable length are printed on a label at the connection end of the cable. Check this information against the shipping documents to ensure the expected product and cable length were received.

### 3.1 Shipping Kit

The CS511 ships with:

(1) Membrane replacement tool
(1) Bottled electrolyte, 250 ml
(2) Teflon membranes
(2) Membrane O-rings

# 4. QuickStart

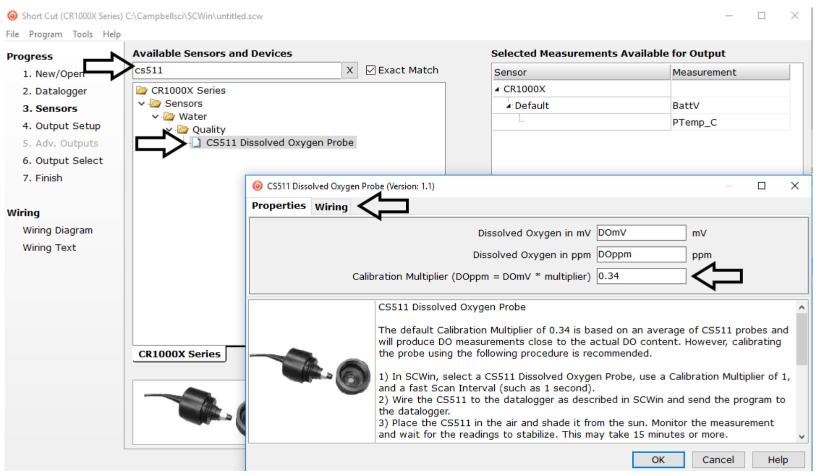
A video that describes datalogger programming using *Short Cut* is available at: *www.campbellsci.com/videos/cr1000x-datalogger-getting-started-program-part-3*. *Short Cut* is an easy way to program your datalogger to measure the sensor and assign datalogger wiring terminals. *Short Cut* is available as a download on *www.campbellsci.com*. It is included in installations of *LoggerNet*, *PC200W*, *PC400*, or *RTDAQ*.

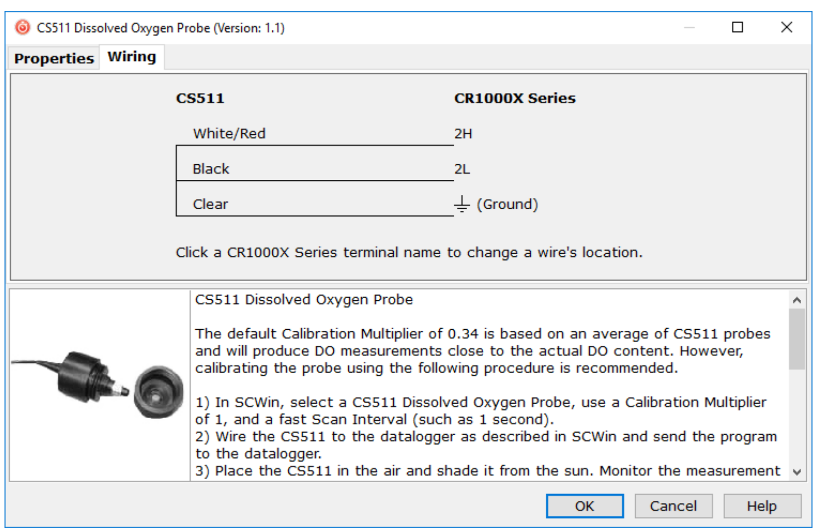
The following procedure also describes using *Short Cut* to program the CS511.

1. Open *Short Cut* and click **Create New Program**.

2. Double-click the datalogger model.

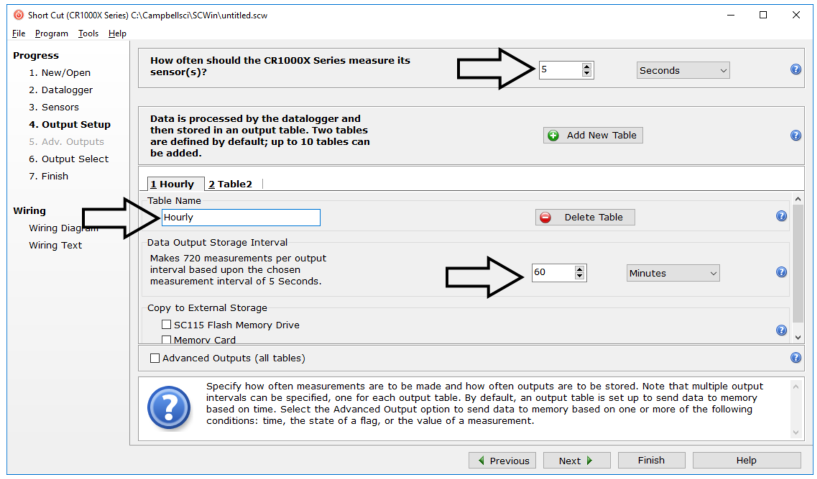
3. In the **Available Sensors and Devices** box, type CS511, or locate the sensor in the **Sensors | Water | Quality** folder. Double-click **CS511 Dissolved Oxygen Probe**. The default calibration value of 0.34 is based on an average. It is preferable to calibrate the sensor by using the procedure provided in Section 7.5, *Calibration* (*p. 8*). Click on the **Wiring** tab to see how the sensor is to be wired to the datalogger.



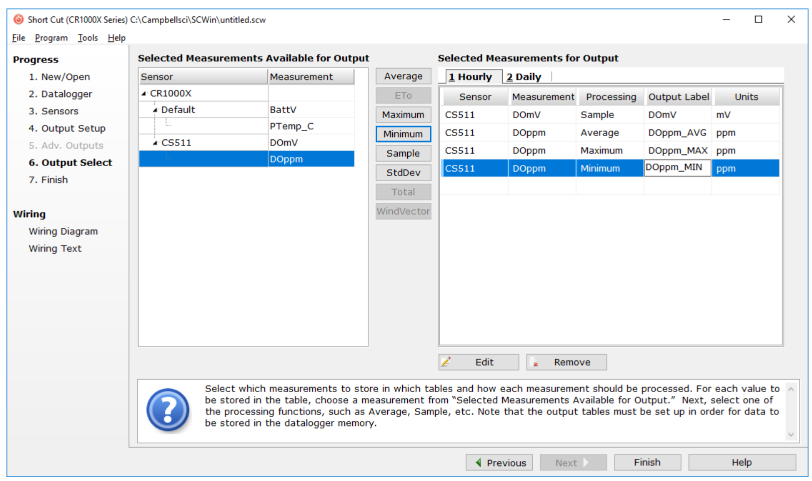



4. Repeat step three for other sensors.

5. In **Output Setup**, type the scan rate, meaningful table names, and the **Data Output Storage Interval**.




6. Select the measurement and its associated output options.




7. Click **Finish** and save the program. Send the program to the datalogger if the datalogger is connected to the computer.

8. If the sensor is connected to the datalogger, check the output of the sensor in the data display in *LoggerNet*, *PC400*, *RTDAQ*, or *PC200W* to make sure it is making reasonable measurements.

# 5. Overview

The CS511 is a galvanic sensor, which produces a millivolt signal proportional to the amount of oxygen present in the measured medium. Oxygen diffuses through the membrane onto the cathode, reacts chemically, and combines with the anode. An electrical current is produced by this chemical reaction which is converted from microamps to millivolts by an in-line resistor. An in-line thermistor also conditions the signal providing automatic temperature compensation. With these features, the sensor produces a linear, millivolt output proportional to the oxygen present in the medium in which it is placed.

The sensor consists of two parts, an upper part with cathode, anode, and cable, and a lower part comprising of a screw-on membrane cap. The CS511 is shipped dry, but has a membrane installed in the cap. With the membrane in place, the cap must be filled with electrolyte solution before the cap is screwed onto the top component.

The CS511 is self-polarizing and requires no external power source.

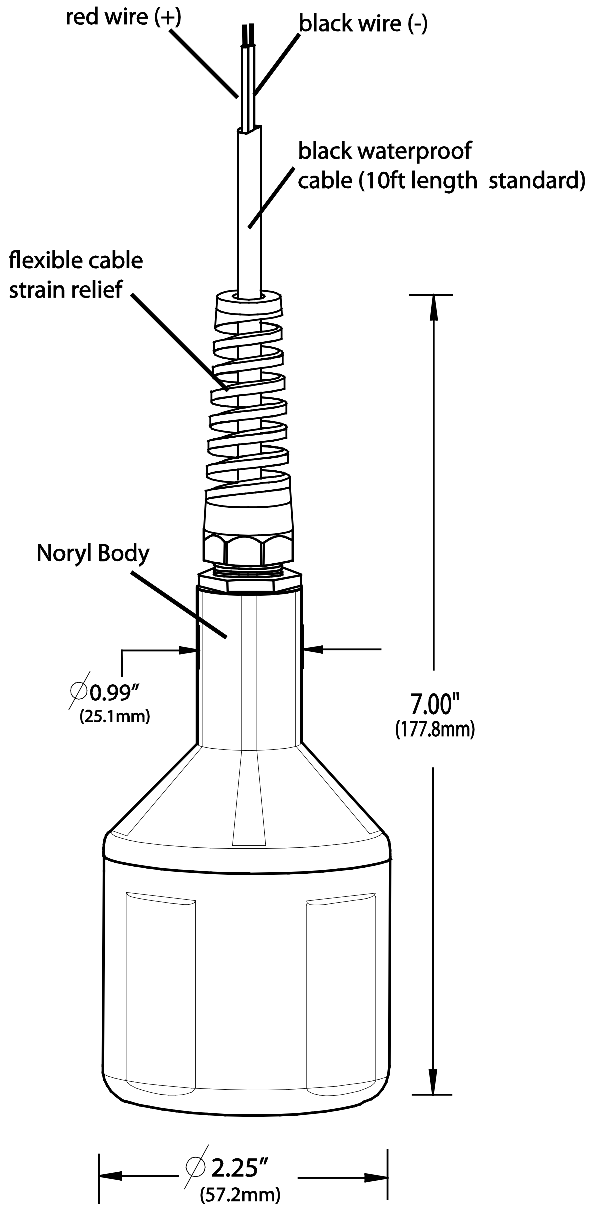
# 6. Specifications

**Features:**

- In-line thermistor provides automatic temperature compensation
- Compatible with the following CRBasic dataloggers: CR200(X) series, CR300 series, CR6 series, CR800 series, CR1000, CR1000X series, CR3000, CR5000, and CR9000(X)

| | |
|---|---|
| **Principle of Measurement:** | Membrane-covered, galvanic oxygen sensor |
| **Output Signal:** | 33 mV ± 9 mV (100% saturation), < 2 mV (0% saturation) |
| **Accuracy:** | Better than ± 2% of reading ± 1 digit when calibration temperature equals measuring temperature ± 5 °C |
| **Response Time:** | 5 min. from 100% to 0% oxygen |
| **Materials of Construction** | |
| **Body:** | Noryl |
| **Anode:** | Zinc |
| **Cathode:** | Silver |
| **Diameter:** | 5.72 cm (2.25 in) |
| **Height:** | 17.78 cm (7 in) from bottom of sensor to end of cable-strain relief |
| **Shipping Weight** | 0.8 kg (1.75 lb) |
| **Cable Jacket Material:** | PVC |
| **Operating Conditions** | |
| **Temperature:** | 0 to 50 °C (32 to 122 °F) |
| **Pressure:** | 0 to 100 psig |
| **Minimum Submersion Depth:** | 60 mm (2.5 in) |
| **Minimum Water Flow:** | 5 cm/s (2 inch/s) across membrane |
| **Calibration:** | In air or in air saturated water |

| | |
|---|---|
| **Temperature Compensation:** | Automatic from 4 to 40 °C (40 to 104 °F) |
| **Range of Dissolved Oxygen:** | 0.5 to 50 ppm |
| **Sensor Electrolyte:** | NaCl + glycerol (prevents freezing) |

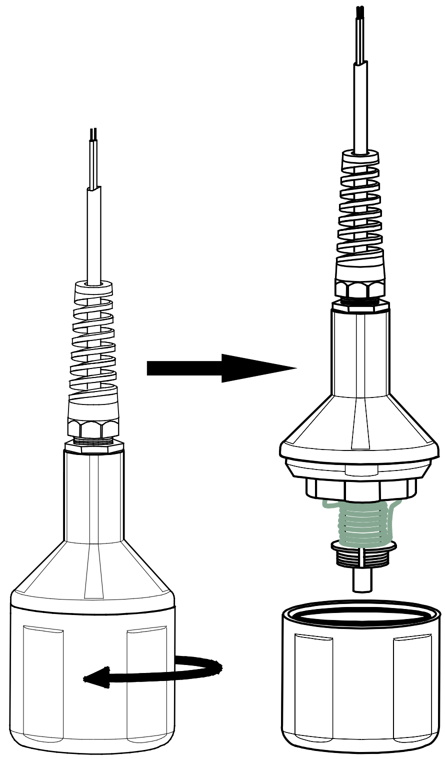



# 7. Installation

If you are programming your datalogger with *Short Cut*, skip Section 7.3, *Wiring to the Datalogger* *(p. 7)*, and Section 7.4, *Programming* *(p. 8)*. *Short Cut* does this work for you. See Section 4, *QuickStart* *(p. 2)*, for a *Short Cut* tutorial.

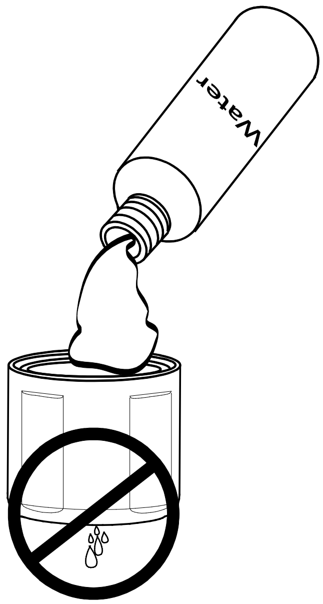
## 7.1 Getting Sensor Ready to Use

1. Unscrew the lower body from the upper body.



2. Inspect the membrane for wrinkles. Replace membrane if wrinkled (see Section 8.1, *Cleaning Sensor and Replacing Membrane* *(p. 10)*).

3. Pour clean water into the lower body and look for leakage around the membrane. Dispose of the water, and if there is leakage, replace membrane (see Section 8.1, *Cleaning Sensor and Replacing Membrane* *(p. 10)*).



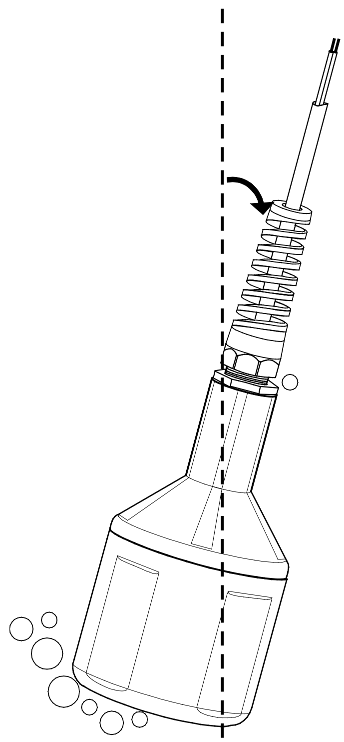
4. Pour fresh electrolyte in the bottom cap and fill to the top of the cap.

5. Keep the sensor upright with the cable pointed upwards (not sideways). Screw the bottom cap onto the upper body until hand tight.

**NOTE** Excess electrolyte will leak out at the joint between the sensor cap and upper body.

## 7.2 Mount Sensor

Mount the CS511 in water at a slight angle, which prevents bubbles from becoming trapped on the membrane.



## 7.3 Wiring to the Datalogger

Datalogger connection is provided in TABLE 7-1. The CS511 can use one differential terminal or one single-ended terminal. Differential wiring is better at rejecting electrical noise and ground loop error.

| TABLE 7-1. CS511 Wire Color, Function, and Datalogger Connection | | | |
|---|---|---|---|
| **Wire Color** | **Wire Function** | **Differential Datalogger Connection** | **Single-Ended Datalogger Connection** |
| White | Signal High | **U** configured for differential input[1], **DIFF H** (differential high, analog-voltage input) | **U** configured for single-ended input[1], **SE** (single-ended analog-voltage input) |
| Black | Signal Reference | **U** configured for differential input[1], **DIFF L** (differential low, analog-voltage input) | ⏚ (analog ground) |
| Clear | Shield | ⏚ (analog ground) | ⏚ (analog ground) |
| [1]**U** terminals are automatically configured by the measurement instruction. | | | |

## 7.4 Programming

*Short Cut* is the best source for up-to-date datalogger programming code.

If your data acquisition requirements are simple, you can probably create and maintain a datalogger program exclusively with *Short Cut*. If your data acquisition needs are more complex, the files that *Short Cut* creates are a great source for programming code to start a new program or add to an existing custom program.

**NOTE** *Short Cut* cannot edit programs after they are imported and edited in *CRBasic Editor*.

A *Short Cut* tutorial is available in Section 4, *QuickStart (p. 2)*. If you wish to import *Short Cut* code into *CRBasic Editor* to create or add to a customized program, follow the procedure in Appendix A, *Importing Short Cut Code Into CRBasic Editor (p. A-1)*. Programming basics for CRBasic dataloggers are provided in the following sections. Complete program examples for select dataloggers can be found in Appendix B, *Example Programs (p. B-1)*.

The **VoltDiff()** or **VoltSE()** can be used to measure the CS511. Choose a voltage range of 100 mV or higher.

## 7.5 Calibration

The multiplier is used to calibrate the CS511 sensor. To calculate the multiplier:

1. Program the datalogger by using a multiplier of one (see Section 4, *QuickStart (p. 2)*, or Section 7.4, *Programming (p. 8)*).

2. Connect the CS511 to the datalogger (see wiring diagram generated by *Short Cut* or Section 7.3, *Wiring to the Datalogger (p. 7)*).

3. If the CS511 has been deployed in the field, gently wipe the membrane with a soft cloth.

4. Place the CS511 in air away from direct sunlight with the membrane facing upward.

5. Place a drop of clean water on the membrane.

6. Wait for readings to stabilize. This may take 15 minutes or more.

7. Determine the air temperature and barometric pressure.

8. Using a calibration chart such as that provided in Appendix C, *Dissolved Oxygen Tables* (*p. C-1*), determine the oxygen concentration of the air.

9. Use the following equation to calculate the multiplier:

   M = P/R

   where:
   M = Multiplier
   P = Concentration in PPM of the air (from the calibration chart)
   R = The signal output of the sensor when using a multiplier of one

10. Change the multiplier in the datalogger program from one to the calculated number (see Section 4, *QuickStart* (*p. 2*)), or Section 7.4, *Programming* (*p. 8*)).

Instead of step 10, the following expression can be used that allows a new multiplier to be added to the program without rewriting, compiling, and downloading the program to the datalogger.

**CRBasic Expression for Entering Multiplier:**

```
DOppm = DOMult * DOmV
```

With this method, the multiplier value is typed into the expression through the Public Table by using the numeric display in *PC200W*, *LoggerNet*, *PC400*, or datalogger keyboard display.

# 8. Maintenance

Campbell Scientific offers maintenance kits that contain membranes, membrane O-rings, washers, and a bottle of electrolyte. A spare parts kit is also available that contains two membrane locks, two tensioning washers, two body O-rings, and one membrane replacement tool. Refer to *www.campbellsci.com/order/cs511-l* for more information.

The CS511 uses a strong, easy-to-clean, and easy-to-change membrane in a screw-on membrane cap. The sensor can be fully overhauled in five minutes.

## 8.1 Cleaning Sensor and Replacing Membrane

1. Unscrew the lower body from the upper body (FIGURE 8-1).

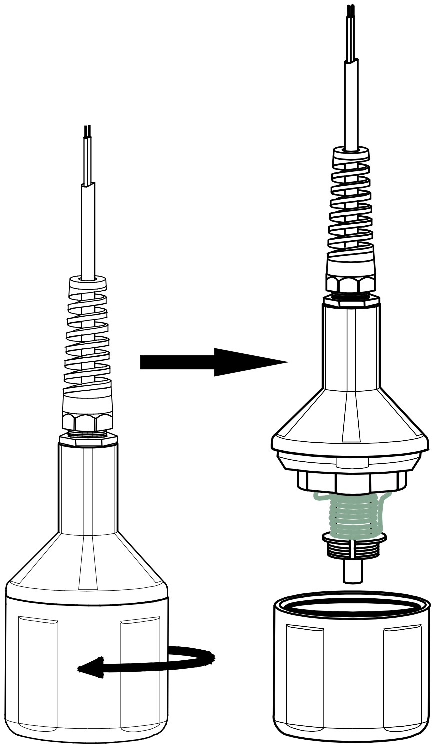


*FIGURE 8-1. Separate the lower body from the upper body*

2. Safely dispose of the electrolyte. Make sure the O-ring does not fall out of the cap.

3. Using the membrane tool, unscrew the membrane lock that is in the lower body (see FIGURE 8-2).

4. Remove and dispose of the membrane and its O-ring as show in FIGURE 8-2.

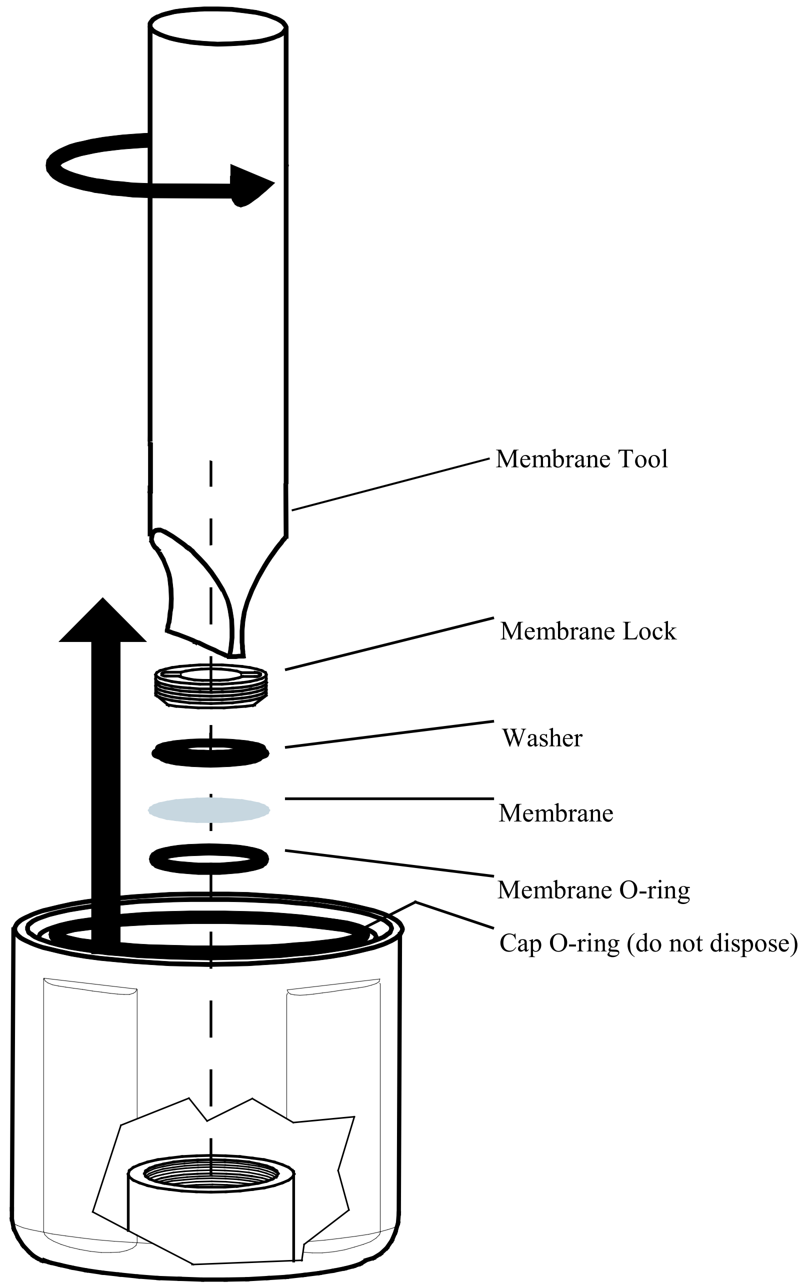



*FIGURE 8-2. Remove membrane and membrane O-ring*

5. To clean, immerse the top part of the sensor in distilled white vinegar (3% acetic acid) for about 30 minutes. If vinegar is unavailable, use a soft toothbrush, automatic dishwasher detergent, and clean water to clean the cathode, anode, and plastic. Rinse all components thoroughly with clean water after cleaning (see FIGURE 8-3).

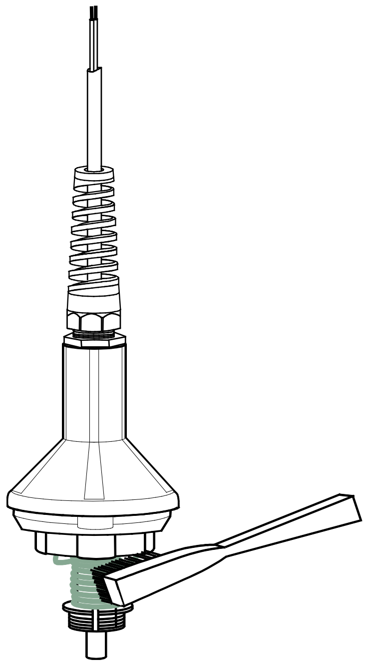


*FIGURE 8-3. Using a toothbrush to clean sensor*

6. Replace the membrane and its O-ring by first placing the new O-ring at the bottom of the membrane cavity (see FIGURE 8-4). Remove the paper backing from a new membrane and place the new membrane on top of the O-ring, and place the washer on top of the membrane. Using the membrane tool, install the membrane lock on top of the washer as shown in FIGURE 8-5. Make sure the cap is upright (not sideways) when securing the membrane lock to the washer.

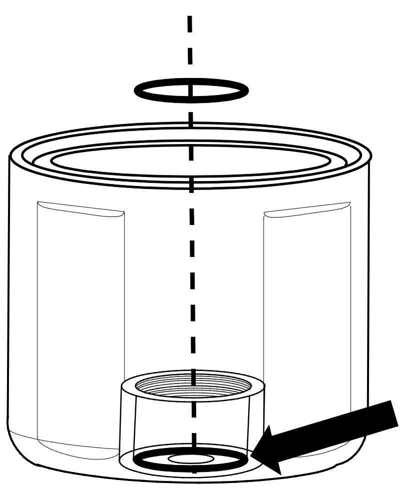


*FIGURE 8-4. Proper O-ring placement*

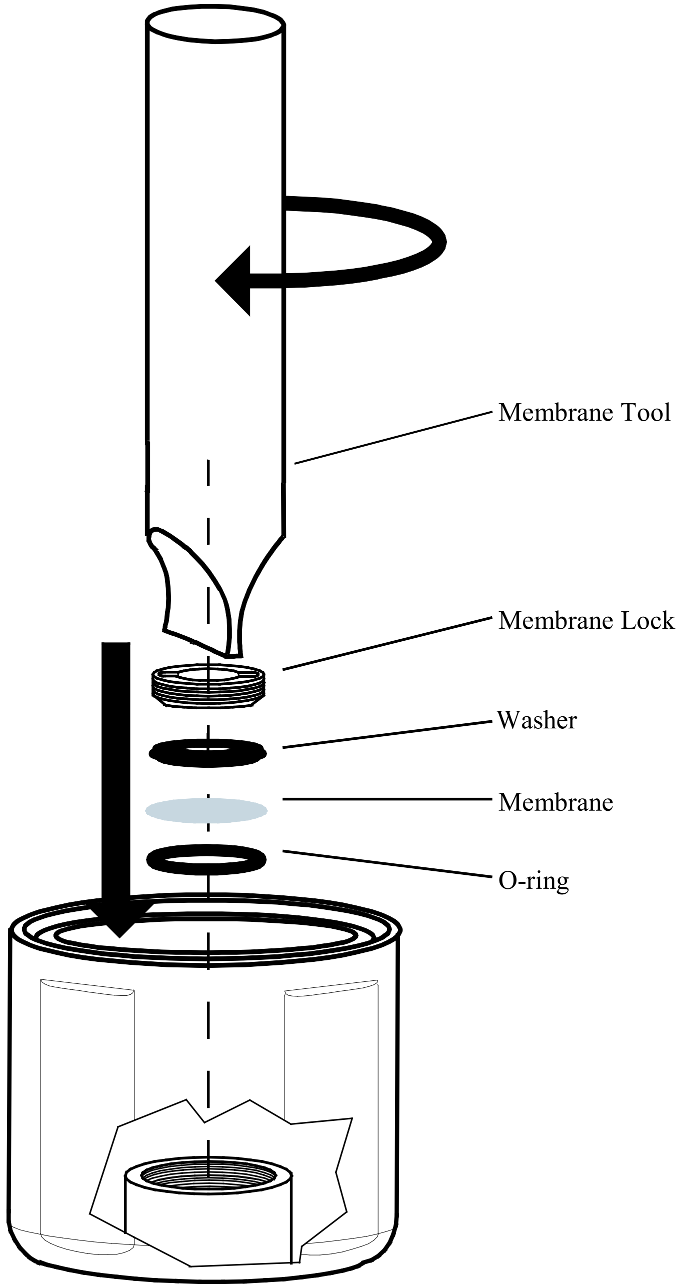



*FIGURE 8-5. Installing membrane*

7. Inspect the membrane for wrinkles; replace membrane if wrinkled.

8. Pour some clean water into the lower body and look for leakage around the membrane (see FIGURE 8-6); replace membrane if there is leakage. If there is no leakage, dispose of the water.

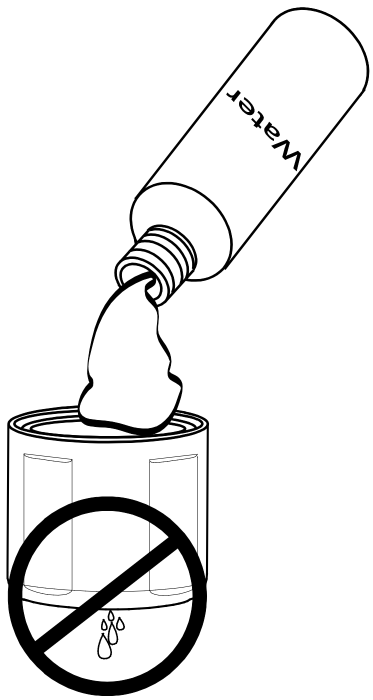



*FIGURE 8-6. Check for leakage*

9. Pour fresh electrolyte into the bottom cap and fill to the top of the cap.

10. Keep the sensor upright so that the cable is pointed upwards (not sideways). Hand tighten the bottom cap onto the upper body.

**NOTE** Excess electrolyte will leak out at the joint between the cap and upper body.

# Appendix A. Importing Short Cut Code Into CRBasic Editor

This tutorial shows:

- Importing a *Short Cut* program into a program editor for additional refinement
- Importing a wiring diagram from *Short Cut* into the comments of a custom program

*Short Cut* creates files, which can be imported into *CRBasic Editor*. Assuming defaults were used when *Short Cut* was installed, these files reside in the C:\campbellsci\SCWin folder:

- .DEF (wiring and memory usage information)
- .CR2 (CR200(X)-series datalogger code)
- .CR300 (CR300-series datalogger code)
- .CR6 (CR6-series datalogger code)
- .CR8 (CR800-series datalogger code)
- .CR1 (CR1000 datalogger code)
- .CR1X (CR1000X-series datalogger code)
- .CR3 (CR3000 datalogger code)
- .CR5 (CR5000 datalogger code)
- .CR9 (CR9000(X) datalogger code)

Import *Short Cut* code and wiring diagram into *CRBasic Editor*:

1. Create the *Short Cut* program following the procedure in Section 4, *QuickStart* *(p. 2)*. Finish the program. On the **Advanced** tab, click the **CRBasic Editor** button. The program opens in CRBasic with the name **noname.CR_**. Provide a name and save the program.

**NOTE** Once the file is edited with *CRBasic Editor*, *Short Cut* can no longer be used to edit the datalogger program.

2. The program can now be edited, saved, and sent to the datalogger.

3. Import wiring information to the program by opening the associated .DEF file. By default, it is saved in the c:\campbellsci\SCWin folder. Copy and paste the section beginning with heading "–Wiring for CRXXX–" into the CRBasic program, usually at the head of the file. After pasting, edit the information such that an apostrophe (**'**) begins each line. This character instructs the datalogger compiler to ignore the line when compiling. You can highlight several lines of CRBasic code then right-click and select **Comment Block**. (This feature is demonstrated at about 5:10 in the *CRBasic | Features* video.)

# Appendix B. Example Programs

## B.1 VoltDiff CR1000X Example

Programming for the CR300 series, CR800, CR850, CR1000, CR3000, and CR5000 is similar to this CR1000X program. TABLE B-1 shows the wiring for the example.

**TABLE B-1. Wiring for CR1000X Example**

| CR1000X Connection | Sensor Wire |
|---|---|
| 1H | White |
| 1L | Black |
| Ground | Clear |

**CRBasic Example B-1. VoltDiff CR1000X Example**

```
'CR1000X

'Declare Variables and Units
Public Batt_Volt
Public DOmV
Public DOppm
Public DOMult

Units Batt_Volt=Volts
Units DOmV=mV
Units DOppm=ppm

'Define Data Tables
DataTable(Hourly,True,-1)
  DataInterval(0,60,Min,10)
  Sample(1,DOmV,FP2)
  Sample(1,DOppm,FP2)
  Sample(1,Batt_Volt,FP2)
EndTable

DataTable(Daily,True,-1)
  DataInterval(0,1440,Min,10)
  Minimum(1,Batt_Volt,FP2,False,False)
EndTable

'Main Program
BeginProg
  Scan(5,Sec,1,0)
    'Default Datalogger Battery Voltage measurement Batt_Volt:
    Battery(Batt_Volt)
    'CS511 Dissolved Oxygen Sensor measurements DOmV and DOppm:
    VoltDiff(DOmV,1,mV200,1,True,0,60,1,0)
    DOppm = DOMult * DOmV
    'Call Data Tables and Store Data
    CallTable(Hourly)
    CallTable(Daily)
  NextScan
EndProg
```

# B.2 VoltSE CR200(X) Program

The CR200(X)-series must use the **VoltSE()** instruction since these dataloggers do not make differential measurements. If the other CRBasic dataloggers use the **VoltSE()** instruction instead of the **VoltDiff()** instruction, their programming will be similar to this example. TABLE B-2 shows the wiring for the example.

**TABLE B-2. Wiring for CR200(X) Example**

| CR200(X) Connection | Sensor Wire |
|---|---|
| SE1 | White |
| Ground | Black |
| Ground | Clear |

**CRBasic Example B-2. VoltSE CR200(X) Program**

```
'CR200(X) Series

'Declare Variables and Units
Public Batt_Volt
Public DOmV
Public DOppm
Public DOMult

Units Batt_Volt=Volts
Units DOmV=mV
Units DOppm=ppm

'Define Data Tables
DataTable(Hourly,True,-1)
  DataInterval(0,60,Min)
  Sample(1,DOmV)
EndTable

DataTable(Daily,True,-1)
  DataInterval(0,1440,Min)
  Minimum(1,Batt_Volt,False,False)
EndTable

'Main Program
BeginProg
  Scan(10,Sec)
    'Default Datalogger Battery Voltage measurement Batt_Volt:
    Battery(Batt_Volt)
    'CS511 Dissolved Oxygen Sensor measurements DOmV and DOppm:
    VoltSE(DOmV,1,1,1,0)
    DOppm = DOMult * DOmV
    'Call Data Tables and Store Data
    CallTable(Hourly)
    CallTable(Daily)
  NextScan
EndProg
```

# Appendix C. Dissolved Oxygen Tables

## C.1 Dissolved Oxygen in Fresh Water

**Solubility of dissolved oxygen (mg/L) as a function of temperature and pressure for moist air, salinity = 0.0 ppt.**

| | | ALTITUDE (Feet/Metres) and equivalent BAROMETRIC PRESSURE (mm Hg/mbar) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 | Feet |
| | | 0 | 152 | 305 | 457 | 610 | 762 | 914 | 1067 | 1219 | 1372 | 1524 | 1676 | 1829 | Metres |
| TEMP. | | 760 | 747 | 733 | 721 | 708 | 695 | 683 | 671 | 659 | 648 | 636 | 625 | 614 | mm Hg |
| °C | °F | 1013 | 995 | 978 | 961 | 944 | 927 | 911 | 895 | 879 | 863 | 848 | 833 | 819 | mbar |
| 0 | 32.0 | 14.60 | 14.34 | 14.09 | 13.84 | 13.60 | 13.36 | 13.12 | 12.89 | 12.67 | 12.44 | 12.22 | 12.01 | 11.80 | |
| 1 | 33.8 | 14.20 | 13.95 | 13.70 | 13.46 | 13.22 | 12.99 | 12.76 | 12.54 | 12.32 | 12.10 | 11.89 | 11.68 | 11.47 | |
| 2 | 35.6 | 13.81 | 13.57 | 13.33 | 13.10 | 12.87 | 12.64 | 12.42 | 12.20 | 11.98 | 11.77 | 11.56 | 11.36 | 11.16 | |
| 3 | 37.4 | 13.45 | 13.21 | 12.98 | 12.75 | 12.52 | 12.30 | 12.09 | 11.87 | 11.66 | 11.46 | 11.26 | 11.06 | 10.86 | |
| 4 | 39.2 | 13.09 | 12.86 | 12.64 | 12.41 | 12.20 | 11.98 | 11.77 | 11.56 | 11.36 | 11.16 | 10.96 | 10.77 | 10.58 | |
| 5 | 41.0 | 12.76 | 12.53 | 12.31 | 12.09 | 11.88 | 11.67 | 11.47 | 11.26 | 11.07 | 10.87 | 10.68 | 10.49 | 10.31 | |
| 6 | 42.8 | 12.44 | 12.22 | 12.00 | 11.79 | 11.58 | 11.38 | 11.18 | 10.98 | 10.79 | 10.60 | 10.41 | 10.23 | 10.05 | |
| 7 | 44.6 | 12.13 | 11.91 | 11.70 | 11.50 | 11.29 | 11.10 | 10.90 | 10.71 | 10.52 | 10.33 | 10.15 | 9.97 | 9.80 | |
| 8 | 46.4 | 11.83 | 11.62 | 11.42 | 11.22 | 11.02 | 10.83 | 10.63 | 10.45 | 10.26 | 10.08 | 9.91 | 9.73 | 9.56 | |
| 9 | 48.2 | 11.55 | 11.34 | 11.15 | 10.95 | 10.76 | 10.57 | 10.38 | 10.20 | 10.02 | 9.84 | 9.67 | 9.50 | 9.33 | |
| 10 | 50.0 | 11.28 | 11.08 | 10.88 | 10.69 | 10.50 | 10.32 | 10.14 | 9.96 | 9.78 | 9.61 | 9.44 | 9.27 | 9.11 | |
| 11 | 51.8 | 11.02 | 10.82 | 10.63 | 10.44 | 10.26 | 10.08 | 9.90 | 9.73 | 9.56 | 9.39 | 9.22 | 9.06 | 8.90 | |
| 12 | 53.6 | 10.77 | 10.58 | 10.39 | 10.21 | 10.03 | 9.85 | 9.68 | 9.51 | 9.34 | 9.17 | 9.01 | 8.85 | 8.70 | |
| 13 | 55.4 | 10.53 | 10.34 | 10.16 | 9.98 | 9.80 | 9.63 | 9.46 | 9.29 | 9.13 | 8.97 | 8.81 | 8.66 | 8.50 | |
| 14 | 57.2 | 10.29 | 10.11 | 9.93 | 9.76 | 9.59 | 9.42 | 9.25 | 9.09 | 8.93 | 8.77 | 8.62 | 8.47 | 8.32 | |
| 15 | 59.0 | 10.07 | 9.89 | 9.72 | 9.55 | 9.38 | 9.22 | 9.05 | 8.89 | 8.74 | 8.58 | 8.43 | 8.28 | 8.14 | |
| 16 | 60.8 | 9.86 | 9.68 | 9.51 | 9.35 | 9.18 | 9.02 | 8.86 | 8.70 | 8.55 | 8.40 | 8.25 | 8.11 | 7.96 | |
| 17 | 62.6 | 9.65 | 9.48 | 9.31 | 9.15 | 8.99 | 8.83 | 8.68 | 8.52 | 8.37 | 8.22 | 8.08 | 7.94 | 7.80 | |
| 18 | 64.4 | 9.45 | 9.29 | 9.12 | 8.96 | 8.80 | 8.65 | 8.50 | 8.35 | 8.20 | 8.06 | 7.91 | 7.77 | 7.64 | |
| 19 | 66.2 | 9.26 | 9.10 | 8.94 | 8.78 | 8.63 | 8.47 | 8.32 | 8.18 | 8.03 | 7.89 | 7.75 | 7.62 | 7.48 | |
| 20 | 68.0 | 9.08 | 8.92 | 8.76 | 8.61 | 8.45 | 8.30 | 8.16 | 8.01 | 7.87 | 7.73 | 7.60 | 7.46 | 7.33 | |
| 21 | 69.8 | 8.90 | 8.74 | 8.59 | 8.44 | 8.29 | 8.14 | 8.00 | 7.86 | 7.72 | 7.58 | 7.45 | 7.32 | 7.19 | |
| 22 | 71.6 | 8.73 | 8.57 | 8.42 | 8.27 | 8.13 | 7.98 | 7.84 | 7.71 | 7.57 | 7.44 | 7.31 | 7.18 | 7.05 | |
| 23 | 73.4 | 8.56 | 8.41 | 8.26 | 8.12 | 7.97 | 7.83 | 7.69 | 7.56 | 7.43 | 7.29 | 7.17 | 7.04 | 6.92 | |
| 24 | 75.2 | 8.40 | 8.25 | 8.11 | 7.96 | 7.82 | 7.69 | 7.55 | 7.42 | 7.29 | 7.16 | 7.03 | 6.91 | 6.79 | |
| 25 | 77.0 | 8.24 | 8.10 | 7.96 | 7.82 | 7.68 | 7.54 | 7.41 | 7.28 | 7.15 | 7.03 | 6.90 | 6.78 | 6.66 | |
| 26 | 78.8 | 8.09 | 7.95 | 7.81 | 7.67 | 7.54 | 7.41 | 7.28 | 7.15 | 7.02 | 6.90 | 6.78 | 6.66 | 6.54 | |
| 27 | 80.6 | 7.95 | 7.81 | 7.67 | 7.54 | 7.40 | 7.27 | 7.14 | 7.02 | 6.90 | 6.77 | 6.65 | 6.54 | 6.42 | |
| 28 | 82.4 | 7.81 | 7.67 | 7.53 | 7.40 | 7.27 | 7.14 | 7.02 | 6.89 | 6.77 | 6.65 | 6.54 | 6.42 | 6.31 | |
| 29 | 84.2 | 7.67 | 7.54 | 7.40 | 7.27 | 7.14 | 7.02 | 6.90 | 6.77 | 6.65 | 6.54 | 6.42 | 6.31 | 6.20 | |
| 30 | 86.0 | 7.54 | 7.41 | 7.28 | 7.15 | 7.02 | 6.90 | 6.78 | 6.66 | 6.54 | 6.42 | 6.31 | 6.20 | 6.09 | |
| 31 | 87.8 | 7.41 | 7.28 | 7.15 | 7.03 | 6.90 | 6.78 | 6.66 | 6.54 | 6.43 | 6.32 | 6.20 | 6.09 | 5.99 | |
| 32 | 89.6 | 7.29 | 7.16 | 7.03 | 6.91 | 6.79 | 6.67 | 6.55 | 6.43 | 6.32 | 6.21 | 6.10 | 5.99 | 5.89 | |
| 33 | 91.4 | 7.17 | 7.04 | 6.92 | 6.79 | 6.67 | 6.56 | 6.44 | 6.33 | 6.22 | 6.11 | 6.00 | 5.89 | 5.79 | |
| 34 | 93.2 | 7.05 | 6.92 | 6.80 | 6.68 | 6.56 | 6.45 | 6.34 | 6.22 | 6.11 | 6.01 | 5.90 | 5.80 | 5.69 | |
| 35 | 95.0 | 6.93 | 6.81 | 6.69 | 6.57 | 6.46 | 6.34 | 6.23 | 6.12 | 6.02 | 5.91 | 5.81 | 5.70 | 5.60 | |
| 36 | 96.8 | 6.82 | 6.70 | 6.59 | 6.47 | 6.36 | 6.24 | 6.13 | 6.03 | 5.92 | 5.82 | 5.71 | 5.61 | 5.51 | |
| 37 | 98.6 | 6.72 | 6.60 | 6.48 | 6.37 | 6.26 | 6.15 | 6.04 | 5.93 | 5.83 | 5.72 | 5.62 | 5.52 | 5.43 | |
| 38 | 100.4 | 6.61 | 6.49 | 6.38 | 6.27 | 6.16 | 6.05 | 5.94 | 5.84 | 5.74 | 5.63 | 5.53 | 5.44 | 5.34 | |
| 39 | 102.2 | 6.51 | 6.39 | 6.28 | 6.17 | 6.06 | 5.96 | 5.85 | 5.75 | 5.65 | 5.55 | 5.45 | 5.35 | 5.26 | |
| 40 | 104.0 | 6.41 | 6.30 | 6.19 | 6.08 | 5.97 | 5.86 | 5.76 | 5.66 | 5.56 | 5.46 | 5.37 | 5.27 | 5.18 | |

## C.2 Dissolved Oxygen in Salt Water

**Solubility of dissolved oxygen (mg/L) as a function of temperature and salinity for moist air at sea level**

| TEMP | | SALINITY - Parts per Thousand | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| °C | °F | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| 0 | 32.0 | 14.60 | 14.11 | 13.64 | 13.18 | 12.74 | 12.31 | 11.90 | 11.50 | 11.11 |
| 1 | 33.8 | 14.20 | 13.73 | 13.27 | 12.83 | 12.40 | 11.98 | 11.58 | 11.20 | 10.83 |
| 2 | 35.6 | 13.81 | 13.36 | 12.91 | 12.49 | 12.07 | 11.67 | 11.29 | 10.91 | 10.55 |
| 3 | 37.4 | 13.45 | 13.00 | 12.58 | 12.16 | 11.76 | 11.38 | 11.00 | 10.64 | 10.29 |
| 4 | 39.2 | 13.09 | 12.67 | 12.25 | 11.85 | 11.47 | 11.09 | 10.73 | 10.38 | 10.04 |
| 5 | 41.0 | 12.76 | 12.34 | 11.94 | 11.56 | 11.18 | 10.82 | 10.47 | 10.13 | 9.80 |
| 6 | 42.8 | 12.44 | 12.04 | 11.65 | 11.27 | 10.91 | 10.56 | 10.22 | 9.89 | 9.57 |
| 7 | 44.6 | 12.13 | 11.74 | 11.37 | 11.00 | 10.65 | 10.31 | 9.98 | 9.66 | 9.35 |
| 8 | 46.4 | 11.83 | 11.46 | 11.09 | 10.74 | 10.40 | 10.07 | 9.75 | 9.44 | 9.14 |
| 9 | 48.2 | 11.55 | 11.19 | 10.83 | 10.49 | 10.16 | 9.84 | 9.53 | 9.23 | 8.94 |
| 10 | 50.0 | 11.28 | 10.92 | 10.58 | 10.25 | 9.93 | 9.62 | 9.32 | 9.03 | 8.75 |
| 11 | 51.8 | 11.02 | 10.67 | 10.34 | 10.02 | 9.71 | 9.41 | 9.12 | 8.83 | 8.56 |
| 12 | 53.6 | 10.77 | 10.43 | 10.11 | 9.80 | 9.50 | 9.21 | 8.92 | 8.65 | 8.38 |
| 13 | 55.4 | 10.53 | 10.20 | 9.89 | 9.59 | 9.30 | 9.01 | 8.74 | 8.47 | 8.21 |
| 14 | 57.2 | 10.29 | 9.98 | 9.68 | 9.38 | 9.10 | 8.82 | 8.55 | 8.30 | 8.04 |
| 15 | 59.0 | 10.07 | 9.77 | 9.47 | 9.19 | 8.91 | 8.64 | 8.38 | 8.13 | 7.88 |
| 16 | 60.8 | 9.86 | 9.56 | 9.28 | 9.00 | 8.73 | 8.47 | 8.21 | 7.97 | 7.73 |
| 17 | 62.6 | 9.65 | 9.36 | 9.09 | 8.82 | 8.55 | 8.30 | 8.05 | 7.81 | 7.58 |
| 18 | 64.4 | 9.45 | 9.17 | 8.90 | 8.64 | 8.39 | 8.14 | 7.90 | 7.66 | 7.44 |
| 19 | 66.2 | 9.26 | 8.99 | 8.73 | 8.47 | 8.22 | 7.98 | 7.75 | 7.52 | 7.30 |
| 20 | 68.0 | 9.08 | 8.81 | 8.56 | 8.31 | 8.07 | 7.83 | 7.60 | 7.38 | 7.17 |
| 21 | 69.8 | 8.90 | 8.64 | 8.39 | 8.15 | 7.91 | 7.69 | 7.46 | 7.25 | 7.04 |
| 22 | 71.6 | 8.73 | 8.48 | 8.23 | 8.00 | 7.77 | 7.54 | 7.33 | 7.12 | 6.91 |
| 23 | 73.4 | 8.56 | 8.32 | 8.08 | 7.85 | 7.63 | 7.41 | 7.20 | 6.99 | 6.79 |
| 24 | 75.2 | 8.40 | 8.16 | 7.93 | 7.71 | 7.49 | 7.28 | 7.07 | 6.87 | 6.68 |
| 25 | 77.0 | 8.24 | 8.01 | 7.79 | 7.57 | 7.36 | 7.15 | 6.95 | 6.75 | 6.56 |
| 26 | 78.8 | 8.09 | 7.87 | 7.65 | 7.44 | 7.23 | 7.03 | 6.83 | 6.64 | 6.46 |
| 27 | 80.6 | 7.95 | 7.73 | 7.51 | 7.31 | 7.10 | 6.91 | 6.72 | 6.53 | 6.35 |
| 28 | 82.4 | 7.81 | 7.59 | 7.38 | 7.18 | 6.98 | 6.79 | 6.61 | 6.42 | 6.25 |
| 29 | 84.2 | 7.67 | 7.46 | 7.26 | 7.06 | 6.87 | 6.68 | 6.50 | 6.32 | 6.15 |
| 30 | 86.0 | 7.54 | 7.33 | 7.14 | 6.94 | 6.75 | 6.57 | 6.39 | 6.22 | 6.05 |
| 31 | 87.8 | 7.41 | 7.21 | 7.02 | 6.83 | 6.65 | 6.47 | 6.29 | 6.12 | 5.96 |
| 32 | 89.6 | 7.29 | 7.09 | 6.90 | 6.72 | 6.54 | 6.36 | 6.19 | 6.03 | 5.87 |
| 33 | 91.4 | 7.17 | 6.98 | 6.79 | 6.61 | 6.44 | 6.26 | 6.10 | 5.94 | 5.78 |
| 34 | 93.2 | 7.05 | 6.86 | 6.68 | 6.51 | 6.33 | 6.17 | 6.01 | 5.85 | 5.69 |
| 35 | 95.0 | 6.93 | 6.75 | 6.58 | 6.40 | 6.24 | 6.07 | 5.92 | 5.76 | 5.61 |
| 36 | 96.8 | 6.82 | 6.65 | 6.47 | 6.31 | 6.14 | 5.98 | 5.83 | 5.68 | 5.53 |
| 37 | 98.6 | 6.72 | 6.54 | 6.37 | 6.21 | 6.05 | 5.89 | 5.74 | 5.59 | 5.45 |
| 38 | 100.4 | 6.61 | 6.44 | 6.28 | 6.12 | 5.96 | 5.81 | 5.66 | 5.51 | 5.37 |
| 39 | 102.2 | 6.51 | 6.34 | 6.18 | 6.03 | 5.87 | 5.72 | 5.58 | 5.44 | 5.30 |
| 40 | 104.0 | 6.41 | 6.25 | 6.09 | 5.94 | 5.79 | 5.64 | 5.50 | 5.36 | 5.22 |

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