Using the Conductivity Assistant:
Calculating Specific Conductance with Sea Water

The Conductivity Assistant (version 2.0 or earlier) shipped with HOBOware® 3.2.1 has been modified to further refine the equations used to calculate specific conductance with sea water using the U24 Conductivity logger (U24-002 and U24-002-C). Version 2.0 and earlier versions of the Conductivity Assistant were not producing the expected measurements when calculating specific conductance with sea water. Careful analysis determined that the Conductivity Assistant needed an additional level of precision to ensure the calculations were meeting the specified accuracy range (see the logger product manual) for the calibrated specific conductance output when used in sea water. This involved improving the output of specific conductance versus time and the output of salinity versus time, using the Practical Salinity Scale 1978, which is a time-tested tool that provides sufficient accuracy for a conductivity-based measurement system for typical ocean waters. The new calculations are available in version 2.1 of the Conductivity Assistant.

Conductivity Assistant Calculations Prior to Version 2.1
Before examining the revised calculations in the new version 2.1, it is helpful to understand how the measurements were calculated in previous versions. Previous versions used the following process to calculate the measurement of salinity of sea water:

1. A linear compensation temperature coefficient of 2.1%/°C was used to calculate the specific conductance \( C_s \) at 25°C for sea water with the following equation:
   \[
   C_s = Y_e / (1 - ((25-T) * a / 100))
   \]
   Where: \( Y_e = \) Electrical Conductivity
   \( a = 2.1 \% / \) degrees C (temp. coeff.)
   \( T = \) water temperature in degrees C

2. A field-measured specific conductance was used to adjust the beginning of the dataset and the end of the dataset to the measured values to compensate for instrument offset and for fouling of the sensor during deployment.

3. The salinity of the sea water was calculated using PSS-78 equations. If field-measured specific conductance values were used to adjust the specific conductivity values in step 2, the electrical conductivity values were likewise adjusted before the salinity was calculated.

The linear compensation coefficient of 2.1%/°C used to calculate the specific conductance at 25°C for sea water represented the coefficient for sodium chloride (the major component salt of sea water). The temperature coefficient for sea water (a mixture of many salts and chemicals) can vary from 1.8 to 2.1 as a function of sea water temperature and salinity. At low temperatures and low salinities, the coefficient approaches 1.8 and can cause a significant difference in the specific conductance calculation causing a likewise difference in salinity.

A hand-held meter was used to measure the calibration points entered into the Conductivity Assistant. The meter needed to use the same temperature compensation techniques as the Conductivity Assistant to be accurate if the calibration points were entered in specific conductance. Most meters can only use linear coefficients for temperature compensation, with 2.1%/°C typically used for sea water.

Conductivity Assistant Version 2.1 Calculations
To improve the accuracy of the specific conductance data provided by the Conductivity Assistant, a non-linear temperature coefficient is generated that is a function of temperature and salinity. This equation is generated using the PSS-78 equations that solve for salinity from conductivity and temperature (the pressure term is assumed to be atmospheric and is neglected). The assumption in using the PSS-78 equations is that for any conductivity/temperature pair, the temperature coefficient of that data will generate a specific conductivity at 25°C that will calculate the same salinity as the original conductivity/temperature pair.
Version 2.1 of the Conductivity Assistant now uses the following process to calculate specific conductance of each measurement with sea water:

1. Calculate the non-linear temperature coefficient (a):
   \[ a = A + B \times T + C \times S + D \times T^2 + E \times S^2 + F \times T \times S \]
   Where:  
   - S = Uncorrected salinity calculated in PSS-78 using the conductivity and temperature pair
   - T = water temperature in degrees C
   - A = 1.86221444E+00
   - B = 7.99141780E-03
   - C = -2.04882760E-03
   - D = -4.79386353E-05
   - E = 1.67997158E-05
   - F = -1.55721008E-05

2. Use the non-linear compensation temperature coefficient of “a”%/°C to calculate the specific conductance at 25°C for sea water using the following equation:
   \[ C_s = Y_e / (1 - ((25-T) \times a / 100)) \]
   Where:  
   - Y_e = Electrical Conductivity
   - a = “see above” % / degrees C (temp. coeff.)
   - T = water temperature in degrees C

How was the non-linear temperature coefficient equation above developed using the PSS-78 equation set (reference the spreadsheet in Figures 1A and 1B)?

- The Practical Salinity Scale 1978 (PSS-78) is valid over a temperature range of -2 to 35°C, a salinity range of 2 to 42 psu, and a conductivity range of 1.91 to 74.86 mS/cm.
- Columns 1 and 2 were selected to cover this range.
- The values of conductivities listed in column 3 were calculated using a spreadsheet macro that iteratively calculated the salinity (per PSS-78) in column 2 with the temperature in column 1 until a value of conductivity was found that caused a solution of salinity within 0.01 of the salinity value of column 2.
- The calculated temperature coefficient of column 4 is the coefficient necessary to change the conductivity in column 3 to the conductivity listed for the same salinity at 25°C using \[ C_s = Y_e / (1 - ((25-T) \times a / 100)) \].
- The data of columns 1, 2, and 4 were stripped of the 25°C values, because the temperature coefficients of 25°C were “NA” or nonexistent, and the remaining dataset was presented to a 3-dimensional, non-linear regression. A good regression solution was the Taylor series depicted below:
   \[ a = A + B \times T + C \times S + D \times T^2 + E \times S^2 + F \times T \times S \]
   WHERE:  
   - A = 1.86221444E+00
   - B = 7.99141780E-03
   - C = -2.04882760E-03
   - D = -4.79386353E-05
   - E = 1.67997158E-05
   - F = -1.55721008E-05
   AND:  
   - T = sea water temperature in degrees C
   - S = sea water salinity
- Column 5 shows the temperature coefficient calculated by the above equation for each temperature and salinity of columns 1 and 2.
• Column 6 shows the specific conductance calculated using the calculated temperature coefficient of column 5 and the conductivity and temperature of columns 3 and 1. Notice the calculated value is very close to the conductivity calculated at the same salinity for 25°C.

• Column 7 shows the percent difference between the calculated specific conductance of column 6 and the conductivity calculated at the same salinity for 25°C. At the bottom of Figure 1B, notice that the minimum and maximum percent differences are -0.1064% to 0.0857% for all points. These errors are primarily caused by curve fit error, but are well within our system’s 3% error.

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Figure 1A
Calibrating a Conductivity File with a Hand-held Conductivity Meter

In the past, a hand-held meter was used to record the specific conductance of the test water at the beginning and the end of each logger deployment. Since the meter cannot perform the new, non-linear temperature compensation required to output specific conductance, you must instead use the meter to record the conductivity and temperature of the water being measured. These values, taken at the beginning and end of each deployment, must then be entered into Version 2.1 of the Conductivity Assistant Version 2.1, which will convert the recorded conductivity and temperature points to specific conductance at 25°C using the non-linear temperature coefficient equation (Taylor series). The Conductivity Assistant adjusts the specific conductance file calculated from the logger data to match the specific conductance points calculated from the meter data.

How the Conductivity Assistant (Version 2.1) Calculates Specific Conductance and Salinity with Sea Water

To calculate specific conductance and salinity for a data series in a logger data file, the Conductivity Assistant:

1. Reads the selected conductivity range for the data series, either low or high.
2. Reads the recorded conductivity and temperature pair for each selected range.
3. Calculates the preliminary salinity using PSS-78 for each pair.
4. Calculates the temperature coefficient using the temperature coefficient equation (Taylor series) with salinity and temperature for each pair.
5. Calculates specific conductance using the temperature coefficient for each pair.
6. Calculates the hand-held meter specific conductance points and adjusts the specific conductance dataset of the logger per the calibration data (if the “Use measured points for calibration” option is selected).
7. Calculates final Salinity using the specific conductance dataset at 25°C in PSS-78.