# Lab: Properties of Seawater - Temperature, salinity, density & oxygen solubility

Written by Prof. D. Scheel, Alaska Pacific University with edited materials from
Unit 1 in Haefner (1996) Exploring Marine Biology: Laboratory & Field Exercises. Oxford University Press, & Exc 2 in Sumich & Dudley (2009) Laboratory and Field Investigations in Marine Life, 9th Ed. Jones & Bartlett Publ.

Objectives

- Learn to use water sampling equipment including hydrometer, refractometer, and depth-profiler
- Measure salinity, temperature and density of seawater, and calculate oxygen solubility;
- Understand relationships between temperature, salinity and density;
- Graphically depict and interpret data on these properties of seawater.

**INTRODUCTION** (after Haefner)

Marine biology is concerned not only with the study of marine organisms, but also with the organisms' ocean environment and their dependence on biotic and abiotic environmental factors. Thus, marine biology includes ecological research that deals with descriptions and experimental analysis of biological processes in the ocean. Since a principle goal of this discipline is to describe the relationships between the organisms and their physical environment, it is not enough to concentrate solely on surveys of the fauna and flora of the seas. It is also vital to understand the marine environment.

Four parameters of ocean water are most important in these regards and are measured routinely: temperature, salinity, density, and dissolved oxygen (DO) concentration. In this exercise you will measure the first three of these and calculate oxygen solubility rather than measure concentration.

Compared to most terrestrial environments, the ocean is a relatively stable medium in which to live. Conditions of temperature, salinity and amounts of dissolved gasses such as oxygen fluctuate only slightly over most daily and seasonal cycles, although abrupt demarcations in space rather than time are typical. However, the variations that do occur, while subtle, importantly determine the types and distributions of marine organisms.

**Temperature** (after Haefner)

The activity, behavior, distribution, and survival of ectothermic marine organisms are controlled by the oceanic temperature range (-2 ˚C to 30 ˚C). Consequently, the metabolism (and many other activities) of these organisms varies with external temperature.

Vertical distribution of temperature, salinity, and density (Fig. 1.1) contribute to marine zonation. An obvious feature of most oceans is the **thermocline (Fig. 1.1 left panel), a zone located beneath the surface in which a rapid decrease in temperature occurs relative to the decrease in depth**. The decrease in temperature is usually accompanied by **dramatic increase in salinity (halocline)** (Fig. 1.1 middle) **and density (pycnocline)**(Fig. 1.1 right). The large density difference on either side of the thermocline (and pycnocline) effectively separates the oceans into layers or zones (Fig. 1.2). This barrier impedes the exchange of gases, nutrients, and organisms between layers.

**Salinity**

Marine organisms live in an environment that includes a vast array of dissolved salts. The concentration of salts is expressed as **salinity (mass of dissolved salts in water per mass of solution)**. This quantity has been both hard to define and to measure precisely. Past definitions have been based on total dissolved material, dissolved solids only, chlorine content, or conductivity of seawater. The current definition, the **Practical Salinity Scale of 1978 is defined only in terms of conductivity**[1]. In practice, measurements of salinity are accurate to within ± 0.003 parts per thousand, and are conducted

[1] Stewart, R.H. 2005. Introduction to physical oceanography. Texas A&M Univ. Retrieved 7 Jul 2008 from http://oceanworld.tamu.edu/resources/ocng_textbook/chapter06/chapter06_01.htm

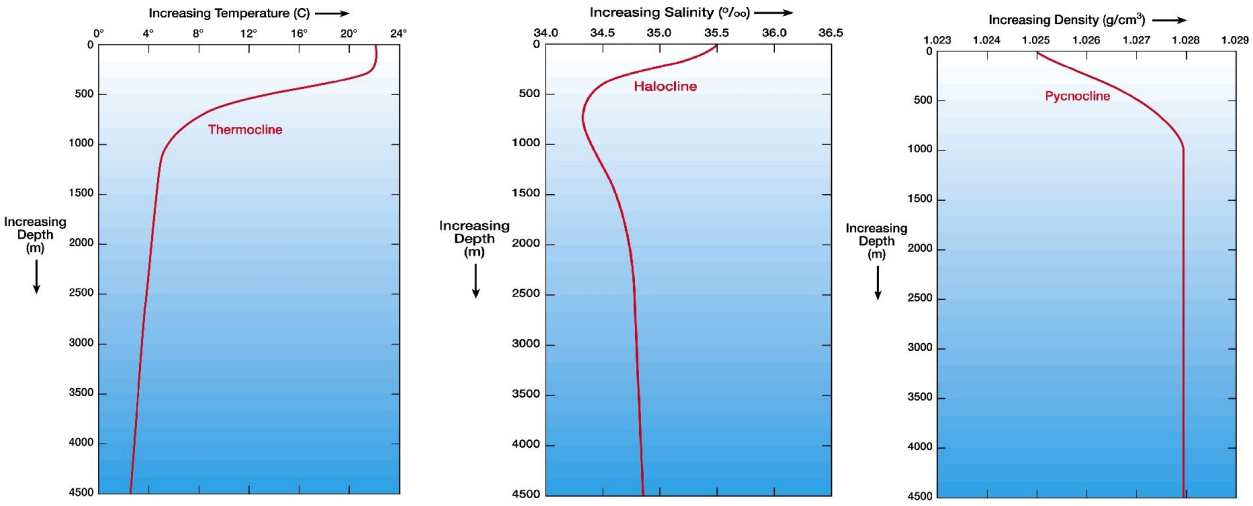



Figure 1.1. This is a simple temperature-depth ocean water profile (left panel). You can see temperature decreases with increasing depth. The thermocline are layers of water where the temperature changes rapidly with depth. This temperature-depth profile is what you might expect to find in low to middle latitudes. A salinity-depth profile (middle panel) reveals a halocline; density-depth (right), the pycnocline. Note the convention, universal in marine science, of plotting depth on the y-axis below the x-axis, thereby representing deeper water as lower on the graph.
Images retrieved 8 Jul 2008 from http://www.windows.ucar.edu/tour/link=/earth/Water/temp.html&edu=high.

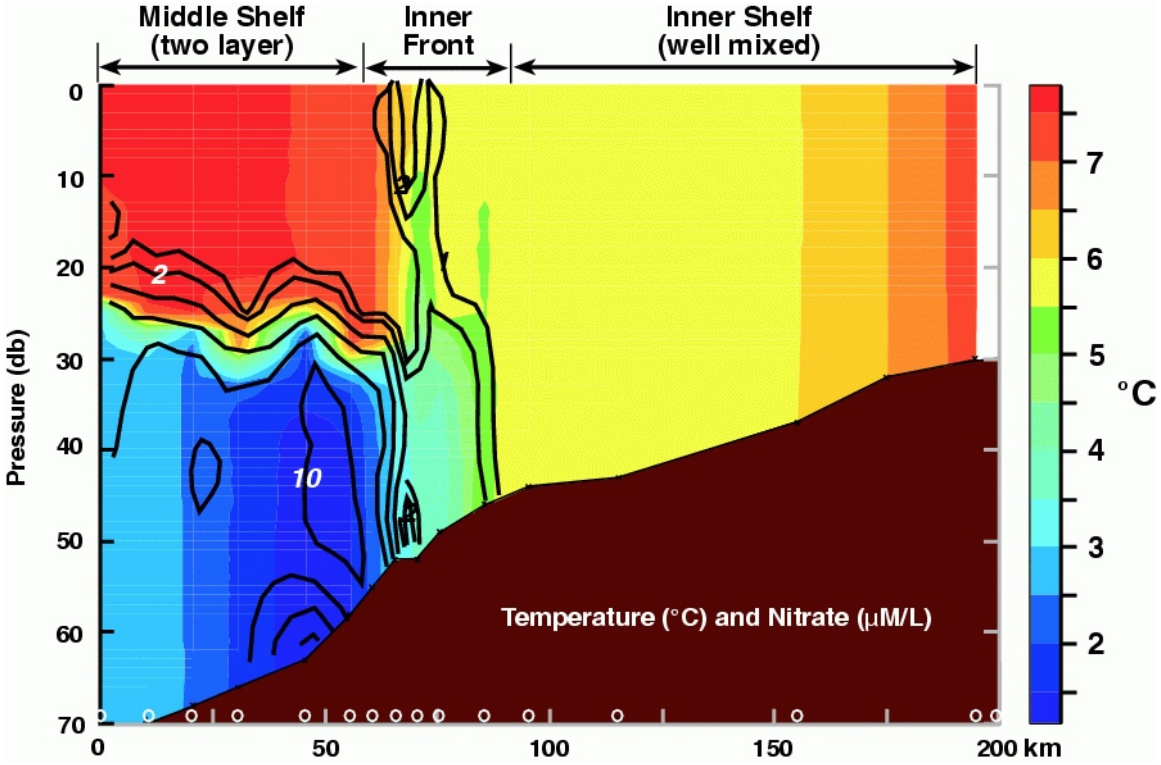



Fig. 1.2. Contours of temperature (color shading; °C) indicating a vertical front near shore, and distinct layers separated by a thermocline in deeper water. Black lines indicate nitrate (mmoles); and the locations of the CTD stations are marked along the bottom axis.(From Kachel et al., in 2002 cited in P.J. Stabeno, G.L. Hunt, Jr., J.M. Napp, J.D. Schumacher. 2005. Physical forcing of ecosystem dynamics on the Bering Sea Shelf, Chapter 30 in The Sea, Vol. 14, A.R. Robinson and K. Brink (eds.). Harvard College. Retrieved 8 Jul 2008 from http://www.pmel.noaa.gov/pubs/outstand/stab2529/stab2529.shtml

primarily as either determinations of density or conductivity. In this lab we will measure the refraction of light through a water sample, which varies by water density.

Salinities are properly expressed on a mass per mass basis (grams solutes per kilogram solution) and as ppt (parts per thousand, also abbreviated $^{o}/_{oo}$) and are reported either as unitless or as ppt. The symbol $^{o}/_{oo}$ is similar to parts per hundred (percent) abbreviated %.

The major dissolved ions in seawater are those that exist at concentrations of at least 1mg/kg (>0.001 $^{o}/_{oo}$). These are, from more to less abundant by mass: $Cl^{-}$, $Na^{+}$, $Mg^{++}$, $SO4^{-}$, $Ca^{++}$, $K^{+}$, $HCO4^{-}$; and their ratio in seawater is constant. Thus it is possible to calculate the concentrations of all of these ions from the known concentration of any one of them. Open ocean salinity is approximately 35 $^{o}/_{oo}$, which means that there are 35 g of dissolved salts in each 1000 g of seawater. Near shore, however, seawater is diluted by freshwater from river discharge. In outer Cook Inlet by Kodiak Island, ocean salinity is typically 35 $^{o}/_{oo}$. However, waters of the upper inlet near Anchorage may be 15 salinity or lower[2].

Marine organisms must maintain reasonably constant internal conditions with respect to salt concentrations. Some species conform to the environment; their internal ionic composition is similar to and varies with, changes in external salinity. Other organisms regulate their internal environments by selectively absorbing some ions and preventing others from entering, or by actively excreting excess ions. The distribution of species in the marine environment depends upon the ability of each species to tolerate changing conditions of salinity.

**Density** (after Sumich & Dudley)

Density is a property of all types of matter, including water. **Density is the ratio of the mass of a substance to its volume and is given in grams per cubic centimeter (g/cm$^3$)**. The density of seawater varies from place to place depending on its salinity (often lower in coastal waters) and temperature. The density of the water in which marine organisms live influences several aspects of their lives, such as the flotation of planktonic and nektonic forms. In addition, sinking masses of higher-density seawater carry oxygen-rich waters from the surface to greater depths as less-dense nutrient rich water moves upward. Ocean productivity depends on these supplies of nutrient rich water. Sinking and rising of ocean water masses due to differences in density drive deep-water ocean currents, which regulate heat-transfer around the globe, and contribute to the formation of global climate regimes.

One gram of pure water has a density of 1.000 g/cm$^3$ at 4˚C, by metric system definition of a gram. Density declines in either direction from this reference temperature, as colder water tends toward the formation of ice crystals which are less dense than water at this reference temperature, while warmer water expands. Thus, above 4 ° C, density decreases curvilinearly with a temperature rise (Fig. 1.3). Similarly, salts dissolved into water increases the mass with minimal volume change, and density increases linearly with a salinity increase. Thus density increases as water becomes colder and more saline.

Two other metrics are closely related to density (g/cm$^3$), but you will be expected to be distinguish among them. First, **specific gravity is the (unitless) ratio of the density of a sample to that of distilled water both at the same temperature**. As you may surmise, at 4˚C (divide by 1.000 g/cm$^3$) the specific gravity does not differ from density in its value, only in its units[3]. However, because specific gravity is a ratio of densities, its exact value will depend on temperature. Second, **a hydrometer reading is the value indicated by a hydrometer floating in the water sample**. Hydrometers are carefully calibrated to float at exactly 1.000 in distilled water at 4˚C. To provide accurate results, hydrometer readings must be corrected with

[2] Note the use in this paragraph of both standards for the unitless scale: a salinity of **35 $^{o}/_{oo}$** or waters of **35 salinity**.

[3] Differences are no more than 0.001 between H, specific gravity and density.

tables for the temperatures at which measurements are taken, but they are numerically close to the specific gravity of a sample.

**Dissolved oxygen solubility** (after Haefner)
Oxygen dissolved in water is essential to aquatic organisms, as oxygen in the air is to terrestrial forms. While the atmosphere is an important source of **dissolved oxygen (DO)**, phytoplankton, macroscopic algae and higher marine plants also increase the amount of DO in the water.

Oxygen is generally not a limiting factor in the ocean; seawater normally contains between 5 and 14 parts per million (ppm)(= mg/L) DO. The survival of many organisms is threatened when the concentration decreases below that range (conditions become **hypoxic**). Oxygen content can be depleted in a variety of ways. For example, increased temperature increases the metabolism of most aquatic animals, causing them to consume more oxygen per unit of time than at a lower temperature. Higher temperature also decreases the solubility of oxygen in water, and thus reduces its availability to aquatic organisms. Bacterial decomposition consumes enormous quantities of oxygen and can cause a system to rapidly become **anoxic (no oxygen)**.

The amount of oxygen that can dissolve in water depends primarily on temperature and salinity (Fig. 1.4). Because these relationships are well defined, oxygen solubility can be predicted from these variables using a **nomograph (a chart relating three or more scales across which a straightedge can be placed to provide a graphical solution for a particular relationship among the scales)**. The calculated values are theoretical – that is, the represent expected conditions, provided that the waters are well-mixed and the supply of oxygen not limiting. If the observed DO concentration equals the expected solubility, the water is said to be fully saturated (**100% saturation**). Biological respiration can reduce DO concentrations to values below saturation level. On the other hand, excessive photosynthetic activity can produce **supersaturated** conditions (greater than 100%).

**PROCEDURES**

**Hydrological stations**

Marine scientists often refer to **stations (a sampling location occupied by the survey vessel)** and distinguish these from **samples (each individual water sample or other record taken at a particular time while on a station)**. A sample may be the surface water at noon, or the water from 100 m depth at a particular time, or the contents of a plankton net towed from 20 m to the surface on station at 06:00.

Examine the Hydrographic Station Log with Water Samples, attached. In addition to its temperature and salinity, each water sample will have an associated date, time, location and depth where it was collected that characterize a particular visit to the hydrological station. Generally, these are known as **metadata (data that characterize other data**). Note that the **types of data (fields)** to be recorded differ between the Stations and the samples. This will also be true between sampling of different types (for example a water sample and a plankton tow) conducted at a single station. However, for a single type of sampling, all **individual samples (records)** should have the same fields. Be sure to record all Station data any time sampling is conducted. This is important whether the sample is left in situ, immediately measured in the field, or taken back to the lab.

Collect water samples from each assigned station, and measure temperature, salinity and density as indicated. If you are participating in the Fall block trip to Prince William Sound, samples will include the lab aquariums and pure water, as well as samples from hydrological stations at (1) upper Valdez arm above the Narrows, (2) lower Valdez arm below the Narrows, (3) outside Tatitlek Narrows, (4) inside Ellamar Bay at low & high tides, and (5) Busby Island shore line. If you are on a different field trip, your instructor will assign stations.

*Surface samples*

For the lab samples, and at shallow sites (numbers 4-5 above) you will collect a surface water sample

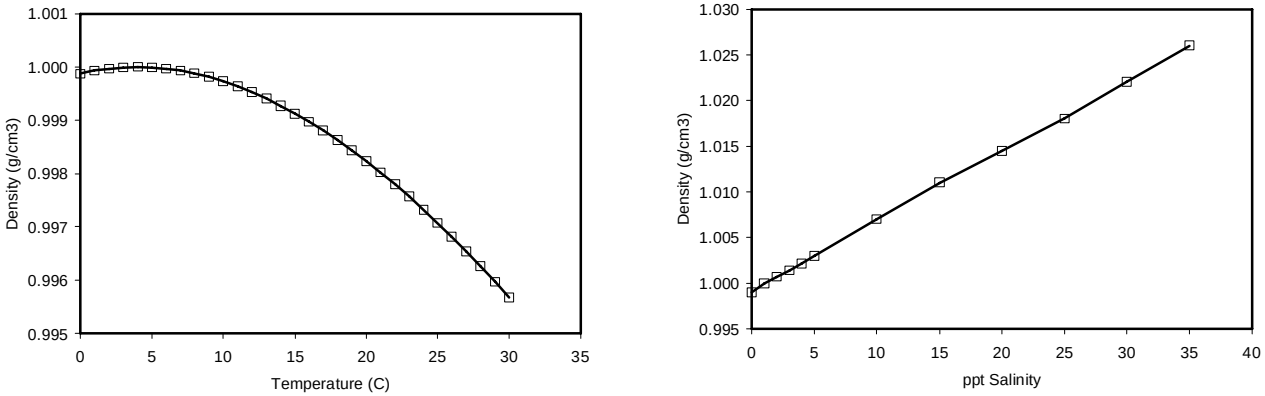



Fig. 1.3. The relationships of density to temperature of pure water (left), or to salinity of water at 15 °C (right). Each y-axis is scaled in thousandths. Note that the scale of density change that occurs over typical temperatures and salinities of seawater is greater for increasing salinity (up to 30 g per liter) than for temperature (5 g/L).

Graphs for this class must follow the format of these examples. Prepare graphs in black and white (do not use color). Different data sets may use different markers or shading. These graphs were prepared in Excel, using the settings: Format plot, area=none, border=black & thick. Clear gridlines. Format data series, marker foreground=black, marker background=none (any shape), size=10, line=black & thick. Format chart, font size=18. Format Y-axis, number decimal places=3. Notice that x-and y-axes labels were entered with units. The chart titles were deleted, and a figure caption provided instead; and legends were not necessary and were deleted (legends may be included where appropriate, or may be indicated in the figure caption).

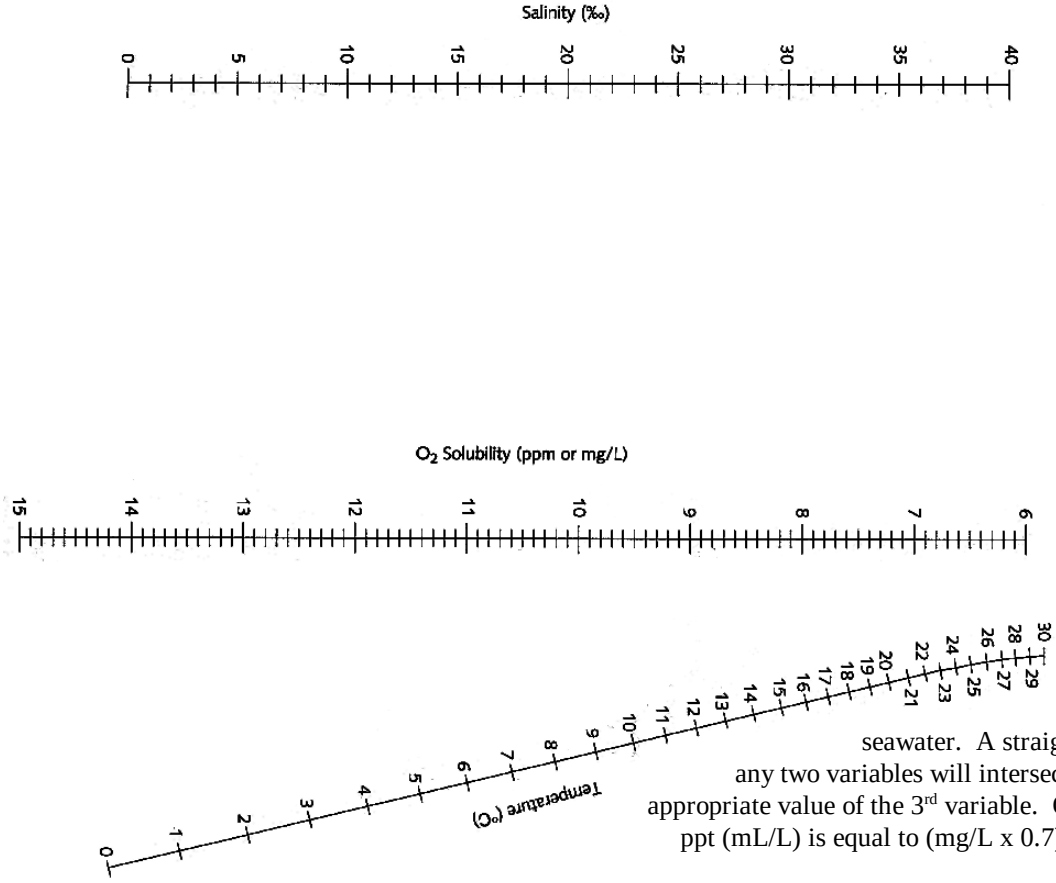



Figure 1.4 Nomograph of oxygen solubility in seawater. A straight line run between any two variables will intersect the 3rd scale at the appropriate value of the 3rd variable. Oxygen solubility in ppt (mL/L) is equal to (mg/L x 0.7). [Haefner Fig. 1.8]

only. Each of these stations will therefore have a single water sample associated with it.

*Profile samples*
At stations over deep water (numbers 1-3 above), you will collect profile water samples, including a surface sample, samples from one or more depths using a water-sample bottle, and a temperature-depth profile using the Sensus data-logger.

1. Collect and measure a surface water sample as described below.

2. The SENSUS data recorder is a small pressure- and temperature-sensitive device made for the recreational dive industry. **Although the sensor itself is waterproof, the accompanying cable and computer interface are not: please keep these dry and out of the rain.** No water should ever be allowed inside the case.

The SENSUS data recorder captures the time, depth, and temperature at regular time intervals (not depth intervals). The unit begins recording whenever the pressure sensor detects a pressure equivalent to 4 feet (or more) of sea water, and stops recording 3 minutes after an ascent to less than 4 feet of sea water. The SENSUS will record depths to 500 feet with an accuracy of ±1 foot. It cannot be lowered below 500 ft without damage, turns on and off as described by water pressure, and data must be downloaded from the unit to a lap-top computer after each SENSUS dive.

3. Attach SENSUS to a metered line, such as the 100-m tape. If you will also collect a water sample from depth, also attach the collection bottle (see below). Lower the line to the maximum depth, and then reel it **slowly** up. **Do not allow SENSUS below 500' or you will damage the unit[4].** Temperatures on the ascent will be more accurate than on the descent as the temperature of the sensor reaches equilibrium with the water. The data logger records at fixed *time* intervals – **a rapid retrieval will not give the sensor time to register the water temperature as it passes through**.

4. On retrieval, detach, rinse and dry the sensor. Ask your professor or T.A. to download the data immediately after each dive, or install the software on your own laptop and download the data. Check that the sample was properly recorded and saved to disk.

5. A water sampling bottle is available, closed at each end with balls pulled tight with a bungee. A quick-release pin allows the closures to be held open, and then released at depth by a sharp upward tug on the line. Use this to retrieve water samples from a few depths at one or two stations (consider 0, 3, 10, 50 & 100 m). If you can determine where a thermocline is, sample the water both above and below the thermocline.

6. Pull both balls back from the openings. Each ball is attached to a metal tube; slide the thin one into the thicker and align the holes. Hold the balls in the open position by sliding the quick-release pin through this hole.

7. Attach the loop in the white line to the end of the line on which you will deploy the sampler. For example, clip this to the end of the 100-m tape on a reel near SENSUS. You may find the unit triggers immediately if its full weight dangles in air from the line. Instead carefully support its weight as you lower it over the side.

8. Be sure enough weight is attached to the line and sampling gear to allow it to sink rapidly but not so much that the water bottle is triggered immediately. It is desirable that the line descend as vertically as possible, although this will be affected by wind, drift and current.

9. When the end of the line appears to have reached the desired depth, yank **sharply** upwards on the line **several times** to trigger the water bottle. If you hold the line at this depth for a few

[4] The maker provided SENSUS's depth limit in feet; your line is marked in *meters*. NASA engineers lost a spacecraft by failing to convert. **Don't make the same mistake.**

minutes, SENSUS should register a pause, allowing you to determine the exact depth from which the water sample was collected.

**Temperature**
Once a sample is removed from the ocean or aquarium, its temperature will begin to change immediately. Therefore use a thermometer to record the temperature immediately on acquiring the sample. The temperature should be obtained at the same time and condition as the hydrometer readings.

SENSUS will collect in-situ temperature data, but it is important to allow the unit several minutes in the water to equilibrate in temperature with its surroundings.

**Determination of Salinity** (after Haefner)
*Calculation of salinity from hydrometer readings*
Salinity and temperature affect the density of water in a regular fashion (see Fig. 1.3). Thus, salinity can be calculated from density of seawater of known temperature. **Hydrometers (calibrated glass floats)** are used to measure the density. Hydrometers work on the **Archimedes Principle, which states that a floating object (such as a hydrometer, an iceberg or a ship) will displace a weight of fluid equal to its own weight**. Consequently, when the hydrometer is place into solutions of different densities, it floats higher or lower, until it just displaces its own weight. In denser fluids it floats higher (displacing less fluid) and in less dense fluids it floats lower. The higher the hydrometer is buoyed by the water sample, the denser the water. A conversion table allows you to calculate salinity from the observed density and temperature readings. The procedure is simple, quick and inexpensive, but less accurate than other methods.

1. Use the same format as the Hydrographic Station Log with Water Samples, attached. Be sure Station metadata are recorded for each sample obtained.

2. Place the water sample in a clear-sided container tall enough to float the hydrometer. In the field, use a plastic 100 to 500 ml graduated cylinder, as these are not as fragile as glass containers. Fill the container near-full with the sample water.

3. Open the hydrometer case. **Hydrometers are made of glass, with lead weights. They are fragile and will break if dropped or miss-handled. *Do not hold the hydrometer by the thin stem*.** Remove the hydrometer and place it in the water sample. Ideally it should be close to the temperature of the water sample to begin with. Small bubbles adhering to the float will badly skew the readings; inspect the hydrometer to ensure any such bubbles have been dislodged.

4. Record the **hydrometer reading, H**, and water sample **temperature** from the hydrometer. H is read at the **meniscus** of the water. Rinse and dry the hydrometer and carefully replace it in its case. Close the cases gently as over-tightening can break the hydrometer.

*Reading salinity from a refractometer*
(after Sumich & Dudley)
Refractometry is an alternative simple and rapid method for measuring seawater salinity. However, refractometers cost about five times the price of a floating glass hydrometer. **The instrument is *not* waterproof, and is fragile. Please handle carefully.**

Refractometry is based on the **refraction, or bending**, of light as it passes through a boundary between transparent materials of different densities (i.e. glass to water). In water, the amount of refraction increases with density (increasing salinity and decreasing temperature). The refractive index of water can be measured with a refractometer, however many are temperature-compensated and scaled for particular uses so that salinity can be read directly rather than the refractive index. The refractometers used in this lab have automatic temperature compensation.

1. Check the calibration of the refractometer by placing 2 drops[5] of pure water (reverse-osmosis, de-ionized or distilled water) on the glass face of the prism. Before doing so, rinse the dropper with the water so that the sample in the dropper is not contaminated by residual salt from previous use. Lower the plastic cover plate onto the water drops so that they are spread evenly between the prism and the cover plate.

2. Aim the prism plate at a bright light source. Look through the eyepiece and if necessary rotate the eyepiece until the scale comes into focus.

3. Read the scale where the sharp boundary line between blue and white crosses the scale values (Fig. 1.5). For pure water, the value should be 1.000 on the density scale or a salinity of 0 $^{o}/_{oo}$. If the reading is higher, suspect contamination from the last user. Carefully rinse the prism and cover plate with pure water. **Do NOT immerse other parts of the refractometer.**

4. Dry the prism and cover plate of the refractometer **with a KimWipe** (paper towels, your fingers, shirts, or other materials may scratch the prism if used to dry it, or may leave lint or other residues behind).

5. Repeat the procedure with 2 drops of your sample and record the salinity reading in the appropriate place on your Station Log under water samples. A temperature-corrected specific gravity scale is also available. Record the reading in the appropriate place on your Station Log under Water Samples. Note the correspondence of this scale to the values in Table 1.1 (below).

6. Rinse and dry the prism , so that the residue of this sample does not contaminate its next use.

[5] There is a dropper and tiny screwdriver in each case. Do not lose these. At times, the pin holding the cover plate can become loose and slip out. Make sure this does not happen to you.

Use the dropper for the samples; to keep it clean, never touch it to anything other than the samples, and rinse it after each use.

Returning the refractometer to its case, ensuring that the inside of the case remains dry so that instrument does not rust.

**Density from Hydrometer reading**

1. Convert the hydrometer reading H (indicated in table 1.2 as "Measured density") to density at 15° C using Table 1.2 from Haefner, attached, and the recorded temperature of the water sample. Record this conversion in the appropriate space on your Station Log under Water Samples.

6. Determine the salinity of the sample from Table 1.1, below, using the temperature-corrected density from the previous step. Record this salinity in your station log.

Table 1.1 Density-salinity conversion Table 15° C (from Haefner Table 1.3)

| Density @ 15 °C | Salinity $^{o}/_{oo}$ | Density @ 15 °C | Salinity $^{o}/_{oo}$ |
|---|---|---|---|
| 0.999 | 0 | 1.015 | 21 |
| 1.000 | 1 | 1.016 | 22 |
| 1.001 | 2 | 1.017 | 23 |
| 1.002 | 4 | 1.018 | 25 |
| 1.003 | 5 | 1.019 | 26 |
| 1.004 | 6 | 1.020 | 27 |
| 1.005 | 8 | 1.021 | 29 |
| 1.006 | 9 | 1.022 | 30 |
| 1.007 | 10 | 1.023 | 31 |
| 1.008 | 12 | 1.024 | 32 |
| 1.009 | 13 | 1.025 | 34 |
| 1.010 | 14 | 1.026 | 35 |
| 1.011 | 15 | 1.027 | 36 |
| 1.012 | 17 | 1.028 | 38 |
| 1.013 | 18 | 1.029 | 39 |
| 1.014 | 19 | 1.030 | 40 |

Salinity values obtained from this table should be considered approximations.

**Oxygen solubility**

We will not measure oxygen content of the water directly in this lab. However, use the nomograph in Fig. 1.4 to find the solubility of oxygen in each of your water samples. Record these values in the appropriate place on your Station Log under Water Samples.

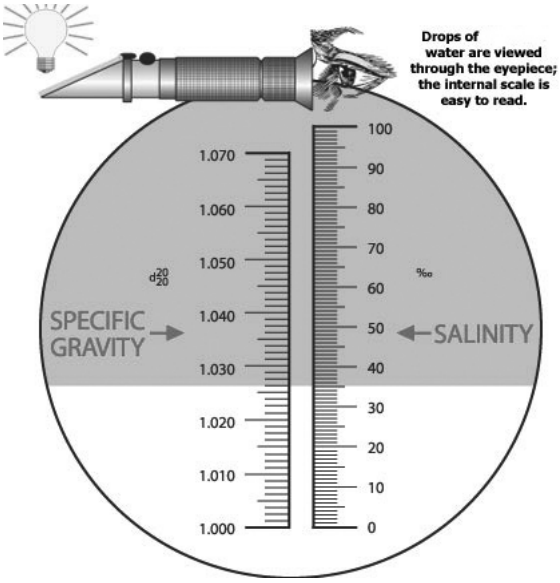



Fig. 1.5. The refractometer is read through the eyepiece with the prism facing a bright light source. The internal scale should be crisp and sharp; if necessary turn the eyepiece to focus. The salinity is read where the line demarcating the blue (or grey) field from the white field crosses the scale. Note the temperature-corrected specific gravity is also provided.

**Table 1.2** Temperature Correction Table (Density Measurements)

| Measured Density | Measured Water Temperature (°C) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6–10 | 11 | 12 | 13–17 | 18 | 19–21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 1.000 | 1.000 | 1.000 | .999 | .999 | .999 | .999 | .999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.001 | 1.002 | 1.002 | 1.002 | 1.002 | 1.003 | 1.003 | 1.003 |
| 1.001 | 1.001 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.001 | 1.001 | 1.002 | 1.002 | 1.002 | 1.003 | 1.003 | 1.003 | 1.003 | 1.004 | 1.004 | 1.004 |
| 1.002 | 1.002 | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 | 1.001 | 1.002 | 1.002 | 1.002 | 1.003 | 1.003 | 1.003 | 1.003 | 1.004 | 1.004 | 1.004 | 1.004 | 1.005 | 1.005 | 1.005 |
| 1.003 | 1.002 | 1.002 | 1.002 | 1.002 | 1.002 | 1.002 | 1.002 | 1.003 | 1.003 | 1.003 | 1.004 | 1.004 | 1.004 | 1.005 | 1.005 | 1.005 | 1.005 | 1.005 | 1.006 | 1.006 | 1.006 |
| 1.004 | 1.003 | 1.003 | 1.003 | 1.003 | 1.003 | 1.003 | 1.003 | 1.004 | 1.004 | 1.004 | 1.005 | 1.005 | 1.005 | 1.006 | 1.006 | 1.006 | 1.006 | 1.006 | 1.007 | 1.007 | 1.007 |
| 1.005 | 1.004 | 1.004 | 1.004 | 1.004 | 1.004 | 1.004 | 1.004 | 1.004 | 1.005 | 1.005 | 1.006 | 1.006 | 1.006 | 1.007 | 1.007 | 1.007 | 1.007 | 1.007 | 1.008 | 1.008 | 1.008 |
| 1.006 | 1.005 | 1.005 | 1.005 | 1.005 | 1.005 | 1.005 | 1.005 | 1.005 | 1.006 | 1.006 | 1.007 | 1.007 | 1.007 | 1.008 | 1.008 | 1.008 | 1.008 | 1.009 | 1.009 | 1.009 | 1.009 |
| 1.007 | 1.006 | 1.006 | 1.006 | 1.006 | 1.006 | 1.006 | 1.006 | 1.006 | 1.007 | 1.007 | 1.008 | 1.008 | 1.008 | 1.009 | 1.009 | 1.009 | 1.009 | 1.010 | 1.010 | 1.010 | 1.010 |
| 1.008 | 1.007 | 1.007 | 1.007 | 1.007 | 1.007 | 1.007 | 1.007 | 1.007 | 1.008 | 1.008 | 1.009 | 1.009 | 1.009 | 1.010 | 1.010 | 1.010 | 1.010 | 1.011 | 1.011 | 1.011 | 1.011 |
| 1.009 | 1.008 | 1.008 | 1.008 | 1.008 | 1.008 | 1.008 | 1.008 | 1.008 | 1.009 | 1.009 | 1.010 | 1.010 | 1.010 | 1.011 | 1.011 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 |
| 1.010 | 1.009 | 1.009 | 1.009 | 1.009 | 1.009 | 1.009 | 1.009 | 1.009 | 1.010 | 1.010 | 1.011 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 |
| 1.011 | 1.010 | 1.010 | 1.010 | 1.010 | 1.010 | 1.010 | 1.010 | 1.010 | 1.011 | 1.011 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.013 | 1.014 | 1.014 | 1.014 | 1.015 |
| 1.012 | 1.011 | 1.011 | 1.011 | 1.011 | 1.011 | 1.011 | 1.011 | 1.011 | 1.012 | 1.012 | 1.013 | 1.013 | 1.013 | 1.014 | 1.014 | 1.014 | 1.014 | 1.015 | 1.015 | 1.015 | 1.016 |
| 1.013 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.013 | 1.013 | 1.014 | 1.014 | 1.014 | 1.015 | 1.015 | 1.015 | 1.015 | 1.016 | 1.016 | 1.016 | 1.017 |
| 1.014 | 1.013 | 1.013 | 1.013 | 1.013 | 1.013 | 1.013 | 1.013 | 1.013 | 1.014 | 1.014 | 1.015 | 1.015 | 1.015 | 1.016 | 1.016 | 1.016 | 1.016 | 1.017 | 1.017 | 1.017 | 1.018 |
| 1.015 | 1.014 | 1.014 | 1.014 | 1.014 | 1.014 | 1.014 | 1.014 | 1.014 | 1.015 | 1.015 | 1.016 | 1.016 | 1.016 | 1.017 | 1.017 | 1.017 | 1.017 | 1.018 | 1.018 | 1.018 | 1.019 |
| 1.016 | 1.015 | 1.015 | 1.015 | 1.015 | 1.015 | 1.015 | 1.015 | 1.015 | 1.016 | 1.016 | 1.017 | 1.017 | 1.018 | 1.018 | 1.018 | 1.018 | 1.019 | 1.019 | 1.019 | 1.019 | 1.020 |
| 1.017 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.017 | 1.018 | 1.018 | 1.019 | 1.019 | 1.019 | 1.019 | 1.020 | 1.020 | 1.020 | 1.020 | 1.021 |
| 1.018 | 1.017 | 1.017 | 1.017 | 1.017 | 1.017 | 1.017 | 1.017 | 1.017 | 1.017 | 1.018 | 1.019 | 1.019 | 1.020 | 1.020 | 1.020 | 1.020 | 1.021 | 1.021 | 1.021 | 1.021 | 1.022 |
| 1.019 | 1.018 | 1.018 | 1.018 | 1.018 | 1.018 | 1.018 | 1.018 | 1.018 | 1.018 | 1.019 | 1.020 | 1.020 | 1.021 | 1.021 | 1.021 | 1.021 | 1.022 | 1.022 | 1.022 | 1.022 | 1.023 |
| 1.020 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.020 | 1.021 | 1.021 | 1.022 | 1.022 | 1.022 | 1.022 | 1.023 | 1.023 | 1.023 | 1.023 | 1.024 |
| 1.021 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.021 | 1.022 | 1.022 | 1.023 | 1.023 | 1.023 | 1.023 | 1.024 | 1.024 | 1.024 | 1.025 | 1.025 |
| 1.022 | 1.021 | 1.021 | 1.021 | 1.021 | 1.021 | 1.021 | 1.021 | 1.021 | 1.021 | 1.022 | 1.023 | 1.023 | 1.024 | 1.024 | 1.024 | 1.024 | 1.025 | 1.025 | 1.025 | 1.026 | 1.026 |
| 1.023 | 1.021 | 1.021 | 1.022 | 1.022 | 1.022 | 1.022 | 1.022 | 1.022 | 1.022 | 1.023 | 1.024 | 1.024 | 1.025 | 1.025 | 1.025 | 1.025 | 1.026 | 1.026 | 1.026 | 1.027 | 1.027 |
| 1.024 | 1.022 | 1.022 | 1.022 | 1.023 | 1.023 | 1.023 | 1.023 | 1.023 | 1.023 | 1.024 | 1.025 | 1.025 | 1.026 | 1.026 | 1.026 | 1.026 | 1.027 | 1.027 | 1.027 | 1.028 | 1.028 |
| 1.025 | 1.023 | 1.023 | 1.023 | 1.023 | 1.024 | 1.024 | 1.024 | 1.024 | 1.024 | 1.025 | 1.026 | 1.026 | 1.027 | 1.027 | 1.027 | 1.027 | 1.028 | 1.028 | 1.028 | 1.029 | 1.029 |
| 1.026 | 1.024 | 1.024 | 1.024 | 1.024 | 1.024 | 1.025 | 1.025 | 1.025 | 1.025 | 1.026 | 1.027 | 1.027 | 1.028 | 1.028 | 1.028 | 1.028 | 1.029 | 1.029 | 1.029 | 1.030 | 1.030 |
| 1.027 | 1.025 | 1.025 | 1.025 | 1.025 | 1.025 | 1.026 | 1.026 | 1.026 | 1.026 | 1.027 | 1.028 | 1.028 | 1.029 | 1.029 | 1.029 | 1.029 | 1.030 | 1.030 | 1.030 | 1.031 | 1.031 |
| 1.028 | 1.026 | 1.026 | 1.026 | 1.026 | 1.026 | 1.027 | 1.027 | 1.027 | 1.027 | 1.028 | 1.029 | 1.029 | 1.030 | 1.030 | 1.030 | 1.031 | 1.031 | 1.031 | 1.031 | 1.032 | 1.032 |
| 1.029 | 1.027 | 1.027 | 1.027 | 1.027 | 1.027 | 1.027 | 1.028 | 1.028 | 1.028 | 1.029 | 1.030 | 1.030 | 1.031 | 1.031 | 1.031 | 1.032 | 1.032 | 1.032 | 1.032 | 1.033 | 1.033 |
| 1.030 | 1.028 | 1.028 | 1.028 | 1.028 | 1.028 | 1.028 | 1.029 | 1.029 | 1.029 | 1.030 | 1.031 | 1.031 | 1.032 | 1.032 | 1.032 | 1.033 | 1.033 | 1.033 | 1.033 | 1.034 | 1.034 |
| 1.031 | 1.029 | 1.029 | 1.029 | 1.029 | 1.029 | 1.029 | 1.030 | 1.030 | 1.030 | 1.031 | 1.032 | 1.032 | 1.033 | 1.033 | 1.033 | 1.034 | 1.034 | 1.034 | 1.034 | 1.035 | 1.035 |

Density of Water at 15 °C

Note: This table provides temperature-corrected densities at 15 °C of water densities measured at other temperatures. For example, if a water sample having a measured density of 1.023 at 22 °C were cooled to 15 °C, the density would be 1.025.

For more accurate results adjust the water temperature of your sample to 15 °C before making a hydrometer reading rather than use this table.

1. Position a ruler or other straight edge on the nomograph so that the measured values of salinity and temperature are on a line. The line will cross the oxygen scale at the oxygen solubility (in mg / L) of the sample.

**Analyses**
You will now complete a graphical examination of your water sample data, and compare water samples taken from different locations and depths. Your samples should include those listed under Stations, above.

1. Provide a table of data called for in the Station Log with Water Samples in your write-up. Be sure to include all stations and water samples.

2. Plot salinity (on the x-axis) vs. temperature-corrected density; and plot temperature (x-axis) vs. H (why not vs. density?). Use a single method (e.g. refractometer) for your salinity data. Be sure to label each point and each axis, include scale and units. Note that you may use the same graph for both curves, as long as you clearly label two different scales and units on the x-axis.

What are the relationships of temperature and salinity to density? Does the effect of temperature on density revealed by your graph differ from the expected curve in Fig. 1.3? Why? What is the importance of density to understanding ocean water masses and currents?

3. Plot temperature (on the x-axis) vs. depth from the SENSUS data. Format your depth axis as noted in Fig. 1.1. Indicate the thermocline for each station, if one exists.

4. Plot salinity (on the x-axis) vs. depth from your water bottle and surface samples for each station where you have water samples from depth. Compare this plot to that of temperature by depth. Does salinity change dramatically near the thermocline? Are the surface waters of different salinity than at depth?

5. Examine spatial trends in salinity & temperature by distance to open ocean. Plot your samples on the map provided and describe any patterns.

The salinity of the open ocean is approximately 35 ppt. Values measured in this exercise are often much lower than this: why? Will this same reason be affected by seasonal temperature extremes; or in turn cause a seasonal affect on ocean water temperature? Did you notice any difference in ocean organisms across sampling sites that might be related to this same factor?

**What to turn in**:
1. Table of data indicated in Analyses #1.
2. Graphs as described in Analyses #2-4
3. Map as described in Analyses #5.
4. Typed answers to questions in Analyses #2-5 demonstrating careful consideration of your results. Use complete sentences. Number your answers with corresponding Analyses section numbers.

All submitted materials must be organized, neat and clear. Tables must have columns and rows aligned and be properly labeled. Graphs must follow examples in Fig. 1.1 and 1.3, with proper labels.

Students may collaborate on data collection and review each other's work, but your report must be your own original work.

Hydrographic Station Log with Water Samples Name _____

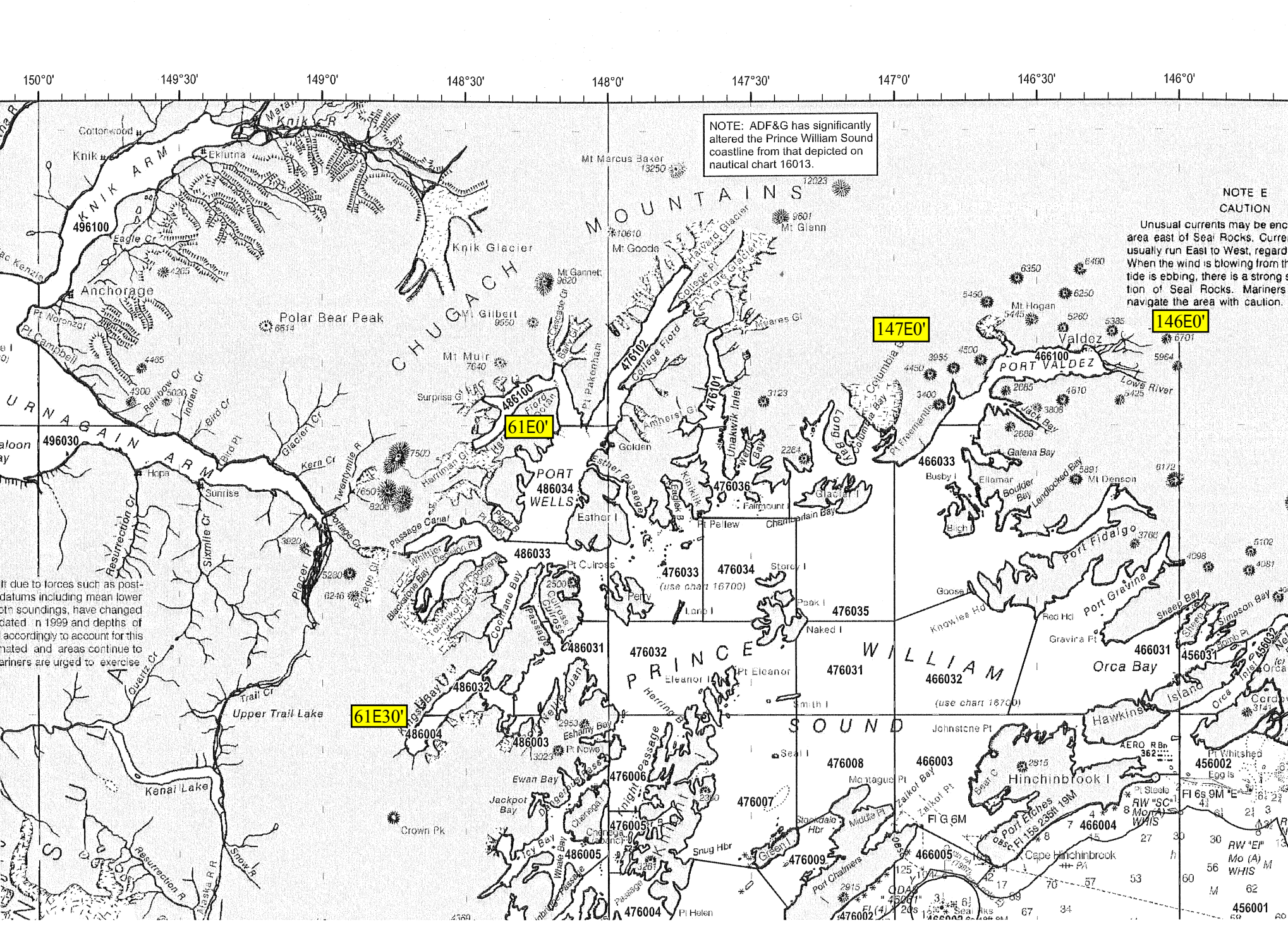
**Station Log** - Fill out one record for each station at which water sampling was conducted.

| Station # | Date | Time | Station name | Latitude | Longitude | Sensus[1] depth m | Observer, comments |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |

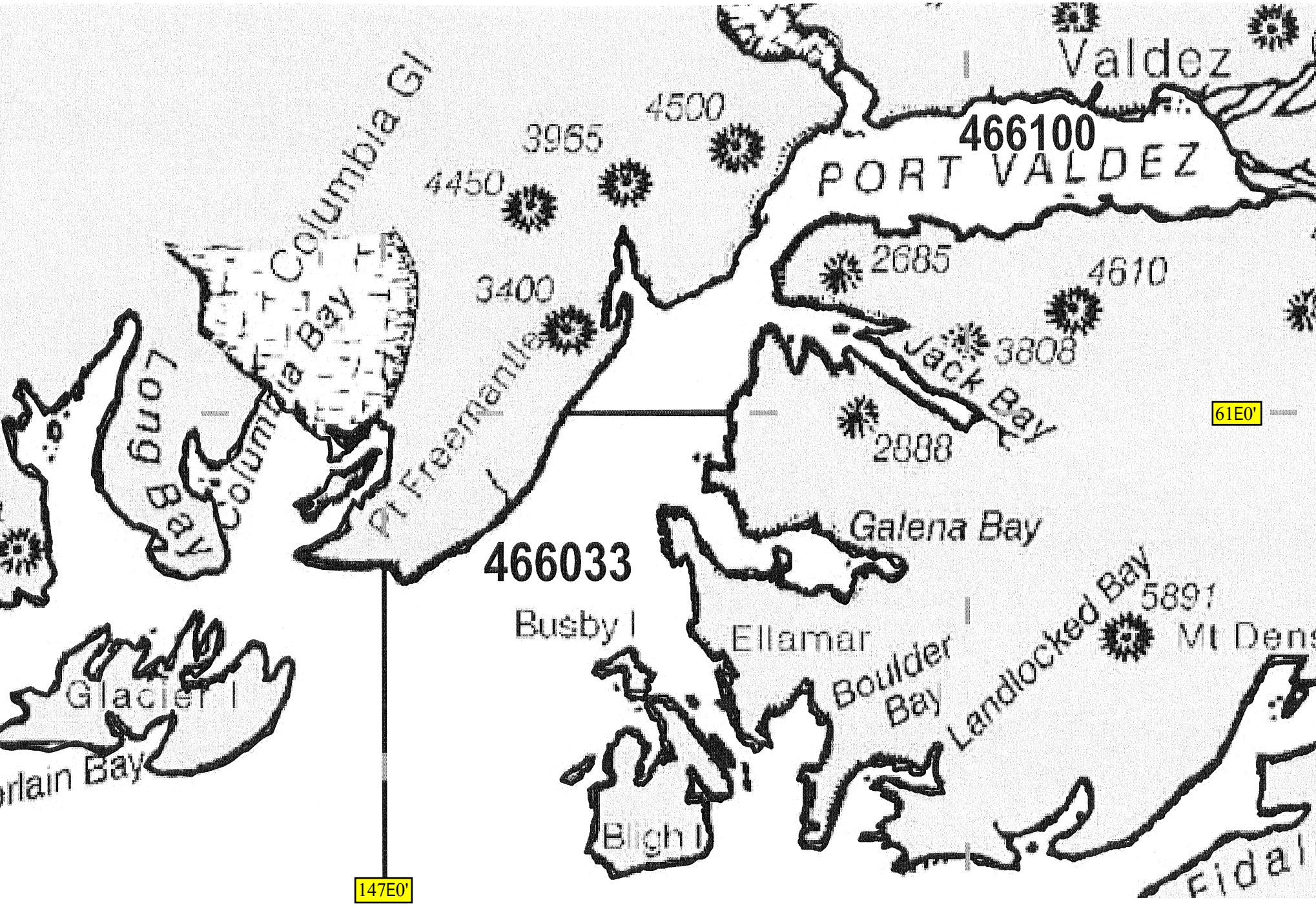
[1] Sensus depth: N=No Sensus profile conducted; otherwise indicate the maximum depth in meters to which the Sensus dive profiler was deployed at this station.

**Water samples** - Fill out one record for each water sample. You may have samples from different depths at a single station.

| Station # | Depth m | Temp C | H | T corr density @ 15 C | Salinity from Table | Salinity from refract. | Sp. gravity 20/20 from refract. | Expected $O_2$ solubility mg / L |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |




...lt due to forces such as post-
...datums including mean lower
...oth soundings, have changed
...dated in 1999 and depths of
...accordingly to account for this
...nated and areas continue to
...ariners are urged to exercise


Valdez
466100
PORT VALDEZ
4500
3965
4450
3400
2685
4610
3808
2888
Jack Bay
Galena Bay
61E0'
466033
Busby I
Ellamar
Boulder Bay
Landlocked Bay
5891
Mt Dens
Bligh I
Fidal
Glacier I
orlain Bay
Columbia Bay
Columbia Gl
Long Bay
Pt Freemantle
147E0'