WATER CONDUCTIVITY IN STREAM ENVIRONMENTS

BACKGROUND

Conductivity, a meaure of electrical current flow through a solution, is expressed in units of microSiemens (μS). Conductivity is the reciprocal of electrical resistance (ohms).

Because conductivity increases nearly linearly with increasing ion concentration, we can use conductivity measurements to estimate ion concentrations in solutions. Seawater conductivity is approximately 5000μS, household tap water is about 110μS, and distilled water is near 0μS.

Conductivity can tell us a lot about the nature of a stream. For example, low-conductivity streams typically have less groundwater input than high-conductivity streams, i.e., they are "precipitation-dominated."

Thus, they also have more dynamic flow and temperature regimes. Conductivity also indicates the degree to which a watershed's bedrock and mineral soil resists erosion.

MEASUREMENT

Water conductivity is measured by the diminution of electrical current passed through a water sample. Higher concentrations of electrolytes in the sample solution permit a larger fraction of the current emitted by one probe to reach the sensor probe, and produce a higher the conductivity measurement (greater μS).

Conductivity is influenced by temperature (μS can change by up to 3% per °C) so measurements are sometimes temperature compensated to correspond to μS at 25° C. Calibration of the conductivity sensor with reference solutions of known conductivity is critical to obtaining good measurements.

BIOLOGICAL RELEVANCE

Organisms in precipitation-dominated streams, indicated by low conductivity, must be able to withstand floods, dry downs, and scouring by anchor ice. Many have adaptations to persist through stressful periods in a state of quiescence or to seek refuge in protected microhabitats.

Most animals in low-conductivity streams must also maintain high internal ion concentrations relative to those in the surrounding environment. Conductivity is linearly related to osmolarity (mOsm / liter = 5.79 + 0.0734 uS for NaCl).

Because these animals are extremely hyperosmotic to their environment, there is a tendency for uptake of water and loss of ions, especially across respiratory surfaces, which are necessarily permeable.

Therefore osmoregulation involves the elimination of water, the retention of ions, and active transport of ions from the external medium into the animal. Freshwater animals exhibit numerous structural and physiological adaptations to minimize the costs associated with osmoregulation.

Nonetheless, it has been estimated that osmoregulation accounts for >30% of the total energetic expenditures of some aquatic organisms.

WATER CONDUCTIVITY

Why is it important?

Electrical Conductivity *(Measures water's ability to conduct an electric current and is directly related to the total dissolved salts –ions- in the water. Called EC for electrical conductivity and is reported in µS/cm = microSiemans per centimeter)*. EC is temperature sensitive and increases with increasing temperature. Most modern probes automatically correct for temperature and standardize all readings to 25°C and then refer to the data as specific EC) estimates the amount of total dissolved salts *(Total dissolved salts or solids in a volume of water; usually in mg/l; estimated by EC)* or the total amount of dissolved ions in the water. EC is controlled by:

1. **Geology** (rock types) - The rock composition determines the chemistry of the watershed soil and ultimately the lake. For example, limestone leads to higher EC because of the dissolution of carbonate minerals in the basin *(Geographic land area draining into a lake or river; also referred to as drainage basin or watershed)*.
2. ***The* size of the watershed** (lake basin) relative to the area of the lake (A_w / A_o ratio) - A bigger watershed to lake surface area means relatively more water draining into the lake because of a bigger catchment area, and more contact with soil before reaching the lake.
3. **"Other" sources of ions *to lakes*** - There are a number of sources of pollutants which may be signaled by increased EC:

3.1 **Wastewater from sewage treatment plants;**

3.2 **Wastewater from septic systems and drain-field on-site** wastewater treatment and disposal systems, non-point source pollutants *(Diffuse source of pollutant(s); not discharged from a pipe; associated with land use such as agriculture or contaminated groundwater flow or on-site septic systems)*.

3.3 **Urban runoff from roads** (especially road salt). This source has a particularly episodic nature with pulsed inputs when it rains or during more prolonged snowmelt periods.

It may "shock" organisms with intermittent extreme concentrations of pollutants which seem low when averaged over a week or month.

3.4 **Agricultural runoff of water** draining agricultural fields typically has extremely high levels of dissolved salts (another major **nonpoint source** of pollutants.

Although a minor fraction of the total dissolved solids *(The amount of dissolved substances, such as salts or minerals, in water remaining after evaporating the water and weighing the residue)* , nutrients, ammonium-nitrogen, nitrate-nitrogen and phosphate from fertilizers, and pesticides, insecticides and herbicides mostly, typically have significant negative impacts on streams and lakes receiving agricultural drainage water.

If soils are also washed into receiving waters, the organic matter *(Substances which contain carbon atoms and carbon-carbon bonds)* in the soil is decomposed by natural aquatic bacteria which can severely deplete dissolved oxygen concentrations.

3.5 **Atmospheric inputs of ions** are typically relatively minor except in ocean coastal zones where ocean water increases the salt load, "salinity", of dry aerosols and wet, precipitation, deposition. This oceanic effect can extend inland about 50-100 kilometers and be predicted with reasonable accuracy.

4. **Evaporation** of water from the surface of a lake concentrates the dissolved solids in the remaining water - and so it has a higher EC. This is a very noticeable effect in reservoirs and lakes in the southern regions, and is, of course, the reason why the Dead Sea in Jordan, Great Salt Lake in Utah, USA or the Caspian Sea in Iran-Russia-Turkmenistan, Azerbaijan, and Kazakhstan are so salty.

5. **Bacterial metabolism in the hypolimnion** when lakes are thermally stratified for long periods of time (this might be depending on the basin shape, lake depth and weather).

   During this period, there is a steady "rain" of detritus *(dead or decaying organic matter; technically called organic detritus to distinguish it from the mineral detritus classified by geologists)* down to the bottom. This material is decomposed by bacteria in the water column *(a conceptual column of water from lake surface to bottom sediments)* and after it reaches the sediments. Their metabolism *(the middle or transitional zone between the well mixed epilimnion and the colder hypolimnion layers in a stratified lake. This layer contains the thermocline -the depth at which the temperature gradient is steepest during the summer; usually this gradient must be at least 1^0C per meter of depth -, but is loosely defined depending on the shape of the temperature profile)* releases the potential energy stored in the chemical bonds of the organic carbon compounds, consumes oxygen (O_2) in oxidizing these compounds, and releases carbon dioxide (CO_2) after the energy has been liberated (burned). This CO_2 rapidly dissolves in water to form carbonic acid (H_2CO_3), bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^-) the relative amounts depending on the pH of the water.

This newly created acid gradually decreases the pH of the water and the "new" ions increase the TDS [TDS (in mg/L or ppm) = 0.67 x EC25 (in **µ**S/cm or micromhos/cm)], and therefore the EC, of the hypolimnion *(The bottom, and most dense layer of a stratified lake. It is typically the coldest layer in the summer and warmest in the winter. It is isolated from wind mixing and typically too dark for much plant photosynthesis to occur)*.

Essentially, they are "eating" organic matter much as we do and releasing CO_2. We oxidize organic carbon using O_2 that we breathe out of the air as an oxidant. We use the energy to drive our metabolism and exhale the oxidized carbon as $CO_{2.}$ The oxygen is simultaneously chemically reduced and exhaled as water vapor (H_2O; the oxidation state of gaseous molecular oxygen is reduced from 0 to -2 in the process).

Other higher aquatic organisms that have aerobic metabolisms, such as zooplankton (The animal portion of the living particles in water that freely float in open water, eat bacteria, algae, detritus and sometimes other zooplankton and are in turn eaten by planktivorous fish), insects and fish also consume oxygen dissolved in the water while releasing CO_2 as they metabolize organic carbon (food items).

WHAT IN THE WORLD ARE MICROSIEMENS PER CENTIMETER (µS/CM)?

These are the units for EC. The sensor simply consists of two metal electrodes that are exactly 1.0cm apart and protrude into the water.

A constant voltage (V) is applied across the electrodes. An electrical current (I) flows through the water due to this voltage and is proportional to the concentration of dissolved ions in the water - the more ions, the more conductive the water resulting in a higher electrical current which is measured electronically.

Distilled or deionized water has very few dissolved ions and so there is almost no current flow across the gap (low EC). As an aside, fisheries biologists who electroshock know that if the water is too soft (low EC) it is difficult to electroshock to stun fish for monitoring their abundance and distribution.

Up until about the late 1970's the units of EC were micromhos per centimeter (µmhos/cm) after which they were changed to microSiemens/cm (1 µS/cm = 1 µmho/cm).

You will find both sets of units in the published scientific literature although their numerical values are identical. Interestingly, the unit "mhos" derives from the standard name for electrical resistance reflecting the inverse relationship between resistance and conductivity - the higher the resistance of the water, the lower its conductivity.

This also follows from *Ohm's Law*, V = I x R where R is the resistance of the centimeter of water. Since the electrical current flow (I) increases with increasing temperature, the EC values are automatically corrected to a standard value of 25°C and the values are then technically referred to as **specific electrical conductivity**.

All WOW conductivity data are temperature compensated to 25°C (usually called specific EC). We do this because the ability of the water to conduct a current is very temperature dependent.

We reference all EC readings to 25°C to eliminate temperature differences associated with seasons and depth. Therefore EC 25°C data reflect the dissolved ion content of the water (also routinely called the TDS or total dissolved salt concentration).

HOW MUCH SALT IS THERE IN SEA & LAKE WATER?

The image below was developed to give you an idea of how much salt (dissolved solids and ions) is present in some of the WOW lakes and to compare them to a range of other aquatic systems.

TDS, in milligrams per liter (mg/L) stands for total dissolved salts or solids and is the weight of material left behind were you to filter a liter of water to remove all the suspended particulates and then evaporate the water from the container (usually done in a drying oven in the lab).

Each of the piles represents the amount of salt present in a liter of water. We used sodium bicarbonate (baking soda) for the lakes and sodium chloride (table salt) for the ocean.

Typical Sea Water:
TDS 35'000 mg/L or 51'500 µS/cm

Atlantic Ocean
35'000 mg/L or 43'000 µS/cm

Great Salt Lake
230'000 mg/L or 158'000 µS/cm

Dead Sea
>330'000 mg/L

Lake Superior
63'000 mg/L or 97'000 µS/cm

Recommended Salinity Levels

<table>
<tr><th>For protection of aquatic ecosystems</th><th>For drinking water</th><th>For recreation</th><th>For agriculture</th></tr>
<tr>
<td>Fresh waters:
TDS should not exceed 1’000 mg/L and EC not exceed 1’500 µS/cm

Estuarine waters: salinity will vary depending upon how far upstream tests are taken. Values at any particular point will change depending upon the state of tide and the amount of fresh water flowing into the system

Typical sea water: TDS 35’000 mg/L or 51’500 µS/cm</td>
<td>TDS should be less than 1’000 mg/L, EC less than 1’500 µS/cm.

500 mg/L TDS is considered good quality</td>
<td>Primary contact: no specific guideline

Secondary contact: no guideline

Visual use: protection of aquatic ecosystems</td>
<td>Irrigation
<table>
<tr><td>µS/cm</td><td>Mg/L</td><td></td></tr>
<tr><td>0 - 650</td><td>0 - 400</td><td>all crops</td></tr>
<tr><td>650 - 1300</td><td>400 - 830</td><td>excludes v. low tolerance crops</td></tr>
<tr><td>1’300 – 3’000</td><td>830 – 2’000</td><td>medium/high tolerance crops only</td></tr>
<tr><td>3’000 – 5’000</td><td>2’000 – 3’200</td><td>high tolerance crops only</td></tr>
<tr><td>5’000 – 8’000</td><td>3’200 – 5’120</td><td>generally too high</td></tr>
<tr><td>>8’000</td><td>>5’120</td><td>too saline or irrigation</td></tr>
</table>
Livestock:
<table>
<tr><td><3’000</td><td><2’000</td><td>poultry</td></tr>
<tr><td><5’000</td><td><3’200</td><td>pigs</td></tr>
<tr><td><5’000</td><td><3’200</td><td>milking cows</td></tr>
<tr><td><7’000</td><td><4’500</td><td>dry dairy cows, horses</td></tr>
<tr><td><9’000</td><td><5’760</td><td>beef cattle</td></tr>
<tr><td><10’000</td><td><6’400</td><td>sheep</td></tr>
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