Developed by Apprise Technologies, Inc., RUSS (Remote Underwater Sampling Station) represents the state-of-the-art in water quality sampling technology. An on-board 386 or 486-based CPU coupled with a communication module provides for remote control, operation of the leveling device, and data acquisition and transfer. The unit is powered by deep-cycle cell batteries that are recharged by solar cells. Buoyancy compensation technology is used to move a sensor package up and down the water column; this system can take samples at up to 27 m depths, with a precision of 0.2 m of the requested depth. (Deep water designs for RUSS have a max. depth of 100 meters with an accuracy of 0.2 meters of requested depth.) The RUSS units are thus able to provide real-time water quality data at user-specified sampling intervals, virtually independent of lake conditions (Betts, 1998; Water Environment Federation, 1997).

The RUSS units sample five critical water quality parameters: temperature, pH, dissolved oxygen, conductivity, and turbidity. A chlorophyll sensor for directly estimating algal biomass is in development and near its beta testing phase. A nitrate sensor with a detection limit of ~ 10 ugN/L is also in development. The only effective time limitations to sampling frequencies are the times required for the sensor unit to descend to a specified depth and for the individual sensors to equilibrate. In reality, the relevance of the data is specific to the event being sampled; turbidity might be relevant on a daily basis, whereas oxygen profiles may change hourly. The precise sampling frequency will therefore depend on the question being asked. The RUSS unit has been initially programmed to collect 1 m interval profiles at ~4 hour intervals seven days per week. Additional event-specific sampling will be programmed by NRRI to collect information relevant to the time-scale of non-point source pollution. This may involve continuous monitoring at a single depth before, during and after a storm, or via intensive profiles at ~ 1 hour frequencies. For more information on how we are dealing with quality assurance, view our QA/QC.

A PDF version of the RUSS parameters is available. You'll need Acrobat Reader installed to view this file.

GLOSSARY

In addition to the following glossary, we have links to other great on-line glossaries and water quality sites in our LINKS section.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

A

Abiotic:

Not alive; non-biological; for example, temperature and mixing are abiotic factors that influence the O_2 content of lake water whereas photosynthesis and respiration are biotic factors that affect O_2 solubility.

Acid:

A solution that is a proton (H^+) donor and has a pH less than 7 on a scale of 0-14. The lower the pH the greater the acidity of the solution.

Acidity:

A measure of how acid a solution may be. A solution with a pH of less than 7.0 is considered acidic. Solutions with a pH of less than 4.5 contain mineral acidity (due to strong inorganic acids), while a solution having a pH greater than 8.3 contains no acidity.

Acid rain:

Precipitation having a ph lower than the natural range of ~5.2 - 5.6; caused by sulfur and nitrogen acids derived from anthropogenic emissions.

Acidification:

The process by which acids are added to a water body, causing a decrease in its buffering capacity (also referred to as *alkalinity* or *acid neutralizing capacity*), and ultimately a significant decrease in pH that may lead to the water body becoming acidic (pH < 7).

Adhesion:

The molecular force of attraction between unlike bodies that that acts to hold them together.

Algae:

Simple single-celled, colonial, or multi-celled, aquatic plants. Aquatic algae are (mostly) microscopic plants that contain chlorophyll and grow by photosynthesis, and lack roots and stems ((non-vascular), and leaves. They absorb nutrients (carbon dioxide, nitrate, ammonium, phosphate and micronutrients) from the water or sediments, add oxygen to the water, and are usually the major source of organic matter at the base of the food web in lakes. Freely suspended forms are called *phytoplankton;* forms attached to rocks, stems, twigs, and bottom sediments are called periphyton.

Alkalinity:

Acid neutralizing or buffering capacity of water; a measure of the ability of water to resist changes in pH caused by the addition of acids or bases and therefore, the main indicator of susceptibility to acid rain; in natural waters it is due primarily to the presence of bicarbonates, carbonates and to a much lesser extent occasionally borates, silicates and phosphates. It is expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate) or as microequivalents per liter (ueq/l) where 20 ueq/l = 1 mg/l of $CaCO_3$. A solution having a pH below about 5 contains no alkalinity.

Anaerobic:

Technically this means "*without air*" but in limnology it is used synonymously with *"anoxic."*

Angle of incidence:

Angle between direction of motion of waves and a line perpendicular to surface the waves are striking.

Angle of reflection:

Angle between direction of motion of waves and a line perpendicular to surface the waves are reflected from.

Anions:

Negatively charged ions.

Anoxia:

Condition of being without dissolved oxygen (O_2).

Anoxic:

Completely lacking in oxygen.

Anthropogenic:

Human caused.

Aquatic respiration:

Refers to the use of oxygen in an aquatic system including the decomposition of organic matter and the use of oxygen by fish, algae, zooplankton, aquatic macrophytes, and microorganisms for metabolism.

Atmospheric (Barometric) Pressure:

Measure of the pressure of the earth's atmosphere per unit area. It is 760 mm Hg at sea level and decreases with increasing elevation.

Attenuation:

Decrease.

Aufwuchs:

The community of algae and other microorganisms that attach to surfaces such as rocks, twigs, and aquatic plants; essentially the same as "*periphyton*" that means "*attached algae*."

TOP

B

Base:

A substance which accepts protons (H^+) and has a pH greater than 7 on a scale of 0-14; also referred to as an alkaline substance.

Basin:

Geographic land area draining into a lake or river; also referred to as *drainage basin* or watershed.

Benthic:

Refers to being on the bottom of a lake.

Benthic zone:

Lake bottom sediment.

Bicarbonate:

The anion HCO_3^{-}.

Bicarbonate Buffering Equilibrium Equation:

See Carbonate Buffering System.

Bioaccumulation:

The increase in concentration of a chemical in organisms that reside in environments contaminated with low concentrations of various organic compounds. Also used to describe the progressive increase in the amount of a chemical in an organism resulting from rates of absorption of a substance in excess of its metabolism and excretion. Certain chemicals, such as pcbs, mercury, and some pesticides, can be concentrated from very low levels in the water to toxic levels in animals through this process.

Bioavailable:

Able to be assimilated (absorbed) by organisms.

Biochemical Oxygen Demand (BOD):

Sometimes referred to as *Biological Oxygen Demand (BOD)*. A measure of the amount of oxygen removed (respired) from aquatic environments by aerobic microorganisms either in the water column or in the sediments. The parameter BOD uses the maximum rate of O_2 consumption over a 5 day period in the dark at 20^0 to estimate the total amount of "biodegradable" organic matter in the system. Typically too insensitive to be useful for pristine lakes and so is used primarily for wastewater "streams" or systems impacted by organic pollution.

Biomanipulation:

Reducing algal blooms by altering the fish community to reduce predation on certain zooplankton (cladocerans such as *daphnia*) that can most efficiently graze on algae.

Biomass:

The weight of a living organism or assemblage of organisms.

Biotic:

Referring to a live organism; see also abiotic.

Birgean Heat Budget:

See Heat Budget.

Buffer:

A substance which tends to keep pH levels fairly constant when acids or bases are added.

Buffering Capacity:

Ability of a solution to resist changes in ph when acids or bases are added; the buffering capacity of natural waters is mostly due to dissolved carbonate rocks in the basin; equivalent to acid neutralizing capacity (anc). Typically considered to be exhausted.

TOP

C

Calorie:

A basic measure of energy where 1 calorie is equal to the total amount of heat required to raise the temperature of 1 gram of water 1 degree Celsius.

Capillary Action:

The action by which water is drawn around soil particles (or any other solid substance like a small bore tube) because there is a stronger attraction between the soil or solid particles and the water molecules themselves.

Carbon Cycle:

The circulation of carbon atoms through the earth's whole ecosystem.

Carbon Dioxide:

A gas which is colorless and odorless; when dissolved in water it becomes carbonic acid; CO_2 is assimilated by plants for photosynthesis in the "dark" cycles of photosynthesis.

Carbonate ion:

The CO3-2 ion in the Carbonate Buffer System the collective term for the natural inorganic chemical compounds related to carbon dioxide that exists in natural waterways. Combined with one proton, it becomes Bicarbonate, HCO3- and with two protons, Carbonic Acid. The carbonate ion forms a solid precipitant when combined with dissolved ions of calcium or magnesium.

Carbonate Buffering System:

The most important buffer system in natural surface waters and wastewater treatment, consisting of a carbon dioxide, water, carbonic acid, *Bicarbonate*, and *Carbonate* ion equilibrium that resists changes in the water's pH. If acid (hydrogen ions) is added to this buffer solution, the equilibrium is shifted and carbonate ions combine with the hydrogen ions to form bicarbonate. Subsequently, the bicarbonate then combines with hydrogen ions to form carbonic acid, which can dissociate into carbon dioxide and water. Thus the system pH is unaltered (buffered) even though acid was introduced.

Carnivores:

"Meat" eaters; organisms that eat other organisms.

Cations:

Positively charged ions.

Chemical Equilibrium:

Concentrations of reactants and products at which a reaction is in balance; there is no net exchange because the rate of the forward reaction is taking place at the same rate of the reverse reaction.

CHEMetrics Water Quality Test Kits:

CHEMetrics, Inc. (website: http://www.chemetrics.com/) is one of a number of companies that market a variety of test kits and field and lab instruments for water quality testing. Additional companies commonly cited are Hach and LaMotte, and there are probably numerous others accessible to the reader through various educational resources or scientific lab products catalogues. *Water on the Web* does not endorse any particular company’s products. Some test kits have been "approved" by state or federal agencies for certain types of tests in specific types of water or wastewater.

Chemocline:

Sharp gradient in chemical concentration; the boundary in a meromictic lake separating an upper layer of less-saline water that can mix completely at least once a year (mixolimnion) from a deeper, more saline (dense) layer (monimolimnion) that never is mixed into the overlying layer.

Chlorophyll:

Green pigment in plants that transforms light energy into chemical energy in photosynthesis.

Clarity:

Transparency; routinely estimated by the depth at which you can no longer see a sechi disk. The Secchi disk is a 20 cm (8 inch) diameter weighted metal plate with alternating quadrants painted black and white that is used to estimate water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi depth.

Coefficient of Heat Transfer:

The ratio of the temperature of an object to the temperature of its surroundings. The change in temperature of an object is directly proportional to the difference between its temperature and the temperature of its surroundings.

Cohesion:

The molecular force between particles within a substance that acts to unite them.

Cohesive Forces:

All the forces of attraction among particles of a liquid.

Conductivity (electrical conductivity and specific conductance):

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 micromhos per centimeter (umhos/cm) which has been recently renamed as uS/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.

Conduction:

Thermal conduction is the transfer of heat between two solid materials that are physically touching each other.

Consumers:

Organisms that must eat other organisms for their energy metabolism; organisms that cannot produce new organic matter by photosynthesis or chemosynthesis (producers).

Convection Currents:

Air or water movement caused by changes in density or thermal (temperature) gradients.

Covalent:

Refers to the chemical bond formed by the sharing of one or more electron pairs between two atoms.

Cyanobacteria:

Bluegreen algae; phylum or organisms that are biochemically bacterial in nature but perform plant photosynthesis.

TOP

D

Decomposition:

The breakdown of organic matter by bacteria and fungi.

Denitrification:

Anaerobic bacterial process metabolism in which nitrate is used instead of oxygen during the oxidation of organic carbon compounds to yield energy (respiration). The process oxidizes organic carbon and (chemically) reduces nitrate to the gaseous end products N_2 (nitrogen gas) or N_2O (nitrous oxide). This is the major process used in wastewater treatment plants to ultimately convert *combined* nitrogen to a non-polluting state.

Density:

The mass of a substance or organism per unit volume (kg/cubic meter; grams/liter).

Density Stratification:

Creation of layers in a water body due to density differences; controlled by temperature, dissolved solids concentration and particle concentration.

Detritus:

Dead or decaying organic matter; technically called organic detritus to distinguish it from the mineral detritus classified by geologists.

Diatom:

Group of algae characterized by glass (silica) cell wall, beautifully ornamented; often the brown stuff attached to rock surfaces.

Diel:

A 24 hour period of time.

Diffusion:

The movement of a substance from an area of high concentration to an area of low concentration. Turbulent diffusion, or mixing, results from atmospheric motions (wind) diffusing water, vapor, heat, and other chemical components by exchanging parcels called eddies between regions in space in apparent random fashion. Molecular diffusion, which operates in stagnant zones, such as at the bottom sediment-water boundary in a deep lake, occurs much, much more slowly and so is important only on a very small scale such as right at the bottom.

Dimictic:

Having two mixing periods, typically in spring and fall.

Dipole:

A molecule that has two opposite electrical poles, or regions, separated by a distance.

Dipole - Dipole Forces:

Intermolecular attraction between the oppositely charged poles of nearby molecules.

Dipole - Induced Dipole Forces:

Very weak forces between a dipole and non-polar molecule that acts like a dipole in the presence of a dipole molecule.

Dipteran:

True flies.

Dissolved Oxygen (DO or O_2):

The concentration of free (not chemically combined) molecular oxygen (a gas) dissolved in water, usually expressed in milligrams per liter, parts per million, or percent of saturation. Adequate concentrations of dissolved oxygen are necessary for the life of fish and other aquatic organisms and the prevention of offensive odors. DO levels are considered the most important and commonly employed measurement of water quality and indicator of a water body's ability to support desirable aquatic life. Levels above 5 milligrams per liter (mg O_2/L) are considered optimal and most fish cannot survive for prolonged periods at levels below 3 mg O_2/L. Levels below 1 mg O_2/L are often referred to as *hypoxic* and when O_2 is totally absent *anoxic* (often called anaerobic which technically means *without air*). Secondary and advanced wastewater treatment systems are generally designed to degrade organic matter to ensure adequate dissolved oxygen in waste-receiving waters (from North American Lake Management Society.

Dissolved Oxygen Profile:

A graph of the amount of dissolved oxygen per unit depth; where the depth is on the z (vertical) axis and dissolved oxygen is on the x (horizontial) axis. Limnologists plot graphs this way but be sure to note that the depth (z) axis is really for the independent variable and the horizontal (x) axis is really for the dependent variable.

Dissolved Solids Concentration:

The total mass of dissolved mineral constituents or chemical compounds in water; they form the residue that remains after evaporation and drying. Often referred to as the *total dissolved salts* (TDS) concentration or dissolved ion concentration. In seawater or brackish water this is approximated by the *salinity* of the water. All of these parameters are estimated by the electrical conductivity (EC).

Drainage lakes:

Lakes having a defined surface inlet and outlet.

Dry deposition:

Fine particulate matter and aerosols settling from the atmosphere onto lake and land surfaces during periods with no precipitation.

TOP

E

Ecological pyramid:

Conceptual scheme whereby the amount of biomass or energy at each level of the food "chain" decreases as you move from primary producers through the different levels of consumers.

Ecoregion:

An environmental area characterized by specific land uses, soil types, surface form, and potential natural vegetation.

Ecosystem:

All of the interacting organisms in a defined space in association with their interrelated physical and chemical environment.

Electrical Conductivity (EC):

See Conductivity.

Electromagnetic Radiation:

Radiation that travels through space at the speed of light that includes light, radio waves, x-rays, and gamma rays.

Endothermic Reaction:

A reaction which absorbs heat; see also exothermic reaction.

Epilimnion:

The upper, wind-mixed layer of a thermally stratified lake. This water is turbulently mixed throughout at least some portion of the day and because of its exposure, can freely exchange dissolved gases (such as O_2 and CO_2) with the atmosphere.

Equilibrium:

See Chemical Equilibrium.

Euphotic zone:

Layer of water where sunlight is sufficient for photosynthesis to occur.

Eutrophic Lake:

A very *biologically productive* type of lake due to relatively high rates of nutrient input. See *Eutrophication*.

Eutrophication:

The process by which lakes and streams are enriched by nutrients (usually phosphorus and nitrogen) which leads to excessive plant growth - algae in the open water, periphyton (*attached* algae) along the shoreline, and macrophytes (the higher plants we often call *weeds*) in the nearshore zone. See the Lake Ecology Primer Biology section for more information about this problem; it remains the biggest pollution problem for Minnesota's (and in fact for the rest of our country as well) lakes . The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile). The less productive a lake is naturally, the more sensitive it is to increased nutrient loads from human-caused disturbances in the watershed.

Evaporation:

The process of converting liquid to vapor.

Excel:

Refers to Microsoft's Excel spreadsheet software.

Exothermic Reaction:

A reaction which gives off heat; see also endothermic reaction.

Export rates:

Amount of a particular nutrient or contaminant annually transported from its source to a lake or stream; usually related to land uses and expressed per unit area per year.

TOP

F

Fetch:

Distance the wind blows over water without appreciable change in direction; relates to intensity of turbulent mixing.

Fix:

Convert CO_2 to carbohydrate or N_2 to $NH4^+$ (carbon fixation and nitrogen fixation);

Flagella:

Whiplike structure that enables motility in certain groups of algae.

Flow Rate:

The rate at which water moves by a given point; in rivers it is usually measured in cubic meters per second (m^3/sec) or cubic feet per second (cfs).

Flushing Rate:

The retention time (turnover rate or flushing rate), the average length of time water resides in a lake, ranging from several days in small impoundments to many years in large seepage lakes. Retention time is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the volume of water passing through the lake per year by the lake volume.

Food Chain:

The transfer of food energy from plants through herbivores to carnivores. An example: insect-fish-bear or the sequence of algae being eaten by zooplankton (grazers; herbivores) which in turn are eaten by small fish (planktivores; predators) which are then eaten by larger fish (piscivores; fish eating predators) and eventually by people or other predators (fish-eating birds, mammals, and reptiles).

Food Web:

Food chains hooked together into a complex interconnected web.

TOP

G

Gas Solubility:

The ability of a gas to dissolve into another substance.

Geographic Information System (GIS):

A computer system which allows for input and manipulation of geographic data to allow researchers to manipulate, analyze and display the information in a map format.

Grazers:

Herbivores; zooplankton in the open water zone.

TOP

H

Hach Water Quality Test Kits:

Hach, Inc. (Website: http://www.hach.com/) is one of a number of companies that market a variety of test kits and field and lab instruments for water quality testing. Additional companies commonly cited are LaMotte and CHEMetrics, and there are probably numerous others accessible to the reader through various educational resources or scientific lab products catalogues. *Water on the Web* does not endorse any particular company's products. Some test kits have been "approved" by state or federal agencies for certain types of tests in specific types of water or wastewater.

Hardwater:

Lakes that have a high buffering capacity and are not generally sensitive to acid deposition. These lakes have dissolved salt concentrations greater than 120 mg/L.

Heat:

Energy that is transferred from one body to another because of a difference in temperature.

Heat Budget:

The amount of heat energy required annually to raise the temperature of a water body from its winter minimum to its summer maximum.

Heat Energy:

An energy form proportional to and associated with molecular motion. Conduction, convection or radiation can transfer heat from one mass of matter to another.

Heat Reflection:

The return of radiant heat energy by a reflecting surface.

Heat of Transformation:

See Latent Heat.

Heat of Vaporization:

The heat required to convert a substance from the liquid to the gaseous state with no temperature change. This is also called the latent heat of vaporization.

Henry's Law:

States that at a given temperature the solubility of a gas is directly proportional to the pressure of the gas directly above the liquid.

Herbivores:

Plant eaters.

Heterogeneous:

Not uniform; patchy.

Holomictic:

Typically mixes completely throughout the water column at least once a year.

Hydrogen:

Colorless, odorless and tasteless gas; combines with oxygen to form water.

Hydrogen Bond:

A type of chemical bond caused by electromagnetic forces, occurring when the positive pole of one molecule (e.g., water) is attracted to and forms a bond with the negative pole of another molecule (e.g., another water molecule).

Hydrogen Ion:

An individual atom of hydrogen which is not attached to a molecule and therefore has a positive (+) charge.

Hydrology:

The study of water's properties, distribution and circulation on Earth.

Hydrostatic Pressure:

Pressure exerted in a column of water.

Hypolimnetic Oxygen Depletion:

A condition where the dissolved oxygen in the bottom layer (hypolimnion) of a water body is gradually consumed through respiration and decomposition faster than it can be replaced over the course of the summer. A similar phenomenon may occur in the winter under ice cover. The rate at which O_2 is depeleted is a measure of the productivity of the system.

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.

TOP

I

Ice-out:

Date when lake thaws.

Impervious surfaces:

Land surfaces such as roads, parking lots, buildings, etc that prevent rainwater from soaking into the soil. The water increases in velocity causing more erosion; it warms causing potential heat stress for downstream trout; it picks up roadway contaminants; and the loss of vegetation removes a "sink" for dissolved nutrients - plant uptake.

Inflow:

Water flowing into a lake.

Inorganic:

Substances of mineral, not carbon origin.

Ion:

An electrically charged particle.

Isothermal:

Constant in temperature.

TOP

J

TOP

K

TOP

L

Lake Profile:

A graph of a lake variable per depth; where the depth is on the z-axis and the variable is on the x-axis. Depth is the independent variable and the x-axis is the dependent variable.

LaMotte Water Quality Testing Kits:

The LaMotte Company (website: http://www.lamotte.com/) is one of a number of companies that market a variety of test kits and field and lab instruments for water quality testing. Additional companies commonly cited are Hach and CHEMetrics, and there are probably numerous others accessible to the reader through various educational resources or scientific lab products catalogues. *Water on the Web* does not endorse any particular company's products. Some test kits have been "approved" by state or federal agencies for certain types of tests in specific types of water or wastewater.

Landuse:

The primary or primary and secondary uses of land, such as cropland, woodland, pastureland, forest, water (lakes, wetlands, streams), etc. The description of a particular landuse should convey the dominant character of a geographic area and establish the dominant types of human activities which are prevalent in each region.

Landscape:

All the natural geographical features, such as fields, hills, forests, and water that distinguish one part of the earth's surface from another part. These characteristics are a result not only of natural forces but of human use of the land as well.

Latent Heat (Energy):

The amount of heat (energy) released from or absorbed by a substance when it undergoes a change of state; also known as Heat of Transformation.

Le Chatelier's Principle:

A principle of equilibrium; states that in a balanced equilibrium, if one or more factors changes, the system will readjust to reach equilibrium.

Leach:

To remove soluble or other constituents from a medium by the action of a percolating liquid, as in leaching salts from the soil by the application of water.

Limnetic zone:

Open water zone.

Littoral:

Nearshore out from shore to the depth of the euphotic zone where it is too dark on the bottom for macrophytes to grow.

Loading Rates:

The rate at which materials (typically suspended sediment, nutrients [N and P], or contaminants) are transported into a water body.

Loricas:

Glass cell covering.

TOP

M

Macrophytes:

Higher aquatic plants; in the sense of "higher" evolutionarily than algae and having roots and differentiated tissues; may be emergent (cattails, bulrushes, reeds, wild rice), submergent (water milfoil, bladderwort) or floating (duckweed, lily pads).

Marl:

Encrustation of calcium carbonate that forms on plants in high ph/alkalinity lakes and on your faucet from the precipitation of calcium carbonate.

Meromictic:

Describing a lake that doesn't mix completely (see chemocline)

Mesotrophic:

Moderately productive; relating to the moderate fertility of a lake in terms of its algal biomass.

Mean Depth:

The average depth of a water body; determined by dividing lake volume by the surface area (also called z mean).

Metabolism:

The chemical and physical processes continually going on in living organisms and cells, by which the energy is provided for cellular processes and activities, and new material is assimilated to repair waste.

Metalimnion:

The middle or transitional zone between the well mixed epilimnion and the colder hypolimnion layers in a stratified lake. This layer contains the thermocline, but is loosely defined depending on the shape of the temperature profile.

Micronutrient:

Trace nutrients required by microrganisms or zooplankton such as molybdenum and cobalt; nitrogen and phosphorus are considered to be macronutrients.

Mixolimnion:

The upper layer of less-saline water that can mix completely at least once a year in a meromictic lake (see chemocline).

Mixture

An aggregate of two or more substances that are not chemically united.

Monimolimnion:

Bottom layer of stagnant water in a meromictic lake that never is completely mixed (see chemocline).

Morphoedaphic Index:

A measure of the potential yield of fishery from a lake; computed by taking the concentration of total dissolved solids (TDS) divided by the mean depth of the lake; it assumes that increasing dissolved salt content reflects increased nutrient content due to increased contact of precipitation with the soil prior to entering a lake.

Morphometry:

Relating to the shape of a lake basin; includes parameters needed to describe the shape of the lake such as volume, surface area, mean depth, maximum depth, maximum length and width, shoreline length, shoreline development (length of the perimeter, or shoreline divided by the calculated diameter of a circle of equivalent area [how convoluted the shoreline is]), depth versus volume and surface area curves.

Motile:

Able to move at will.

TOP

N

Neuston:

(1) The collection of minute or microscopic organisms that inhabit the surface layer of a body of water. (2) Organisms resting or swimming on the surface of still bodies of water.

Nitrification:

Bacterial metabolism in which ammonium ion (NH_4^+) is oxidized to nitrite (NO_2^-) and then to nitrate (NO_3^-) in order to yield chemical energy that is used to *fix* carbon dioxide into organic carbon. The process is a type of chemosynthesis which is comparable to photosynthesis except that chemical energy rather than light energy is used. These bacteria are aerobic and so require dissolved oxygen in order to survive.

Nitrogen Fixation:

The conversion of elemental nitrogen in the atmosphere (N2) to a form (e.g., ammonia) that can be used as a nitrogen source by organisms. Biological nitrogen fixation is carried out by a variety of organisms; however, those responsible for most of the fixation in lakes are certain species of bluegreen algae.

Non-motile:

Not able to move at will.

Non-polar Molecule:

A molecule that does not have electrically charged areas (poles).

Non-polar Gas:

A gas that is electrically neutral.

Nonpoint source:

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.

Nuisance blooms:

Referring to obnoxious and excessive growths of algae caused by excessive nutrient loading; often due to scum forming cyanobacteria (bluegreen algae) that can regulate their buoyancy to float high in the water column to obtain sunlight.

Nutrient loading:

Discharging of nutrients from the watershed (basin) into a receiving water body (lake, stream, wetland); expressed usually as mass per unit area per unit time (kg/ha/yr or lbs/acre/year.

TOP

O

Oligotrophic:

Very unproductive; lakes low in nutrients and algae, usually very transparent with abundant hypolimnetic oxygen if stratified.

Omnivorous:

Capable of eating plants, fungi and animals.

Organic:

Substances which contain carbon atoms and carbon-carbon bonds.

Outflow:

Water flowing out of a lake.

Outliers:

Data points that lie outside of the normal range of data. Ideally, outliers must be determined by a statistical test before they can be removed from a data set.

Oxygen:

An odorless, colorless gas; combines to form water; essential for aerobic respiration.

Oxygen Solubility:

The ability of oxygen gas to dissolve into water.

TOP

P

Paleolimnology:

The study of the history of lakes via the analysis of organisms and chemistry of lake bottom sediments.

Parameter:

Whatever it is you measure; a particular physical, chemical, or biological property that is being measured.

Partial Pressure:

The pressure exhibited by a single gas in a gas mixture.

Periphyton:

Attached algae; the green slime that attaches shoreline and bottom vegetation and the brown stuff attached to rock surfaces.

Petri dish:

A shallow, round glass dish + lid used for culturing microorganisms.

pH

A measure of the concentration of hydrogen ions.

pH Profile:

A graph of the pH level per depth; where the depth is on the z-axis and pH level is on the x-axis. Depth is the independent variable and the x-axis is the dependent variable.

pH Scale:

A scale used to determine the alkaline or acidic nature of a substance. The scale ranges from 1-14 with 1 being the most acidic and 14 the most basic. Pure water is neutral with a pH of 7.

Phosphorus:

Key nutrient influencing plant growth in lakes. Soluble reactive phosphorus (PO_4^{-3}) is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis:

The process by which green plants convert carbon dioxide (CO_2) dissolved in water to sugars and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Photosynthesizers:

Organisms that produce their energy via phtosynthesis.

Phytoplankton:

Microscopic floating plants, mainly algae, that live suspended in bodies of water and that drift about because they cannot move by themselves or because they are too small or too weak to swim effectively against a current.

Planktivores:

Animals that eat plankton; usually refers to fish that feed on zooplankton but can also refer to fish that graze on algae; includes invertebrate predators, such as the phantom midge.

Polarity:

An unsymmetrical distribution of electron density found in a covalent bond.

Polar gas:

A gas which is made up of molecules that have electrically charged areas (poles).

Polar molecule:

A molecule in which one structural end (an atom or atoms) possesses a slight negative charge and another structural end possesses a slight positive charge but the charges do not cancel one another out but rather create two separate poles.

Polymictic:

Mixes completely intermittently.

Ppb:

Part-per-billion; equivalent to a microgram per liter (ug/l).

Ppm:

Part-per-million; equivalent to a milligram per liter (mg/l).

Pressure (p):

The force exerted per unit area.

Primary consumers:

First level of consumers according to the ecological pyramid concept; organisms that eat herbivorous grazers.

Primary producers:

Organisms that convert co_2 to biomass. Usually refers to photosynthesizers, but also includes the chemosynthetic bacteria that use chemical instead of light energy to ***fix*** co_2 to biomass.

Primary Productivity:

The productivity of the photosynthesizers at the base of the food chain in ecosystems. This refers to the yield of new biomass (plant) growth during a specified time period. The entire year's accumulation is termed annual production. In the open water of lakes it is typically estimated by measured growth rates of phytoplankton (algae), either via O_2 accumulation in light relative to dark bottles of lake water or by the uptake of added radioactive carbon dioxide in sealed bottles of lake water.

Productivity:

The time rate of production of biomass for a given group of organisms; essentially the net growth rate of organisms.

Profile:

A vertical, depth by depth characterization of a water column, usually at the deepest part of a lake.

TOP

Q

TOP

R Radiation:

The movement of energy through any medium via heat, light or radio waves.

Radioisotopes:

Radioactive isotopes; radioactive forms of carbon, phosphorus, and other nutrients are used to measure rates of their absorption into biological communities; radioisotopes derived from fallout from atmospheric nuclear weapons testing are used to date layers of lake sediments

Relative depth:

A measure of how deep a lake is relative to its surface area, "*high*" being associated with "*small but deep*" z_r =[88.6 *z_{max}]/ð%a for maximum depth and area.

Respiration:

The metabolic process by which organic carbon molecules are oxidized to carbon dioxide and water with a net release of energy. Aerobic respiration requires, and therefore consumes, molecular oxygen (algae, *weeds*, zooplankton, benthic invertebrates, fish, many bacteria, people). Certain bacteria can use nitrate in place of oxygen (denitrifiers) or sulfate (sulfate reducers), but only under anaerobic (anoxic) conditions - typically present only in the sediments or in the hypolimnion after prolonged oxygen depletion has occurred.

TOP

S Saturation:

The point at which a substance has the maximum amount of another substance at a given temperature and pressure; also see supersaturation.

Secchi Disk:

A disk with a 4-6 inch radius that is divided into 4 equal quadrates of alternating black and white colors. It is lowered into a section of shaded water until it can no longer be seen and then lifted back up until it can be seen once again. Averaging the two depths gives the clarity of the water; see also clarity.

Secondary consumers:

Consumers such as plankton eating fish or predaceous zooplankton that eat other zooplankton.

Sedimentation:

The removal, transport, and deposition of detached soil particles by flowing water or wind. Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, precipitated calcium carbonate (marl), and soil and organic matter eroded from the lake's watershed.

Seepage lakes:

Lake having an inlet or an outlet but not both; primary water inputs are precipitation and groundwater.

Sewage sludge:

The solid portion of sewage that contains organic matter, and a whole community of algae, fungi, bacteria and protozoans that consume it. The terms Biosolids, Sludge, and sewage sludge can be used interchangeably.

Shoreline:

The zone where lake and land meet. Shorelands are defined as the lands 1000 ft from the ordinary high water level.

Softwater lakes:

Lakes with low buffering capacity (alkalinity) that are most sensitive to acid deposition inputs.

Solubility:

The ability of a substance to dissolve into another; also see gas solubility.

Solute:

A substance which can be dissolved into another substance.

Solution:

A homogenous mixture of two substances.

Solvent:

A substance which has the ability to dissolve another; also see Universal Solvent.

Specific conductance:

A measure of the ability of water to conduct an electrical current as measured using a 1-cm cell and expressed in units of electrical conductance (EC), i.e. siemans (uS or mS) at 25 C.

Specific Heat:

The amount of heat required to raise the temperature of one gram of substance one degree Celsius.

Spring turnover:

Period of complete or nearly complete vertical mixing in the spring after ice-out and prior to thermal stratification.

States of Matter:

The three basic forms (or states) which a substance can take: solid, liquid, or gas; a fourth form, called a plasma (an ionized gas), is also possible but only at extremely high temperatures.

Stormwater discharge:

Precipitation and snowmelt runoff from roadways, parking lots, roof drains that is collected in gutters and drains; a major source of nonpoint source pollution to water bodies and a major headache to sewage treatment plants in municipalities where the stormwater is combined with the flow of domestic wastewater (sewage) before entering the wastewater treatment plant.

Stratification:

An effect where a substance or material is broken into distinct horizontal layers due to different characteristics such as density or temperature.

Stratified:

Separated into distinct layers.

Stratigraphic:

Relating to stratigraphy, the branch of geology which treats the formation, composition, sequence and correlation of the layered rocks as parts of the earth's crust.

Substrate:

Attachment surface or bottom material in which organisms can attach or live-within; such as rock substrate or sand or muck substrate or woody debris or living macrophytes.

Supersaturation:

When a substance is more highly concentrated (more saturated) in another substance than is normally possible under normal temperature and pressure.

Surface Tension:

A phenomenon caused by a strong attraction towards the interior of the liquid action on liquid molecules in or near the surface in such a way to reduce the surface area.

Suspended Sediment (SS or Total SS[TSS]):

Very small particles which remain distributed throughout the water column due to turbulent mixing exceeding gravitational sinking; also see turbidity.

Suspension:

A heterogeneous mixture in which solute-like particles settle out of solvent-like phase some time after their introduction.

TOP

T

TDS:

Total dissolved salts or solids in a volume of water; usually in mg/l; estimated by EC (electrical conductivity).

Temperate:

Refers to lakes located in a climate where the summers are warm and the winters moderately cold. The Temperate Zone is between the Tropic of Cancer and the Arctic Circle.

Temperature:

A measure of whether a substance is hot or cold.

Temperature Profile:

A graph of the temperature per depth; where the depth is on the z-axis and temperature is on the x-axis.

Tertiary consumers:

Larger consumers in the fourth trophic level like adult northern pike, ospreys and humans that eat fish.

Thermal stratification:

Existence of a turbulently mixed layer of warm water (epilimnion) overlying a colder mass of relatively stagnant water (hypolimnion) in a water body due to cold water being denser than warm water coupled with the damping effect of water depth on the intensity of wind mixing.

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.

Topography:

Configuration of physical surface of land; includes relief imprints and locations of all man-made and natural features.

Total Dissolved Solids (TDS):

The amount of dissolved substances, such as salts or minerals, in water remaining after evaporating the water and weighing the residue.

Tributary:

Feeder stream.

Trophic State:

Eutrophication is the process by which lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae. The extent to which this process has occurred is reflected in a lake's trophic classification or state: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Trophic webs:

Conceptual model of the interconnections of species of organisms according to their different feeding groups.

Turbidity:

Degree to which light is blocked because water is muddy or cloudy.

Turnover:

Fall cooling and spring warming of surface water act to make density uniform throughout the water column. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content. However, warming may occur too rapidly in the spring for mixing to be effective, especially in small sheltered kettle lakes.

Two story fishery:

An upper warm water fishery overlying a deeper coldwater salmonid (trout or salmon) fishery; typically these are relatively deep and unproductive lakes that maintain oxygen >5 ppm in much of the hypolimnion throughout the summer.

TOP

U Universal Solvent:

A substance that has the ability to dissolve both bases and acids, such as water.

TOP

V Vertical extinction coefficient:

A measure of the ability of a particular water sample to exponentially attenuate(decrease) light shining on it. It is the constant **k** in the equation i (z) = i(0)* exp(-k*z) where z is any depth in meters, and "**exp**" refers to the base "**e" the** for the exponential.

TOP

W

Water column:

A conceptual column of water from lake surface to bottom sediments.

Water Density:

The ratio of water's mass to its volume; water is the most dense at four degrees Celsius.

Watershed:

All land and water areas that drain toward a river or lake; also called Drainage Basin or Water Basin.

Watershed area: lake surface area ratio:

A_w:a_0 ; a measure relating to how much land area is there relative to lake area in a given watershed.

Weathering:

The mechanical and chemical breakdown and dissolution of rocks.

Wet deposition:

Precipation of all kinds.

Winkler Titration Kit:

A "wet" chemistry analytical procedure used to determine the oxygen content of water via the Winkler reaction.

Winterkill:

A sudden and dramatic mass fish death caused by insufficient oxygen in a frozen lake.

TOP

X

TOP

Y

TOP

Z

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.

TOP

TEMPERATURE

Why Is it Important?

Most aquatic organisms are poikilothermic - i.e., "cold-blooded" - which means they are unable to internally regulate their core body temperature. Therefore, temperature exerts a major influence on the biological activity and growth of aquatic organisms. To a point, the higher the water temperature, the greater the biological activity. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have preferred temperature ranges. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are few, or none. For example, we would generally not expect to find a thriving trout fishery in ponds or shallow lakes because the water is too warm throughout the ice-free season.

THE Q_{10} RULE

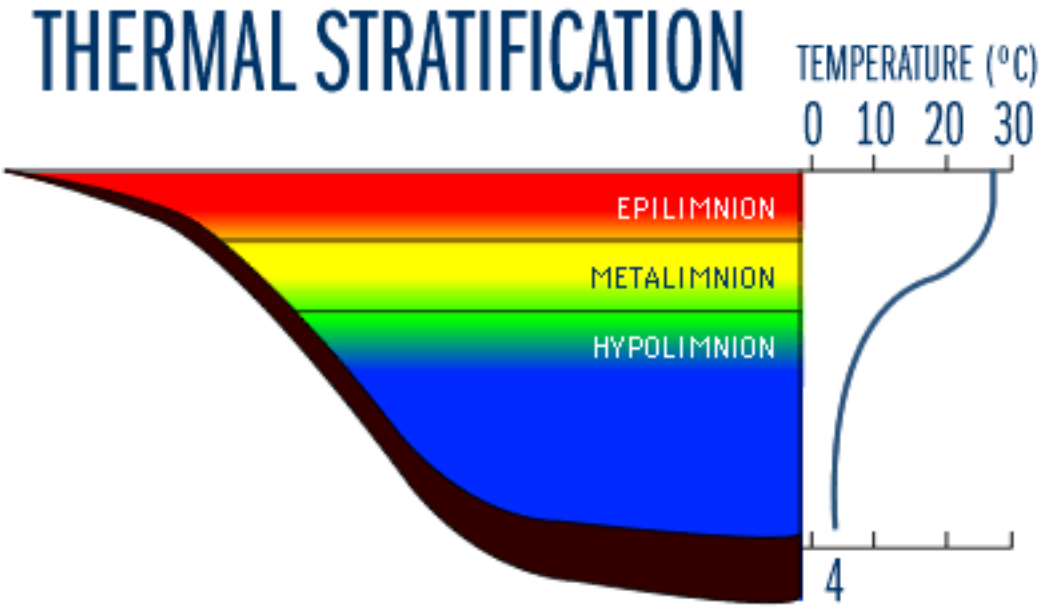
Changes in the growth rates of cold-blooded aquatic organisms and many biochemical reaction rates can often be approximated by this rule which predicts that growth rate will double if temperature increases by 10°C (18°F) within their "preferred" range.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen that cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures. Temperature is reported in degrees on the Celsius temperature scale (C).

Reasons for Natural Variation

The most obvious reason for temperature change in lakes is the change in seasonal air temperature. Daily variation also may occur, especially in the surface layers, which are warm during the day and cool at night. In deeper lakes (typically greater than 5 m for small lakes and 10 m for larger ones)

during summer, the water separates into layers of distinctly different density caused by differences in temperature. Unlike all other fluids, however, as water approaches its freezing point and cools below 4°C, the opposite effect occurs and its density then begins to decrease until it freezes at 0°C (32°F). This is why ice floats. This process is called thermal stratification. The surface water is warmed by the sun, but the bottom of the lake remains cold. You can feel this difference when diving into a lake. Once the stratification develops, it tends to persist until the air temperature cools again in fall. Because the layers don't mix, they develop different physical and chemical characteristics. For example, dissolved oxygen concentration, pH, nutrient concentrations, and species of aquatic life in the upper layer can be quite different from those in the lower layer. It is almost like having two separate lakes. The most profound difference is usually seen in the oxygen profile since the bottom layer is now isolated from the major source of oxygen to the lake - the atmosphere.



When the surface water cools again in the fall to about the same temperature as the lower water, the stratification is lost and the wind can turbulently mix the two water masses together because their densities are so similar (fall turnover). A similar process also may occur during the spring as colder surface waters warm to the temperature of bottom waters and the lake mixes (spring turnover). The lake mixing associated with a turnover often corresponds with changes in many other chemical parameters that in turn affect biological communities. Watch for these changes in your lake this fall and spring.

Because light deceases exponentially with depth in the water column, the sun can heat a greater proportion of the water in a shallow lake than in a deep lake and so a shallow lake can warm up faster and to a higher temperature. Lake temperature also is affected by the size and temperature of inflows (e.g., a stream during snowmelt, or springs or a lowland creek) and by how quickly water flushes through the lake. Even a shallow lake may remain cool if fed by a comparatively large, cold stream.

Expected Impact of Pollution

Thermal pollution (i.e., artificially high temperatures) almost always occurs as a result of discharge of municipal or industrial effluents. Except in very large lakes, it is rare to have an effluent discharge. In urban areas, runoff that flows over hot asphalt and concrete pavement before entering a lake will be artificially heated and could cause lake warming, although in most cases this impact

is too small to be measured. Consequently, direct, measurable thermal pollution is not common. In running waters, particularly small urban streams, elevated temperatures from road and parking lot runoff can be a serious problem for populations of cool or cold-water fish already stressed from the other contaminants in urban runoff. During summer, temperatures may approach their upper tolerance limit. Higher temperatures also decrease the maximum amount of oxygen that can be dissolved in the water, leading to oxygen stress if the water is receiving high loads of organic matter. Water temperature fluctuations in streams may be further worsened by cutting down trees which provide shade and by absorbing more heat from sunlight due to increased water turbidity.

REFERENCES

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA (360) 407-7472.

Moore, M.L. 1989. NALMS management guide for lakes and reservoirs. North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA (http://www.nalms.org).

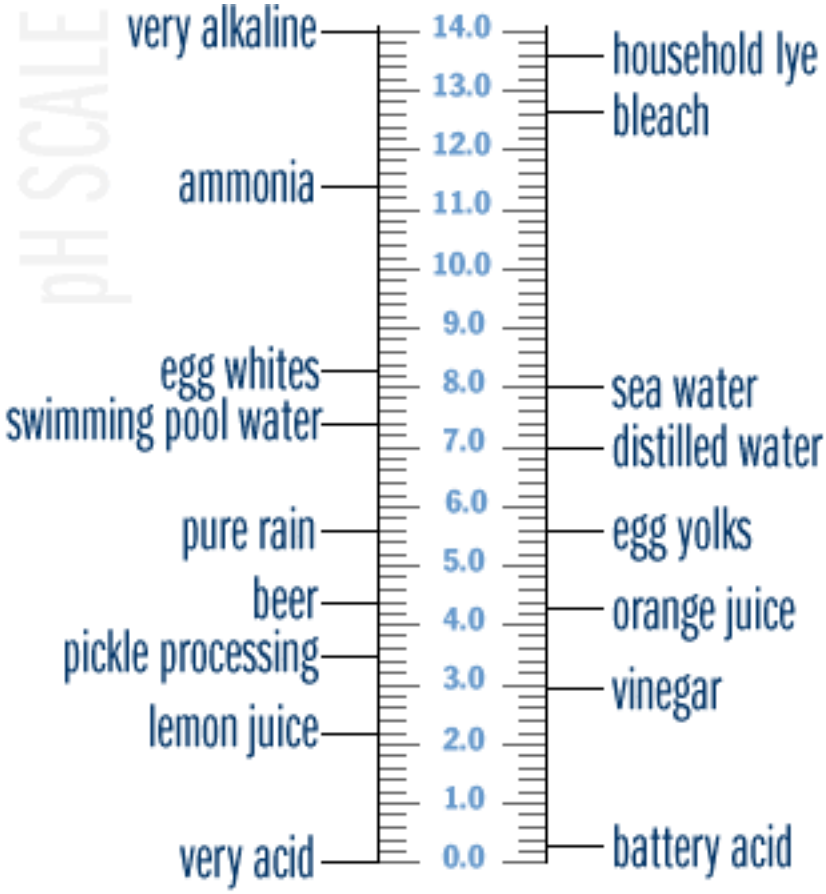
SENSOR PARAMETERS

- temperature
- pH
- dissolved oxygen
- conductivity
- turbidity

pH

Why Is it Important?

The pH of a sample of water is a measure of the concentration of hydrogen ions. The term pH was derived from the manner in which the hydrogen ion concentration is calculated - it is the negative logarithm of the hydrogen ion (H^+) concentration. What this means to those of us who are not mathematicians is that at higher pH, there are fewer free hydrogen ions, and that a change of one pH unit reflects a tenfold change in the concentrations of the hydrogen ion. For example, there are 10 times as many hydrogen ions available at a pH of 7 than at a pH of 8. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH of less that 7 are acidic; substances with pH greater than 7 are basic.



The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH may also determine whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble.

Reasons for Natural Variation

Photosynthesis uses up dissolved carbon dioxide which acts like carbonic acid (H_2CO_3) in water. CO_2 removal, in effect, reduces the acidity of the water and so pH increases. In contrast, respiration of organic matter produces CO_2, which dissolves in water as carbonic acid, thereby lowering the pH. For this reason, pH may be higher during daylight hours and during the growing season, when photosynthesis is at a maximum. Respiration and decomposition processes lower pH. Like dissolved oxygen concentrations, pH may change with depth in a lake, due again to changes in photosynthesis and other chemical reactions. There is typically a seasonal decrease in pH in the lower layers of a stratified lake because CO_2 accumulates. There is no light for plants to fix CO_2 and decomposition releases CO_2.

Fortunately, lake water is complex; it is full of chemical "shock absorbers" that prevent major changes in pH. Small or localized changes in pH are quickly modified by various chemical reactions, so little or no change may be measured. This ability to resist change in pH is called buffering capacity. Not only does the buffering capacity control would-be localized changes in pH, it controls the overall range of pH change under natural conditions. The pH scale may go from 0 to 14, but the pH of natural waters hovers between 6.5 and 8.5.

Expected Impact of Pollution

When pollution results in higher algal and plant growth (e.g., from increased temperature or excess nutrients), pH levels may increase, as allowed by the buffering capacity of the lake. Although these small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the lake and may aggravate nutrient problems. For example, a change in pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen.

Values for pH are reported in standard pH units, usually to one or two decimal places depending upon the accuracy of the equipment used.

> **Since pH represents the negative logarithm of a number, it is not mathematically correct to calculate simple averages or other summary statistics.**

Instead, pH should be reported as a median and range of values; alternatively the values could be converted to hydrogen ion concentrations, averaged, and re-converted to pH values.

Generally, during the summer months in the upper portion of a productive or eutrophic lakes, pH will range between 7.5 and 8.5. In the bottom of the lake or in less productive lakes, pH will be lower, 6.5 to 7.5, perhaps. This is a very general statement to provide an example of the differences you might measure.

The Case of Acid Rain

An important exception to the buffering of pH changes in lakes is the case of lakes affected by acid rain. Lakes that have received too much rain with a low pH (acid rain), lose their buffering capacity. At a certain point, it takes only a small bit of rain or snowmelt runoff for the pH to change. After that point, change occurs relatively quickly. According to the EPA, a pH of 5-6 or lower has been found to be directly toxic to fish (for additional information, see our acid rain links).

REFERENCES

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA (360) 407-7472.

Moore, M.L. 1989. NALMS management guide for lakes and reservoirs. North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA (http://www.nalms.org).

SENSOR PARAMETERS

- temperature
- pH
- dissolved oxygen
- conductivity
- turbidity

DISSOLVED OXYGEN

Why Is It Important?

Like terrestrial animals, fish and other aquatic organisms need oxygen to live. As water moves past their gills (or other breathing apparatus), microscopic bubbles of oxygen gas in the water, called dissolved oxygen (DO), are transferred from the water to their blood. Like any other gas diffusion process, the transfer is efficient only above certain concentrations. In other words, oxygen can be present in the water, but at too low a concentration to sustain aquatic life. Oxygen also is needed by virtually all algae and all macrophytes, and for many chemical reactions that are important to lake functioning.

Reasons for Natural Variation

Oxygen is produced during photosynthesis and consumed during respiration and decomposition.

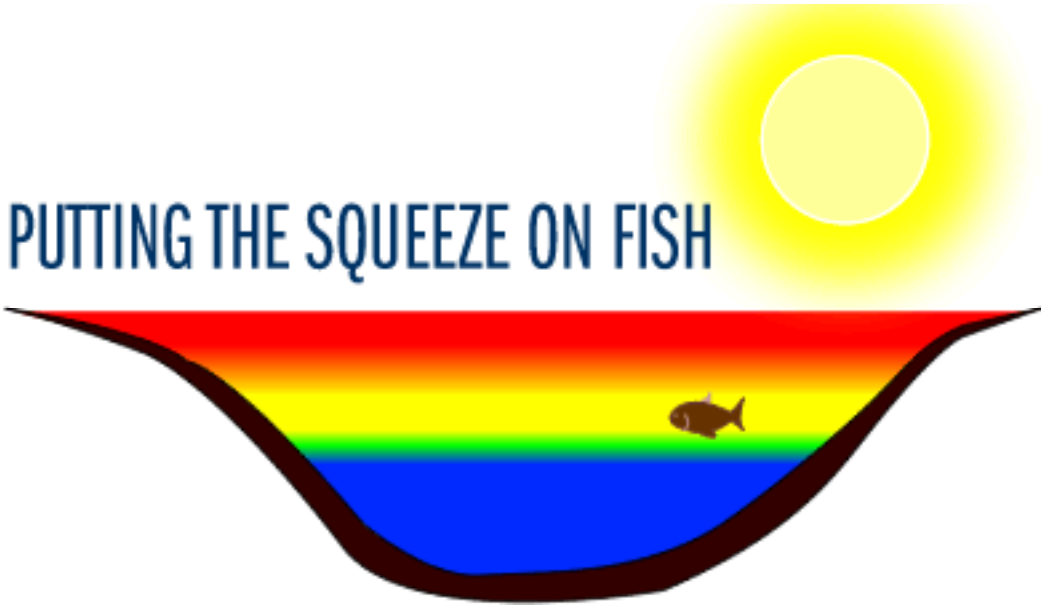
Because it requires light, photosynthesis occurs only during daylight hours. Respiration and decomposition, on the other hand, occur 24 hours a day. This difference alone can account for large daily variations in DO concentrations. During the night, when photosynthesis cannot counterbalance the loss of oxygen through respiration and decomposition, DO concentration may steadily decline. It is lowest just before dawn, when photosynthesis resumes.

Other sources of oxygen include the air and inflowing streams. Oxygen concentrations are much higher in air, which is about 21% oxygen, than in water, which is a tiny fraction of 1 percent oxygen. Where the air and water meet, this tremendous difference in concentration causes oxygen molecules in the air to dissolve into the water. More oxygen dissolves into water when wind stirs the water; as the waves create more surface area, more diffusion can occur. A similar process happens when you add sugar to a cup of coffee - the sugar dissolves. It dissolves more quickly, however, when you stir the coffee.

Another physical process that affects DO concentrations is the relationship between water temperature and gas saturation. Cold water can hold more of any gas, in this case oxygen, than warmer water. Warmer water becomes "saturated" more easily with oxygen. As water becomes warmer it can hold less and less DO. So, during the summer months in the warmer top portion of a lake, the total amount of oxygen present may be limited by temperature. If the water becomes too

warm, even if 100% saturated, O_2 levels may be suboptimal for many species of trout.

	Instream Dissolved Oxygen
I. SALMONID WATERS	
A. Embryo and larval stages	
No production impairment	11
Slight production impairment	9
Moderate production impairment	8
Severe production impairment	7
Limit to avoid acute mortality	6
B. Other life stages	
No production impairment	8
Slight production impairment	6
Moderate production impairment	5
Severe production impairment	4
Limit to avoid acute mortality	3
II. NON-SALMONID WATERS	
A. Early life stages	
No production impairment	6.5
Slight production impairment	5.5
Moderate production impairment	5
Severe production impairment	4.5
Limit to avoid acute mortality	4
B. Other life stages	
No production impairment	6
Slight production impairment	5
Moderate production impairment	4
Severe production impairment	3.5
Limit to avoid acute mortality	3
III. INVERTEBRATES	
No production impairment	8
Moderate production impairmenT	5
Limit to avoid acute mortality	4



Mid-summer, when strong thermal stratification develops in a lake, may be a very hard time for fish. Water near the surface of the lake - the epilimnion - is too warm for them, while the water near the bottom - the hypolimnion - has too little oxygen. Conditions may become especially serious during a spate of hot, calm weather, resulting in the loss of many fish. You may have heard about summertime fish kills in local lakes that likely results from this promlem.

Dissolved oxygen concentrations may change dramatically with lake depth. Oxygen production occurs in the top portion of a lake, where sunlight drives the engines of photosynthesis. Oxygen consumption is greatest near the bottom of a lake, where sunken organic matter accumulates and decomposes. In deeper, stratified, lakes, this difference may be dramatic - plenty of oxygen near the top but practically none near the bottom. If the lake is shallow and easily mixed by wind, the DO concentration may be fairly consistent throughout the water column as long as it is windy. When calm, a pronounced decline with depth may be observed.

Seasonal changes also affect dissolved oxygen concentrations. Warmer temperatures during summer speed up the rates of photosynthesis and decomposition. When all the plants die at the end of the growing season, their decomposition results in heavy oxygen consumption. Other seasonal events, such as changes in lake water levels, volume of inflows and outflows, and presence of ice cover, also cause natural variation in DO concentrations.

Expected Impact of Pollution

To the degree that pollution contributes oxygen-demanding organic matter (like sewage, lawn clippings, soils from streambank and lakeshore erosion, and from agricultural runoff) or nutrients that stimulate growth of organic matter, pollution causes a decrease in average DO concentrations. If the organic matter is formed in the lake, for example by algal growth, at least some oxygen is produced during growth to offset the eventual loss of oxygen during decomposition. However, in lakes where a large portion of the organic matter is brought in from outside the lake, oxygen production and oxygen consumption are not balanced and low DO may become even more of a problem.

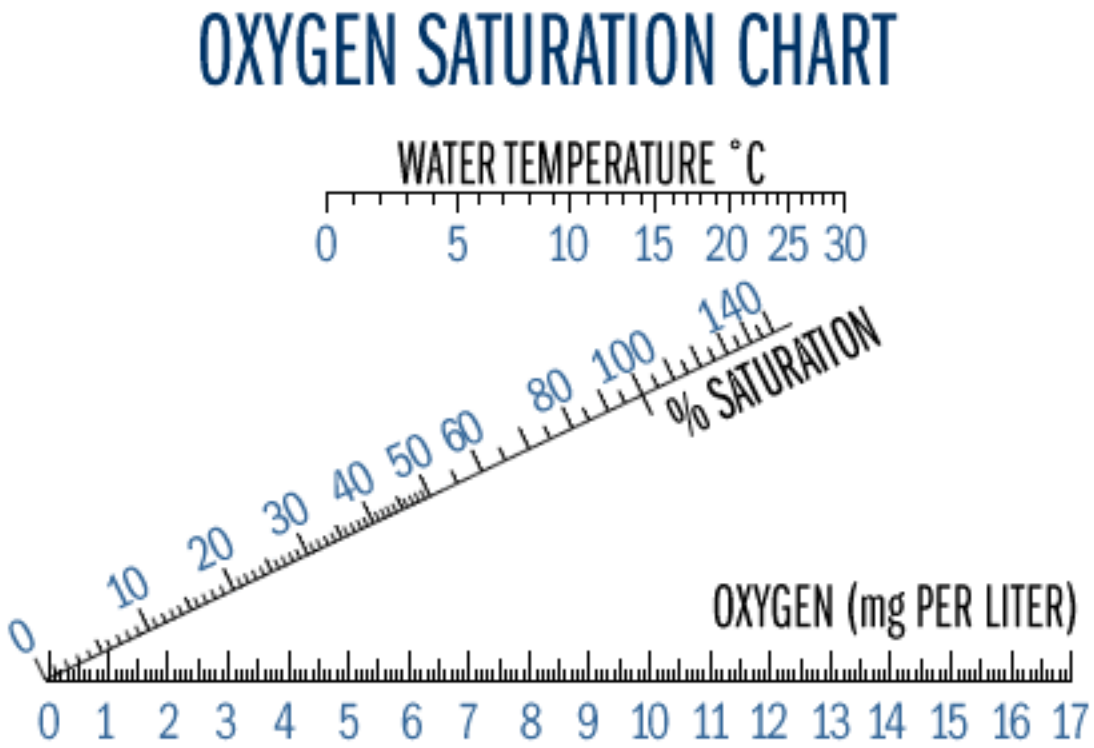
The development of anoxia in lakes is most pronounced in thermally stratified systems in summer and under the ice in winter when the water mass is cut-off from the atmosphere. Besides the direct effects on aerobic organisms, anoxia can lead to increased release of phosphorus from sediments that can fuel algal blooms when mixed into the upper euphotic (sunlit) zone. It also leads to the buildup of chemically reduced compounds such as ammonium and hydrogen sulfide (H_2S, rotten egg gas) which can be toxic to bottom dwelling organisms. In extreme cases, sudden mixing of H_2S into the upper water column can cause fish kills.

Dissolved oxygen concentrations are most often reported in units of milligrams of gas per liter of water - mg/L. (The unit mg/L is equivalent to parts per million = ppm).

DO - % saturation

Oxygen saturation is calculated as the percentage of dissolved O_2 concentration relative to that when completely saturated at the temperature of the measurement depth. Recall that as temperature increases, the concentration at 100% saturation decreases. The elevation of the lake, the barometric pressure, and the salinity of the water also affect this saturation value but to a lesser extent. In most lakes, the effect of dissolved solutes (salinity) is negligible; but the elevation effect due to decreased partial pressure of oxygen in the atmosphere as you go up (recall the breathing difficulties faced by Mt. Everest climbers) is about 4% per 300 meters (1000 feet). The DO

concentration for 100% air saturated water at sea level is 8.6 mg O_2/L at 25°C (77°F) and increases to 14.6 mg O_2/L at 0°C. Use the chart below for nomagrams for calculating saturation.



DETERMINING PERCENT SATURATION THE "QUICK AND EASY" METHOD

For a quick and easy determination of the percent saturation value for dissolved oxygen at a given temperature, use the saturation chart above. Pair up the mg/l of dissolved oxygen you measured and the temperature of the water in degrees C. Draw a straight line between the water temperature and the mg/l of dissolved oxygen. The percent saturation is the value where the line intercepts the saturation scale. Streams with a saturation value of 90% or above are considered healthy. Note that this nomogram assumes that the lakes are at sea level whereas they are actually at about 1000-1200 feet elevation. Since gas pressures decrease with elevation, the true values will be about 5% lower. The RUSS and ancillary manual data in the WOW website are all corrected for this effect.

REFERENCES

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA (360) 407-7472.

Moore, M.L. 1989. NALMS management guide for lakes and reservoirs. North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA (http://www.nalms.org).

RUSS PARAMETERS
BACK INDEX FORWARD

SENSOR PARAMETERS

- temperature
- pH
- dissolved oxygen
- conductivity
- turbidity

ELECTRICAL CONDUCTIVITY

Why is it important?

Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), 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.

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:

   A. *wastewater* from sewage treatment plants (**point source** pollutants; see: links)

   B. *wastewater* from septic systems and drainfield on-site wastewater treatment and disposal systems (**nonpoint source** pollutants; see: links)

   C. *urban runoff* from roads (especially road salt; see: links). 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 (see: *Measures of Variability Lesson* and other links)

(D) *agricultural runoff* of water draining agricultural fields typically has extremely high levels of dissolved salts (another major **nonpoint source** of pollutants; see: links). Although a minor fraction of the total dissolved solids, 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 in the soil is decomposed by natural aquatic bacteria which can severely deplete dissolved oxygen concentrations (see above).

(E) *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 in the southwestern US (the major type of lake in arid climates), and is, of course, the reason why the Great Salt Lake in Utah and Mono Lake, California and Pyramid Lake, Nevada are so salty.

5. *bacterial metabolism in the hypolimnion* when lakes are thermally stratified for long periods of time (in Minnesota this might be May - November depending on the basin shape, lake depth and weather). During this period, there is a steady "rain" of detritus (dead stuff, mostly algae and washed in particulate material from the watershed) down to the bottom. This material is decomposed by bacteria in the water column and after it reaches the sediments. Their metabolism releases the potential energy stored in the chemical bonds of the organic carbon compounds, consumes oxygen 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, and therefore the EC, of the hypolimnion. 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, insects and fish also consume oxygen dissolved in the water while releasing carbon dioxide as they metabolize organic carbon (food items).

What in the world are microSiemens per centimeter (µS/cm)?

These are the units for electrical conductivity (EC). The sensor simply consists of two metal electrodes that are exactly 1.0 cm 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 lakewater?

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 unless you work on Lake Mead in southern Nevada where you can just set it outside for a few minutes in the summer). 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.

CONDUCTIVITY AND TOTAL DISSOLVED SALT VALUES		
	EC (µS/cm)	**TDS** (mg/L)
Divide Lake	10	4.6
Lake Superior	97	63
Lake Tahoe	92	64
Grindstone Lake	95	65
Ice Lake	110	79
Lake Independence	316	213

Lake Mead	850	640
Atlantic Ocean	43,000	35,000
Great Salt Lake	158,000	230,000
Dead Sea	?	?

Divide is a softwater, acid rain *sensitive* lake in northeastern Minnesota; Superior and Tahoe are ultra-oligotrophic lakes; Ice and Independence are WOW lakes; Mead is an unproductive reservoir (the largest in the U.S.) but has a high TDS due to the salt content of the Colorado River which provides >98% of its water; the Atlantic Ocean overlies the lost Kingdom of Atlantis and possibly Jimmy Hoffa; the Great Salt Lake is an enormous hypersaline lake near Salt Lake City, Utah - it is the relict of what was once a huge inland freshwater sea that dried up, thereby concentrating the remaining salts after the water evaporated.

REFERENCES

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA (360) 407-7472.

Moore, M.L. 1989. NALMS management guide for lakes and reservoirs. North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA (http://www.nalms.org).

TURBIDITY

PHOTO BY PETER WOLTER, NATURAL RESOURCES RESEARCH INSTITUTE, UNIVERSITY OF MINNESOTA DULUTH

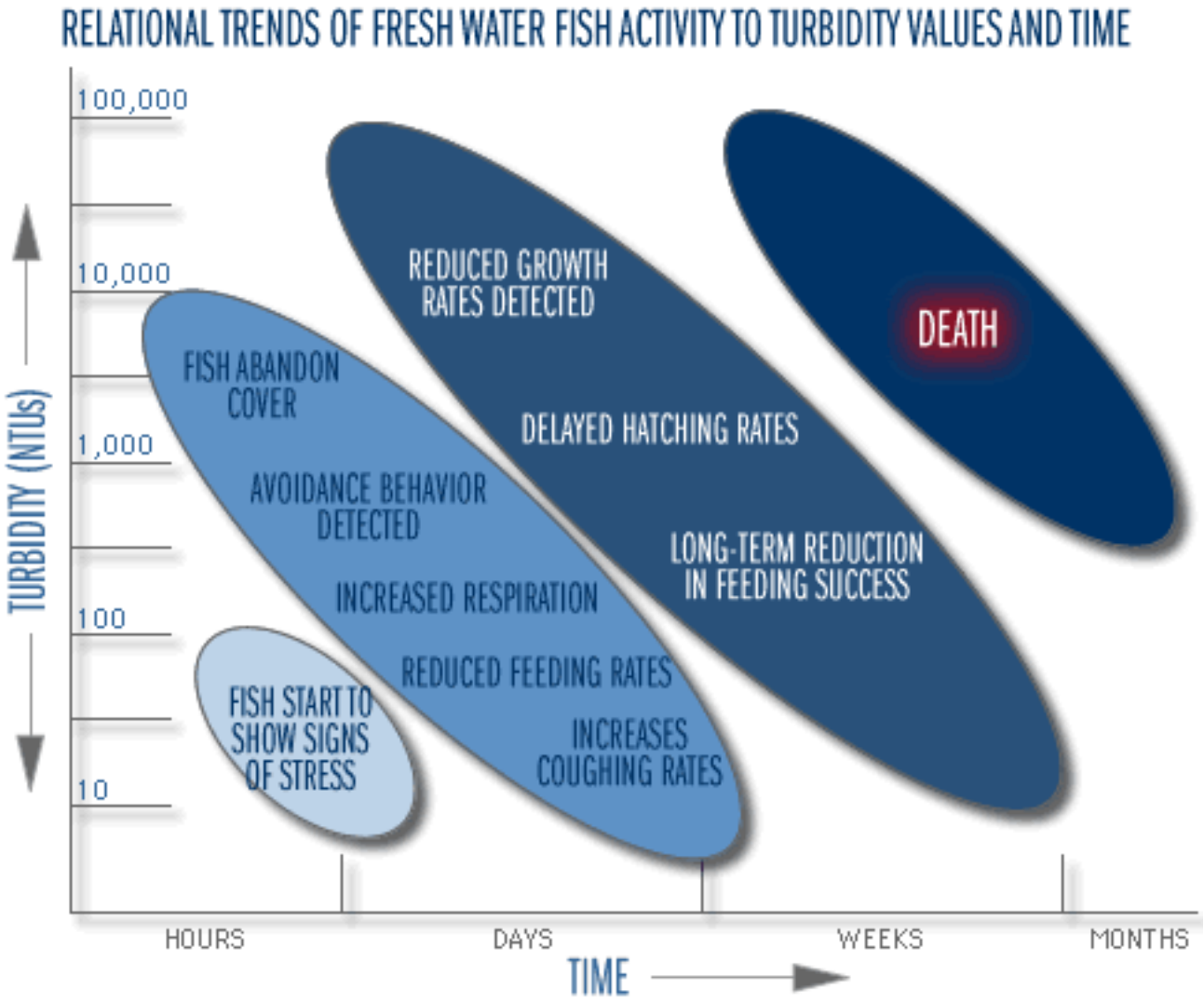
Why Is it Important?

Turbidity refers to how clear the water is. The greater the amount of total suspended solids (TSS) in the water, the murkier it appears and the higher the measured turbidity. The major source of turbidity in the open water zone of most lakes is typically phytoplankton, but closer to shore, particulates may also be clays and silts from shoreline erosion, resuspended bottom sediments (this is what turns the western arm of Lake Superior near Duluth brown on a windy day), and organic detritus from stream and/or wastewater discharges. Dredging operations, channelization, increased flow rates, floods, or even too many bottom-feeding fish (such as carp) may stir up bottom

sediments and increase the cloudiness of the water.

High concentrations of particulate matter can modify light penetration, cause shallow lakes and bays to fill in faster, and smother benthic habitats - impacting both organisms and eggs. As particles of silt, clay, and other organic materials settle to the bottom, they can suffocate newly hatched larvae and fill in spaces between rocks which could have been used by aquatic organisms as habitat. Fine particulate material also can clog or damage sensitive gill structures, decrease their resistance to disease, prevent proper egg and larval development, and potentially interfere with particle feeding activities. If light penetration is reduced significantly, macrophyte growth may be decreased which would in turn impact the organisms dependent upon them for food and cover. Reduced photosynthesis can also result in a lower daytime release of oxygen into the water. Effects on phytoplankton growth are complex depending on too many factors to generalize.

Very high levels of turbidity for a short period of time may not be significant and may even be less of a problem than a lower level that persists longer. The figure below shows how aquatic organisms are generally affected.



Reasons for Natural Variation

Algal turbidity varies seasonally and with depth in a complex manner as discussed previously in response to physical, chemical and biological changes in the lake. Inorganic and detrital particles from the watershed vary largely in response to hydrological events such as storms and snowmelt.

Even relatively small amounts of wave action can erode exposed lakeshore sediments, in this case a minepit lake from northeastern Minnesota. Can you guess what mineral was mined here?

Impacts

The major effect turbidity has on humans might be simply aesthetic - people don't like the look of dirty water. However, turbidity also adds real costs to the treatment of surface water supplies used for drinking water since the turbidity must be virtually eliminated for effective disinfection (usually by chlorine in a variety of forms) to occur. Particulates also provide attachment sites for heavy metals such as cadmium, mercury and lead, and many toxic organic contaminants such as PCBs, PAHs and many pesticides.

Turbidity is reported by RUSS in nephelometric units (NTUs) which refers to the type of instrument (turbidimeter or nephelometer) used for estimating light scattering from suspended particulate material. Turbidity can be measured in several ways. Turbidity is most often used to estimate the TSS (total suspended solids as [mg dry weight]/L) in the lake's tributaries rather than in the lake itself unless it is subject to large influxes of sediments. For the WOW project we will attempt to develop empirical (meaning: based upon direct measurements) relationships between TSS and turbidity for each system since turbidity is easily measured and TSS analyses are not very sensitive at the typically low concentrations found in the middle of most lakes. Also, TSS is a parameter that directly relates to land uses in the watershed and is a key parameter used for modeling efforts and for assessing the success of mitigation and restoration efforts.

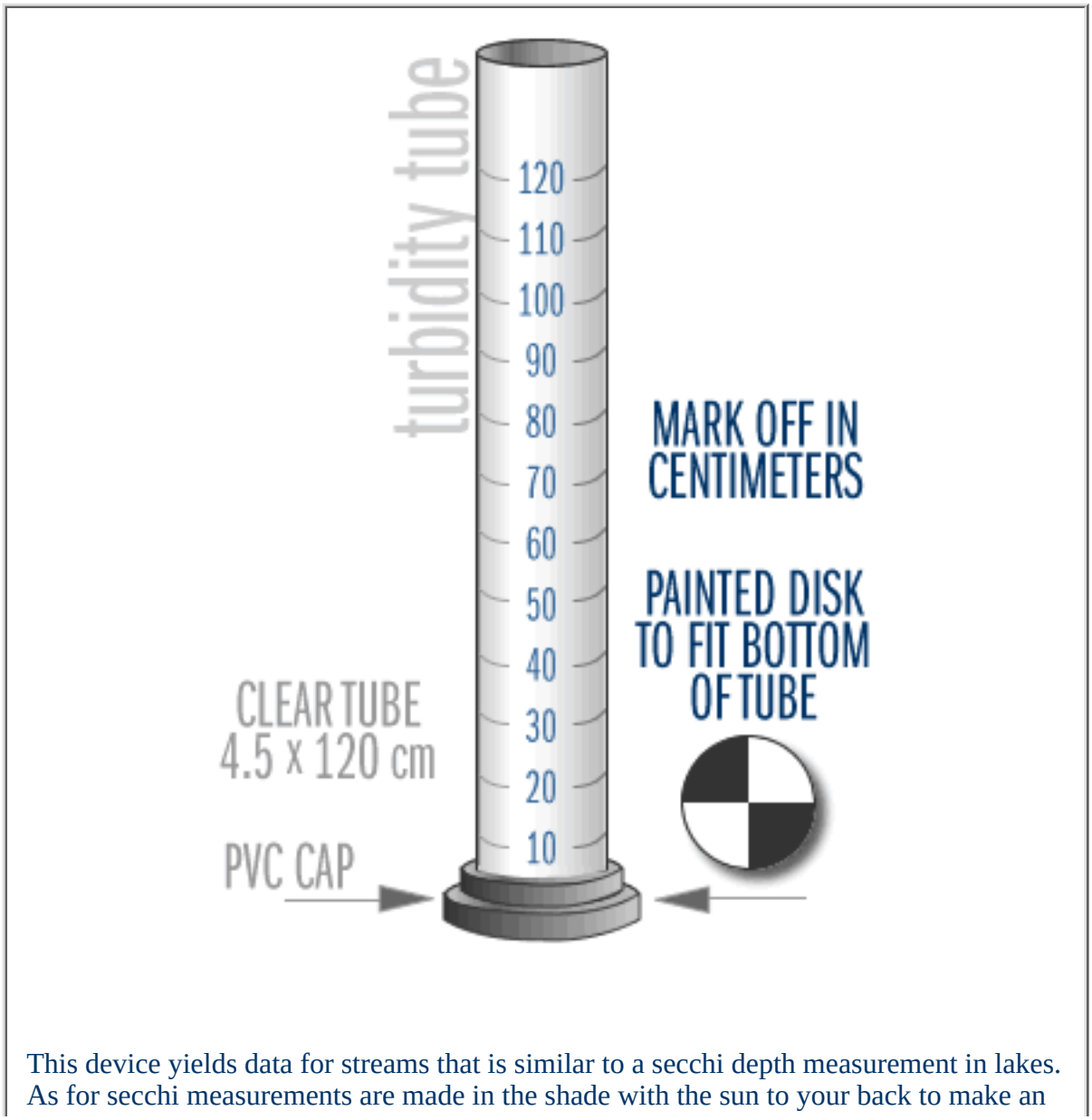
What in the world are Nephelometric Turbidity Units (NTU's)?

They are the units we use when we measure *Turbidity*. The term *Nephelometric* refers to the way the instrument estimates how light is scattered by suspended particulate material in the water. The

Nephelometer, also called a *turbidimeter*, attached to the RUSS unit has the photocell (similar to the one on your camera or your bathroom nightlight) set at 90û to the direction of the light beam to estimate *scattered* rather than absorbed light. This measurement generally provides a very good correlation with the concentration of particles in the water that affect clarity.

In lakes and streams, there are 3 major types of particles: algae, detritus (dead organic material), and silt (inorganic, or mineral, suspended sediment). The algae grow in the water and the detritus comes from dead algae, higher plants, zooplankton, bacteria, fungi, etc. produced within the water column, and from watershed vegetation washed in to the water. Sediment comes largely from shoreline erosion and from the resuspension of bottom sediments due to wind mixing.

Usually, we measure turbidity to provide a cheap estimate of the *total suspended solids* or sediments (*TSS*) concentration (in milligrams dry weight/L). TSS measurement requires you to filter a known volume of water through a pre-weighed filter disc to collect all the suspended material (greater than about 1 micron in size) and then re-weigh it after drying it overnight at ~103°C to remove all water in the residue and filter. This is tedious and difficult to do accurately for low turbidity water - the reason why a turbidimeter is often used. Another even cheaper method is to use an inexpensive devise called a Turbidity Tube. This is a simple adaptation for streams of the Secchi disk technique for lakes. It involves looking down a tube at a black and white disk and recording how much stream water is needed to make the disk disappear.



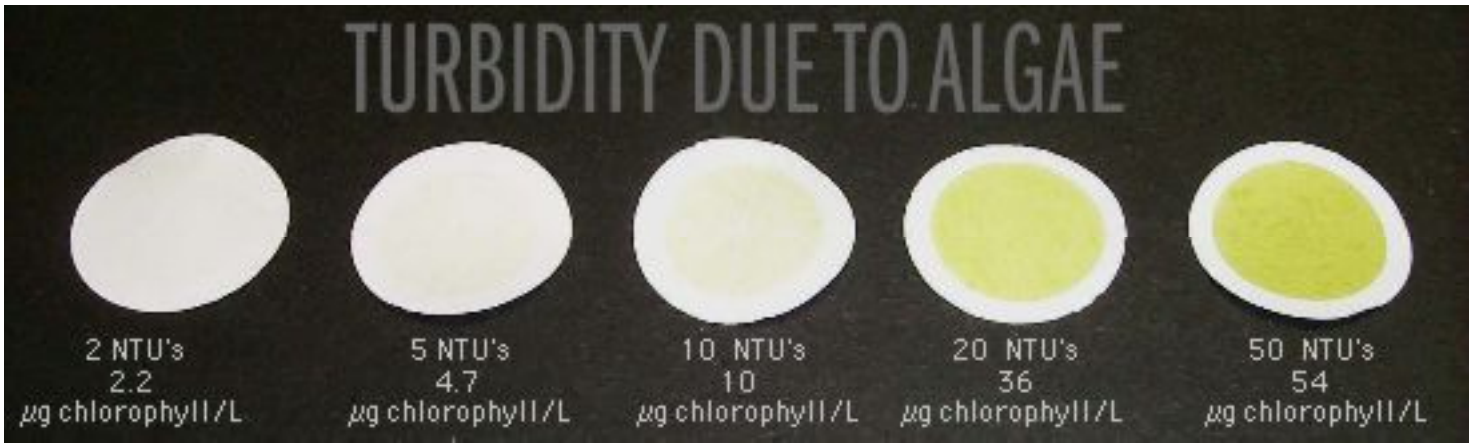
This device yields data for streams that is similar to a secchi depth measurement in lakes. As for secchi measurements are made in the shade with the sun to your back to make an

accurate and reproducible reading - the shadow of the observer should be adequate.

1. Pour sample water into the tube until the image at the bottom of the tube is no longer visible when looking directly through the water column at the image. Rotate the tube while looking down at the image to see if the black and white areas of the decal are distinguishable.
2. Record this depth of water on your data sheet to the nearest 1 cm. Different individuals will get different values and all should be recorded, not just the average. It is a good idea to have the initials of the observer next to the value to be able identify systematic errors.
3. If you see the image on the bottom of the tube after filling it, simply record the depth as > the depth of the tube. Then construct a longer tube, more appropriate for your stream.

Turbidity is a standard measurement in stream sampling programs where suspended sediment is an extremely important parameter to monitor. It may also be useful for estimating TSS in lakes, particularly reservoirs, since their useful lifetime depends upon how fast the main basin behind the dam fills with inflowing sediments from mainstem and tributary streams and from shoreline erosion. In the WOW lakes, direct inputs of sediments from tributaries are probably too low to significantly affect the turbidity of the water column out in the main lake. However, algal densities, particularly in the more eutrophic lakes in the Minneapolis Metro area represent enough particulate material to be easily measureable by the RUSS turbidity sensors. Although chlorophyll sensors (fluorometers) would be the best way for us to estimate algal abundance (we lack the funding at present), in these lakes the turbidity sensors provide an alternate estimate of algae.

The figures below were developed to show how both organic (algae) and inorganic (silt and sediment) particulates affect turbidity values. The first set of images show filter discs prepared by filtering identical volumes of water from Lake Independence, with their corresponding values of turbidity and chlorophyll. The second set shows another set of filters generated using a nearshore water sample from an erodible area.



The experiment: Filter equal volumes of water from mid-lake and nearshore at Lake Independence through fine-mesh filters.

Why Is it Important?

The secchi disk depth provides an even lower "tech" method for assessing the clarity of a lake. A Secchi disk is a circular plate divided into quarters painted alternately black and white. The disk is attached to a rope and lowered into the water until it is no longer visible. Secchi disk depth, then, is a measure of water clarity. Higher Secchi readings mean more rope was let out before the disk disappeared from sight and indicates clearer water. Lower readings indicate turbid or colored water. Clear water lets light penetrate more deeply into the lake than does murky water. This light allows photosynthesis to occur and oxygen to be produced. The rule of thumb is that light can penetrate to a depth of about 2 - 3 times the Secchi disk depth.

Clarity is affected by algae, soil particles, and other materials suspended in the water. However, Secchi disk depth is primarily used as an indicator of algal abundance and general lake productivity. Although it is only an indicator, Secchi disk depth is the simplest and one of the most effective tools for estimating a lake's productivity.

Reasons for Natural Variation

Secchi disk readings vary seasonally with changes in photosynthesis and therefore, algal growth. In most lakes, Secchi disk readings begin to decrease in the spring, with warmer temperature and increased growth, and continue decreasing until algal growth peaks in the summer. As cooler weather sets in and growth decreases, Secchi disk readings increase again. (However, cooler weather often means more wind. In a shallow lake, the improved clarity from decreased algal growth may be partly offset by an increase in concentration of sediments mixed into the water

column by wind.) In lakes that thermally stratify, Secchi disk readings may decrease again with fall turnover. As the surface water cools, the thermal stratification created in summer weakens and the lake mixes. The nutrients thus released from the bottom layer of water may cause a fall algae bloom and the resultant decrease in Secchi disk reading.

Rainstorms also may affect readings. Erosion from rainfall, runoff, and high stream velocities may result in higher concentrations of suspended particles in inflowing streams and therefore decreases in Secchi disk readings. On the other hand, temperature and volume of the incoming water may be sufficient to dilute the lake with cooler, clearer water and reduce algal growth rates. Both clearer water and lower growth rates would result in increased Secchi disk readings.

The natural color of the water also affects the readings. In most lakes, the impact of color may be insignificant. But some lakes are highly colored. Lakes strongly influenced by bogs, for example, are often a very dark brown and have low Secchi readings even though they may have few algae.

Expected Impact of Pollution

Pollution tends to reduce water clarity. Watershed development and poor land use practices cause increases in erosion, organic matter, and nutrients, all of which cause increases in suspended particulates and algae growth.

Secchi disk depth is usually reported in feet to the nearest tenth of a foot, or meters to the nearest tenth of a meter. Secchi disk readings can be used to determine a lake's trophic status. Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state since unproductive lakes are usually much clearer than productive lakes.

REFERENCES

Michaud, J.P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA (360) 407-7472.

Moore, M.L. 1989. NALMS management guide for lakes and reservoirs. North American Lake Management Society, P.O. Box 5443, Madison, WI, 53705-5443, USA (http://www.nalms.org).

QUALITY ASSURANCE

Proper Quality Assurance and Quality Control (QA/QC) protocols are essential to WOW. We have gone to great lengths to assure the accuracy of our data - the following sections describe these measures in detail.

What are Quality Assurance and Quality Control?

QA/QC basically refers to all those things good investigators do to make sure their measurements are *right on* (accurate; the absolute *true* value), reproducible (precise; consistent), and have a good estimate of their uncertainty. In the regulatory arena, this aspect of data collection is as crucial to the final outcome of a confrontation as the numbers themselves. It specifically involves following established rules in the field and lab to assure everyone that the sample is representative of the site, free from outside contamination by the sample collector (no dirty hands touching the water) and that it has been analyzed following standard QA/QC methods. This typically involves comparing the sample to a set of known samples for estimating ***accuracy*** and by replicating the measurement to estimate its ***precision***. The U.S. Environmental Protection Agency has lots to add should you wish to learn more of the technical aspects of a Quality Assurance Program (QAP). See also the WOW Lessons about data quality and interpretation for further information.

http://www.epa.gov/owowwtr1/monitoring/volunteer/qappexec.htm contains The Volunteer Monitor's Guide to: Quality Assurance Project Plans. 1996. EPA 841-B-96-003, Sep 1996, U.S. EPA, Office of Wetlands, Washington, D.C. 20460, USA

DATA TYPES

There are basically two sets of environmental data that are collected for WOW:

(1) **conventional water quality parameters** such as nutrients (N- and P-series of nutrients), chlorophyll, clarity, fecal coliform bacteria, manual field profiles for temp, DO, EC, etc. These are based upon traditional methods where a trained staff person records measurements at different depths from a sensor lowered over the side of a boat and collects water from discrete depths that are returned to the lab for analysis.

(2) **remotely sensed and controlled R.U.S.S.** (Remote Underwater Sampling System) units that control the depth and sampling interval of water quality sondes housing depth, temperature, DO, pH, EC and turbidity probes. Data may be transmitted via cellular phone/modem to our base computer/website immediately upon completion of a depth profile, or may be stored on board the RUSS and downloaded less frequently (each morning, currently) to save connection costs.

Conventional data quality assurance procedures follow guidelines set by the U.S.EPA (1987; 1989a,b), and APHA (1998). Water chemistry and manual field profiles are collected by trained staff limnologists and technicians at both Hennepin Parks (HP under Principal Investigator/Limnologist John Barten's supervision) and the Natural Resources Research Institute (NRRI under Co-Principal Investigator / Limnologist Rich Axler). Both the Hennepin Parks Water

Quality Laboratory and the NRRI Central Analytical Laboratory are certified annually by the Minnesota Department of Health for Federal Safe Drinking Water Act and Clean Water Act parameters (Ameel et al. 1993, 1998; Axler and Owen 1994; Archer and Barten 1995, 1996; Barten 1997; MCWD 1997). The certification procedure involves blind analyses of certified performance standards and an in-depth site inspection and interview approximately every other year. The NRRI lab has also been certified over the past decade by the Minnesota Pollution Control Agency and the Minnesota Department of Natural Resources for low-level water quality analyses in pristine, acid-sensitive lake monitoring programs and for sediment contaminant analyses in the St. Louis River and Upper Mississippi Rivers.

RUSS QA/QC is performed at a number of levels. The sensors are either Hydrolab H20 or YSI 6820 probe/sonde instruments; both HP and NRRI staff follow the Instrument Manuals for calibration and maintenance procedures. Our staff also have extensive experience with these calibration procedures and with their importance in interpreting field data and distinguishing systematic errors associated with deteriorating, or bio-fouled probes. In 1998 and 1999 we gained considerable experience in dealing with problems associated with continuous sensor deployment; the resultant protocols are included in our WOW efforts. Other aspects of the data management process are discussed in Host et al. (2000a, 2000b).

NRRI contributed to the initial development of the RUSS technology. During the preliminary and early stages of Water on the Web, numerous tests were conducted in regard to the accuracy and precision of in-situ data. Since both the YSI and Hydrolab systems are well established and used for numerous state and federal monitoring programs, the principal concerns related to the time allowed for sensor equilibration at each depth . Of all the sensors that we use, dissolved oxygen is most susceptible to erroneous values from inadequate stabilization- the error being greatest in regions with steep depth-gradients in DO. Following our collaborative work on this topic with Apprise Technologies, Inc., the company subsequently ran a nearly yearlong experiment in Lake Waco, Texas with Hydrolab, Inc. comparing RUSS-transmitted data to conventional datalogger data. The data sets agreed within sensor specifications. Both sensor companies have internal quality control systems (YSI is ISO14001 registered) that guarantee the consistent quality of their sensors. Apprise has worked independently with both companies to integrate these sensor packages with their RUSS units. As a part of these programs, the RUSS technology was independently field-tested by both companies and both YSI and Hydrolab have audited the Apprise facilities for QA/QC compliance. Apprise has also implemented an internal quality system based on the ISO9000 system and has been extremely helpful in dealing with problems that occasionally arise with the Lake Access and WOW units. A more complete description of our current protocols follows:

RUSS SENSOR RESOLUTION & REPORTING LIMITS

On the RUSS unit, the on-board computer processes a user-submitted instruction sequence, the sensor package is sent to a specified depth, and a series of feedback corrections are made until the sensors are stabilized within 0.2 m of the specified depth. Output from the sensors is monitored to assess when the readings on all parameters have stabilized to a specified criterion, usually a coefficient of variation <20% for a running set of 10 consecutive measurements over an interval of ~1 minute. Dissolved oxygen typically requires the most amount of time to stabilize on average, in part because of the occurrence of steeper depth gradients for this parameter. Depending on the site characteristics and the specific O2-sensor, as much as 3-5 minutes may be required for complete equilibration. Once stabilized, readings on all parameters are stored in buffer memory on the on-board computer. The raw data stream is a simple string of comma-delimited ASCII text containing a time signature, depth, and parameter values (Table 1).

Table 1. Output from Lake Access RUSS unit on Halsteds Bay, Lake Minnetonka, MN, 6/4/2000.

Unit: EMPT2 site: Halsteds Bay

Site	Sample Date	Sample Time	Depth (m)	Temp oC	pH	EC @ 25 C (uS/cm)	O2 (mg/L)	O2 (% sat)	Turb (NTU)
Halsteds	06/04/2000	00:10:58	1	18.3	8.4	406	10.0	107	11
Halsteds	06/04/2000	00:11:43	2	18.3	8.4	407	10.1	107	6
Halsteds	06/04/2000	00:13:34	3	18.2	8.4	407	10.0	106	3
Halsteds	06/04/2000	00:15:13	4	17.9	8.3	410	9.1	97	15
Halsteds	06/04/2000	00:17:04	5	17.6	8.2	411	8.0	84	5
Halsteds	06/04/2000	00:18:55	6	17.3	8.0	414	6.7	70	4
Halsteds	06/04/2000	00:20:34	7	16.7	7.8	419	4.9	50	9
Halsteds	06/04/2000	00:22:25	8	16.3	7.6	425	1.8	18	14

To date we have set the reporting limits for RUSS data based on instrument specifications and prior knowledge of the magnitude of typical field variations. This information is presented within the RUSS data section of the WOW web site. The resolution, i.e. the smallest reading shown for a particular parameter is likely to be considerably lower than the error associated with differences in time, with depth fluctuations, and with sensor drift and calibration accuracy. Periodic examination of the RUSS data stream with Apprise Technologies, Inc. has generally confirmed the estimated accuracy reported below (Table 2). An important, and greatly underestimated element of the WOW projects has been to assess the accuracy of these data by comparison with approximately biweekly manual profiles. However, it is likely that the relative precision of the data between depths within a water column profile and within a few hours to a day will be better than from week-to-week.

Ideally, if all of the RUSS sensors behaved according to sensor-manufacturer's specifications (Table 2) we could simply post the data on the Lake Access web site and assume it is accurate to these levels. However, except for temperature, all of the sensors require routine maintenance and calibration. When using these sensors for manual profiling, that is, visiting lake sites by boat, we always re-calibrate the pH, EC and turbidity sensors using individual standard solutions with known values, and the DO by air calibration. Experience has taught us that the sensors remain stable during the course of a sampling day.

Table 2. Reporting limits for RUSS sensor data (Hydrolab or YSI sensors)

Depth (m)	Temp (oC)	DO (mg/L)	DO % saturation	pH	EC (uS/cm)	Turbidity (NTUs)
Resolution (what is reported by the RUSS sensors)						
± 0.12	± 0.1	± 0.1	± 0.1	± 0.1	± 1	± 1
Estimated Accuracy (what we really trust)						
± 0.3	± 0.15	± 0.2	± 2	± 0.2	± 10	± ~3

However, when deployed for continuous operation, as for the RUSS unit, the sensors are colonized gradually by a biofilm of algae and less noticeably by bacteria and fungi as well. As this material builds up, its metabolic activity interferes with the sensor's ability to accurately sample the surrounding water. One can easily picture the effect of fine filaments of algae wafting intermittently between the electrodes of the EC sensor or in the light path of the turbidimeter giving seemingly erratic values with wide swings as the sensors move up and down. An anomalous spike in the Ice Lake EC data during July 1998 (see shaded region in the Surface Trends for Ice Lake on the WOW site), are a good example of this effect and are the basis of a lab lesson (***Increased Conductivity: Are Culverts The Culprits?*** *in draft*). DO and turbidity probes are most susceptible to

these changes, followed by pH and EC.

SENSOR MAINTENANCE AND CALIBRATION

Lake Access and WOW staff set up the following protocols to minimize these biofouling and instrument drift effects to quality assure the RUSS data:

***** Clean and re-calibrate sensors frequently (about every 2 weeks) and perform manual profiles with an independent instrument at the same time

***** Compare independent manual profiles with near-simultaneous RUSS data prior to cleaning (re-calibration). This provides assurance that data from the previous period are accurate. We calculate test statistics for each parameter as:

$$\text{RPD (relative \% - difference)} = \frac{|\text{Manual}-\text{RUSS}|}{\text{RUSS}} \times 100$$

and

$$\text{DELTA} = |\text{Manual}-\text{RUSS}|$$

for each parameter. They PASS according to rules in Table 2

Table 2. Quality Assurance Criteria for RUSS Sensors

SENSOR	RPD	DELTA
Temperature	< 5%	< 0.2 oC
DO	< 10 %	< 0.5 mg O2/L
EC	< 10 %	< 5 uS/cm
pH	< 10 %	< 0.2 units
turbidity	< 10 %	< 5 NTUS

If the data "passes", it is considered acceptable for the previous period. If not, we examine it in the context of our understanding of the limnology of the individual lake and other data (nutrients, chlorophyll, trends, etc.) and then either delete it from the database or allow it to be posted. We have to be careful not to delete anomalous data that may simply reveal real dynamic changes. The sheer volume of data (218,720,430,742,644,316,434,172,687,130 values to date) has been taxing and we lack the resources to always be as current as we would like. In the interim, data are posted as *provisional* . Dates of calibrations and these manual data are posted in the DATA section of WOW and are available within easily accessible Excel files - these will soon be posted on the Lake Access site as well. The three Data Visualization Tools (DVTs) developed for Lake Access and Water on the Web are also helpful in rapidly displaying the data in a variety of formats to help identify anomalous data. We are currently in the process of adding 'calibration date flags' to the control panels of the Profile Plotter and Color Mapper DVTs and to the DxT Profiler to allow the user to more easily keep track of calibration dates as the data stream is being viewed.

The first year of WOW, 1998, taught us that we were understaffed for the frequency of maintenance required for continuous RUSS operation at Ice Lake and Lake Independence. With an additional three units being deployed for 1999 and 2000, we set

up collaborations with Itasca Soil and Water Conservation District (for Ice Lake), Hennepin Parks (for Lake Independence and Lake Minnetonka), the Minnesota Department of Natural Resources Regional Fisheries for Grindstone Lake, and the Minnesota Pollution Control Agency staff for the St Louis River site (still in development as of July 2000). Lake Access and WOW staff work with these folks to clean and re-calibrate all sensors approximately every 1-3 weeks depending on the site. The less productive sites (Grindstone and Ice lakes) generally require less maintenance.

DATA TRANSMISSION AND INITIAL QA SCREENING

The program that imports the RUSS data currently is scheduled to run every day at 7:30 AM. The RUSS base station software is used to call each RUSS and download data that has been collected since the last call. A file containing real-time data (RTD) collected during the duration of the call is also created. These new profile data and RTD files are stored on the base station computer as plain ASCII text files, one file for each day's data. The data files from each site are stored in a separate directory on the computer. Table 1 (above) is an sample of an original profile data file created by the RUSS base station.

The Conversion Process

A program (the importer) is now launched. It reads data files that have been created or changed since the last time it was run, and converts the data to the format used by the report generating and data visualization programs. Additionally, the original data files are copied to the web server so they are accessible for immediate QA/QC. Profile data files are copied to http://wow.nrri.umn.edu/data/ and RTD files are copied to http://wow.nrri.umn.edu/rtd/ .

The importer parses the first line of a new or modified RUSS data file and tests to make sure that the Unit and Site correspond to what is expected. If not, an error message is generated and no further action is taken with this file. This will catch errors that could occur if, for example, a data file from Halsteds Bay was somehow stored in the Lake Independence directory. Next, it reads the line containing the column descriptions, and compares it with what is expected. If it differs, an error message is generated and no further action is taken with this file. This will catch errors that could occur if, for example, a new parameter is being read by the RUSS, but the importer hasn't been updated to handle the change. Now, each data line is read and converted to a "Reading". A set of readings is combined to form a "Profile" in the data base. Specific data is rejected by the importing program if it is outside these ranges:

temperature	< -1 or > 35 oC
pH	<5 or > 10
specific conductance (EC25)	<1 or > 600 uS/cm
dissolved oxygen (DO)	< -1 or > 20 mg/L O2/L
DO % saturation	< -5 or > 200 %
turbidity	< -5 or > 100NTU (note: turbidity values between -5 and 0 are set = 0)

There is no direct indication in the raw data files of where one profile ends and the next begins, so the importer applies some heuristics to decide how to assign readings to profiles. The values listed below are those in current use, but they can be changed. Since only the actual time is reported on each data line, the importer assigns a "scheduled" time

to the new profile, using the nearest :00 or :30 minute time value before the time reported for the first reading in the profile. Subsequent readings are added to the same profile provided that:

1) the reading is from a lower depth, and
2) the reading was taken within 30 minutes of the previous one

When the importer either comes to a line where the reading no longer qualifies for the current profile or it reaches the end of the data file, it will add the new profile to the data base provided that:

1) the first reading starts within 3 meters of the surface,
2) there are at least 4 readings in the profile, and
3) the date is not in the future

Instead it will generate an appropriate error message in the log file, and disregard the profile. This helps eliminate partial or invalid profiles that could be caused by RUSS hardware problems.

If it is winter and the RUSS is installed on ice, we set the minimum upper depth to 1 or 2 meters to minimize the risk of the unit becoming trapped in the hole through the ice. The data importer then creates a default reading at 0 meters, listing a temperature of 0 oC, with all other parameters blank (since we don't know what their true values are). The time for this reading is set equal to the scheduled time. The timestamp of each reading is expected to be unique, and can be used as the key value in a database. There is the possibility that the first actual reading in the profile could have the same timestamp as the bogus reading, so the readings in the profile are checked for duplicate times. If found, 5 seconds are added to the time of the deeper reading, and the change is noted in the log file.

Sometimes a sensor for a particular parameter at a particular site will go bad. In this case, the importer program can be customized to reject that parameter when importing the data from the site. Data stored in buffer memory is transmitted to the base station via cellular phone at specified intervals, or at the request of the user. Standard parity-based error correction techniques are used to ensure that data were not altered during transmission. At the base station, a JAVA based application adds the raw data to a standardized relational database (DBMS) file. For archival purposes the original ASCII data are stored in a compressed data format (ZIP) file. The ASCII and DBMS files are periodically downloaded to an off-site location via File Transfer Protocol (FTP).

FINAL DATA REVIEW & POSTING

At present (July 2000), funding limitations have precluded adherence to a rigorous schedule for removing the provisional label from RUSS data. In part this is a due to the need to review ancillary water chemistry data before making final decisions when the RUSS data are questionable. All water chemistry data posted on the Lake Access and WOW sites however, have passed QA/QC prior to being posted, although this typically takes from 30-60 days after collection.

Despite regular maintenance and calibration schedules, occasional RUSS data anomalies still occur. To date, they have virtually always been associated with DO and/or turbidity data although there have been recurring problems with the pH probe at the WOW Grindstone Lake site.

The most troublesome anomalies are those that occur within the calibration window of time, are not flagged by our automated screening tools and are not unreasonable values in terms of the range of values previously measured for that depth stratum and time of year. These errors have not been trivial to identify and require careful examination in a

complete limnological (lake/watershed/climate) context by a professional limnologist. The process is adequately described as Best Professional Judgement (BPJ). In some cases we have decided to adjust data by calculating correction factors when there is accurate calibration data spanning the period in question and when the results estimated by interpolation are consistent with the rest of the data set. In other cases we have simply rejected the data - omitting it from the website. Data deletions are summarized and circulated to all limnological staff and archived in a hidden section of the Lake Access and WOW websites. The WOW project sends a periodic e-mail newsletter providing data updates to all teachers and researchers using the site for educational or research purposes; you can subscribe to this newsletter at http://wow.nrri.umn.edu/wow/contactus.html.

SUMMARY

The QA/QC of near-real time remotely collected sensor data has provided challenges that were not present under traditional sampling regimes. We have attempted to develop rigorous protocols for each step of the data aquisition effort, and believe these protocols suit the needs of projects such as Lake Access and Water on the Web. Nonetheless, as these technologies become more common in resource management, future efforts must be directed toward the unique problems posed by real-time data collection.

ACKNOWLEGEMENTS

RIchard Axler, Elaine Ruzycki, and Norm Will contributed to the development, testing, and documentation of these QA/QC protocols.

REFERENCES

Ameel, J.J., Axler, R.P. and Owen, C.J. 1993. Persulfate digestion for determination of total nitrogen and phosphorus in low-nutrient waters. Amer. Environ. Labor. October 1993, p.1-11.

Ameel, J., E. Ruzycki and R.P. Axler. 1998. Analytical chemistry and quality assurance procedures for natural water samples. 6th edition. Central Analytical Laboratory, NRRI Tech. Rep. NRRI/TR?98/03.

APHA. 1998. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, D.C.

Archer, A. and J. Barten. 1995. Quality assurance manual. Hennepin Parks Water Quality Laboratory. September 1995. Hennepin Parks, 3800 County Road 4, Maple Plain, MN 55359.

Archer, A. and J. Barten. 1996. Laboratory Procedures Manual. Hennepin Parks Water Quality Laboratory. October 1996. Hennepin Parks, 3800 County Road 4, Maple Plain, MN 55359.

Axler, R.P. and C.J. Owen.1994. Fluorometric measurement of chlorophyll and phaeophytin: Whom should you believe? Lake and Reservoir Management 8:143-151.

Barten, J. 1997. Water quality monitoring plan. Hennepin Parks, 3800 County Road 4, Maple Plain, MN 55359.

EPA. 1987. Handbook of methods for acid deposition studies-Laboratory analysis for

water chemistry. EPA/600/4-87-026

EPA 1989a. Preparing perfect project plans. US EPA Risk Reduction Engineering Laboratory, Cincinnati, OH, EPA/600/9-89/087.

EPA.1989b. Handbook of methods for acid deposition studies-Field operations for surface water chemistry. EPA/600/4-89-020.

EPA. 1996. The Volunteer Monitor's Guide to: Quality Assurance Project Plans. EPA 841-B-96-003, Sep 1996, U.S. EPA, Office of Wetlands, Washington, D.C. 20460, USA (http://www.epa.gov/owowwtr1/monitoring/volunteer/qappexec.htm)

Host, G., N. Will, R.Axler, C. Owen and B. Munson. 2000a. Interactive technologies for collecting and visualizing water quality data. URISA Journal (In Press; refereed: http:// wow.nrri.umn.edu/urisa)

Host, G.E. , B. H. Munson, R. P. Axler, C. A. Hagley, G. Merrick and C. J. Owen. 2000b. Water on the Web: Students monitoring Minnesota rivers and lakes over the Internet. AWRA Spec.Ed. (Dec., 1999). (refereed: www.awra.org/proceedings/www99/w74/index.htm.).

MCWD. 1997. Quality assurance - quality control assessment report. Lake Minnetonka Monitoring Program 1997. Minnehaha Creek Watershed District, 2500 Shadywood Road, Excelsior, MN 55331-9578.