Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen in water that is available to aquatic organisms. DO is necessary to support fish spawning, growth, and activity.

Why do we measure dissolved oxygen?

DO is an important indicator of the overall biological health of a waterbody and is required for a waterbody to support aquatic life. It is generally measured in the field along with water temperature, turbidity (clarity), specific conductance, and pH. This information is then assessed against water quality standards to determine whether the water is fit for aquatic life.

Figure 1 is a generalized illustration of how DO affects fish health – sensitivities vary by species. In the range labeled as "too low", DO is too low to support fish. In the "stressful" range, DO conditions impede spawning and reproduction, and limit growth and activity. A higher DO is needed to be "supportive" of fish spawning, growth, and activity. Different levels of DO are required to support aquatic life depending on the species present and their stages of life (spawning, larvae, etc.). Trout, for example, require higher DO, while carp can survive in lower DO conditions. Among the macroinvertebrates, many immature insects require a high DO content, while other species such as aquatic worms and snails can tolerate lower DO concentrations. Hypoxic (low DO concentration) or anoxic (virtually no DO) conditions do not support fish or macroinvertebrate populations.

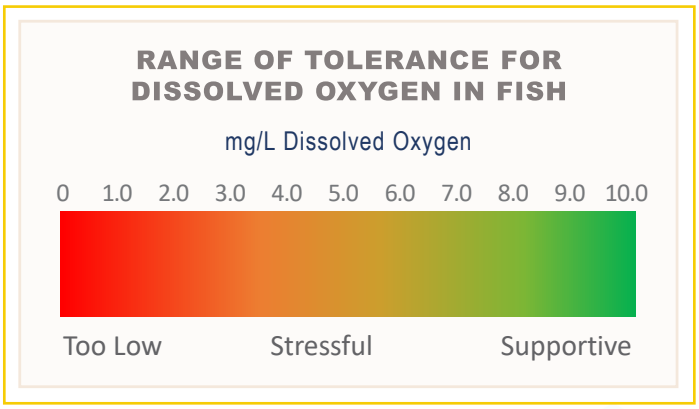

Figure 1. General freshwater fish tolerance for dissolved oxygen concentrations – tolerances vary by species.

What affects dissolved oxygen?

The primary sources of oxygen in surface waters are transfer of oxygen from the air and by plants and algae in the water due to photosynthesis. When the water is in equilibrium with the atmosphere and is holding as much DO as expected for the temperature, barometric pressure, and salinity conditions, it is said to be saturated. Aeration or photosynthesis can cause DO concentrations to become even higher and exceed saturation (the water becomes supersaturated).

For factsheets on other water quality parameters, visit: epa.gov/awma/factsheets-water-quality-parameters.

For more information about the CWA Section 106 Grants Program, visit: epa.gov/water-pollution-control-section-106-grants.

Seasonal cycles

Seasonal changes in water temperature (T) of lakes affect DO concentrations. Figure 2 shows these seasonal changes in a eutrophic (nutrient rich) lake.

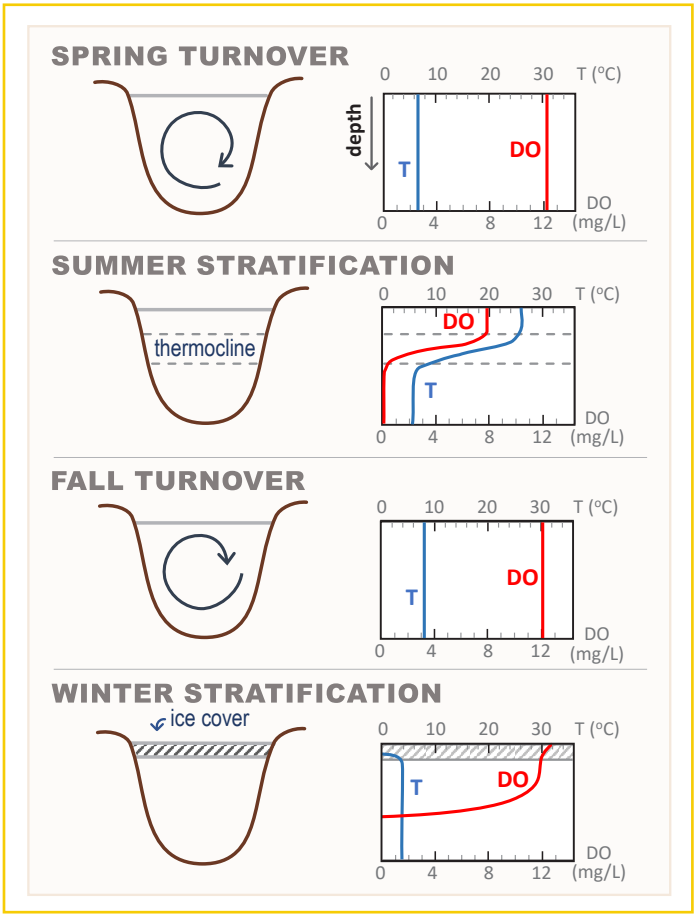

Figure 2. DO and temperature trends in eutrophic (nutrient rich) lakes by season. Adapted from Wetzel (1975)

After spring turnover occurs, the lake water is evenly mixed, so the temperature and DO are generally the same throughout the lake. During summer stratification, the top layer of the lake is warm and DO is high from the transfer of oxygen in the air and from algae due to photosynthesis. As depth increases, temperature decreases and DO also decreases as there is less photosynthesis and more organisms are consuming DO. After fall turnover occurs, the lake water is evenly mixed, so the temperature and DO are generally the same throughout the lake. During winter stratification, when the top of the lake freezes, the cold water just beneath the ice can hold the most DO, and the sunlight shining through the ice allows algae to photosynthesize. DO then decreases with depth as there is less photosynthesis and more organisms consume DO deeper in the water.

These seasonal factors combine to amplify the daily DO cycles described next. Warmer water and high nutrient concentrations (eutrophication) can result in excess algal growth. The eventual die-off of algae in an algal bloom and the increased rate of decomposition of organic matter in warmer temperatures ultimately reduce DO.

Other factors that can affect DO concentrations include:

Salinity – Increased salinity reduces the ability for water to absorb DO.

Altitude – Lower barometric pressure at higher elevations reduces the ability for water to absorb DO.

Daily cycles

DO levels in surface waters usually follow a daily cycle (Figure 3). During the day, oxygen is added to the water through photosynthesis by aquatic plants and algae and can create saturated, or even supersaturated surface waters. At night, photosynthesis stops, and DO levels drop as oxygen is consumed through respiration by aquatic plants and animals. Therefore, DO levels in surface water will likely be lowest early in the morning, and aquatic organisms are most vulnerable at that time (assuming all other conditions are the same). DO levels rise again during the day as photosynthesis resumes.

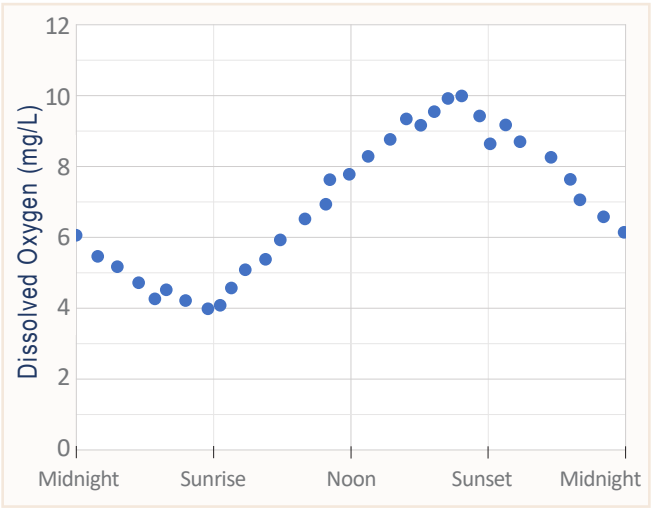

Figure 3. Generalized depiction of daily variation in dissolved oxygen concentrations.

Other water quality parameters

Changes in DO levels may be associated with changes in other water quality parameters. For example:

- **Chlorophyll *a*** – Chlorophyll *a* can be a useful indicator of an emerging algal bloom. During a bloom, DO can increase due to photosynthesis by the algae. Later, DO concentrations may decline because of oxygen consumption by consuming dead algae.
- **pH** – pH may change throughout the day along with DO fluctuations. As algae and aquatic plants draw carbon dioxide (CO_2) out of the water during photosynthesis, pH may increase throughout the day. At night, when aquatic plants, algae, and decomposers respire, they return CO_2 to the water, and pH decreases again.
- **Minerals** – Under anoxic conditions, minerals (such as iron oxide) in the sediment can dissolve, largely due to microbial activity. Any phosphorus associated with these minerals will also be released into the water further exacerbating nutrient rich (eutrophic) conditions.

What are EPA's recommended criteria for dissolved oxygen?

EPA's *Quality Criteria for Water* (1986) establishes recommended criteria for DO concentrations to protect aquatic life. Water quality criteria provide guidance for setting region-specific standards and can be adopted or adjusted as appropriate.

Criteria are based on the lowest DO concentrations needed by freshwater fish. Freshwater criteria are broken down into warmwater fish and coldwater fish because certain species such as trout and salmon require higher DO levels than others (such as pike). Table 1 shows the freshwater criteria.

Table 1. Recommended criteria for the protection of aquatic life in freshwaters (mg/L of DO).

	Coldwater Criteria		Warmwater Criteria	
	Early Life Stages[1,2]	Other Life Stages	Early Life Stages	Other Life Stages
30 Day Mean	NA[3]	6.5	NA	5.5
7 Day Mean	9.5 (6.5)	NA	6.0	NA
7 Day Mean Minimum	NA	5.0	NA	4.0
1 Day Minimum[4,5]	8.0 (5.0)	4.0	5.0	3.0

1 *These are water column concentrations recommended to achieve the required intergravel DO concentrations shown in parentheses. The 3 mg/L differential is discussed in the criteria document. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.*

2 *Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.*

3 *NA (not applicable).*

4 *For highly manipulatable discharges, further restrictions apply.*

5 *All minima should be considered as instantaneous concentrations to be achieved at all times.*

Source: USEPA (1986)

How do we measure dissolved oxygen?

DO can be measured at discrete points in time or continuously. Monitoring sensors (continuous monitoring) allow assessment of DO changes throughout the day and are a cost-effective option for collecting DO data. DO can be measured using water quality probes, which often report DO measurements in both mg/L (milligrams of oxygen in a liter of water) and percent saturation. Concentrations can vary greatly, ranging from 0 mg/L to as high as 12 mg/L or more. Low DO concentrations are considered hypoxic. Concentrations below 0.2 mg/L are often considered anoxic (virtually no oxygen).

DO can vary both horizontally and vertically in a waterbody. Water samples should, therefore, be taken at regular increments across a waterbody and at various depths (or depth integrated, which is a sample that represents the entire water column). Also, because DO levels vary throughout the day, an hourly profile can be informative. If a single sample is to be taken, consider sampling as early in the morning as possible, when the DO levels are likely to be at a minimum.

What are the challenges of using dissolved oxygen as a water quality parameter?

Because DO varies naturally throughout the day and throughout the waterbody, it can be difficult to determine if low DO measurements are a true reflection of the overall DO levels of the waterbody. This can make it challenging to assess whether the waterbody is attaining water quality criteria.

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