

Lecture 9, Dissolved Oxygen Modeling and Introduction to Biotransformation and Biodegradation

Conrad Dan Volz, DrPH, MPH

Assistant Professor

Director, [Center for Healthy Environments and Communities](#)

Director, [Environmental Health Risk Assessment Certificate Program](#)

Bridgeside Point, 100 Technology Drive

Room 564, BRIDG

Pittsburgh, PA 15219-3130

Email: cdv5@pitt.edu

<http://www.pitt.edu/~cdv5/>

Dissolved Oxygen= DO Dissolved Oxygen Modeling in Surface Waters

- DO is critical for the sustainability of aquatic ecosystems (freshwater, brackish water, seawater) and the terrestrial ecosystems ecological receptors (osprey, gulls, raccoons etc.) that depend on them.
- Most organisms in water require O₂ for respiration so the DO level determines if the water is suitable for inhabitation by appropriate species.
- At equilibrium with atmospheric pressure DO is approximately = 10 ppm or 10 mg/L
- At 760 mm Hg-water saturated air

DO (T,[chloride]) \Rightarrow T \downarrow than DO \uparrow and as [Chloride] \uparrow than DO \downarrow

See Table 2.4 on page 91 of Hemond Text from APHA 1960

Dissolved Oxygen Modeling in Surface Waters

- If temperature is held constant and chloride concentration increases then DO decreases. If chloride concentration is held constant and temperature increases then DO decreases.
- Why does O₂ solubility increase as the water temperature decreases—O₂ slips into pockets that exist in the loose hydrogen bonded network of H₂O molecules without forcing them apart. The O₂ is then caged by the H₂O molecules—weakly pinning them in. The dissolution of O₂ is weakly exothermic—so cooling shifts the reaction equilibrium more to the dissolved form.

Mechanisms of O₂ to DO

1. Diffusion from surrounding air-The DO in water obeys Henry's Law where the mass of a gas that will dissolve into a solution is proportional to the partial pressure of the gas over the solution. So the higher the air pressure than the higher is the O₂ partial pressure.
 - Given this-Does water at sea level or in a mountain stream dissolve more oxygen at the same temperature?----Why?
 - See Handout 6.2-6 Solubility of Oxygen in Water at Various Temperatures and Pressures-Source USGS, Weiss 1970
 - Also—high humidity lowers O₂ partial pressure therefore all things being equal will lower DO slightly.

Deriving DO in mg/L or ppm

- A simple empirical equation that will give DO in mg of oxygen per liter of water (ppm) is:
 - $0^{\circ}\text{C} < t < 30^{\circ}\text{C}$ $\text{DO} = (P - p) \cdot 0.678 / (35 + t)$
 - $30^{\circ}\text{C} < t < 50^{\circ}\text{C}$ $\text{DO} = (P - p) \cdot 0.827 / (49 + t)$
- Where P is barometric pressure in torr, temperature is t in centigrade and H₂O vapor pressure is p in torr.
Remember that 1 atmosphere is equal to 760 mm Hg = 760 torr = 14.7 psi
- From Standard Methods for the Examination of Water and Wastewater, 12th Edition, APHA, NY, NY, 1965, pp. 408-410.

Mechanisms of O₂ to DO

2. Aeration – rapid movement, waterfalls. Natural water courses with stones, producing eddy currents etc.
3. Photosynthesis – As a waste product of the photosynthetic cycle.

DO and Effect on Aquatic Life

- If DO goes over 110 ppm it can be very harmful to fish life-fish can develop gas bubble disease.
- As DO goes less than 5 ppm aquatic life is put under stress
- If DO is under 1-2 ppm even for a few hours fish kills can result.
- **So thinking question:**
 - What could happen to trout in a mountain stream if a mining operation uses water for cooling and releases water 10 degrees C above input temperatures?

Conductivity and DO Relationship

- **Another Factor-** Conductivity in water is proportional to the concentration of total dissolved solids (TDS). As water conductivity increases than DO decreases
- TDS are most usually sulfates, bicarbonates and chlorides of calcium, magnesium and sodium.
- What is the biggest threat to conductivity increases in the Monongahela River watersheds and why???

Loss of DO in Water

- **DO is a Function of the Organic Waste Concentration or Sewerage in Water**
 - DO decreases as [sewerage-organic waste] increases.
 - Why; Bacteria use O₂ to oxidize this waste thus releasing CO₂ and mineralizing the organic waste.
 - Therefore if O₂ is consumed faster than it can be replenished (by diffusion, photosynthesis or aeration) than DO will of course decrease.

Biochemical or Biological Oxygen Demand (BOD)

- Measure of the amount of O₂ required by bacteria to degrade dissolved or suspended organic matter per unit volume of H₂O.
- Therefore it is an indirect measure of the organic content in the water.
- BOD(5) - A five day test where a fully saturated water sample is incubated at 20°C and the amount of DO that has been consumed is measured.
- BOD(5) is expressed as the mg of DO used to oxidize the organic waste in one Liter of water (mg/L).
- Review Figure 2-22 in Text page 139 This is quite a problem in Pittsburgh because of Combined Sewer Overflows (CSO), Sanitary Sewer Overflows (SSO) and Wastewater Treatment Plant Overflows (WWTPO)
- At Outfalls the O₂ demand is greatest where BOD is maximum. The rate of decay and recovery is a factor of the dissolution of O₂ from the atmosphere (which depends on what?), photosynthesis, aeration, and benthic oxygen demand (O₂ consumption by the bottom sediment).

Streeter-Phelps Model for Mass Balances of O₂ and BOD in a River or Stream

- Allows estimation of the DO sag as a function of distance from injection.
- Assume a stream initially saturated with O₂ that receives a point source BOD.
- BOD decays typically at first order rate constant $-K_{\text{BOD}}$ of 0.2/day.
- - So if τ = travel time than $\text{BOD} = \text{BOD}_0 e^{-K_{\text{BOD}}\tau}$
- Remember to use mass balance in calculations so that $\text{Rate of O}_2 \text{ inflow} - \text{Rate of O}_2 \text{ outflow} + \text{rate of O}_2 \text{ reaeration} - \text{rate of O}_2 \text{ consumption by BOD} = 0$
- Can calculate the travel time maximum at which DO is minimum after a point source release by using formula 2-68

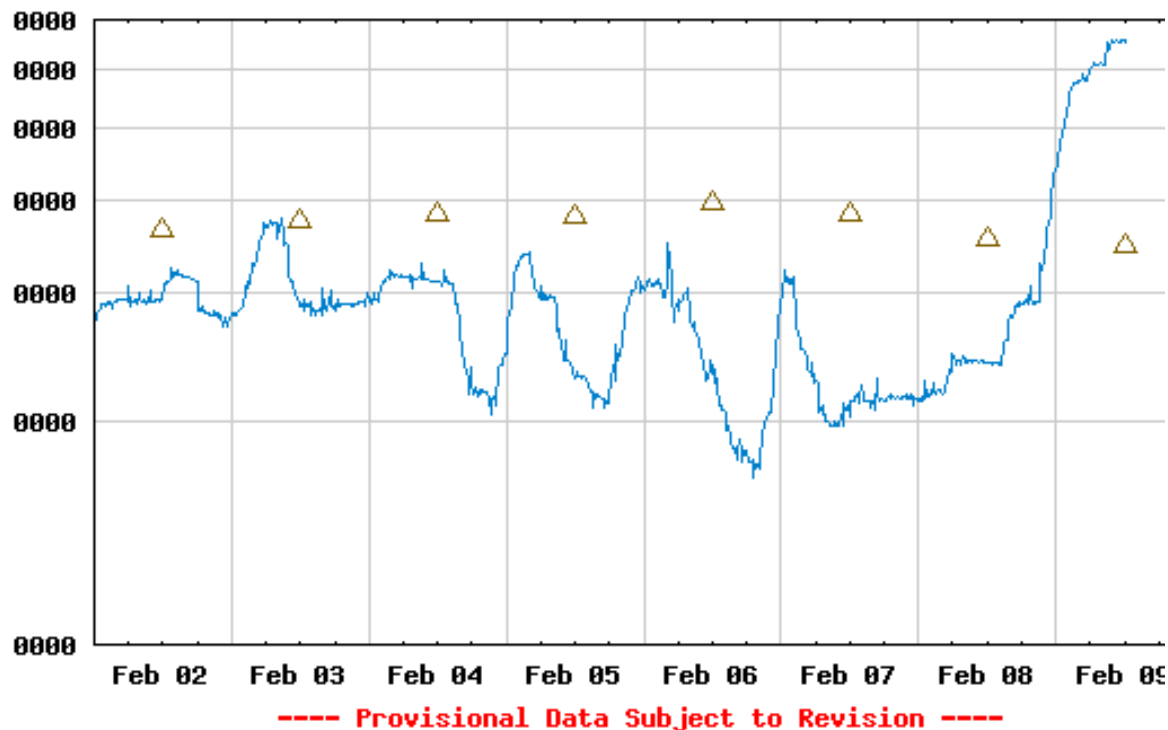
Biotransformation and Biodegradation

- Biotransformation – the changing of either organic or inorganic pollutants from one chemical species to another. This term is often used instead of biodegradation but this is not really correct because a transformation may not necessarily be degradation. One instance of this is elemental Hg given off by coal fired power plants and incinerators. The elemental Hg falls to water and can be transformed into methylmercury by the methylating action of bacteria. Methylmercury is highly toxic and is quite persistent in the environment.
- Biodegradation – describes the biotransformation-of an organic pollutant. Transformations in oxic water tend to favor less toxic offspring compounds. The term **mineralization** is used to denote the process where the organic compound is converted into inorganic compounds generally mineral salts, CO₂ and water.
- Partial Biodegradation – refers to intermediate biotic transformations that are not only inorganic in nature. For instance, benzene is degraded by aerobic microorganisms via aromatic hydroxylation to phenol and water. Phenol is an intermediate in a chain of biodegradation.
- Biotransformation and degradation are mediated via fungi (aerobic) and bacteria (aerobic and/or anaerobic). The microbes generally harvest energy from the transformation.
- Transformations are performed by microbes using enzymes which act as catalytic agents for the reaction-Bacteria can be changed genetically to transform organic pollutants by insertion of plasmids into their cells-plasmids are small circular molecules of DNA

Homework

- Opening of a combined sewer overflow gate in wet weather conditions on the Ohio River creates an initial BOD of 225 mg/liter immediately downstream. K_{bod} is 0.25/day and K_{o_2} is 2.0 per day. The river temperature is 4 degrees centigrade.
- A. How far in distance downstream is the maximum DO sag given the following current river discharge for today by the USGS. Make and state any assumptions needed regarding initial DO levels.

USGS 03086000 Ohio River at Sewickley, PA



△ Median daily statistic (75 years) — Discharge

**Current discharge at recording point is
65,000 cfs**

Assume river width of .25 mile and depth of 16 ft uniform across the cross-section of the river where discharge was measured.

Homework

- B--- What is the minimum DO in the river where the maximum DO sag occurs.?
- C---- Will fish be able to survive where DO is minimum?

Also problem 33 on page 186 of text. Lets rephrase the question- **A scientist has lost a large NIH grant because of lack of funding on anthrax research. He becomes despondent and irrational and wants to teach someone a lesson and dumps a culture of weaponized anthrax into a river 900 meters upstream of an intake pipe for a municipal water system-follow the remainder of the question as stated and answer parts a., b., and c.----also d. of what relevance is it that this is weaponized anthrax?**