Water Pollution

Water Quality Characteristics

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Lecture Headings

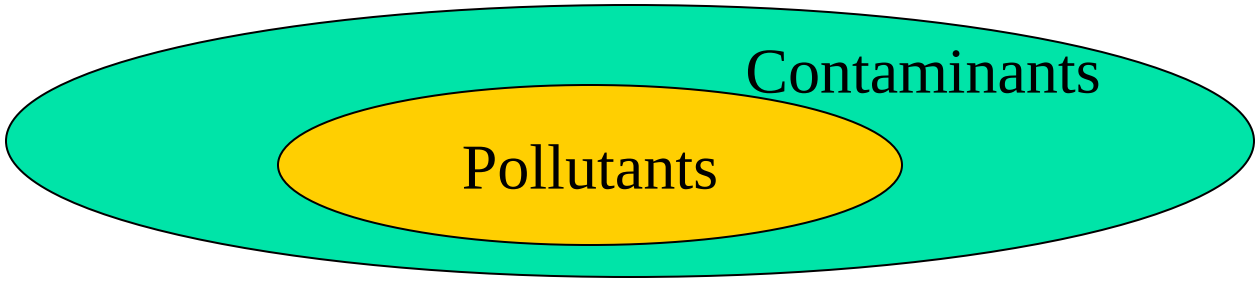
- Water Pollution
- Basic Water Quality Parameters
- Inorganic Chemicals
- Organic Chemicals
- Waterborne Diseases
- Water Quality Management

Introduction

- Water quality management is the science that predicts how much waste is too much for a body of water
- **Assimilated-** amount of waste that can be tolerated by a body of water
- Determined by knowing the type of pollutants discharged and their effect on water quality
- Water quality is affected by natural factors:
  - Historical uses in the watershed
  - Geometry of the watershed area
  - Climate of the region
- Good water quality protects drinking water as well as wildlife

Water Quality Definitions

- **Contaminant** - any constituent in the water deleterious to a particular end use regardless of its origin and whether it occurs in the watershed, source or in a water supply system
- **Pollutant** - any constituent in the water source deleterious to a particular end use that is of anthropogenic origin
- Pollutant = subset of contaminant



Types of Pollution

- Disease-causing Agents – pathogen
- Oxygen Demanding Agents – organic waste: manure
- Water-soluble Inorganic Chemicals – acids, toxic metals
- Inorganic Plant Nutrients – nitrogen and phosphorus
- Organic Chemicals – oil, pesticides, detergents, Pharmaceuticals, MTBE
- Sediment or Suspended Material – erosion, soil
- Water-soluble Radioactive Isotopes – radon uranium
- Heat – electric and nuclear power plants
- Genetic Pollution

Water pollution: point and non-point sources

Water pollution can come from a single source
Point Source
or a variety of dispersed sources
non-point source

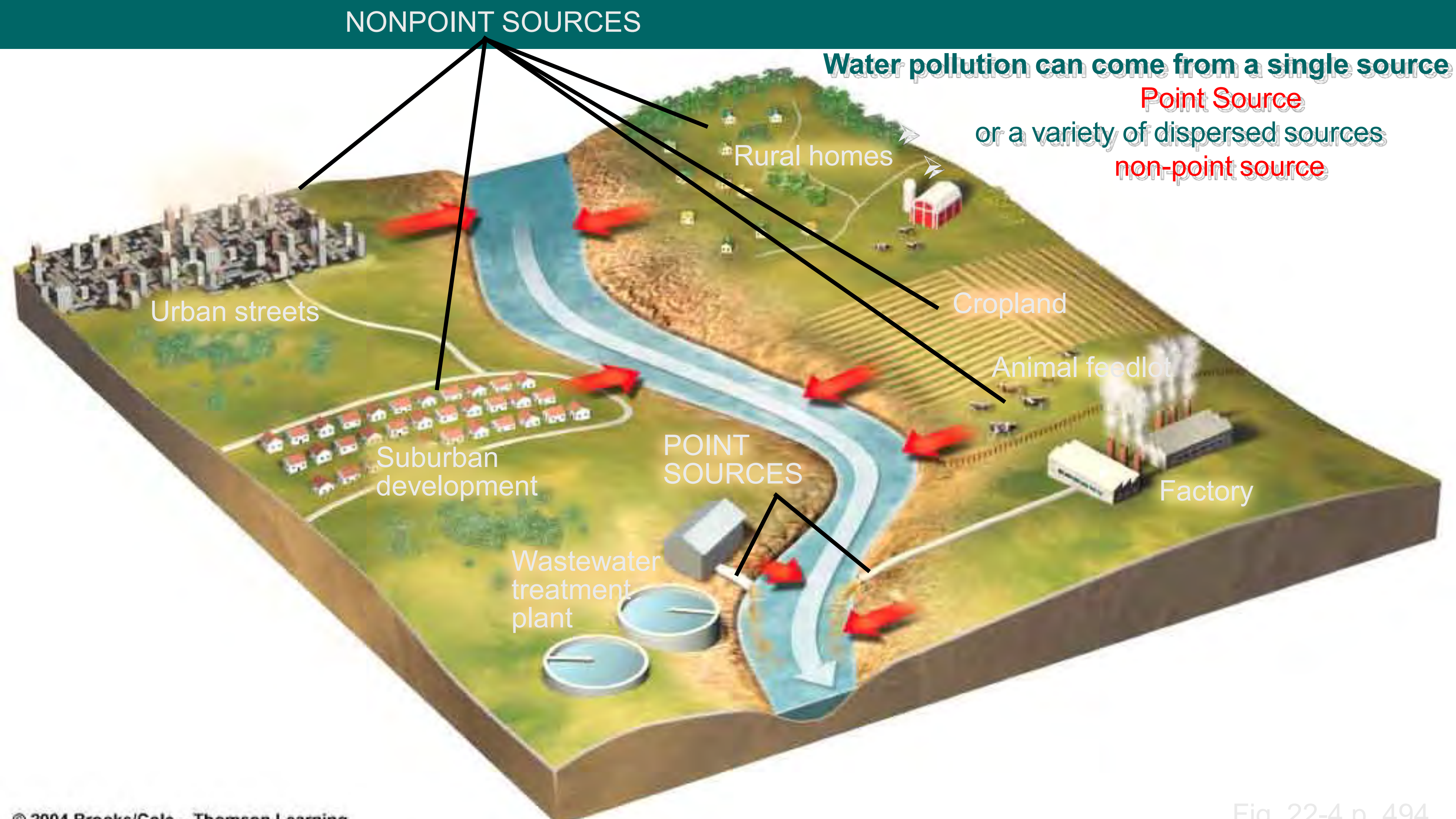
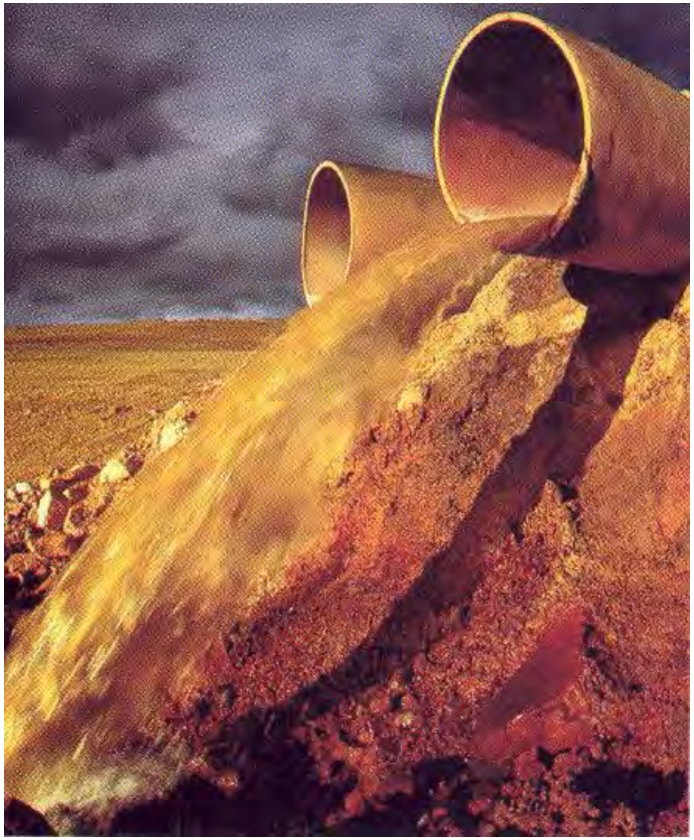


Fig. 22-4 p. 494

Point Source Pollution

- Contamination discharged through a pipe or other discrete, identifiable location
- Relatively easy to quantify and evaluate impact
- Historically, the focus of regulation



Point Sources of Pollutants

- **Point sources -** collected by a network of pipes or channels and conveyed to a single point of discharge in receiving water
- Point sources include domestic sewage and industrial wastes
- **Municipal sewage -** domestic sewage and industrial wastes that are discharged into sanitary sewers - hopefully treated
- Point source pollution can be controlled by waste minimization and proper wastewater treatment

Nonpoint Source Pollution

- Contamination from a diffuse source
  - Ag fields
  - Stormwater runoff
  - Feedlots
  - Atmospheric depostion
- Difficult to measure
- Difficult to control
- Focus of recent regulatory efforts

Soil erosion from a farm field

Nonpoint Sources

- This type of pollution occurs during rainstorms and spring snowmelt
- Pollution can be reduced by changing land use practices

Combined Sewer Flow

- Nonpoint pollution from urban storm water collects in combined sewers
- **Combined sewers-** carry both storm water and municipal sewage

Lack of minimal discharge results in severe pollution of the Vishnumati river in Kathmandu (Nepal).

Lecture Headings

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- Inorganic Chemicals
- Organic Chemicals
- Waterborne Diseases
- Water Quality Management

Water Quality Parameters

- Dissolved Oxygen
- Temperature
- Solids (TDS, SS)
- Biochemical Oxygen Demand
- NOD
- COD
- Solids (TSS,TDS)
- Turbidity
- pH
- Conductivity
- Salinity
- Hardness
- Alkalinity
- Trace Elements
- Nutrients: N & P
- Toxic Organic Compounds

Concentration Level

pH, Coliform Group Bacteria

Surrounding Environment

BOD, COD, SS, TN, TP

NOx-N

Human Health

Acute Toxicity

Hg, Cr, Cd, As, Pb, ...
Solvents (TCE, PCE, Benzene, ...),

Zn

Ecosystem

Chronic Toxicity

Carcinogenic Toxicity

Dioxin, Endocrine disruptors

%

10^4

ppm (mg/L)

10^3

ppb (μg/L)

10^3

ppt (ng/L)

Oxygen- Demanding Material

- **Dissolved Oxygen (DO)-** fish and other higher forms of aquatic life that must have oxygen to live
- **Oxygen- Demanding Material-** anything that can be oxidized in the receiving water resulting in the consumption of dissolved molecular oxygen - BOD, COD
- Almost all naturally occurring organic matter contributes to the depletion of DO

Oxygen

- Oxygen in water is called dissolved oxygen (DO); measured as ppm or mg/L.
- DO is affected by
  - Temperature
  - Agitation
  - Photosynthesis
  - Dissolved solids
  - Altitude

Dissolved Oxygen

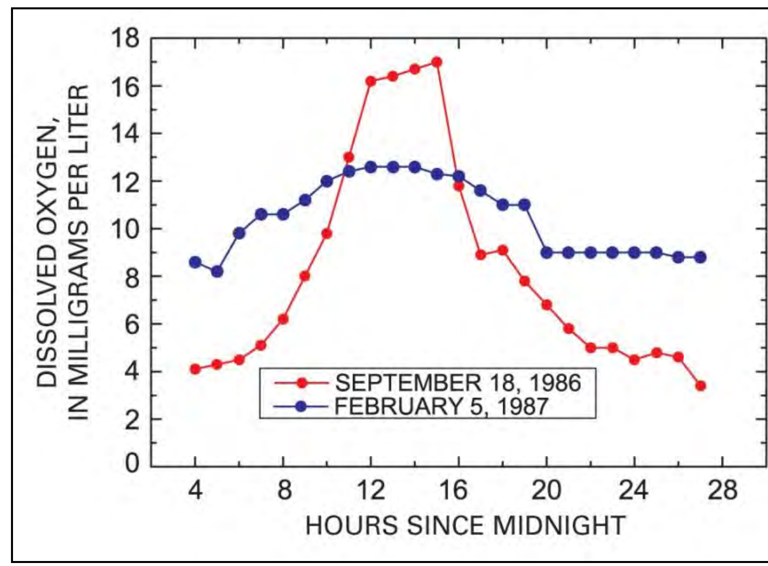
- Atmosphere consists of 21% O_2
- Water consists of <1% O_2
- When water and atmosphere come into *intimate* contact, O_2 tends to diffuse into water
  - Occurs as water passes over riffles, rapids, and falls and to a lesser extent in still water
- Aquatic plants also pump O_2 into water
  - During the day when they are undergoing *photosynthesis*

Photosynthesis

$106CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+$

g $C_{106}H_{263}O_{110}N_{16}P + 138O_2$

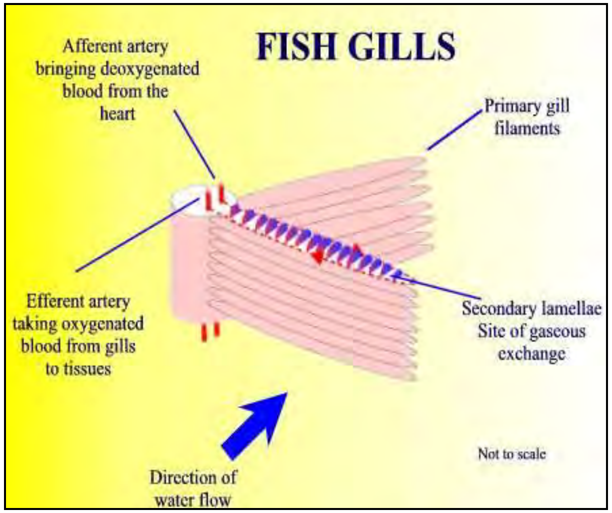
Oxygen



High rates of photosynthesis produce high DO during the day; respiration produces low DO at night

Dissolved Oxygen

- Fish depend on DO in water
  - O_2 diffuses from water to blood in gills
- When DO concentrations drop below 5 milligrams per liter (mg/L) most fish have trouble
- DO levels below 1-2 mg/L for a few hours can lead to large fish kills



www.fishdoc.co.uk

Effects of Oxygen Depletion

- Effects of low DO on ecosystem communities and populations
  - How much DO is enough?
  - Rapid decrease in DO can cause massive ***fish kills***
  - So-called ***dead zones*** form if DO level falls enough

DO level (mg/L)	Qualitative effect
6 – 15	OK
4 – 6	Stressed
2 – 4	Choking
1 –2	Dying
0 – 1	Dead

- Effects of low DO on chemical composition
  - Converts chemicals to their to *reduced* state
    - Methane (CH_4), hydrogen sulfide (H_2S), and ammonia (NH_3) instead of carbon dioxide (CO_2), sulfate (SO_4^{2-}) or nitrate (NO_3^-)
  - Reduced forms of metals frequently more soluble
    - Metals can become more mobile
    - Increases exposure of humans and animals to toxic metals

Dissolved Oxygen

- Dissolved oxygen can also be expressed as % saturation

- 80-124% = excellent
- 60-79% = ok
- < 60% = poor

Effects of Oxygen on Fish

- Fish require more oxygen in warmer water than in cooler water.
- Fish require more oxygen after feeding.
- Oxygen consumption is proportional to size and number of fish in a system.
- Smaller fish consume more oxygen per unit weight than larger fish.
- Fish require more oxygen if they have impaired gill function or are exposed to stressors.

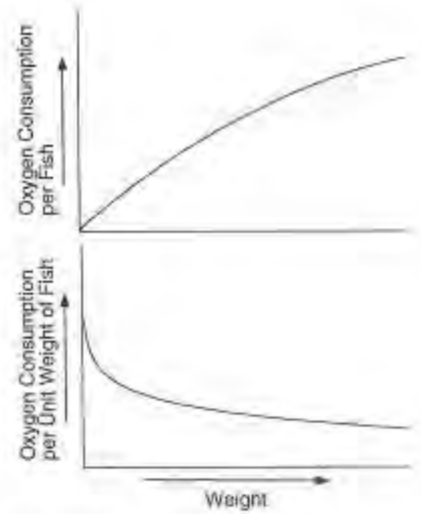


Figure 2 Oxygen consumption rates of fish as a function of weight. The upper panel is based on weight of the individual. The lower panel is oxygen consumption per unit mass. Upper panel calculated as $M = aW^b$ where M = total oxygen consumption of fish, W = weight of fish, a and b are species-specific constants; lower panel calculated as $M/W = aW^{(b-1)}$ (Hill and Wyse 1989). The exponent b was assumed to be 0.8, which is common, but not exclusive, for fishes (Fry 1971). One was substituted for a in all calculations.

Effects of Oxygen

- Metabolic O_2 need is based on fish size & water temperature (BOD). O_2 consumption is proportional to fish size (smaller fish need more oxygen).
- O_2 consumption increases after feeding; is greater for swimming fish.

- 10% of fish's energy is used to breathe (<2% for humans).
- Compressed air is bad; gas bubble disease.
- Gas supersaturation = adding gases to water under pressure or heat; raises saturation >100%; embolism & pop-eye.

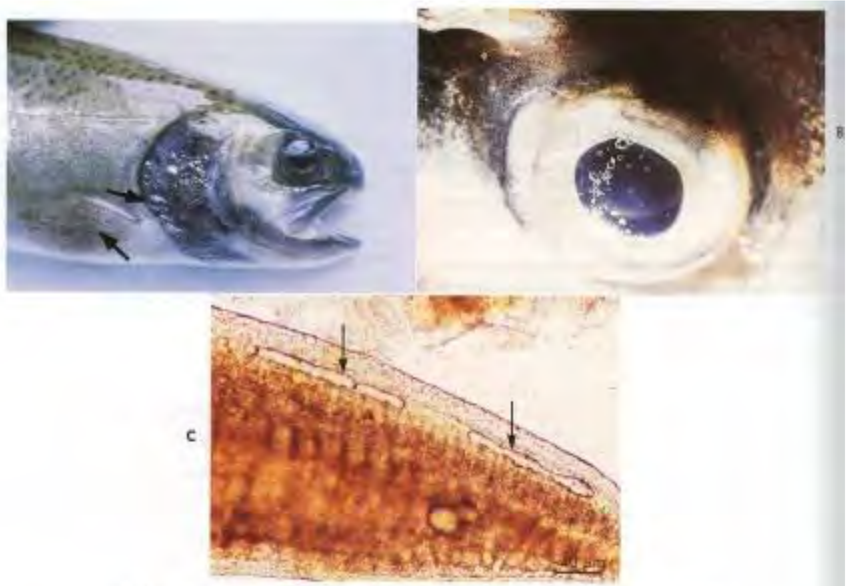


Fig. 11-10 A, Gas emboli in the fins and opercula of a trout (*arrows*). B, Gas emboli (*arrow*) in the eye (anterior chamber) of a European sea bass. C, Gas emboli (*arrows*) in the gills of a European sea bass.

(*A* photograph courtesy of H. Moller; *B* and *C* photographs courtesy of A. Colorni.)

Temperature

- Temperature affects physical, chemical, and biological processes in water
  - Chemical example: DO decreases as temperature increases
  - Biological example: fish seek *thermal refuges*
- Loss of streamside shade trees causes temperature to increase

Riparian Vegetation

Warm water makes some substances more toxic (cyanide, phenol, xylene, zinc) and, if combined with low DO, they become even more toxic

Temperature

- Most aquatic organisms are cold-blooded and have an ideal temperature range, specific to the organism:
- Diatoms 15-25 degrees C
- Green algae 25-35 degrees C
- Blue greens 30-40 degrees C
- Salmonids – cold water fish

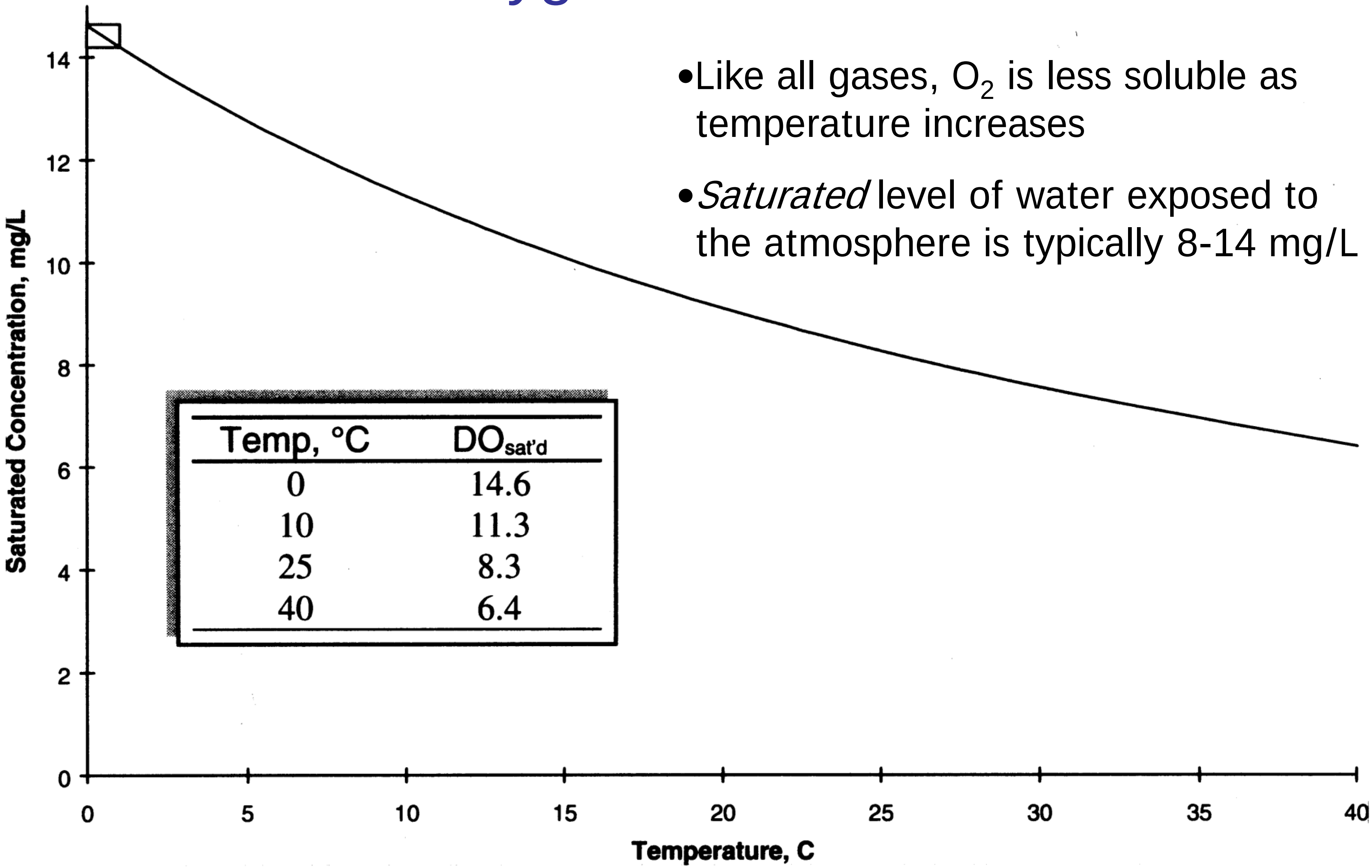
Temperature

- Fish metabolic rate decreases at low temperatures; increases at high temperatures.
- Egg development strongly correlated to water temperature.
- Thermal shock

Category	Optimum temperature (^oC)	Type
Coldwater	<15	Trout, salmon
Coolwater	15 – 25	Perch, walleye, pike
Warmwater	>25	Sunfish, bass, minnows

Saturated Oxygen Levels in Fresh Water

- Like all gases, O_2 is less soluble as temperature increases
- *Saturated* level of water exposed to the atmosphere is typically 8-14 mg/L



Temp, °C	$DO_{sat'd}$
0	14.6
10	11.3
25	8.3
40	6.4

Biochemical oxygen demand

- **Biochemical oxygen demand (BOD)-** oxidation of an organic compound is carried out by microorganisms using the organic matter as a food source
- BOD is measured by finding the change in dissolved oxygen concentration before and after bacteria is added to consume organic matter

Biochemical Oxygen Demand

- Organic Matter + $O_2 \rightarrow CO_2 + H_2O$ + new cells + stable products (SO_4^{2-}, PO_4^{3-}, NO_3)
  - Amount of oxygen required to ***aerobically*** degrade an organic waste
  - Units of mg O_2 required / liter of waste (mg/L)

BOD

- **Ultimate BOD-** maximum amount of oxygen consumption possible when waste has been completely degraded
- Numerical value of the rate constant k of BOD depends on:
  - Nature of waste and T
  - Ability of organisms in the system to use the waste

Nature of the waste

- Materials that are rapidly degraded have large BOD constants
- Materials that degrade slowly are almost undegradable in the BOD test
- BOD rate constant depends on the relative proportions of the various components
- Easily degradable organics are more completely removed than less readily degradable organics during wastewater treatment

5 day BOD test

1) A special 300 mL BOD bottle is filled with a sample of water that has been appropriately diluted and inoculated with microorganisms
2) Blank samples containing only the dilution water are also placed in BOD bottles and sealed
3) The sealed BOD bottles containing diluted samples and blanks are incubated in the dark at 20°C for the desired number of days
4) After five days has elapsed, the samples and blanks are removed from the incubator and the dissolved oxygen concentration in each bottle is measured.

Other Measures of Oxygen Demand

Nitrogenous Oxygen Demand

- So far we have dealt only with carbonaceous demand (demand to oxidize carbon compounds)
- Many other compounds, such as proteins, consume oxygen
- Mechanism of reactions are different

Nitrogenous Oxygen Demand

- Nitrification (2 step process)

$$2\ NH_3 + 3O_2 \rightarrow 2\ NO_2^- + 2H^+ + 2H_2O$$

$$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$$

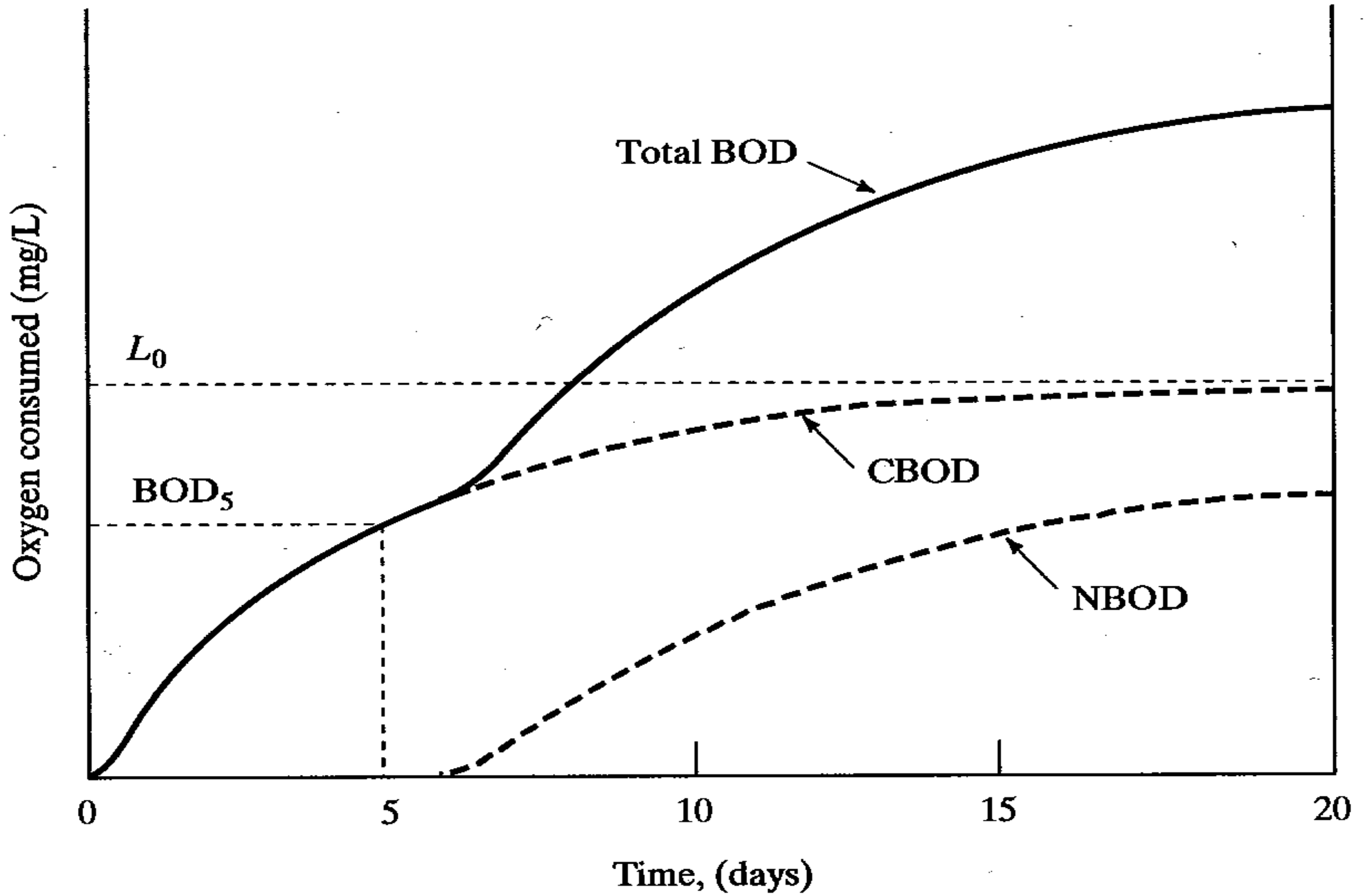
  - Overall reaction:

$$NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$$

- Theoretical NBOD =

$$\frac{\text{grams of oxygen used}}{\text{grams of nitrogen oxidized}} = \frac{4 \times 16}{14} = 4.57\ g\ O_2/g\ N$$

Nitrogenous Oxygen Demand



Nitrogenous oxygen demand

- Untreated domestic wastewater

  ultimate-CBOD = 250 - 350 mg/L

  ultimate-NBOD = 70 - 230 mg/L

  Total Kjeldahl Nitrogen (TKN) = total concentration of organic and ammonia nitrogen in wastewater: 15 - 50 mg/L as N

  Ultimate NBOD ≈ 4.57 x TKN

Chemical Oxygen Demand

- Chemical oxygen demand - similar to BOD but is determined by using a strong oxidizing agent to break down chemical (rather than bacteria)
- Still determines the equivalent amount of oxygen that would be consumed
- Value usually about 1.25 times BOD

Suspended Solids

- Particles not completely dissolved in water.
- Usually organic molecules:
  - Decaying matter
  - Uneaten food
  - Animal waste
  - Algae
  - Bacteria/protozoans
- Can include inorganic minerals from:
  - Erosion
  - Agricultural runoff
  - Physical action
- Can be used as indicators of turbidity & light; affect photosynthesis (good/bad), bury eggs, & clog gills of fish (should be below 80-100 mg/L).
- Dissolved solids = particles <0.45 mm

Total Dissolved Solids

- Refers to any minerals, salts, metals, etc. dissolved in water. (Includes anything present other than the pure water (H20) molecule and suspended solids.
- TDS is based on the electrical conductivity of water.
- In drinking water, a limit of 500 mg/L is desirable for palatability.
- Direct relationship with water hardness.

Suspended Solids

- With an increase in the amount of sediment comes:

  - Increase of turbidity
  - Decrease of light penetration
  - Increase in amount of bacteria
  - Increase in solids settled on the bottom which causes animal habitats to be destroyed

Suspended Solids

- **Suspended solids-** organic and inorganic particles that are carried by wastewater into a receiving water
- A slower flow causes particles to settle and form **sediment**
- **Colloidal particles-** do not settle, cause an increase in the turbidity of surface water
- **Organic suspended solids-** exert oxygen demand
- **Inorganic suspended solids-** result from soil erosion

Turbidity

- Measures clarity of water
- Measured as light penetration in nephelometric turbidity units (NTU)
- Also measured with a Secchi disk
  - Record the depth at which you can no longer see the banded colors on the disk

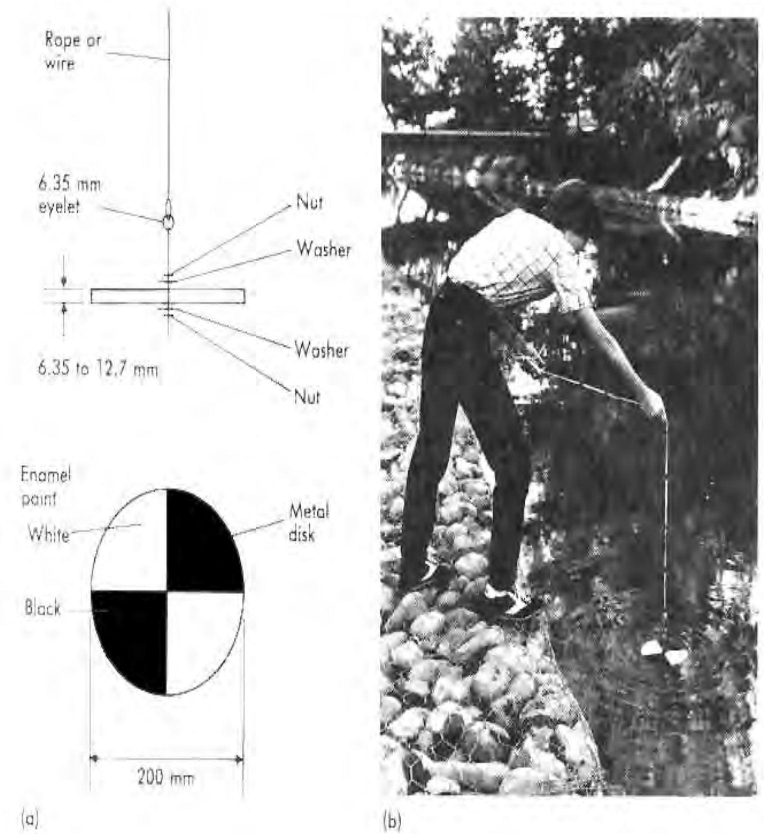


FIGURE 2.4

Secchi disk used to assess light penetration in water: (a) construction details and (b) application.

Secchi disk depth comparison from clear (left) to murky (right)
http://earthobservatory.nasa.gov/Study/WaterQuality/water_quality2.html

Turbidity

- Turbidity caused by plankton, chemicals, silt, etc.
- Most common causes of excess turbidity are plankton and soil erosion (due to logging, mining, farming, construction)
- The higher the turbidity the less light is available for photosynthesis.
- Higher turbidity also raises water temperature lowering the dissolved oxygen available.
- Reservoir release (Fe and Mn)

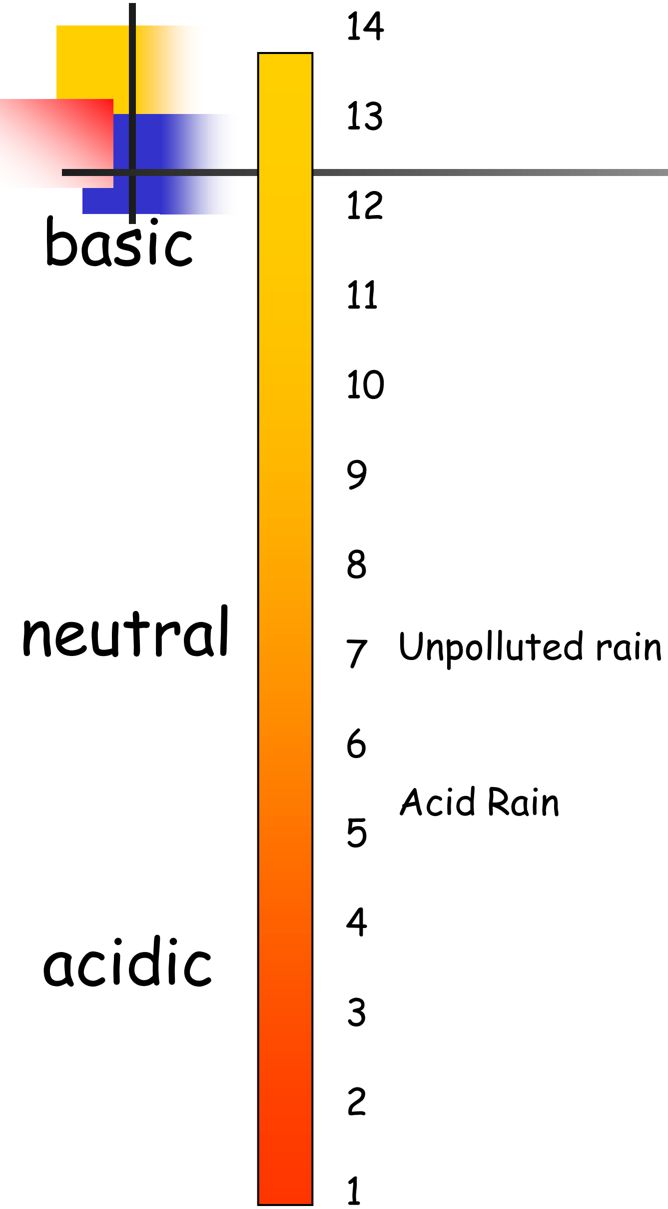
Turbidity

- Excess Turbidity can be a problem:
  - Light can't penetrate through the water – photosynthesis may be reduced or even stop – algae can die
  - Turbidity can clog gills of fish and shellfish –can be fatal
  - Fish cannot see to find food, but can hide better from predators

pH

- pH measures the degree of acidity or alkalinity of the water (each number is a 10-fold difference)
- 0-6 = acid; 7 = neutral; 8-14 = base
- Ideal for fish = 6.5 –8.2
  - pH outside the range can cause damage to gills, eyes, sking,etc.
- Ideal for algae = 7.5 – 8.4
- Acid waters make toxic chemicals (Al, Pb, Hg) more toxic than normal, and alter trophic structure (few plants, algae)

pH



- Good indicator of natural water quality
- Important for aquatic life
- Sandstone/Shale watersheds ~6.0 to 7.0
- Limestone watersheds ~7.0 – 8.0
- Impacted by acid rain, mine drainage

Geology

Igneous Rock

Sedimentary Rock

Sedimentary rocks often contain carbonates, which increase pH