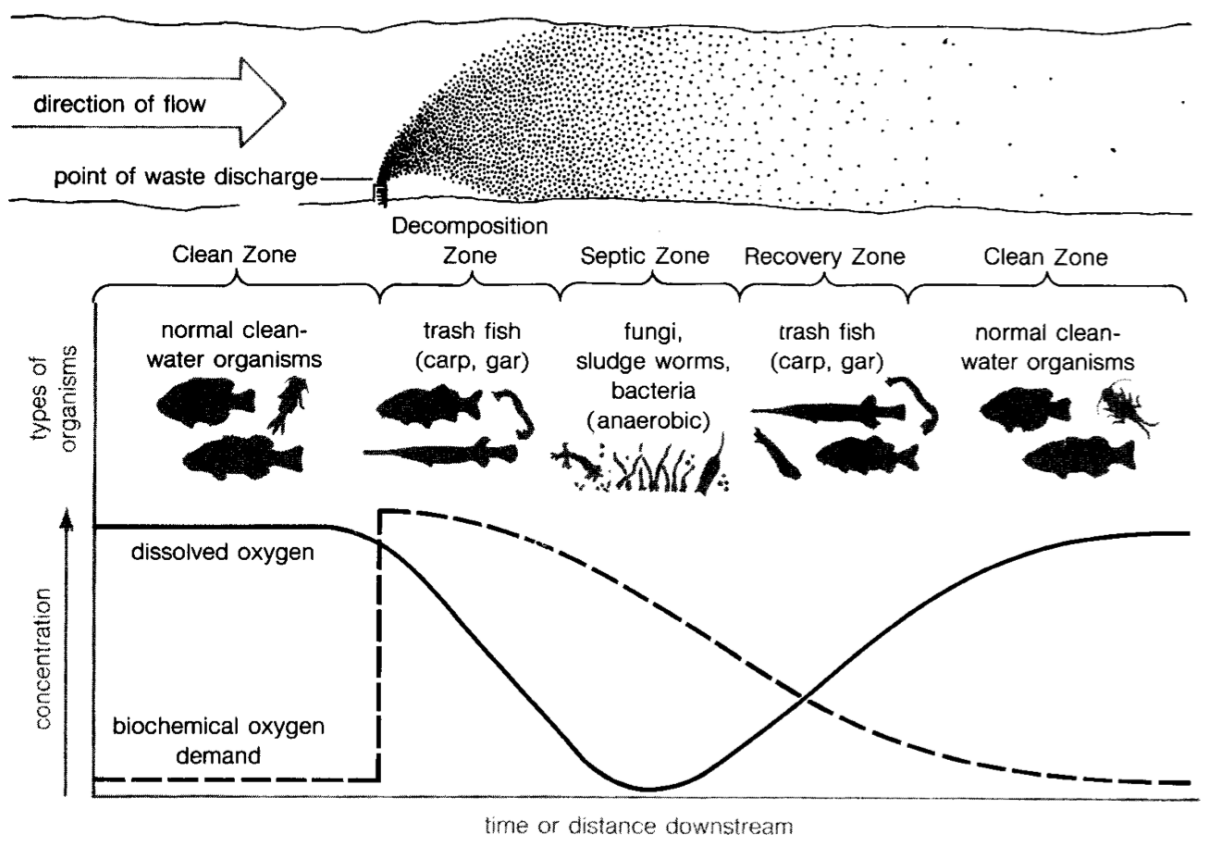
Sewage Discharges and Oxygen Depletion in Natural Waters



Outline of Topics

Human and Animal Waste

What are the common sources of human and animal waste that might contaminate natural waters?

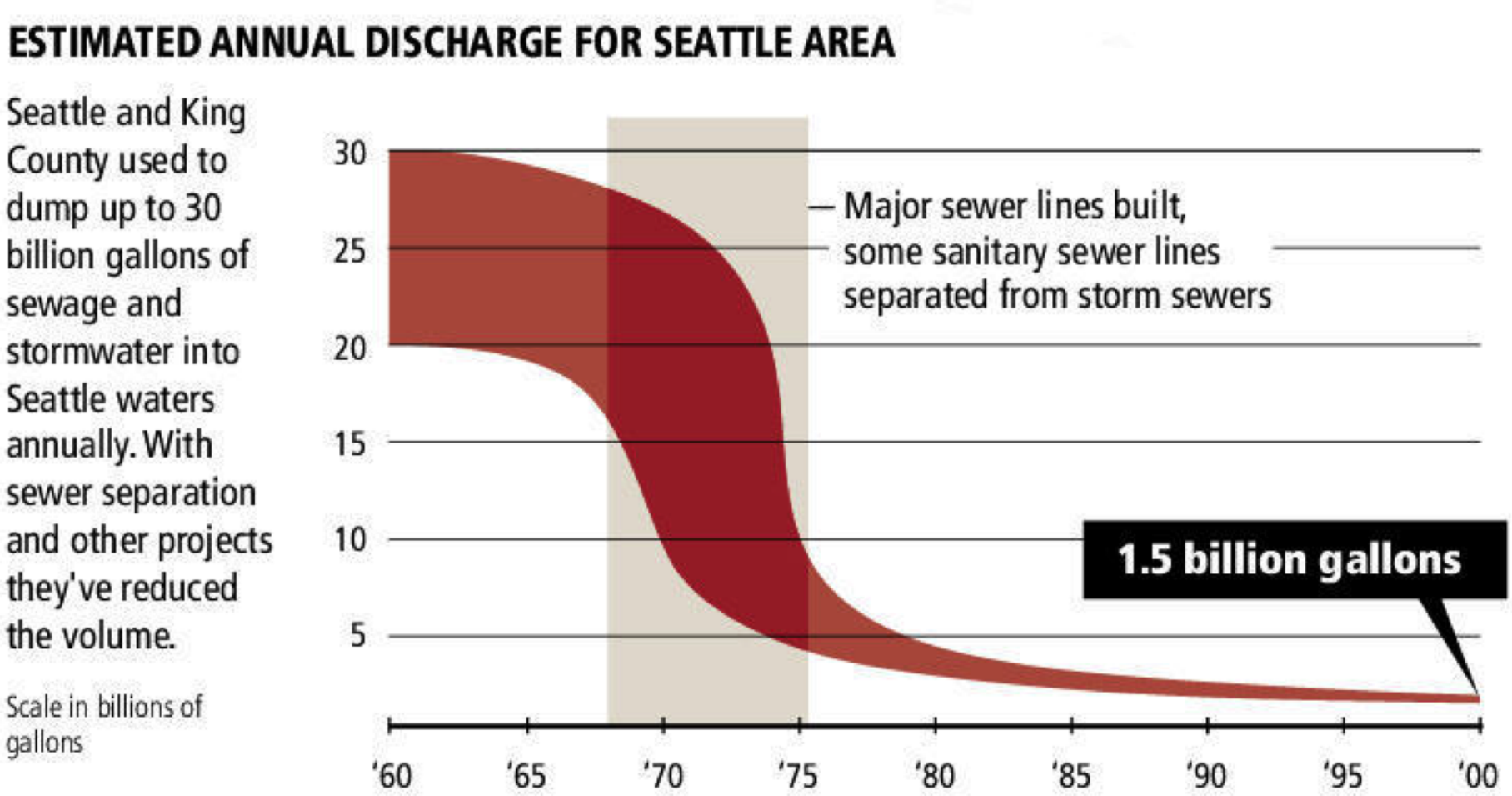
- *Municipal wastewater* (ie, sewage)
  - Especially from combined sewer overflows (CSOs)
  - Treated sewage discharge from POTW (publicly owned treatment works)
- *Septic tanks*
  - Subsurface disposal/treatment system for each home
  - When sewer lines are not available (eg, sparsely populated areas)
  - Consists of a buried septic tank and either a leaching field or seepage pit
- *Livestock waste*
  - Any agricultural operation that includes livestock
  - Animal feeding operation (AFOs): confined livestock, no crops
  - Large AFOs are a particular concern
  - **Concentrated animal feedlot operations** (CAFOs) are defined by the number of animals in the AFO
  - As of 2003, regulated as point sources under the NPDES portion of the Clean Water Act

Sewage Discharges (Lecture Question)

What pollutants are present in raw sewage discharges? What are the resulting effects on ecosystem and human health?

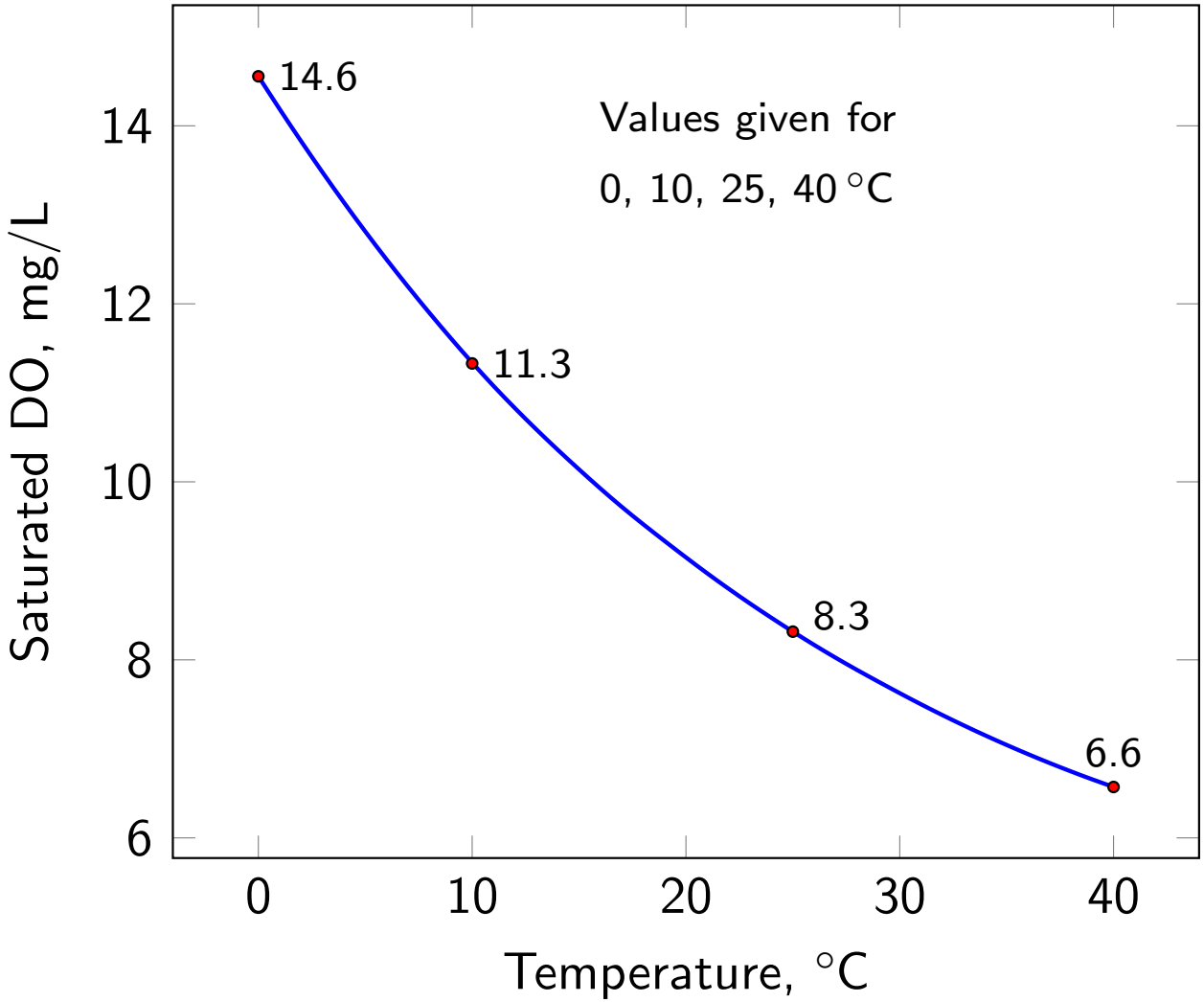
- Pathogens
  - Coliform count is usually 10^5–10^6/mL in raw sewage
  - Cause various waster-borne diseases. The most serious water pollution problem in developing countries.
- Degradable Organic Pollution
  - 'High BOD waste.' BOD of raw sewage: 100-400 mg/L (typically 200 mg/L), which dauses oxygen depletion
- Nutrients: nitrogen, phosphorus. Associated with eutrophication and related problems.
- Suspended Solids: increases turbidity and siltation in receiving water body
- Toxic Chemicals: disinfection byproducts (DBPs), pharmaceuticals and personal-care products (PPCPs), surfactants (especially linear alkyl sulfonates, LASs), anything else poured down the drain (toxic metals, etc), stormwater runoff (in combined systems)

Lecture question: What is a *combined sewer overflow* (CSO) event?



- *Seattle*: 1212 overflow events in 2001
- Over 500 million gallons of combined storm water and raw sewage flowed into Puget Sound

So what are typical DO levels in fully oxygenated natural waters?



Saturated DO is the level of dissolved oxygen that is in equilibrium with the air above the water.

Effects of Low DO

How much DO is enough for organisms?

DO Level, mg/L	Qualitative Effect
6–15	OK
4–6	Stressed
2–4	Choking
1–2	Dying
0–1	Dead

- Rapid decrease in DO can cause massive fish kills
- So-called *dead zones* form if DO falls enough

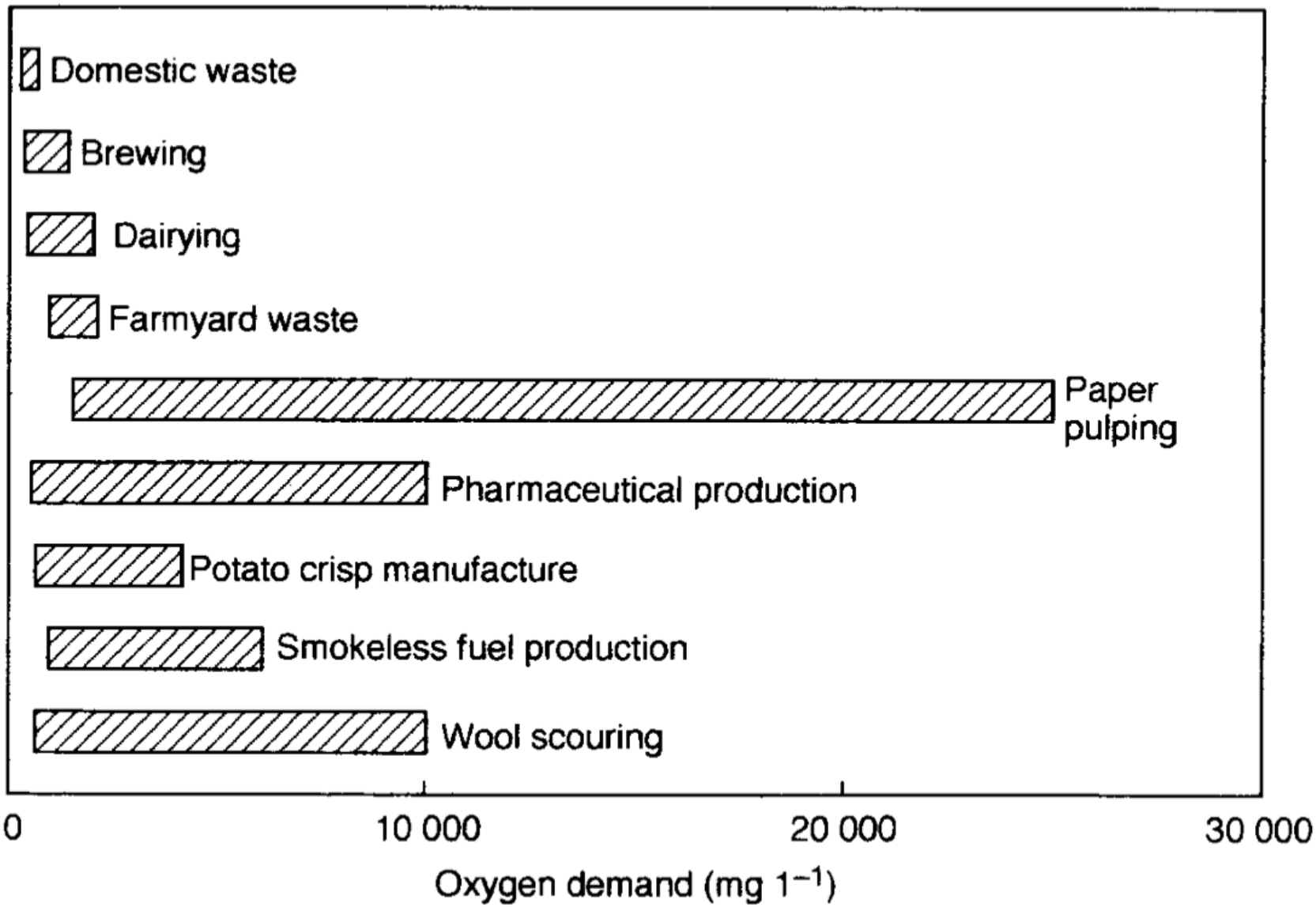
BOD Pollution

What is *biological oxygen demand* (BOD)?

- When organic material is decomposed (mostly microbial aerobic respiration) it 'demands' oxygen
- Oxygen demand represents a potential loss of DO in a water body
  - Important factor: relative rates of oxygen loss and replenishment
  - If the rate of oxygen loss due to decomposition exceeds the rate of oxygen replenishment (eg due to dissolution of gaseous O_2), then the DO level falls
- Oxygen demand can be quantified by measurement of BOD
  - BOD measurement:
    1. collect a sample of known volume;
    2. measure the DO level;
    3. seal and incubate at constant temperature for 5 or 7 days;
    4. measure the DO level again. The BOD is the difference between the two DO measurements.
  - BOD is determined by the amount of degradable material present in the water. Usually, it is mostly due to organic material ('CBOD') but can also be due to other chemicals in their reduced state (eg, NH_3).

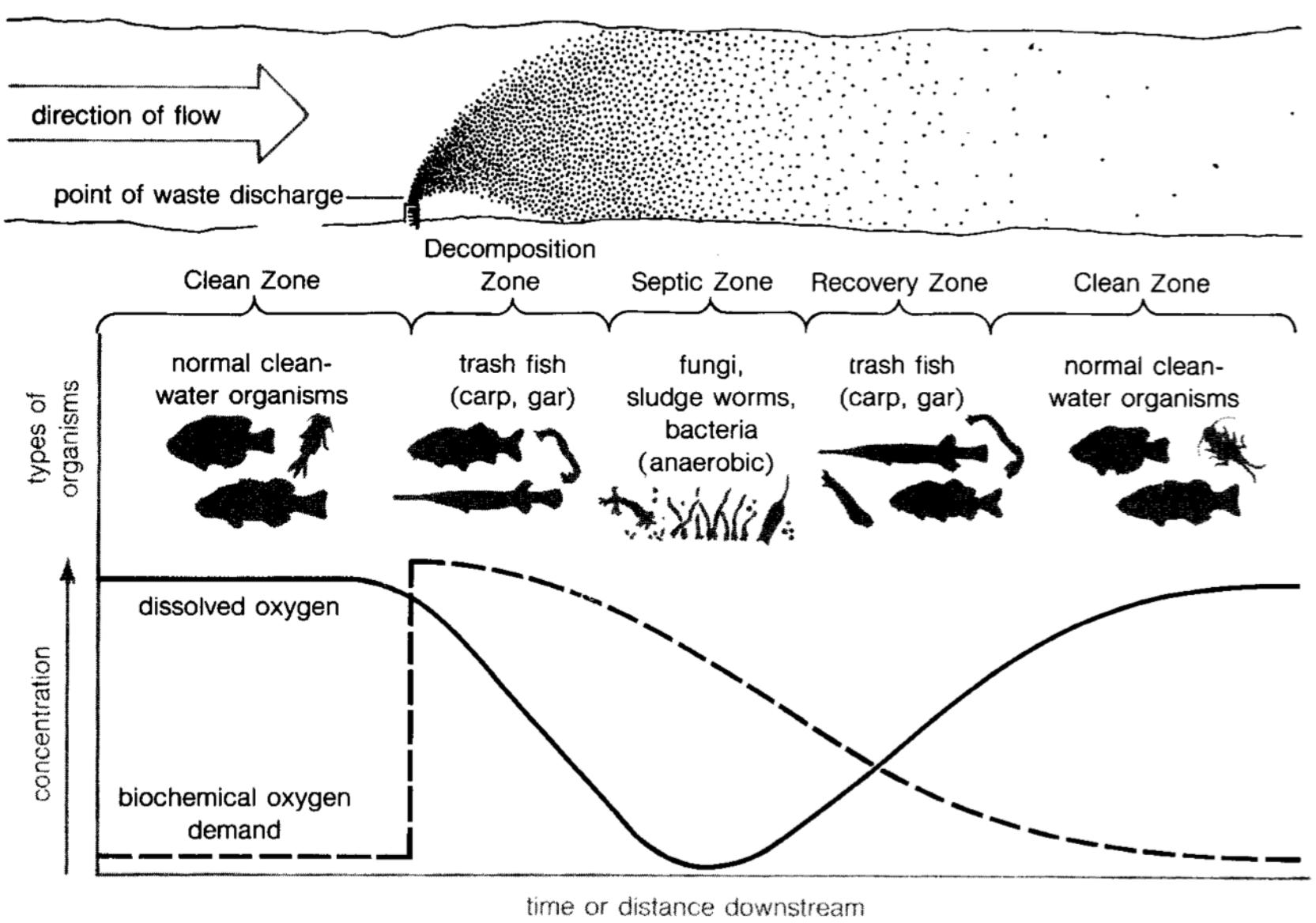
BOD Pollution

What are some major sources of high-BOD waste?

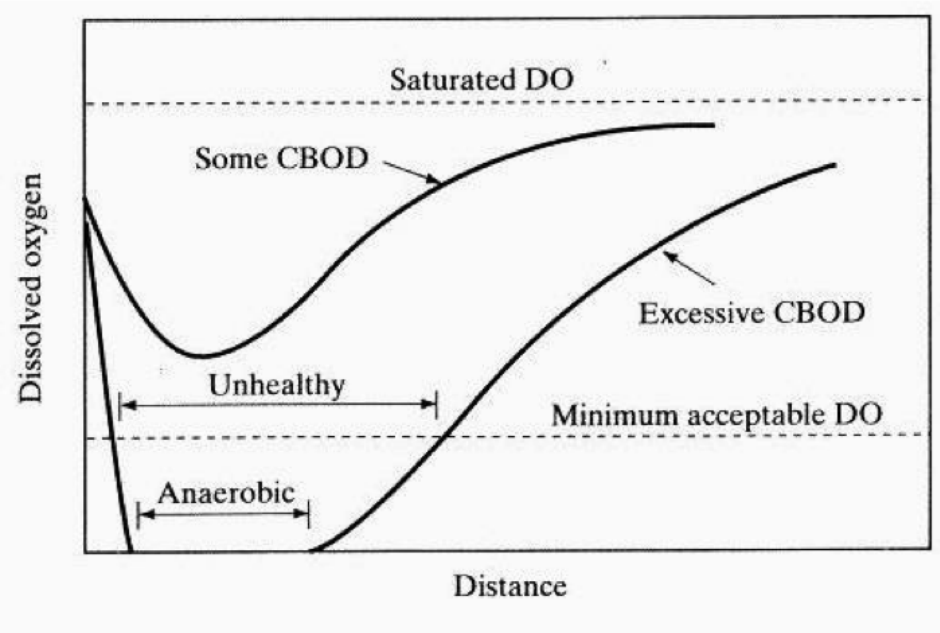


Oxygen Sag Curves

What is an *oxygen sag curve* in a river or lake?

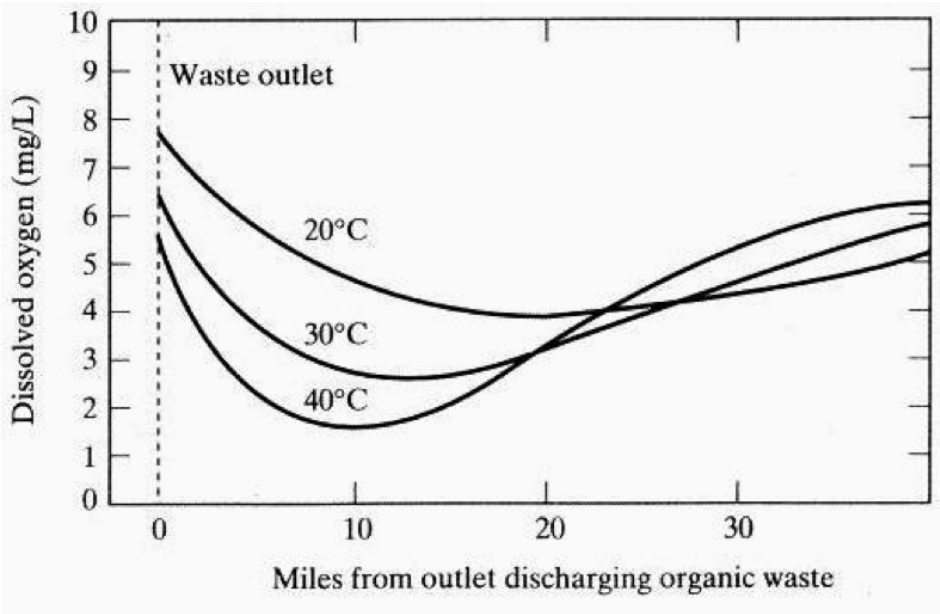


How does BOD level or temperature affect the sag curve?



Effects of BOD level:

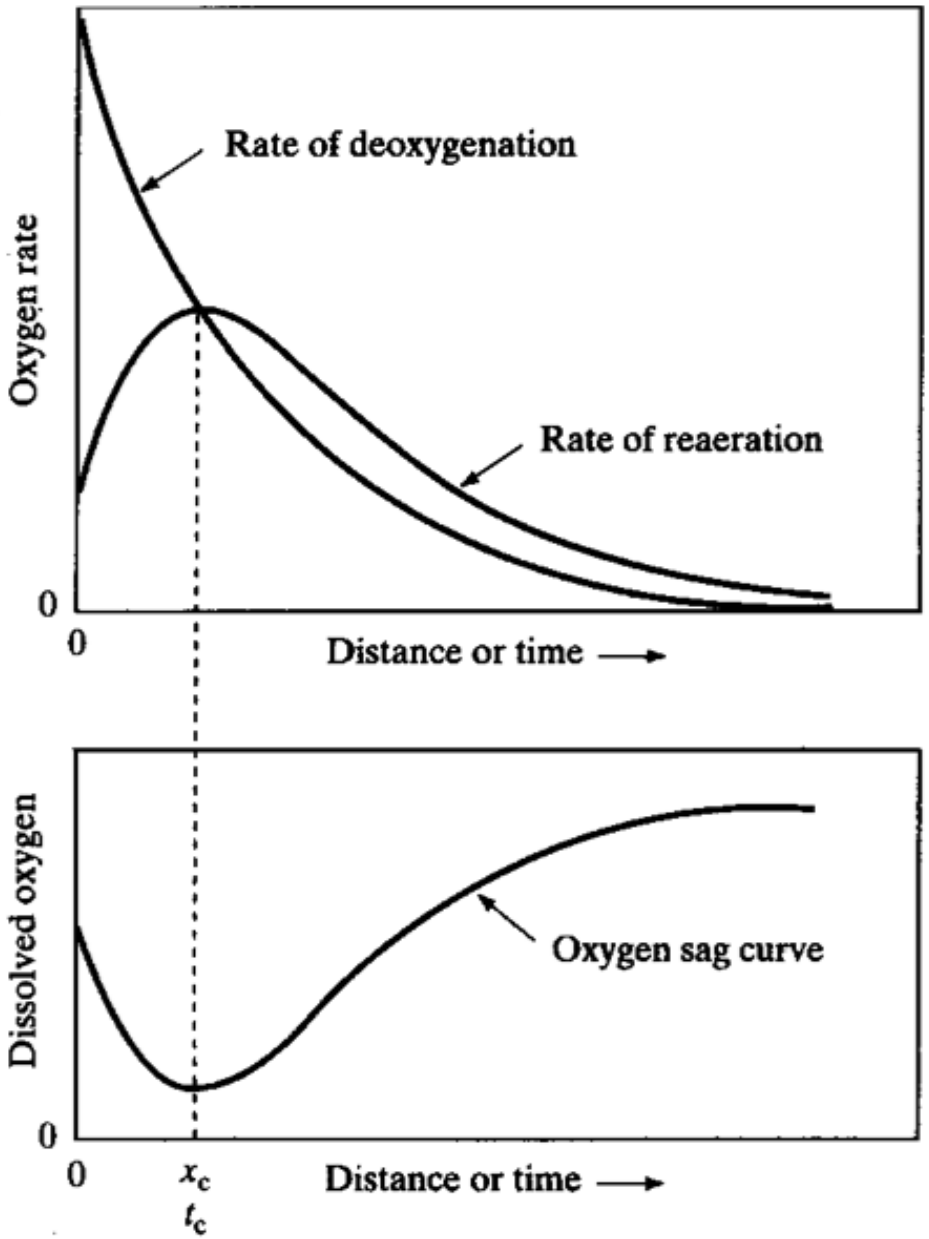
- sag becomes more severe
- longer distance/time at unhealthy DO levels



Effects of temperature:

- sag deepens and shortens
- may cause unhealthy DO levels

Explain the dynamics of oxygen sag curves.



- Dynamic equilibrium

$$O_2(g) \rightleftharpoons O_2(aq)$$

- Decomposition of BOD waste decreases DO
- DO falls as long as decomposition rate exceeds net dissolution rate
- Decomposition rate proportional to BOD level
- Dissolution rate proportional to *oxygen deficit*

$$\delta = DO_{satd} - DO$$

- *Minimum of curve is when the rates are equal*
- Question: what happens to DO of a lake with constant BOD waste

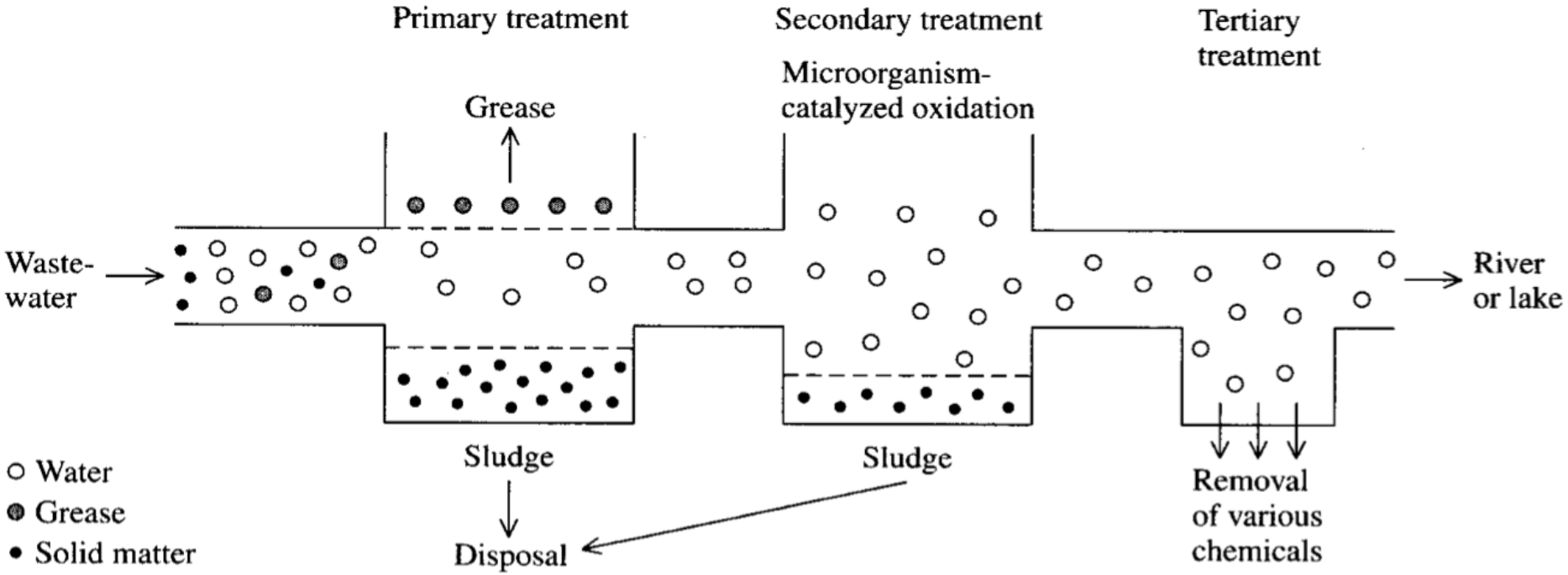
Sewage Treatment (Lecture Question)

How does the Clean Water Act regulate sewage discharges?

- CWA passed in 1972
- Regulates sewage discharges (among other things) as point sources of pollution
  - A major problem at the time
  - Requires all Publicly-Owned Treatment Works (POTWs, ie sewage treatment plants) to obtain discharge permits
  - Under the National Pollutant Discharge Elimination System (NPDES)
- Requires that all POTWs meet a minimum of secondary treatment level of sewage. A big help in reducing BOD, but:
  - problems remain
  - BOD still a little high
  - nutrient levels not reduced very much with only secondary treatment levels
  - and neither are toxics (metals, organics)

Sewage Treatment Plants (Lecture Question)

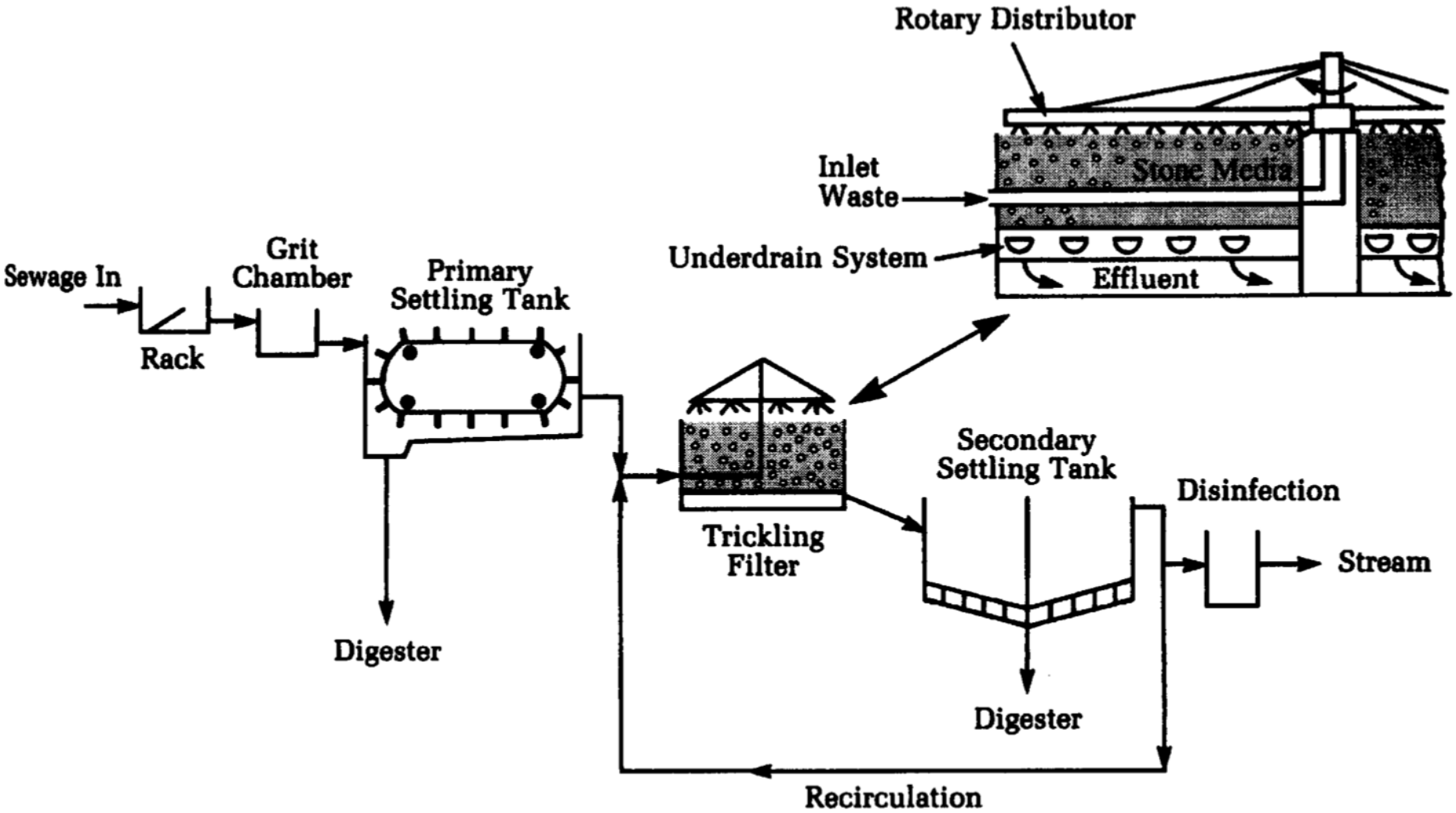
Describe in some detail the processes in the primary and secondary treatment of sewage.



- *Primary treatment*: physical separation for removal of bulky solids and oil/grease
- *Secondary treatment*: bioreactor primarily intended to reduce BOD

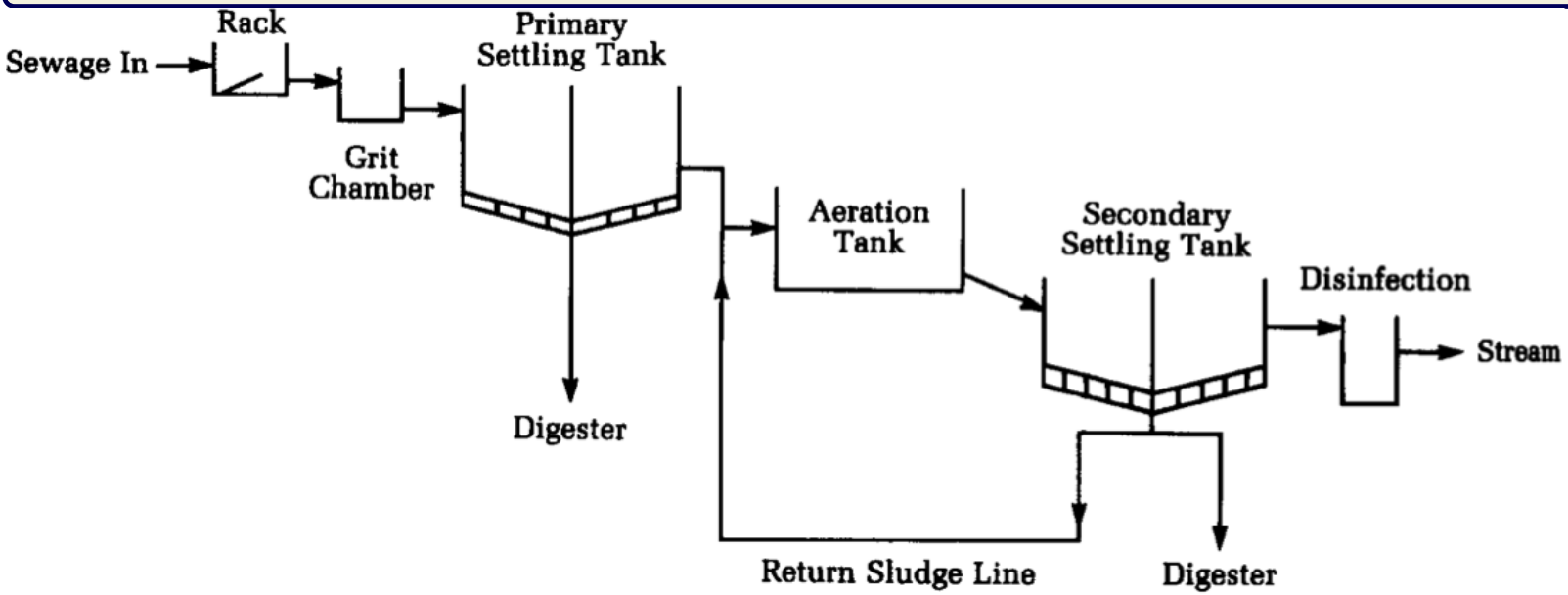
Secondary Treatment: Trickling Filters

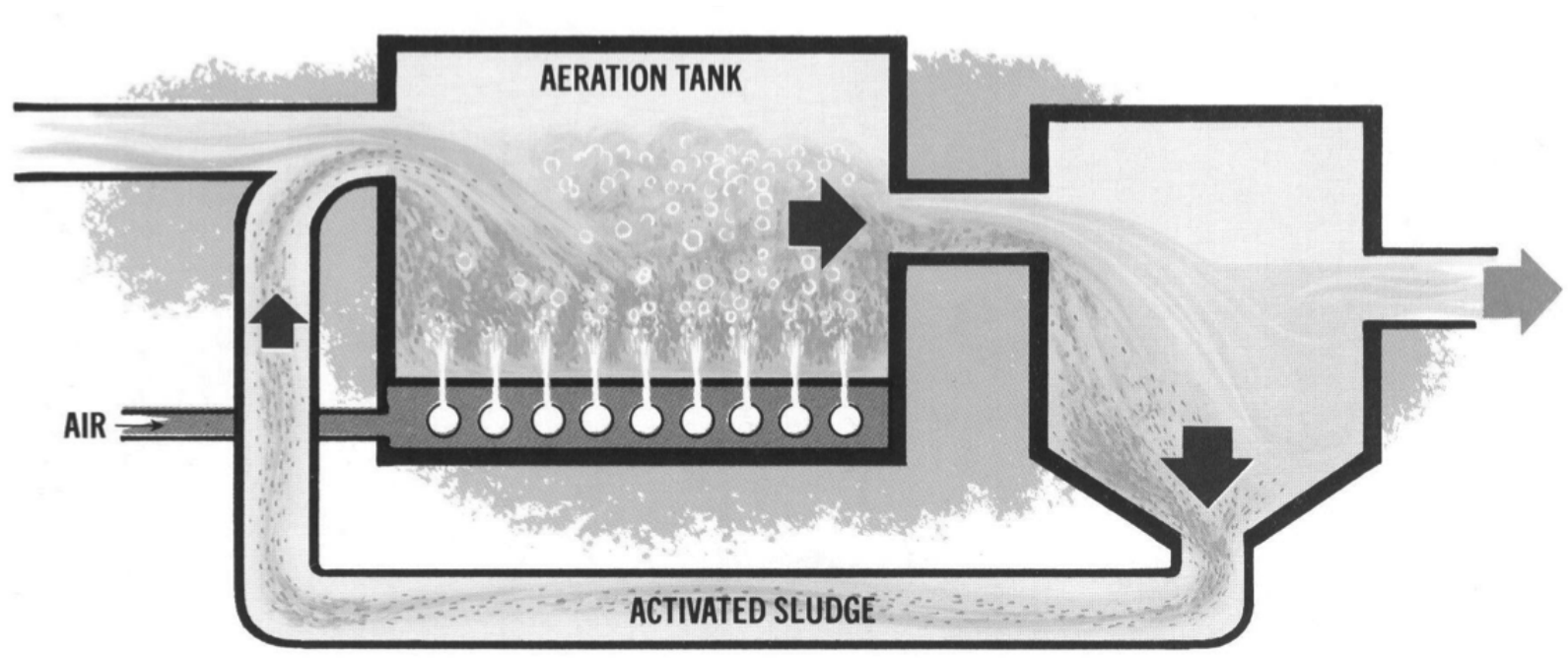
What is the *trickling filter* method of sewage treatment?



Secondary Treatment: Activated Sludge Method

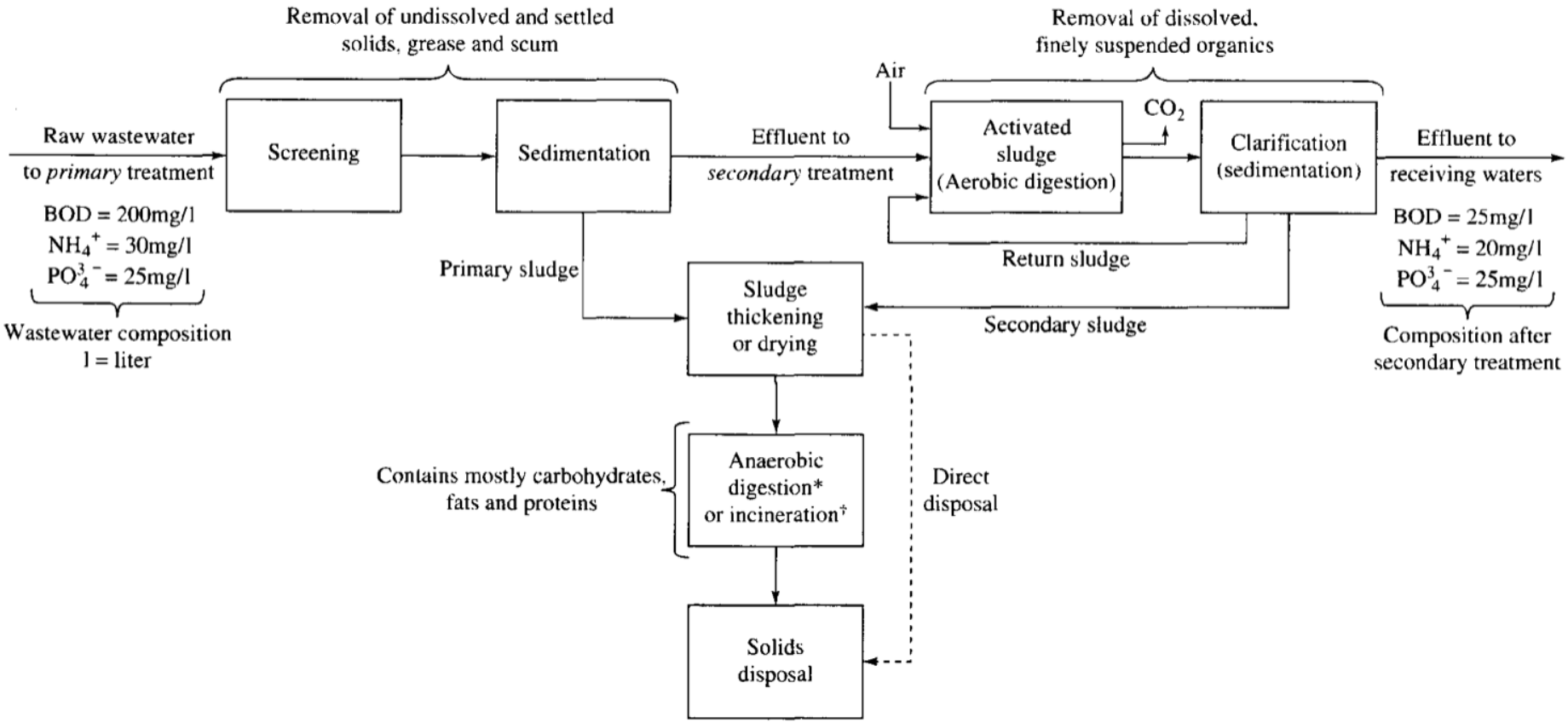
What is the *activated sludge* method of sewage treatment?





Primary and Secondary Treatment: Effects

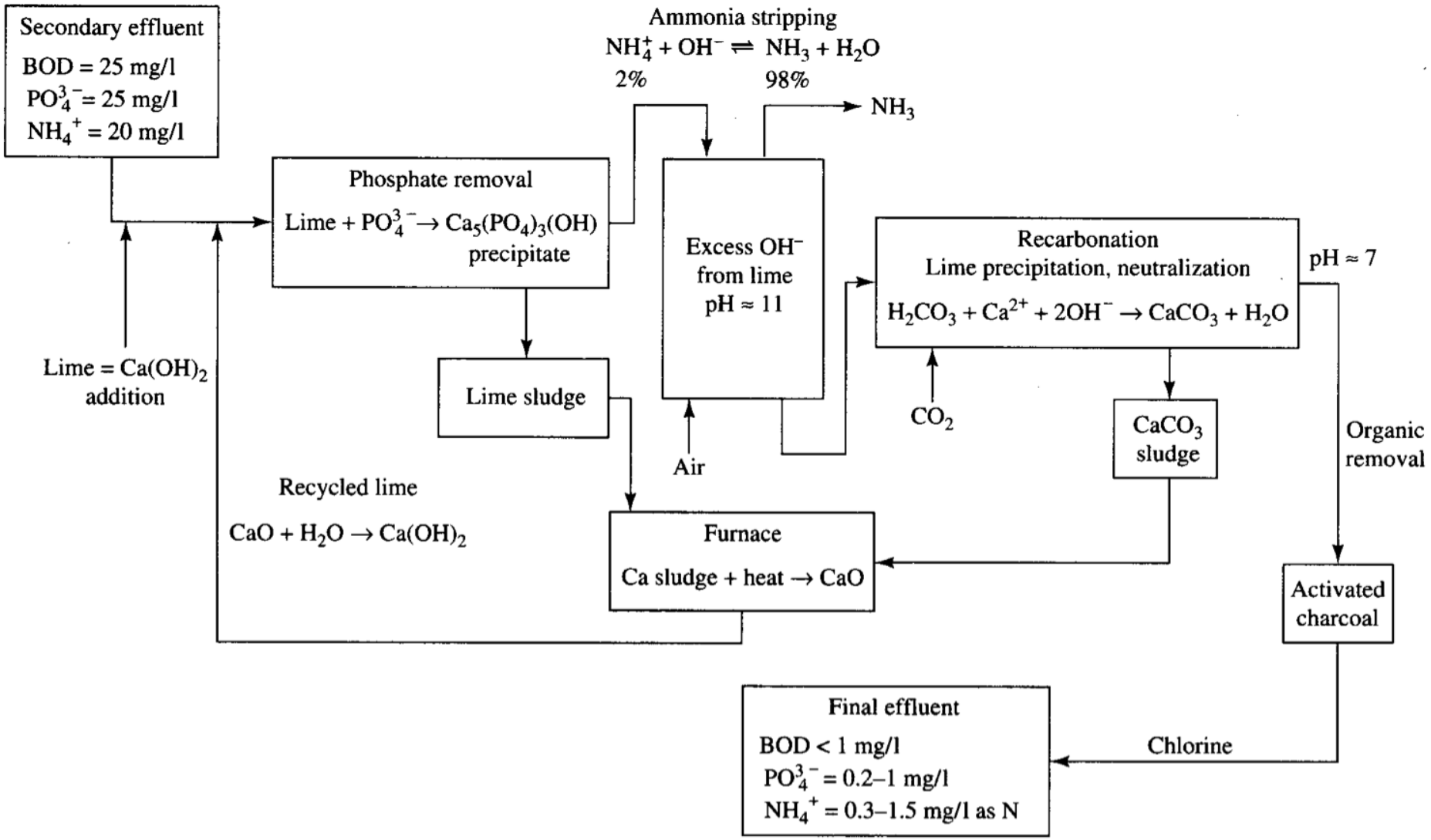
How effective if primary and secondary treatment in decreasing the impact that sewage discharges have on water quality?



* Typically, 50% of the sludge can be digested anaerobically to produce methane gas.
† Dried sludge can be burned as low-quality fuel with a heat value of about 13.5 kJ/g.

Advanced (Tertiary) Treatment: Lecture Question

What are the methods used in advanced (tertiary) sewage treatment? How do they help safeguard water quality?

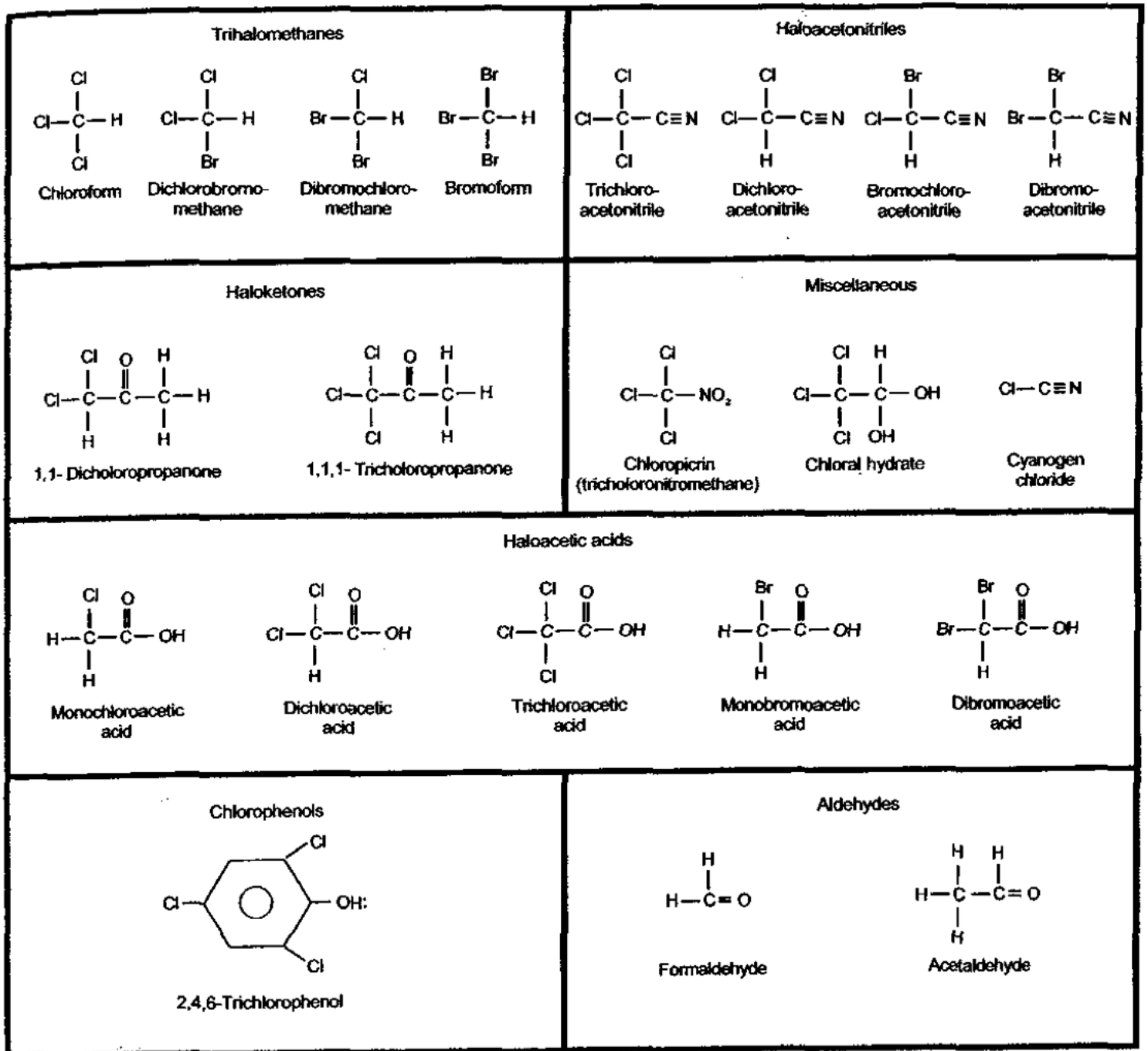


Disinfection Methods (Lecture Question)

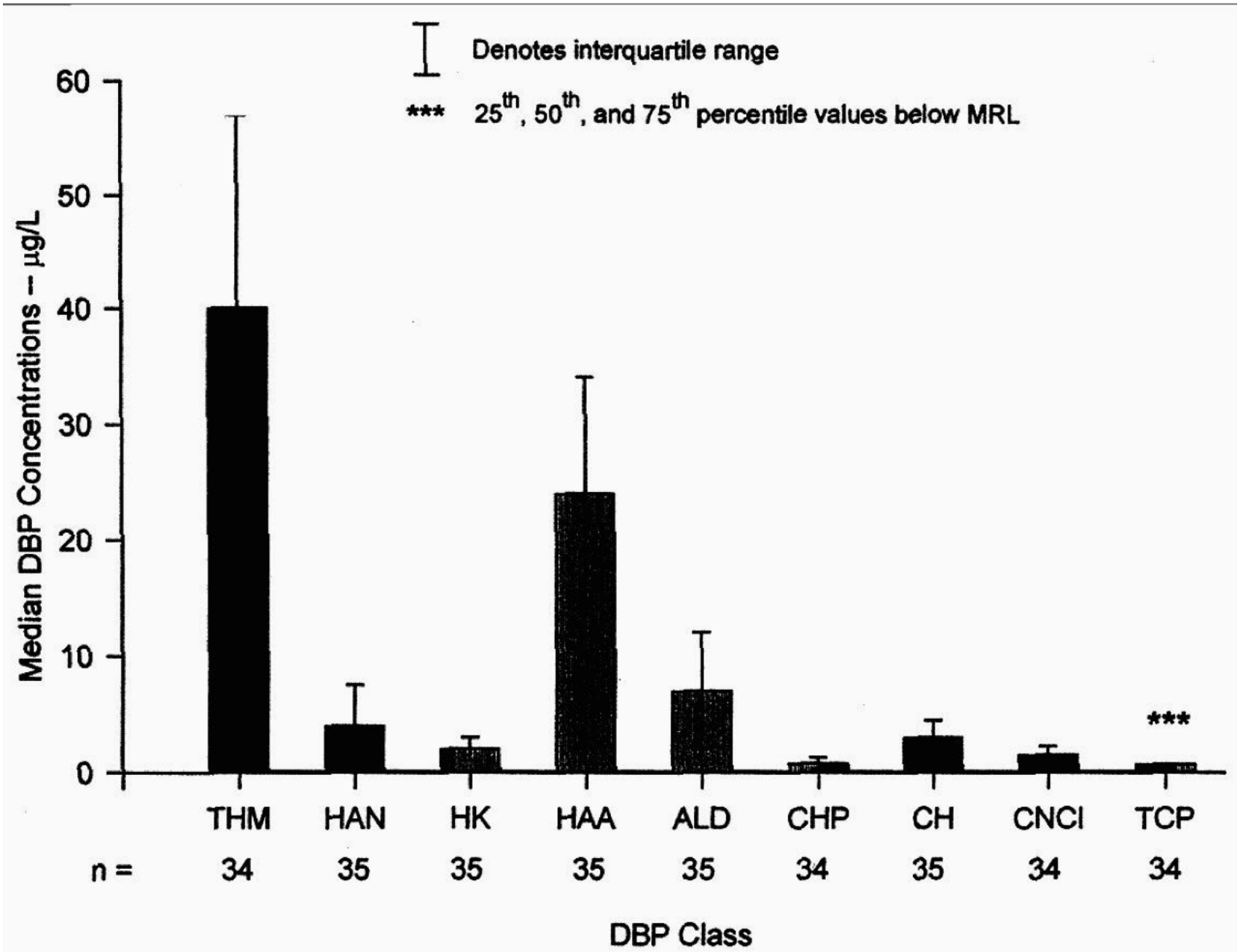
What are the main methods of disinfection used in sewage treatment?

- Chlorination
  - Applied either as chlorine gas or as a hypochlorite (OCl-) salt
  - pH control is important
  - Advantages: cheap, residual disinfection
  - Disadvantages: many disinfection byproducts (DBPs), such as THMs, HAAs, chloramines
- Alternatives
  - Ozonation
  - UV light
  - With alternative treatments, a lesser amounts of chlorine often also used for residual disinfection (or as a backup if coliform counts get too high).

What are *disinfection byproducts* produced by chlorination?



What are the most common chlorination DBPs found in natural waters?



Sewage Sludge (Lecture Question)

What is sewage sludge ('biosolids') and what is done with it?

- Wastewater treatment generates large quantities of solid waste
  - Collectively this is called 'sludge' or, more euphemistically, 'biosolids'
  - Contains all solid material removed from the waste stream, including: human waste, microorganisms, and toxic chemicals
  - Volume dwarfs that of municipal solid waste (ie, 'trash')
- Sludge is very watery
  - Looks essentially like muddy water in original form
  - Only 1-10% solid
- Usually dewatered at the treatment plant
  - Texture of a wet sponge
  - 11-40% solid at this point

Disposal of Sewage Sludge

What happens to sewage sludge?

- Land application/recycling (40-50%)
  - 67% of that used as fertilizer on crops
    Must be treated to remove pathogens. There is continued uncertainty over health effects due to pathogens and pollutants in the sludge
  - 12% of that to public: given away or sold
  - 9% of that applied to damaged lands: usually to revitalize closed mines
  - 3% of that sprayed onto forests: slope cannot exceed 10-20%
- Sanitary landfill (50%)
  - Direct
  - Incineration: resulting ash is landfilled