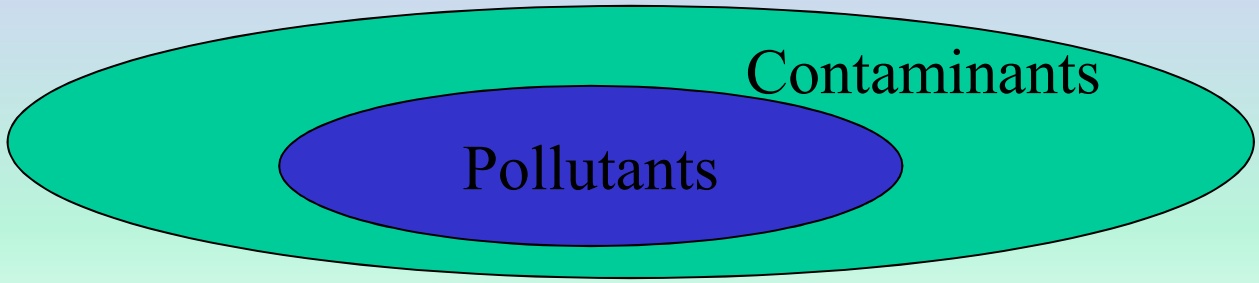
Water Pollution: Types, Causes, Consequences, Regulation and Economics

Freshwater pollution and its control

- Water for human consumption and other organisms needs to be…
  - Disease-free
  - Nontoxic
- Half of the world's major rivers are seriously depleted and polluted
  - They poison surrounding ecosystems
  - Threaten the health and livelihood of people
- The invisible pollution of groundwater has been called a "covert crisis"

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



Water Pollution

- Any chemical, biological and physical change in water quality that has a harmful effect on living organisms or makes it unusable for agriculture
  - The massive quantity of pollutants produced by > 6 billion humans, their machines, plants, animals
  - The limited supply of fresh liquid water into which most water-destined pollutants are discharged
  - The growing number of 'technological pollutants' released into the environment, i.e. manufactured synthetic materials

bss.sfsu.edu/ehines/geog600/Freshwater%20and%20ocean%20Pollution.ppt

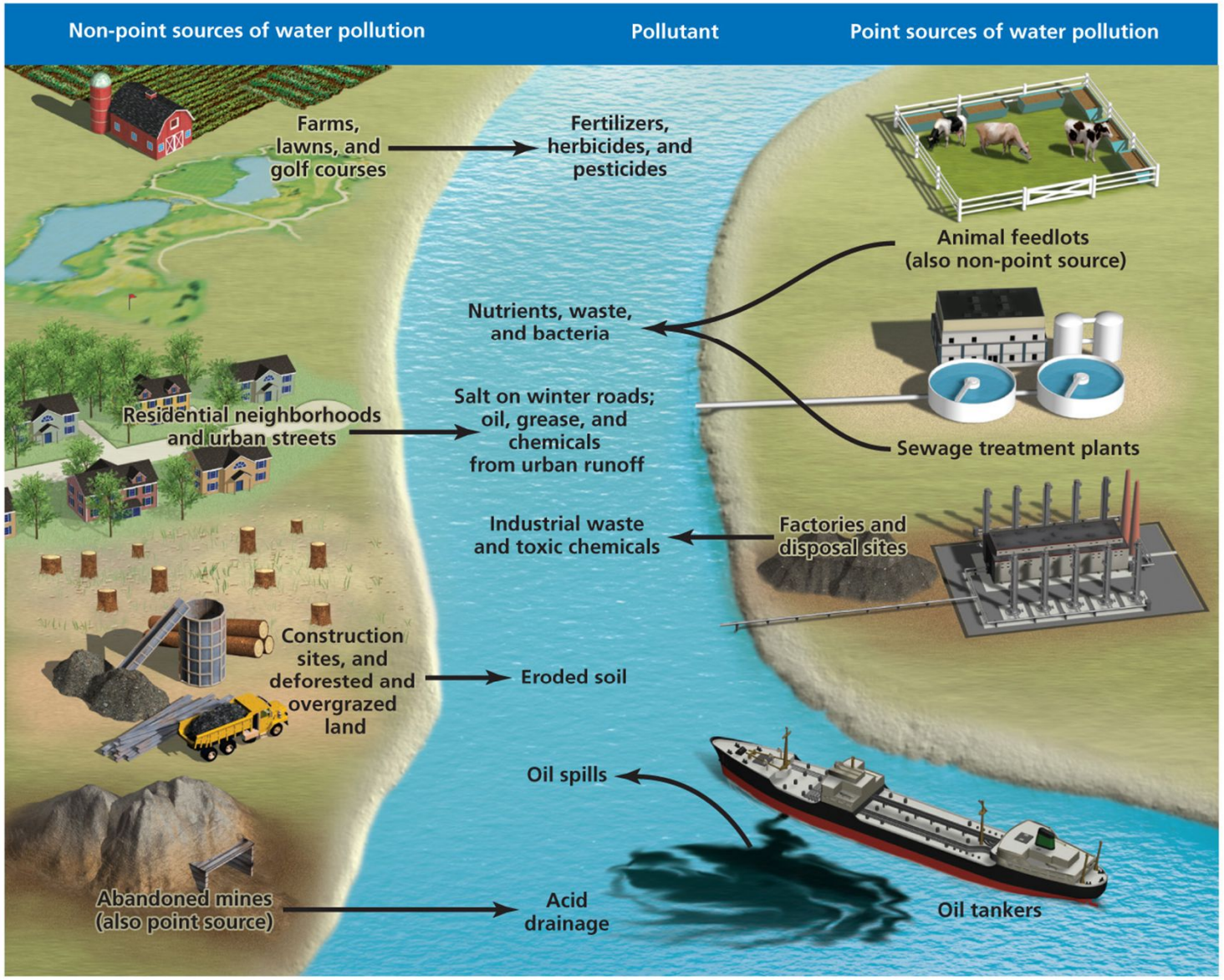
Types of Pollution

- Disease-causing Agents – pathogens
- Oxygen Demanding Agents – organic waste: manure
- Inorganic Plant Nutrients – nitrogen and phosphorus
- Sediment or Suspended Material – erosion, soil
- Toxic Chemicals – acids, heavy metals, organics
- Heat – electric and nuclear power plants

Point and nonpoint source water pollution

- **Point source water pollution** = discrete locations of pollution
  - Factory or sewer pipes
- **Nonpoint source water pollution** = pollution from multiple cumulative inputs over a large area
  - Farms, cities, streets, neighborhoods
- The U.S. Clean Water Act
  - Addressed point sources
  - Targeted industrial discharge
- In the U.S., nonpoint sources have a greater impact on quality
  - Limit development on watershed land surrounding reservoirs

Freshwater pollution sources



Pathogens and waterborne diseases

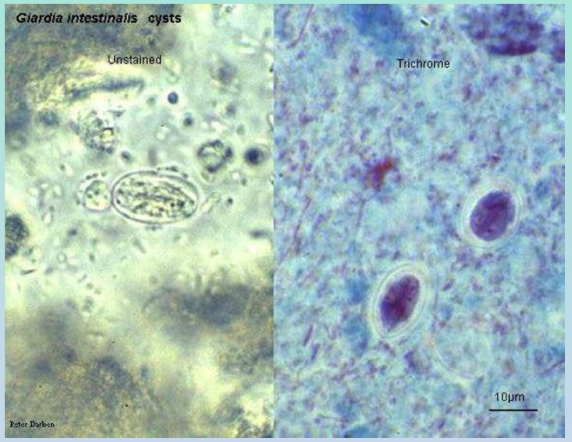
- Enters water supply via inadequately treated human waste and animal waste via feedlots
- Causes more human health problems than any other type of water pollution
- Fecal coliform bacteria indicate fecal contamination of water
  - The water can hold other pathogens, such as giardiais, typhoid, hepatitis A

Waterborne Pathogens

- Disease symptoms usually are explosive emissions from either end of the digestive tract

Escherichia coli

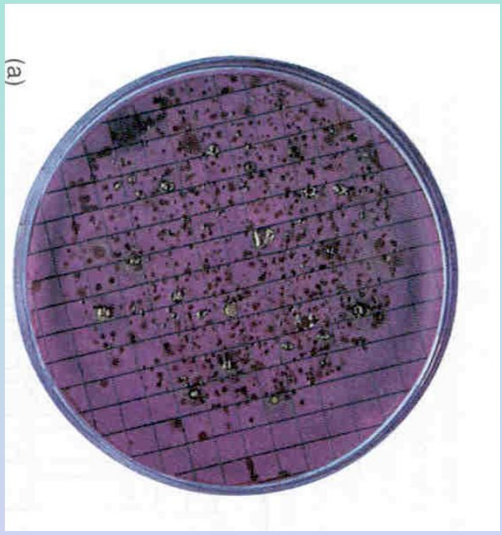
Vibrio sp.



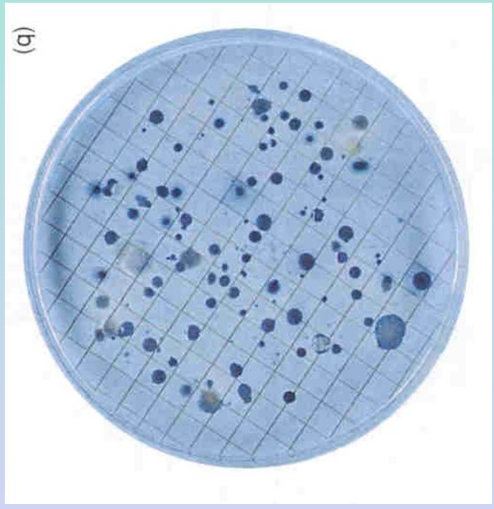
Giardia sp.*

Barbara E. Moore, Ph.D., Department of Biology, University of Texas at San Antonio

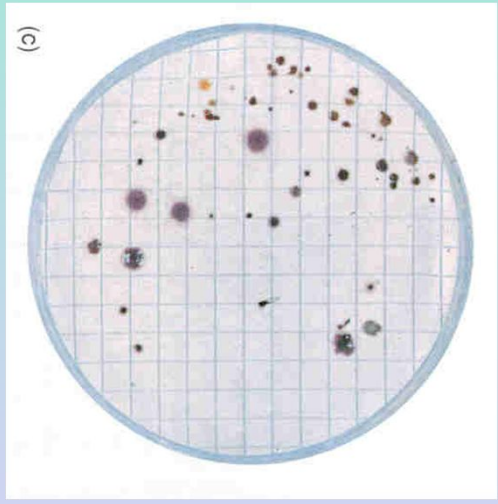
Indicator Tests



Total coliform
[Endo agar]



Fecal coliform
[m-FC agar]



Fecal streptococci
[M-enterococcus]

Prescott et al., Microbiology

Barbara E. Moore, Ph.D., Department of Biology, University of Texas at San Antonio

Pathogens cause massive human health problems

- Currently, 1.1 billion people are without safe drinking water
- 2.4 billion have no sewer or sanitary facilities
  - Mostly rural Asians and Africans
- An estimated 5 million people die per year
- Solutions:
  - Treat sewage
  - Disinfect drinking water
  - Public education to encourage personal hygiene
  - Government enforcement of regulations

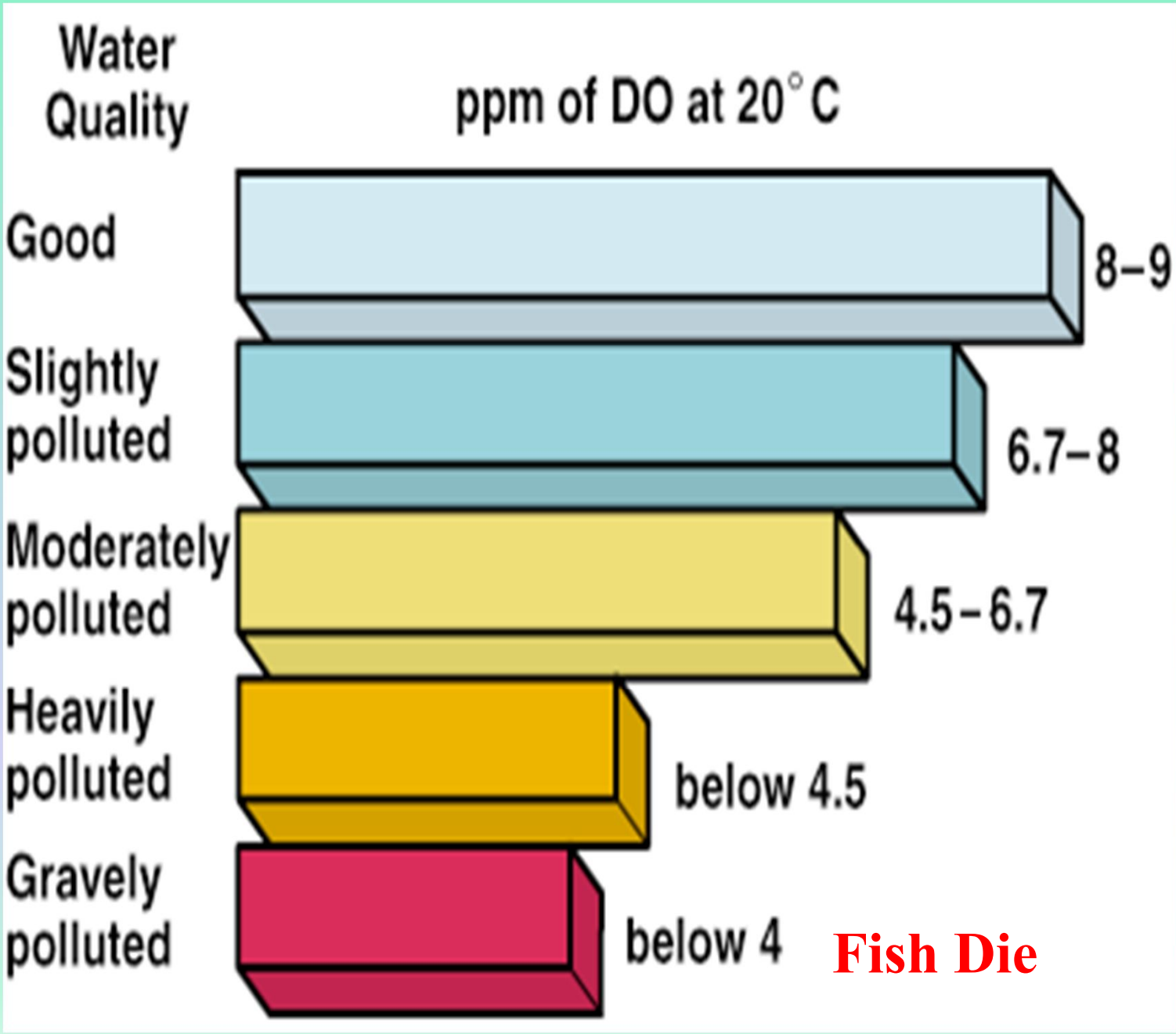
Biological Oxygen Demand (BOD)

- BOD: Oxygen is removed from water when organic matter is consumed by bacteria.
- Low oxygen conditions may kill fish and other organisms.

Sources of organic matter

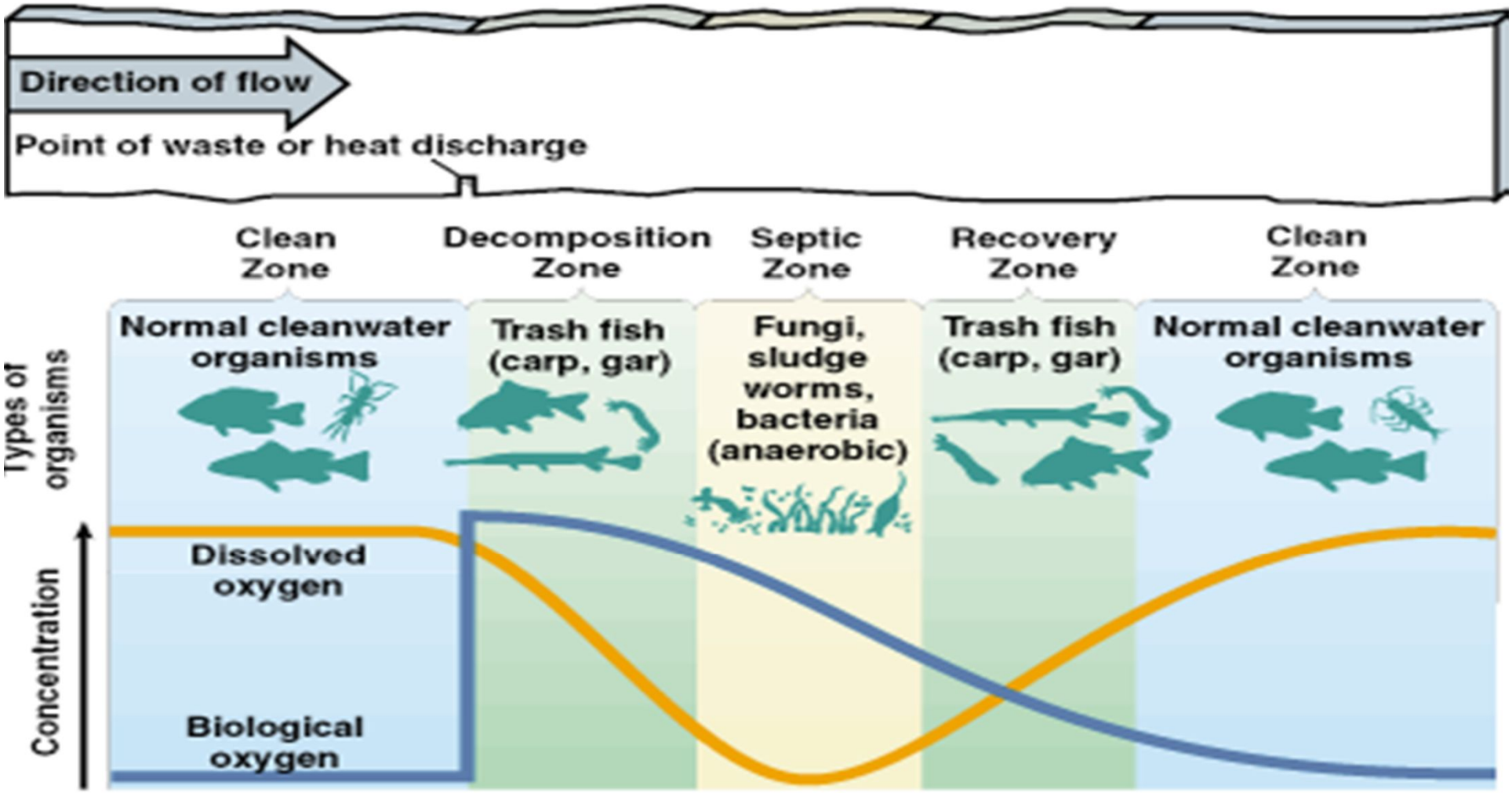
- Natural inputs-- bogs, swamps, leaf fall, and vegetation aligning waterways.
- Human inputs-- pulp and paper mills, meat-packing plants, food processing industries, and wastewater treatment plants.
- Nonpoint inputs-- runoff from urban areas, agricultural areas, and feedlots.

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt


Water Quality
ppm of DO at 20°C
Good
8–9
Slightly polluted
6.7–8
Moderately polluted
4.5–6.7
Heavily polluted
below 4.5
Gravely polluted
below 4
Fish Die

Pollution of Streams and Lakes

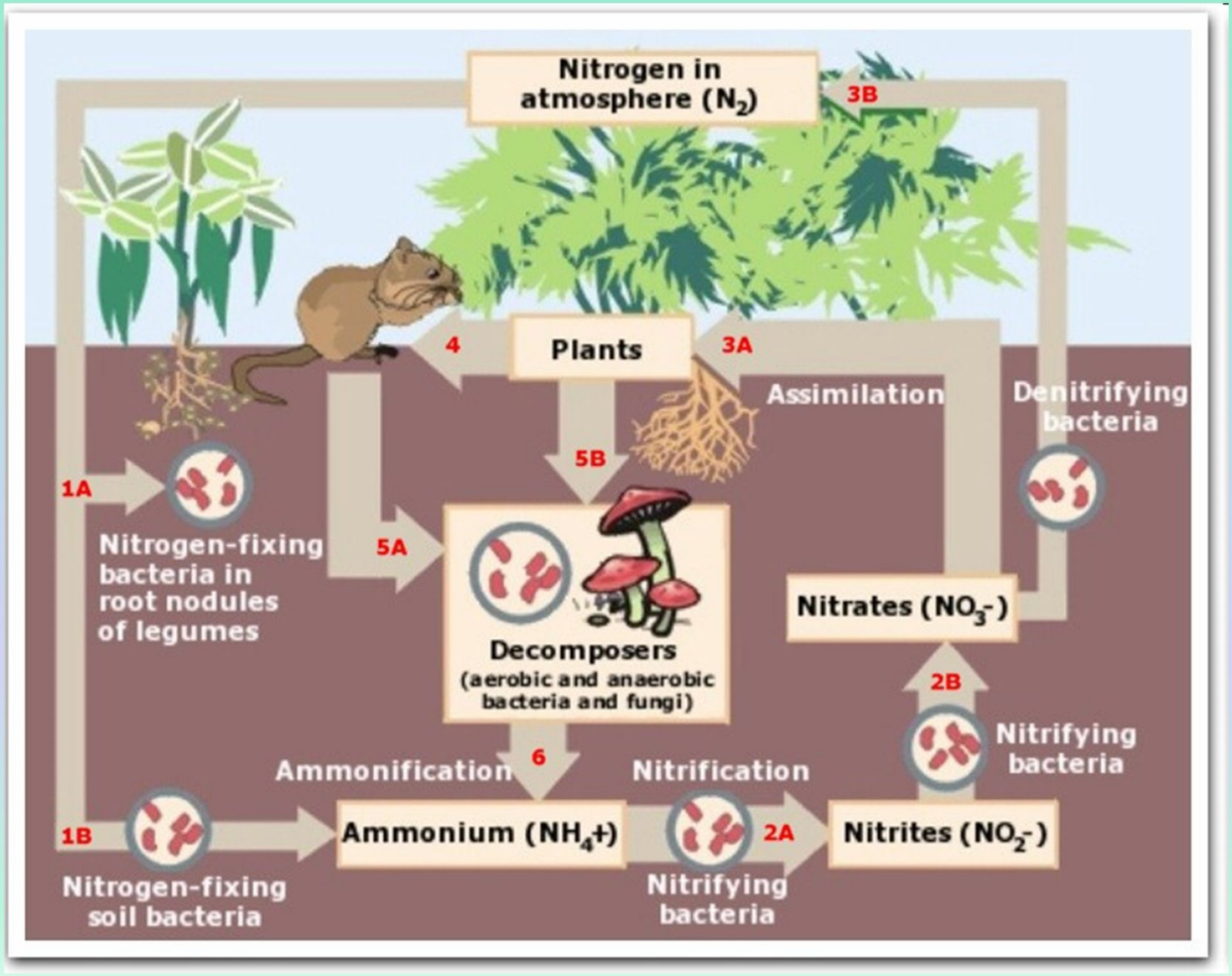
flowing water can recover rapidly by dilution and decay



Nutrient pollution

- **Pollution** = the release of matter or energy into the environment that causes undesirable impacts on the health and well-being of humans or other organisms
- Nutrient pollution from fertilizers, farms, sewage, lawns, golf courses
  - Leads to eutrophication
- Solutions
    - Phosphate-free detergents
    - Planting vegetation to increase nutrient uptake
    - Treat wastewater
    - Reduce fertilizer application

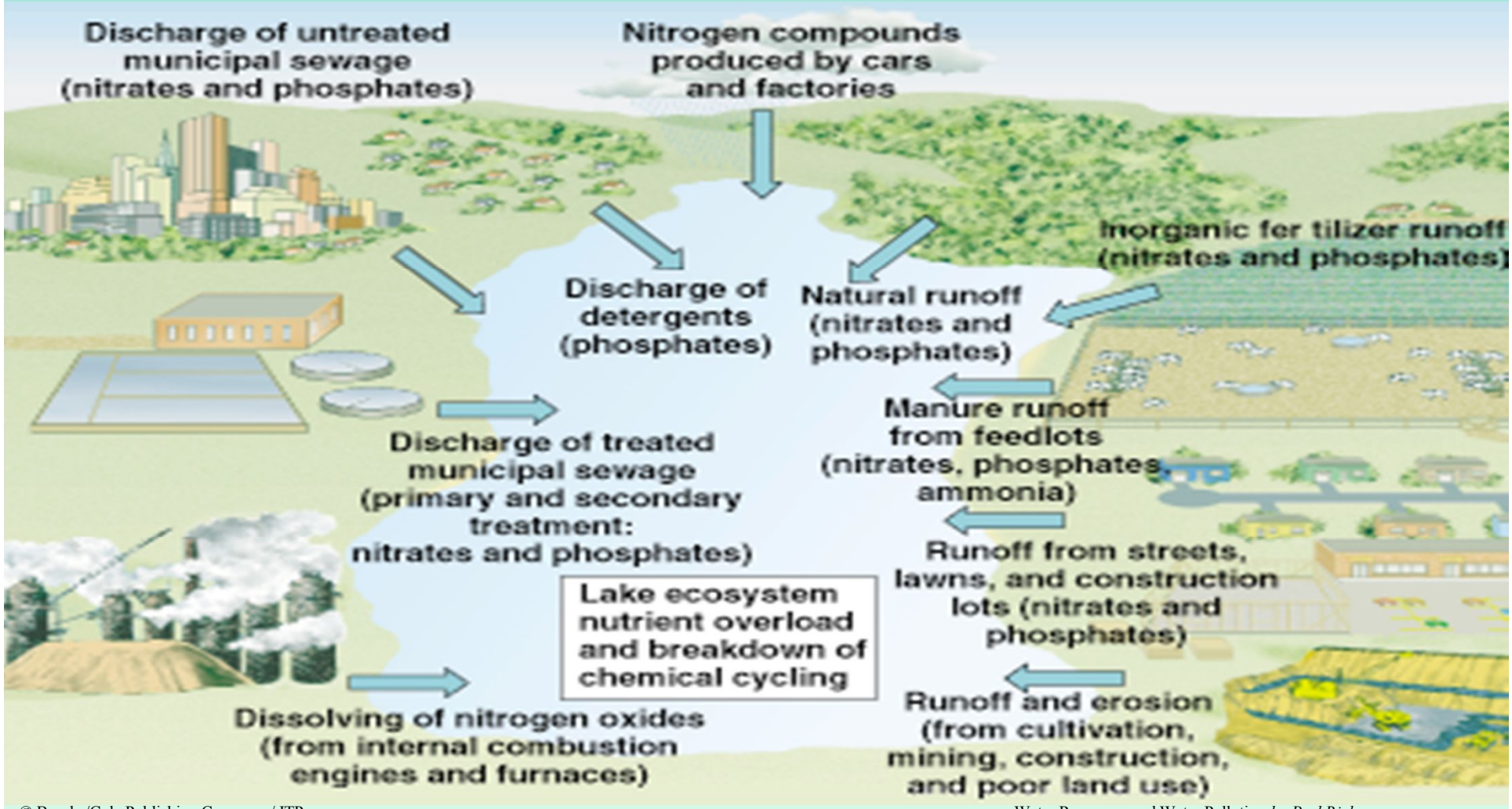
Nitrogen Cycle



Quiz

Eutrophication

Accelerated results with human input of nutrients to a lake



Eutrophication is a natural process, but…

- Human activities dramatically increase the rate at which it occurs

(a) Oligotrophic water body

(b) Eutrophic water body

Sediment pollution

- Sediment can impair aquatic ecosystems
  - Clear-cutting, mining, poor cultivation practices
  - Dramatically changes aquatic habitats, and fish may not survive
  - Solutions: better management of farms and forests; avoid large-scale disturbance of vegetation

Toxic chemicals

- From natural and synthetic sources
  - Pesticides, petroleum products, synthetic chemicals
  - Arsenic, lead, mercury, acid rain, acid drainage from mines
- Effects include: poisoning animals and plants, altering aquatic ecosystems, and affecting human health
- Solutions:
  - Legislating and enforcing more stringent regulations of industry
  - Modify industrial processes
  - Modify our purchasing decisions

Thermal pollution

- Warmer water holds less oxygen
  - Dissolved oxygen decreases as temperature increases
  - Industrial cooling heats water
  - Removing streamside cover also raises water temperature
- Water that is too cold causes problems
  - Water at the bottom of reservoirs is colder
  - When water is released, downstream water temperatures drop suddenly and may kill aquatic organisms

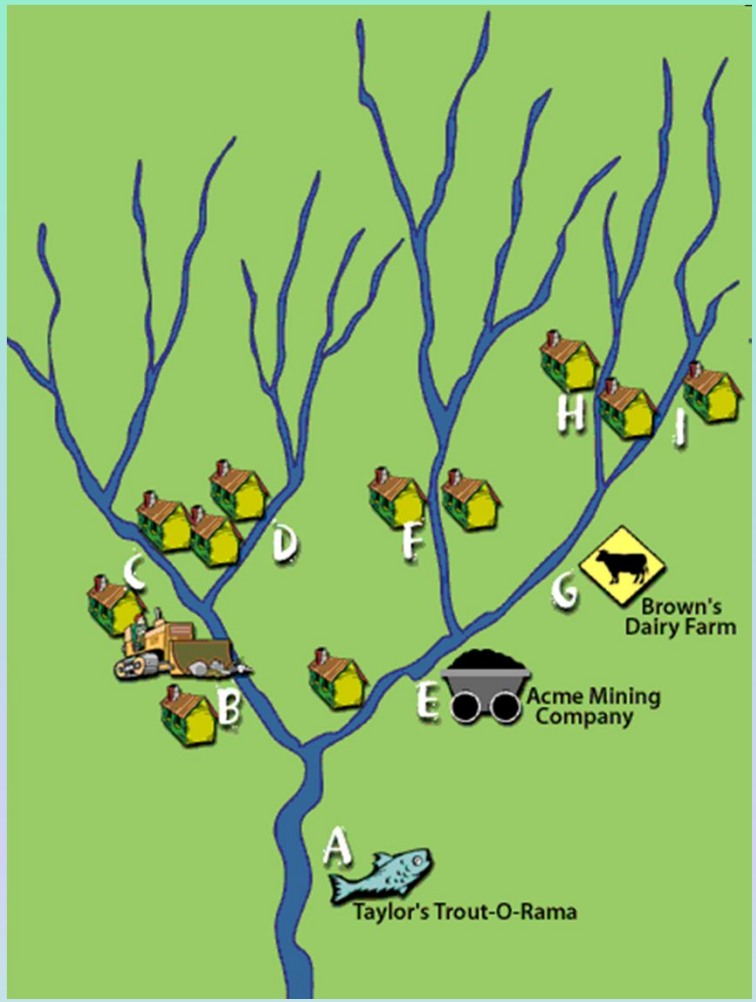
Indicators of water quality

- Scientists measure properties of water to characterize its quality
  - Biological indicators: presence of disease-causing organisms; benthic macroinvertebrate diversity
  - Chemical indicators: pH, nutrient concentration, taste, odor, hardness, dissolved oxygen
  - Physical indicators: turbidity, color, temperature

What's Happening in the Bear Creek Watershed?

Situation The scarcity of clean surface water was once a concern primarily of state and federal agencies. Recently it has attracted the attention of local communities. Community members are turning to environmental consulting companies such as yours for advice. Your company - Earth, Wind, and Water, Inc. - has helped many public agencies and private businesses in the small town of Oak View. Earth, Wind, and Water, Inc. monitors environmental quality. It develops practices that environmentally and economically benefit Oak View.

Your newest client, Mr. Charles Taylor, owns Taylor's Trout-A-Rama. Taylor's Trout-A-Rama is a local streamside catch-and-release campsite. Mr. Taylor is upset over the fact that the fish in that stretch of Bear Creek have been dying. His business, like the trout, is going belly-up. He has called on your firm to figure out what is killing the fish in that section of Bear Creek, and how to stop it. Preliminary fieldwork has been done on Bear Creek and is available for your analysis.



Click the Pic!

Water Quality Standards

- In most countries, water quality standards have gradually emerged and are still evolving for different water uses
- Standards are a function of
  - our ability to detect and remove contaminants
  - our understanding and/or fear of their actual or possible impacts

isis.csuhayward.edu/alss/Geography/

U.S. Water Quality Standards

- The EPA have recorded at least 700 contaminants that have been found in municipal drinking water supplies around the country, many of which are harmful to humans
- The EPA currently requires the monitoring and reporting of some 83 variables and have set maximum contaminant levels for each (MCLS). This will likely increase soon

isis.csuhayward.edu/alss/Geography/ mlee/geog4350/4350c4f01.ppt

Legislative efforts reduce pollution

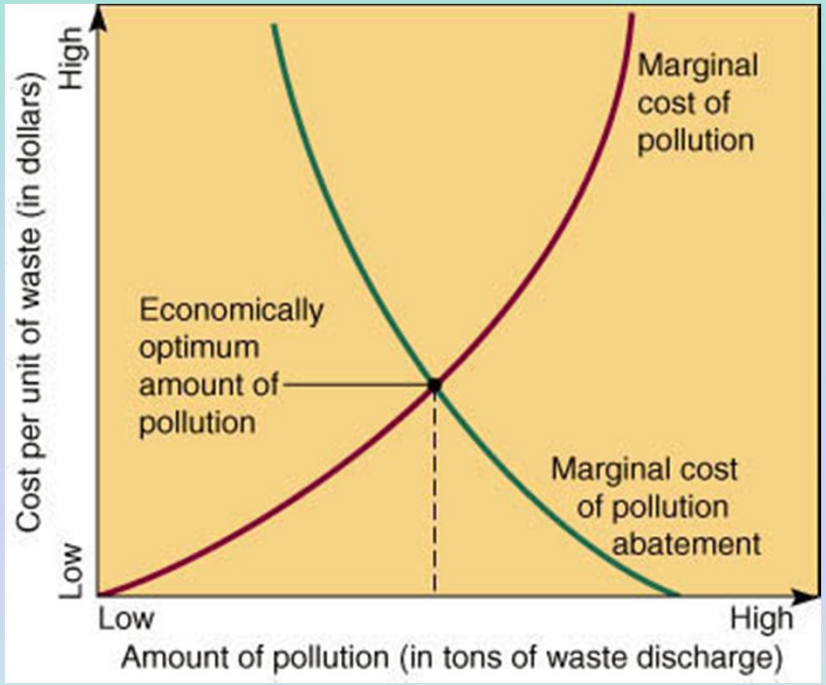
- Federal Water Pollution Control Act (1972)
  - Renamed the Clean Water Act in 1977
  - Illegal to discharge pollution without a permit
  - Standards for industrial wastewater
  - Funded sewage treatment plants
- Because of legislation, the situation is much better than it was
- Other nations have also reduced pollution

Legal Attempts to Control Water Pollution

1. Clean Water Act 1977, now a state-federal partnership
2. The Porter-Cologne Water Quality Control Act 1987
3. Federal Water Pollution Control Act 1972 amended to create:
4. Safe Drinking Water Act, 1974, amended 1996
5. London Dumping Convention (1975) is the international treaty regulating disposal of wastes generated by normal operation of vessels

What is the optimal amount of pollution? (If there is such a thing?)

- If pollution exceeds the optimum amount of pollution
  - the harm done exceeds the cost to reduce it.
- If pollution is small it may cost too much to control the small amount.



Clean Water Act

- The Clean Water Act is a 1977 amendment to the Federal Water Pollution Control Act of 1972
  - Set the basic structure for regulating discharges of pollutants in the US
- The law gave EPA the authority to set water quality standards for industry and for all contaminants in surface waters
  - Attain water quality levels that make these waterways safe to fish and/or swim in
  - Restore and maintain the chemical, physical, and biological integrity of the nation's water
- The CWA makes it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a permit (NPDES) is obtained
- The amounts and types of pollutants than can be discharged or allowed to run in to waters from watersheds are regulated

Safe Drinking Water Act

- The Safe Drinking Water Act (1974) was established to protect the quality of drinking water in the U.S
- This law focuses on all waters actually or potentially designed for drinking use, whether from above ground or underground sources

It is better to prevent pollution

- It is far better to prevent groundwater contamination than correct it
- Other options are not as good:
  - Removing just one herbicide from water costs $400 million
  - Pumping, treating, and re-injecting it takes too long
- Restricting pollutants above aquifers would shift pollution elsewhere
- Consumers can purchase environmentally friendly products
  - Become involved in local “river watch” projects

Sewage Treatment and BOD

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Wastewater Treatment Objectives

- Wastewater treatment systems take human and industrial liquid wastes and make them safe enough (from the public health perspective) to return to the aquatic or terrestrial environment.
- In some cases, wastewater can be clean enough for reuse for particular purposes.
- Wastewater treatment systems use the same processes of purification that would occur in a natural aquatic system only they do it faster and in a controlled situation.

Sewage or Wastewater Treatment

- Sewage or wastewater is composed of sewage or wastewater from:
  - Domestic used water and toilet wastes
  - Rainwater
  - Industrial effluent (**Toxic industrial water is pretreated**)
  - Livestock wastes

** microbes degrade organic compounds

** elimination of pathogens occurs

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Wastewater Treatment

Types of treatment systems include: Septic Tanks or Wastewater Treatment Plants (WWTPs).

- Septic Tanks typically treat small volumes of waste (e.g., from a single household, small commercial/industral)
- WWTPs typically treat larger volumes of municipal or industrial waste.

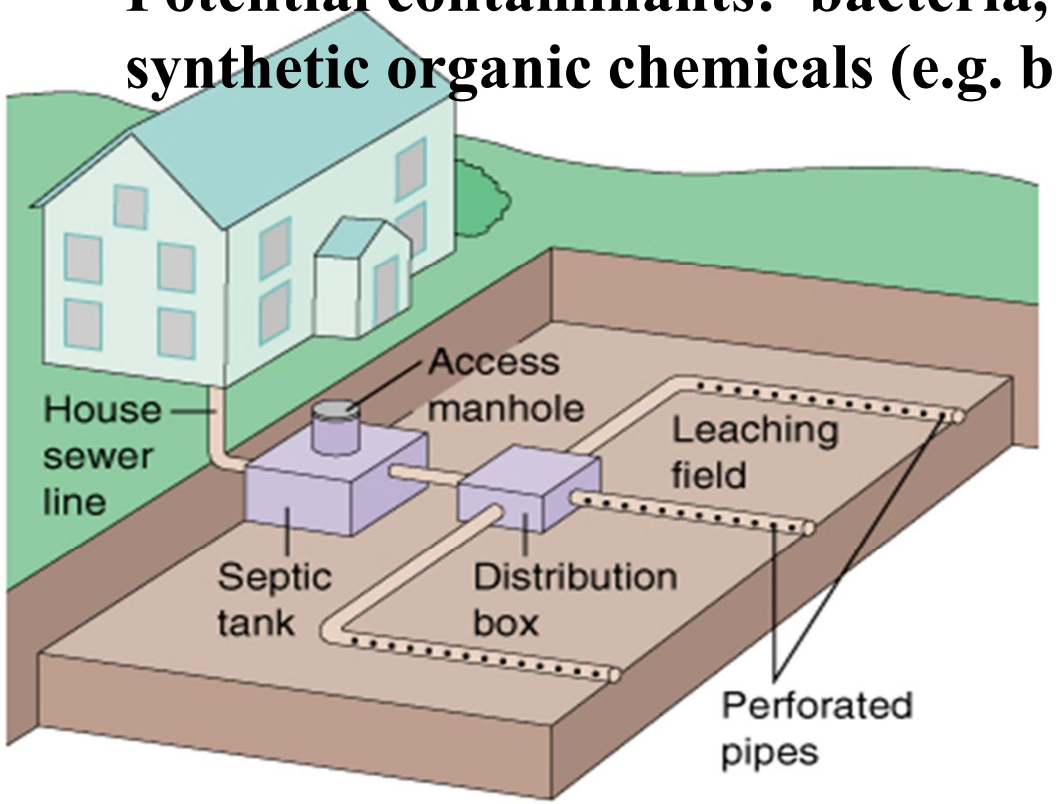
http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

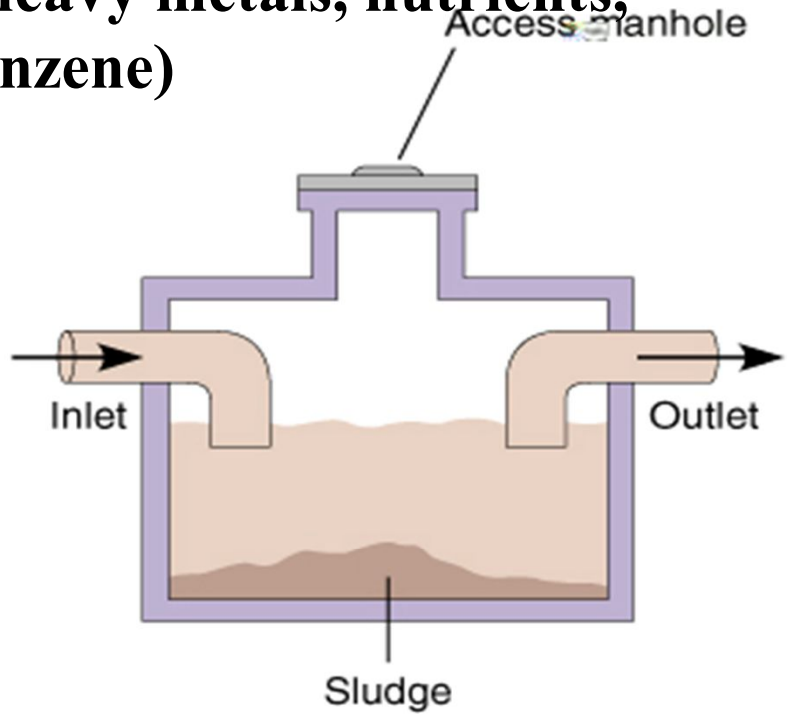
Decentralized Alternatives

- In rural areas or in particular urban communities in the U.S., human wastewater will be treated through individual septic tank systems (pumped or leachfield varieties)
- Wastewater is filtered, microorganisms killed and chemicals adsorbed and/or diluted in its passage through the soils and rocks of the leachfield
- In developing countries, urban wastewater is seldom treated and instead flows raw through collectors to receiving water bodies (like in the US 100 years ago)
- The solution for many developing nations is centralized oxidation lagoon systems (but this needs space) or the use of individual ventilated pit-latrines, especially for shanty towns and rural villages

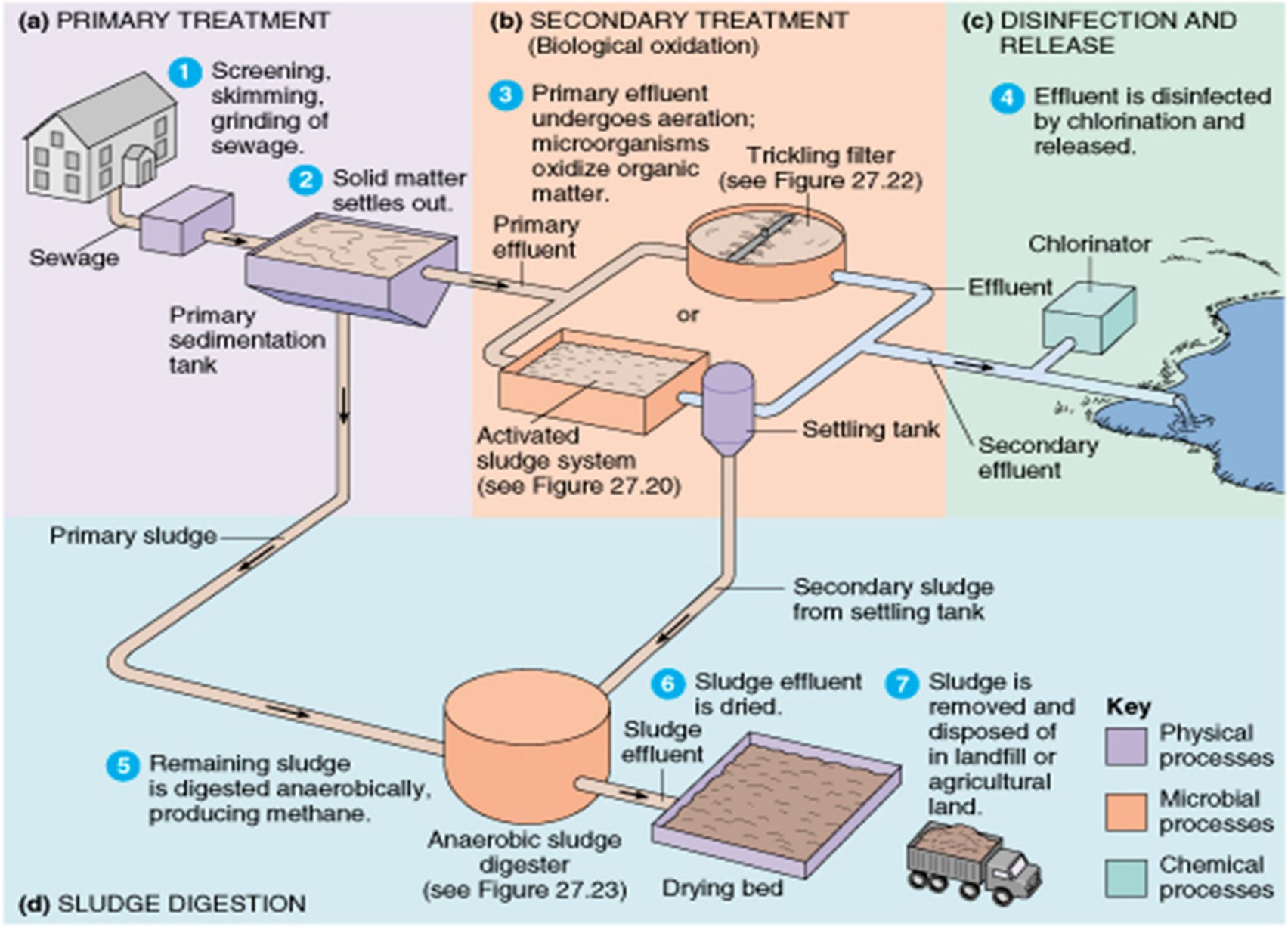
Septic Tanks

- **Approx. 22 million systems in operation (30% of US population)**
- **Suitability determined by soil type, depth to water table, depth to bedrock and topography**
- **Commonly fail due to poor soil drainage**
- **Potential contaminants: bacteria, heavy metals, nutrients, synthetic organic chemicals (e.g. benzene)**





Overview of Wastewater Treatment Processes



Sewage Treatment

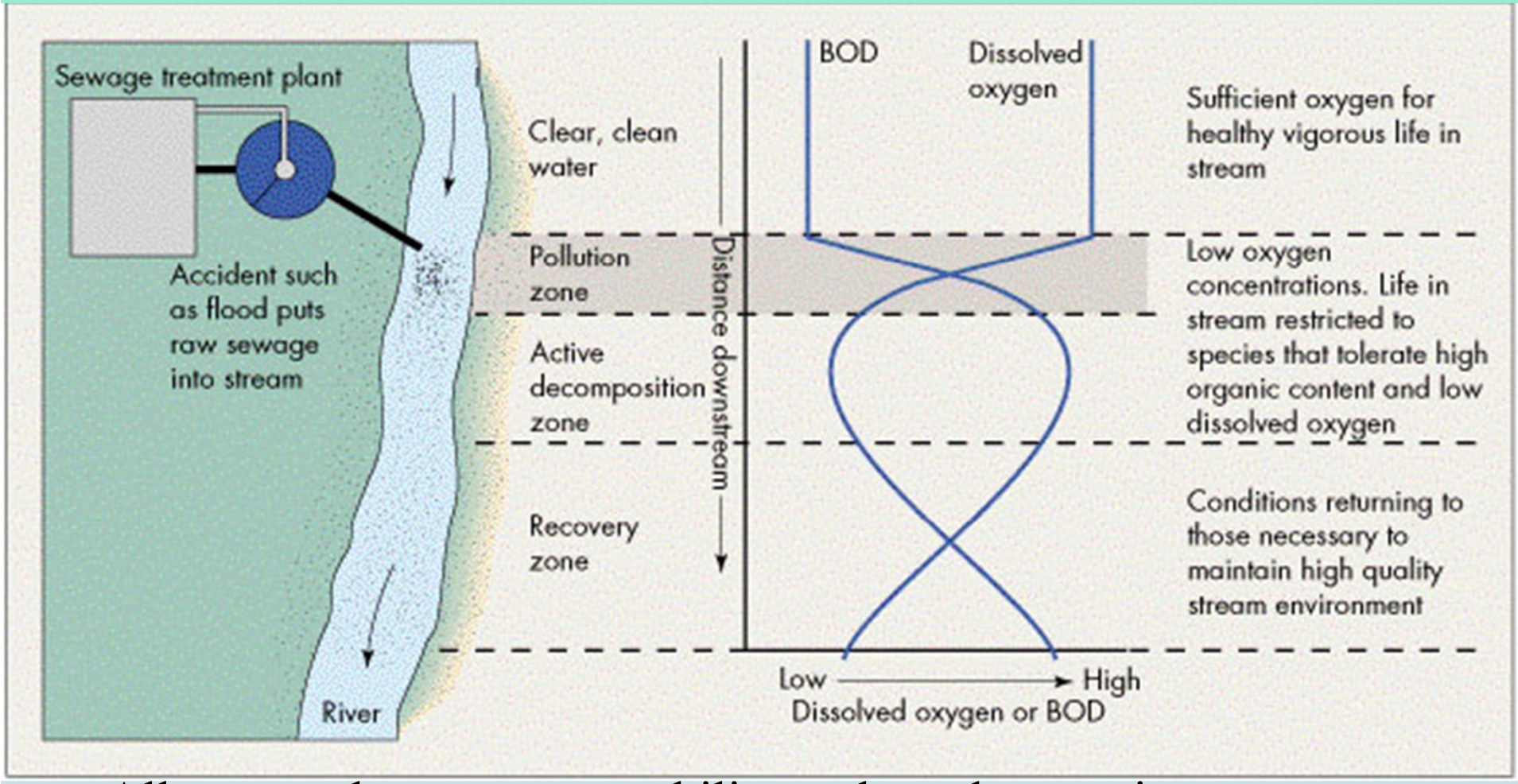
Wastewater or sewage treatment is a multistep process:

1. Primary Treatment (Physical Process)

- Removal of large objects using grates and screens
- Settling to remove suspended solids (primary sludge)
  - flocculating chemicals are added to enhance sedimentation

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

BOD Effects on Water Quality



All streams have some capability to degrade organic waste. Problems occur when stream is overloaded with biochemical oxygen-demanding waste.

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Sewage Treatment

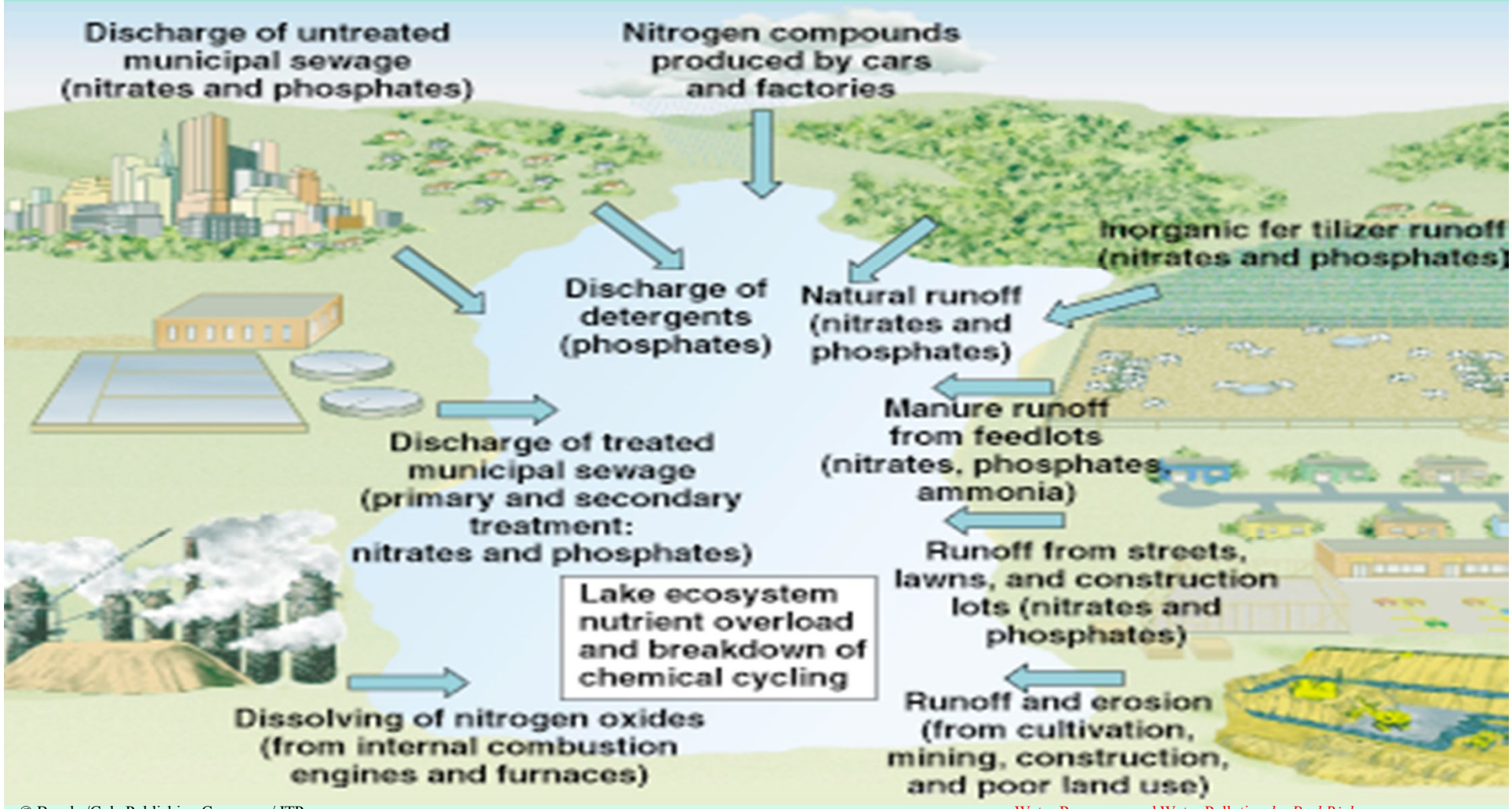
- <u>Secondary Treatment (Microbial Process)</u>
  - Supernatant or primary effluent contains high levels of dissolved organic load (Biological Oxygen Demand)
  - Aeration to stimulate aerobic degradation
    - activated sludge reactor
    - trickling filter reactor

} bacteria degrade organic carbon to CO_2

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Eutrophication

Accelerated results with human input of nutrients to a lake



Water Resources and Water Pollution *by Paul Rich*

Sewage Treatment

- Tertiary Treatment (Physicochemical Process)
- Precipitation
- Filtration
- Chlorination

expensive process, sharply reduces inorganic nutrients (PO_4, NO_3)

- Treated water is discharged to waterways
- Used for irrigation
- Recycled into drinking water

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Sewage Treatment

Pathogen Removal by Activated Sludge

- More than 90% of *E.coli*. and Salmonella are destroyed
- Bacteria are removed by inactivation, grazing by ciliated protozoa, and adsorption to sludge solids
- Viruses are removed mainly by adsorption process

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Anaerobic Digestion of Sludge

- Sludges from the primary and secondary treatment settling tanks are pumped into an anaerobic digester
- Sludges contain cellulose, proteins, lipid and other insoluble polymers
- Anaerobic bacteria digest the sludge to methane and carbon dioxide

http://www.lcusd.net/lchs/mewoldsen/Water_Pollution_LCHS.ppt

Wastewater Virtual Tours

- Oro Loma Treatment Plant
- San Diego Metropolitan Wastewater Dept.
- Blue Plains Treatment Plant Wash DC

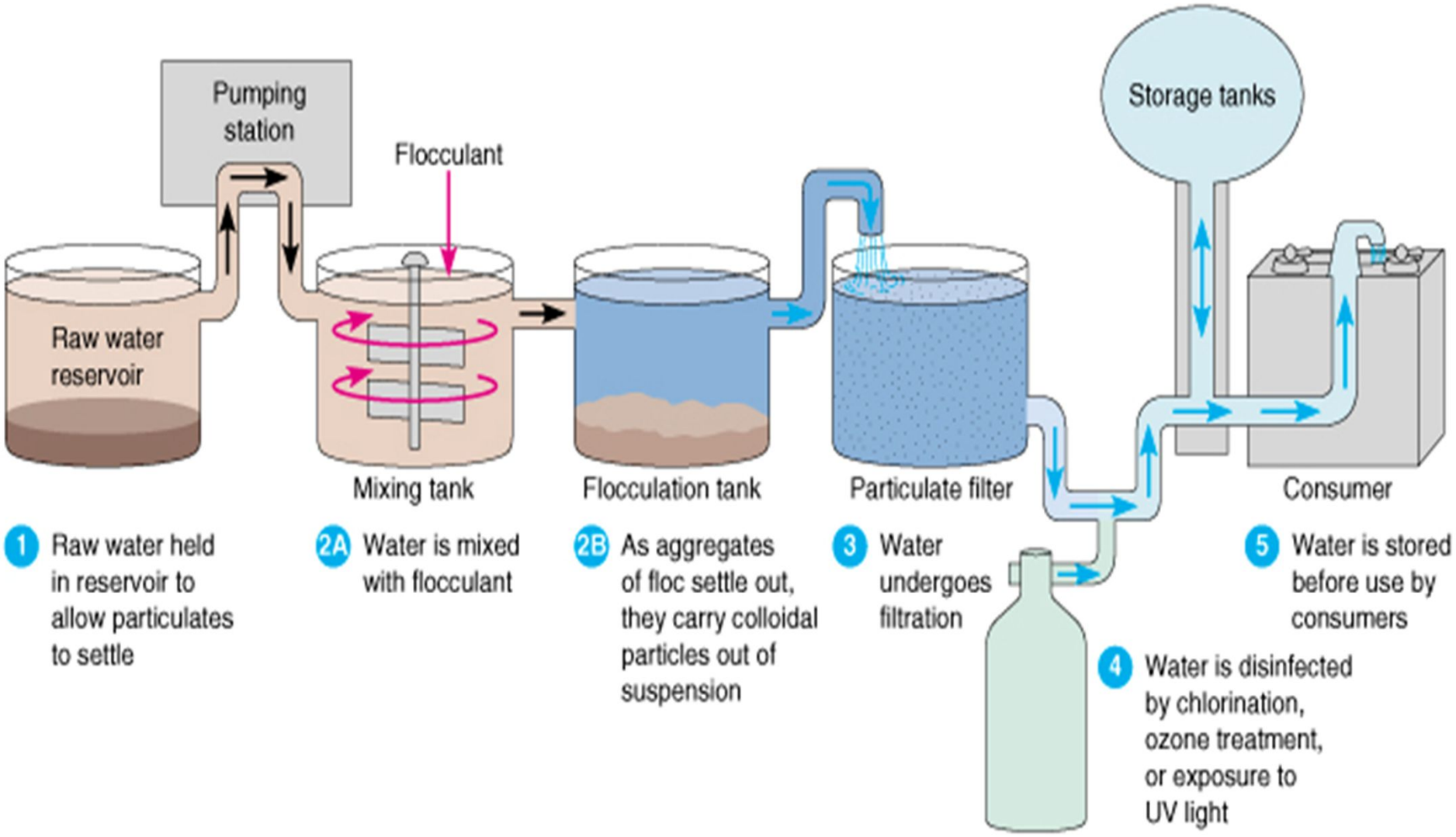
Drinking Water Quality

- Much of the world's drinking water is contaminated and poses serious health threats
- Most drinking water is purified by storage in reservoir (suspended matter settles), and treated by sand filters, activated charcoal, and addition of chlorine
- U.S. Safe Drinking Water Act of 1974 requires EPA to establish national drinking water standards
- Many using bottled water and home filters; bottled water is often more contaminated than tap water

Water Quality Standards

- The EPA (Environmental Protection Agency) sets Maximum Contaminant Levels (MCLs) for drinking water
- There are standards for numerous contaminants, two of which cause an immediate health threat if exceeded
  - Coliform bacteria -because they may indicate presence of disease causing organisms
  - Nitrate - can cause ‘blue baby syndrome”—nitrate reacts with blood and blood can’t carry as much oxygen

Municipal Water Purification Plant



Water Treatment Stages

Depending on the type of treatment plant and the quality of raw water, treatment generally proceeds in the following sequence of stages:

1. Screening
2. Aeration
3. pH correction
4. Coagulation and flocculation
5. Sedimentation
6. Pre-chlorination and dechlorination
7. Filtration
8. Disinfection
9. pH adjustment

- As required, adsorption or other advanced process will be added, depending on the chemistry of the treated water.

Initial Stages

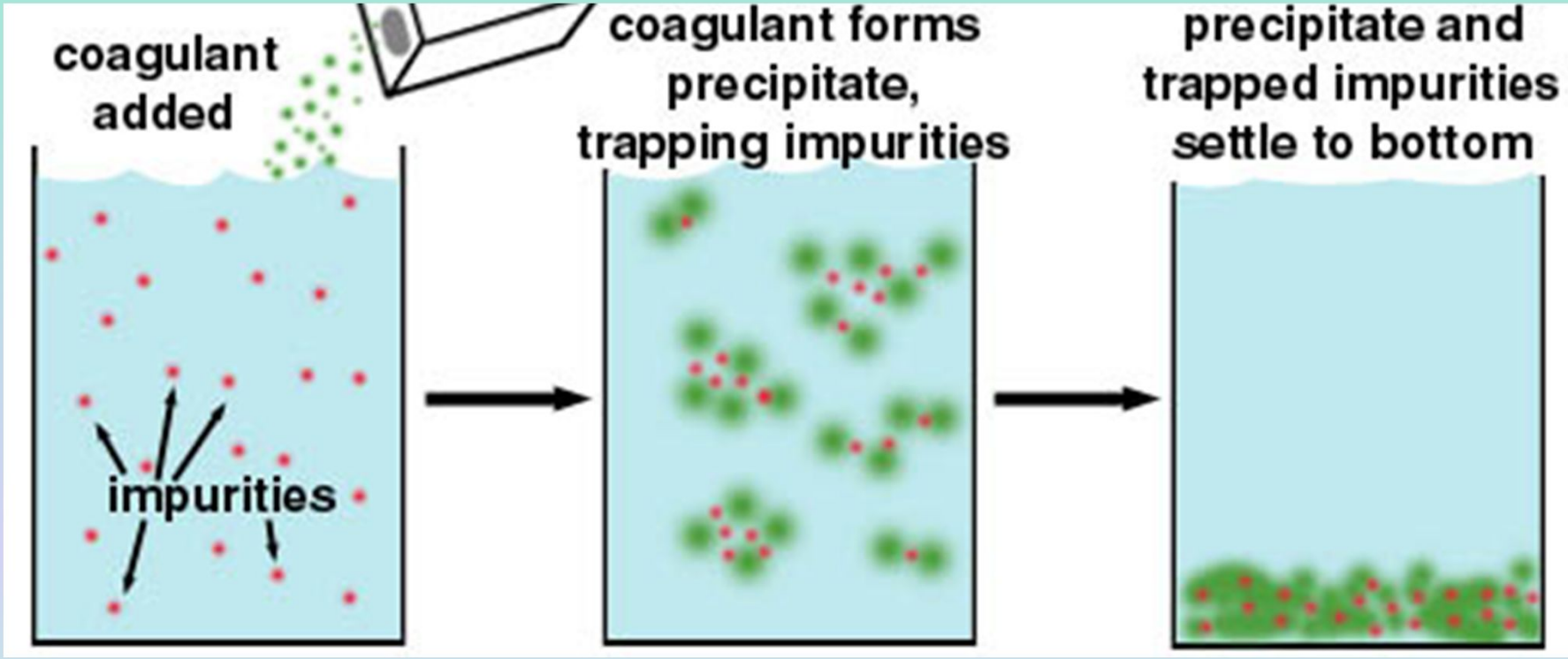
- **Screening** - the removal of any coarse floating objects, weeds, etc. from the water.
- **Aeration** - dissolving oxygen into the water to remove smell and taste, promote helpful bacteria to grow, and precipitate nuisance metals like iron and manganese.
- **pH correction** - preparing for coagulation and to help precipitate metals.

Major Clean Up

- **Coagulation and flocculation** - causes the agglomeration and sedimentation of suspended solid particles through the addition of a coagulating agent (usually aluminum sulfate and/or iron sulfate) to the raw water along with a polymer to help form a floc.
- **Sedimentation** - Floc settles out and is scraped and vacuumed off the bed of large sedimentation tanks. Clarified water drains out of the top of these tanks in a giant decanting process.
- **Pre-chlorination and dechlorination** - mostly to kill algae that would otherwise grow and clog the water filters. Also kills much of the remaining unprotected bacteria.

isis.csuhayward.edu/alss/Geography/ mlee/geog4350/4350c4f01.ppt

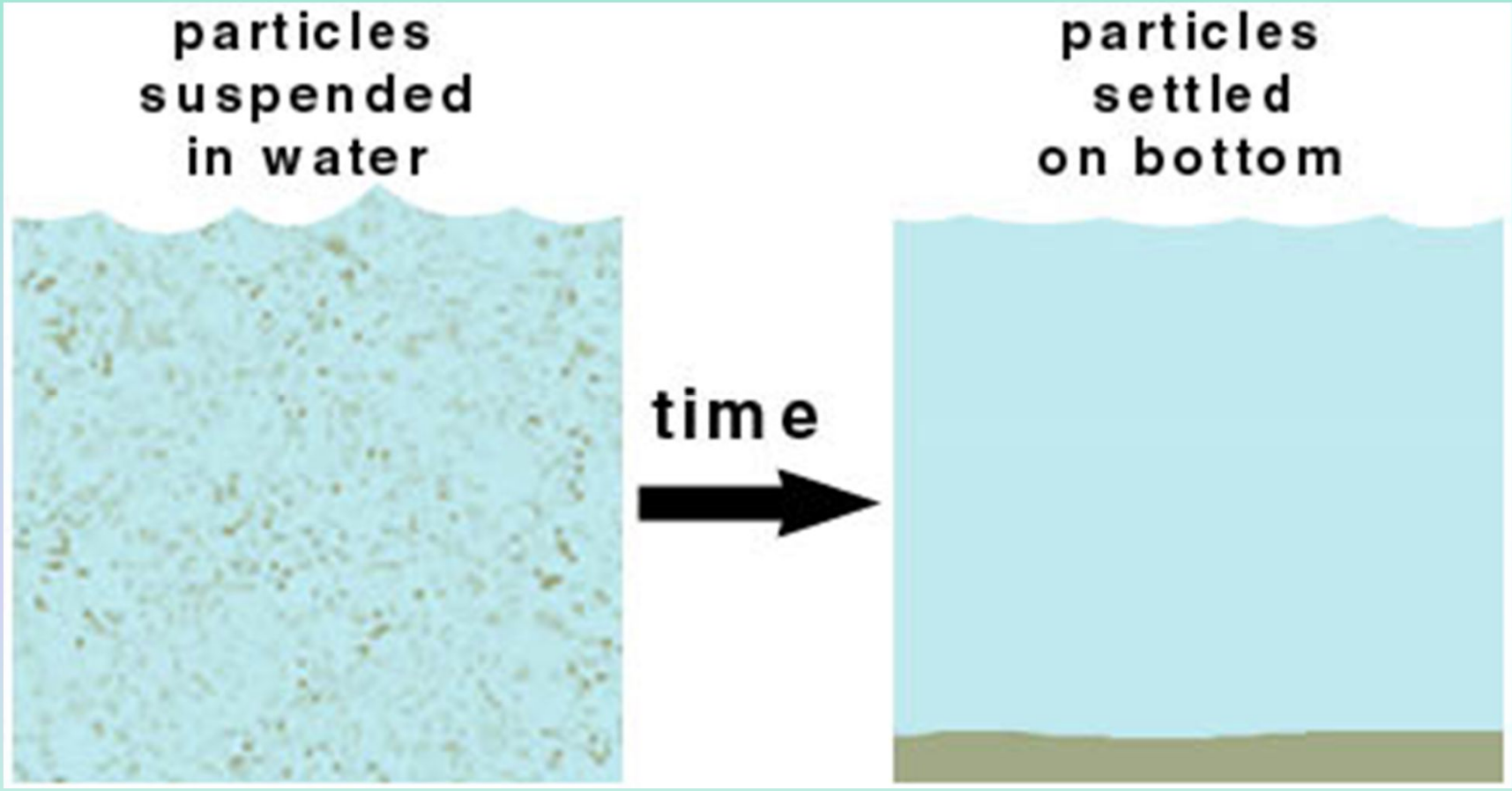
Coagulation



- **Rachel Casiday, Greg Noelken, and Regina Frey, Washington University (http://wunmr.wustl.edu/EduDev/LabTutorials/Water/PublicWaterSupply/PublicWaterSupply.html)**

isis.csuhayward.edu/alss/Geography/ mlee/geog4350/4350c4f01.ppt

Sedimentation



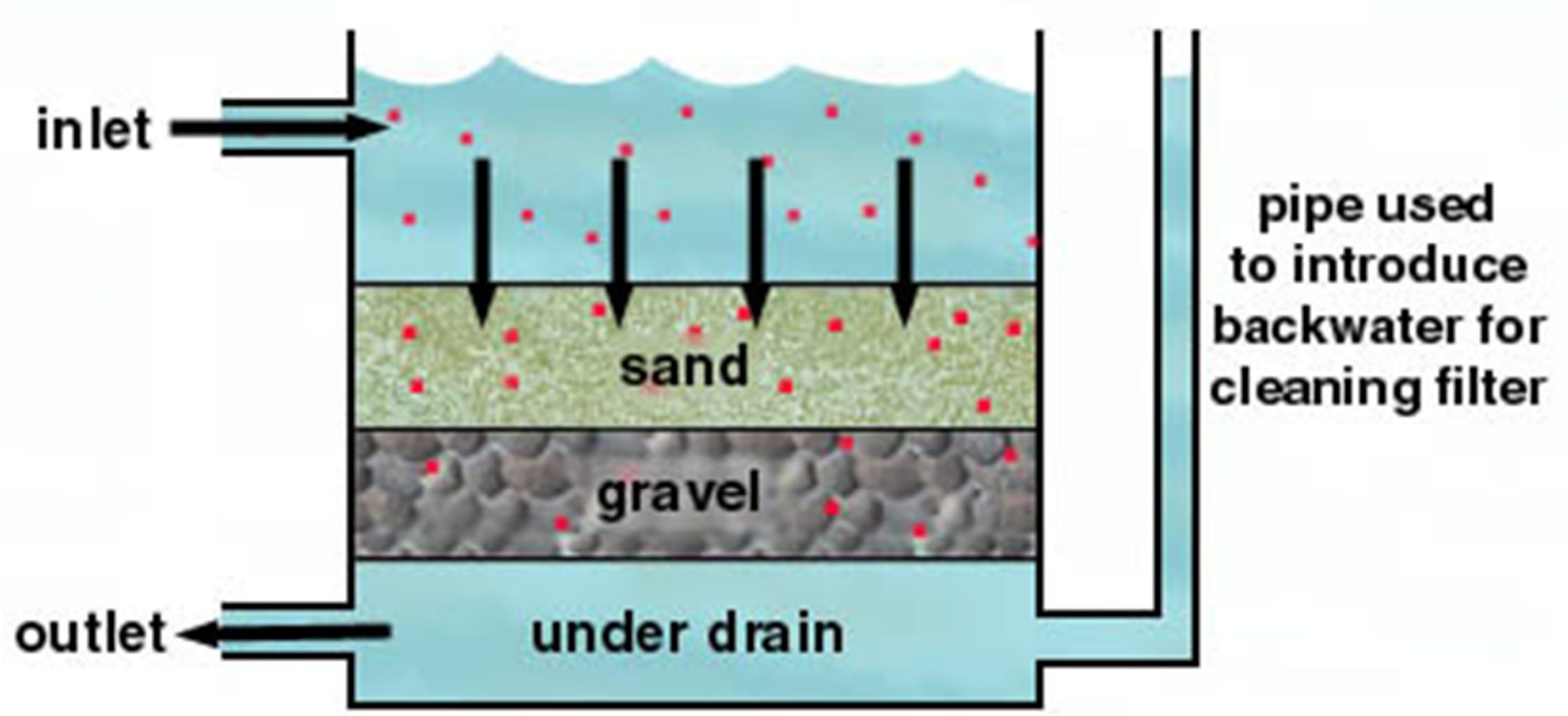
- **Rachel Casiday, Greg Noelken, and Regina Frey, Washington University (http://wunmr.wustl.edu/EduDev/LabTutorials/Water/PublicWaterSupply/PublicWaterSupply.html)**

  isis.csuhayward.edu/alss/Geography/ mlee/geog4350/4350c4f01.ppt

Filtering Out What's Left

- Either slow or rapid **filtration** (depends on size of plant/volume of water considerations)
- Rapid-sand filters force water through a 0.45-1m layer of sand (d=0.4-1.2mm) and work faster, needing a smaller area. But they need frequent back-washing
- Slow-sand filters (d=0.15-0.35mm) require a much larger area but reduce bacteriological and viral levels to a greater degree due to the Schmutzdecke layer. The top 1 inch must be periodically scraped off and the filter occasionally back-washed

Filtration



- **Rachel Casiday, Greg Noelken, and Regina Frey, Washington University (http://wunmr.wustl.edu/EduDev/LabTutorials/Water/PublicWaterSupply/PublicWaterSupply.html)**

  isis.csuhayward.edu/alss/Geography/ mlee/geog4350/4350c4f01.ppt

Final Touches

- **Disinfection** - water completely free of suspended sediment is treated with a powerful oxidizing agent usually chlorine, chlorine then ammonia (chloramine), or ozone.
  - A residual disinfectant is left in the water to prevent reinfection.
  - Chlorine can form harmful byproducts and has suspected links to stomach cancer and miscarriages.
  - Many agencies now residually disinfect with Chloramine.
- **pH adjustment** - so that treated water leaves the plant in the desired range of 6.5 to 8.5 pH units.

Additional Steps

- **Heavy metal removal**: most treatment plants do not have special stages for metals but rely on oxygenation, coagulation and ion exchange in filters to remove them. If metals persist, additional treatment would be needed
- **Troublesome organics:** Activated carbon filters are required where soluble organic constituents are present because many will pass straight through standard plants, e.g. pesticides, phenols, MTBE and so forth