Water Pollution

Chapters 13 and 20
Living in the Environment, 11th Edition, G. T. Reid

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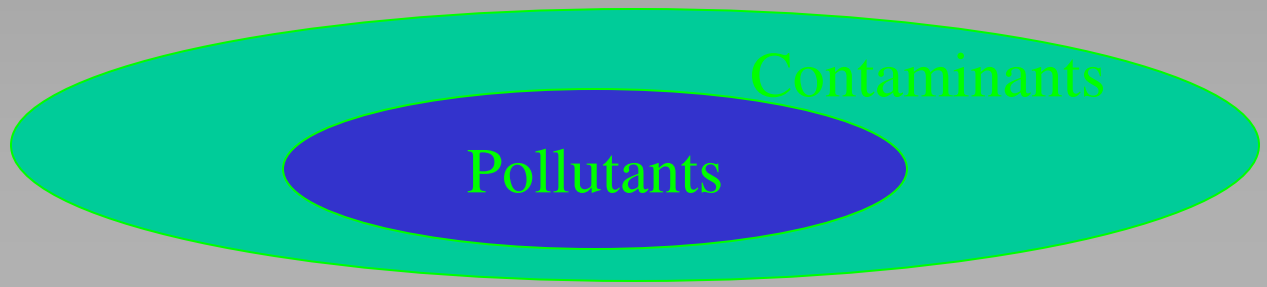
Water Quality Definitions

- **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 intended purpose. (Potable, Agricultural, Swimming etc.).
  - 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

- Types and Sources of Pollution
- Pollution of Streams and Lakes
- Ocean Pollution
- Groundwater Pollution
- Drinking Water Quality
- Waste Water Treatment
- Water Legislation

Sources of Pollution

- **Point sources** (e.g., factories, sewage treatment plants, mines, oil wells, oil tankers)
- **Nonpoint sources** (e.g., acid deposition, substances picked up in runoff, seepage into groundwater)
  - Agriculture is largest source of water pollution. (64% of pollutants into streams and 57% of pollutants entering lakes)

Types of Pollution

- Unwanted biological activity – pathogens
- Oxygen Demanding Agents – organic waste: manure
- Water-soluble Inorganic Chemicals – acids, toxic metals
- Inorganic Plant Nutrients – nitrogen and phosphorus
- Organic Chemicals – oil, pesticides, detergents
- Sediment or Suspended Material – erosion, soil
- Water-soluble Radioactive Isotopes – radon uranium
- Etc.

E. coli outbreak in Walkerton

- In May 2000 the small community of Walkerton, Ontario was laid waste by a toxic strain of **E. coli:0157**.
  - The contamination came from the public water supply.
  - Six people died in the first week including a two year old daughter of a local medical doctor.
  - Four new cases surfaced in late July, all very young children.
  - Over a thousand innocent people were infected.

What must the water producer be wary of ?

- Can only be determined via a methodical & critical approach of individual situation.
  - Opportunistic bio-organisms!
  - Typical water borne organisms.
  - Your plant environment.
  - Point-of-use or client environment!

Opportunistic Organisms

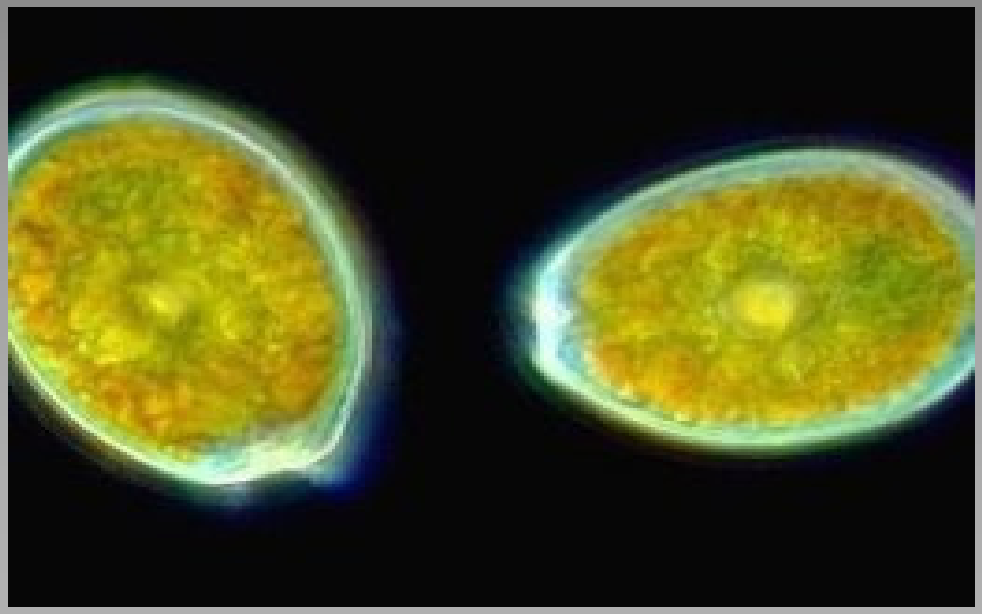
- *The **Berkeley Pit**, abandoned open pit copper mine in Butte, Montana 40 billion gallons of acidic, metal-contaminated water.*
- *Considered too toxic to support life until two organic chemists at the University of Montana, discovered that the pit is a rich source of unusual extremophiles. In the course of their on-going investigation, the two self-described 'bio-prospectors' have also discovered an uncommon yeast, which might play a significant role in cleaning up the site.*

Berkeley Pit: Butte, Montana

Metal Reducing Bacteria

Arsenic-Driven Biological Activity: GFAJ-1

- A bacterium - California's Mono Lake.
- Use arsenic which is usually poisonous to life, as one of its key nutrient elements.



Lake Mono: California - Eastern Sierra Mountains

More common however:

- Typical water borne organisms.
- Natural inherent biological organisms.

❖ If the environment or conditions are even remotely favourable the infestation will occur as a matter of course.

Waterborne Bacteria

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

Escherichia coli

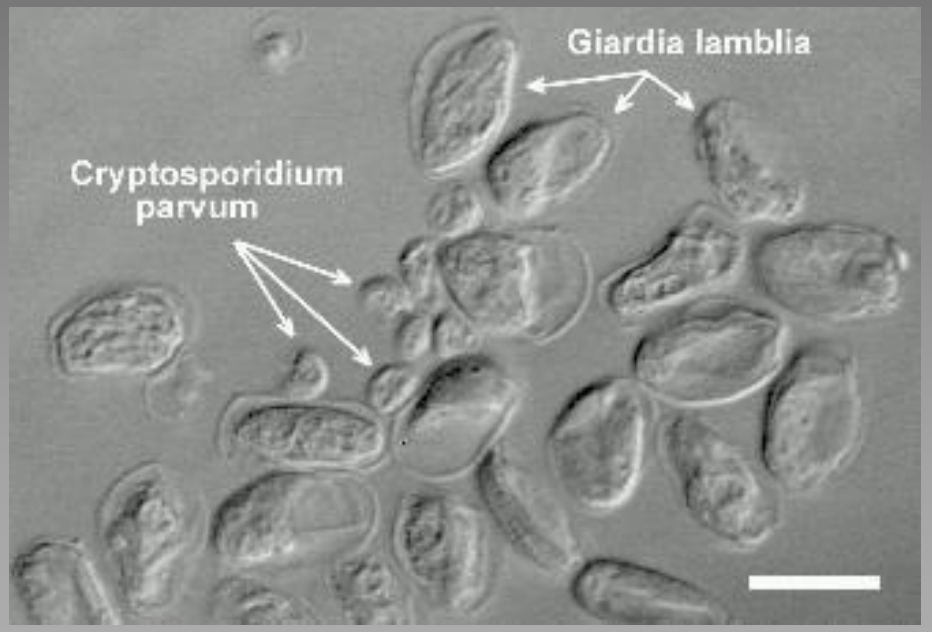
Vibrio sp.

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

Waterborne Protozoans

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

Giardia sp.*



Cryptosporidium Parvum *

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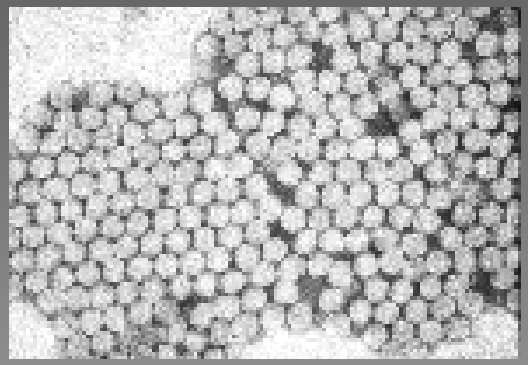
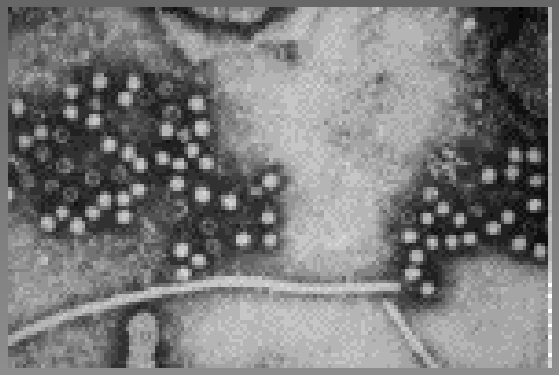
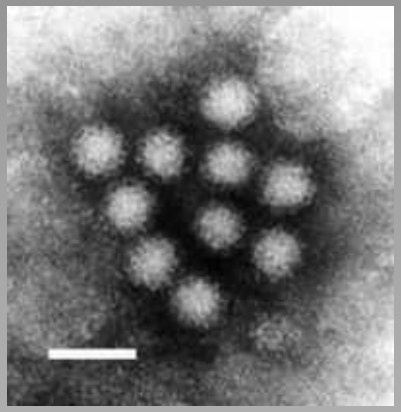
Waterborne Human Viruses



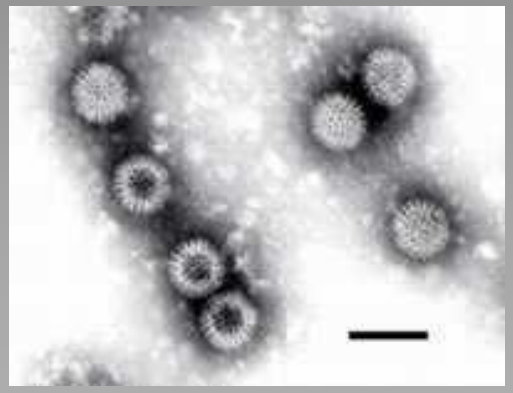
Hepatitis A virus



Hepatitis E virus



Norwalk virus*



Rotavirus*

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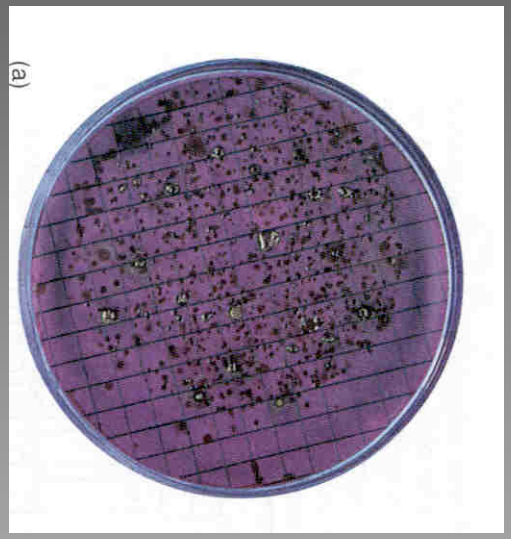
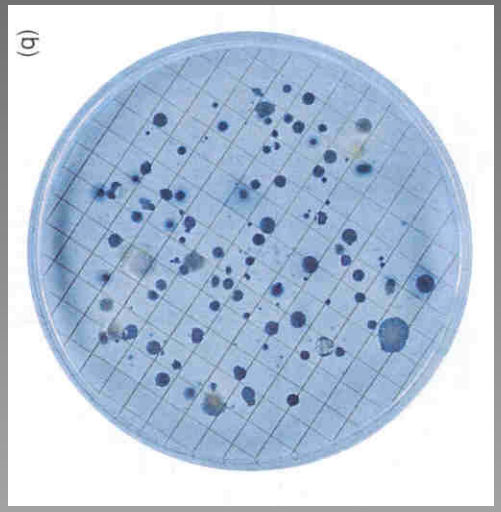
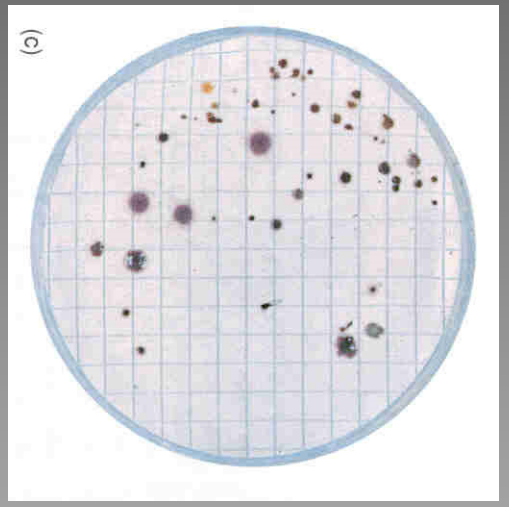
Indicator Tests



Total coliform
[Endo agar]



Faecal coliform
[m-FC agar]



Fecal streptococci
[M-enterococcus]

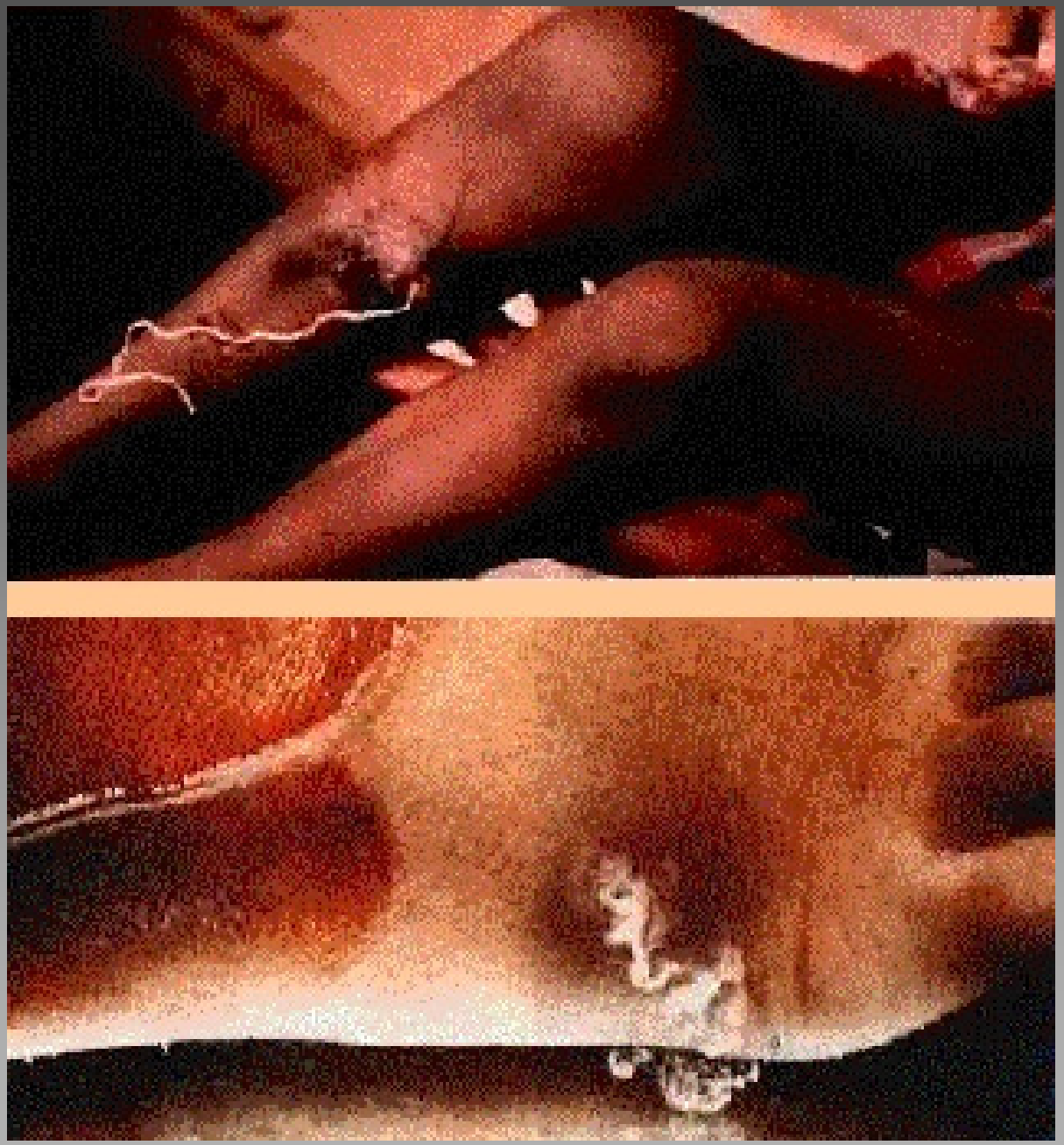
Prescott et al., Microbiology

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

Case Study on Eradicating Dracunculiasis

Guinea Worm Disease

- People have suffered from Guinea Worms for centuries – the "fiery serpent" was mentioned in the bible
- People are infected by drinking water that contain the larvae in a tiny freshwater crustacean called Cyclops
- A year later, larvae mature into 3 feet worms that emerge through skin blisters
- This is such a *painful process* that men and women can't work, children can't attend school



The Guinea Worm grows down the leg and its sex organs appear at the ankle or on the foot usually, bursting when it senses water, releasing ova.

http://www.pmeh.uiowa.edu/fuortes/63111/GUINEA/

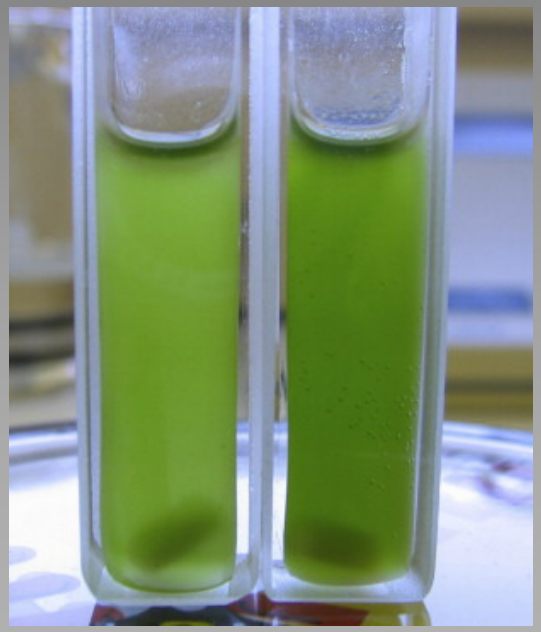
- No vaccine for Guinea worm is available.
- People do not seem to build up any resistance and the disease can be reinfected over and over.
- No research is being conducted for any vaccine or cure.
- Worms are removed slowly each day by winding around a stick.

http://www.pmeh.uiowa.edu/fuortes/63111/GUINEA/

Aquastore-Potable-Water-Storage-Reservoirs

Typical water borne organisms:

- First sign that all was not well
  - Lab incubated green-algae

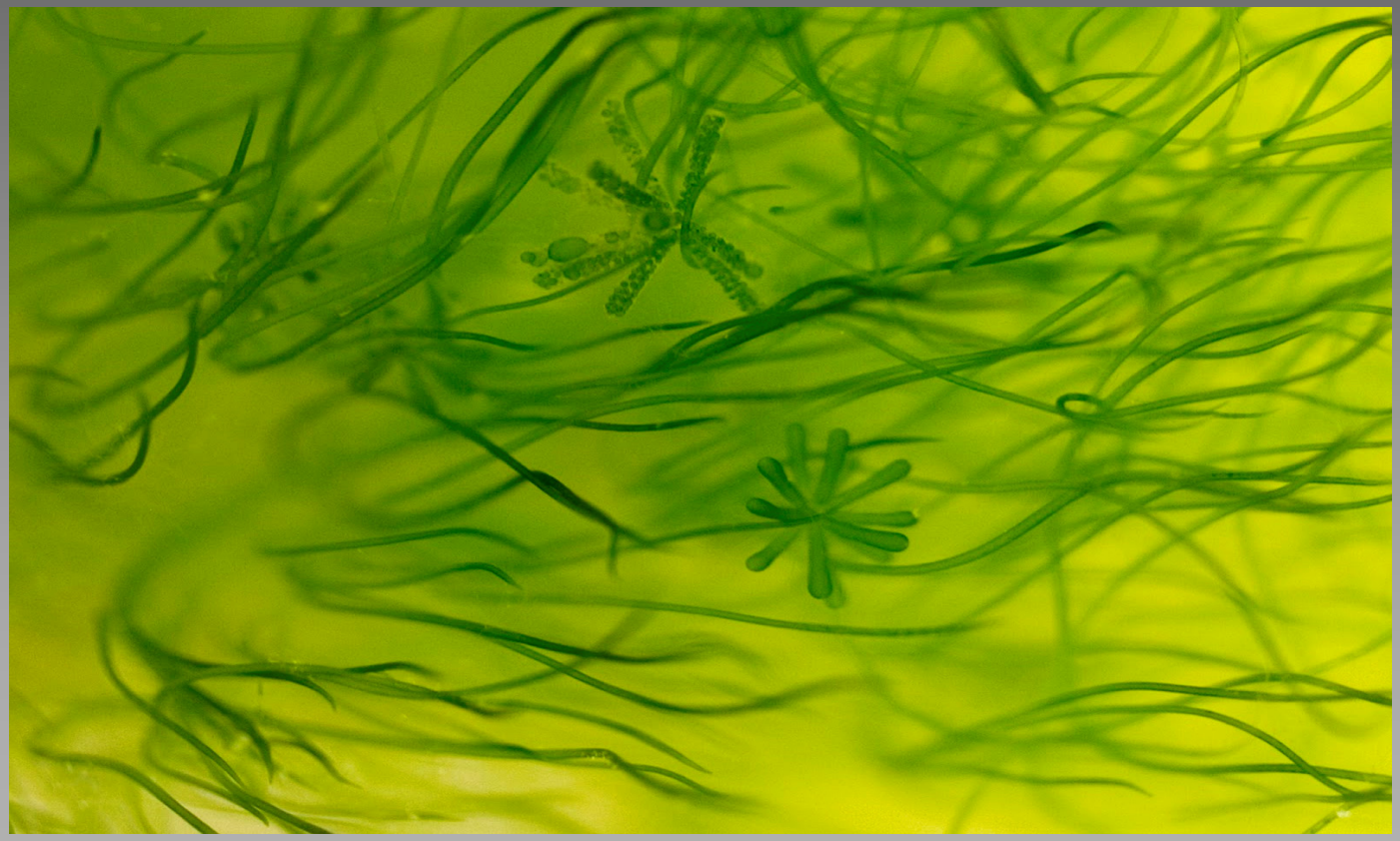


From what appeared to be a clean lab sample bottle which showed up perfect analytical data, apart from a macro-biological count of

- 2-organisms per litre

- Second sign that all was not well
  - Drain water from the reservoirs.

- Third sign that all was not well.
- Must note the end-users stopped using the water & the reservoirs remained stagnant for +-4-days.



Fresh Water Reservoir - Taipei


ALGAE GROWING ON RESERVOIR WALLS
PHORMIDIUM
ULOTHRIX
CLADOPHORA
GOMPHONEMA
ACHNANTHES
TETRASPORA
VAUCHERIA
STIGEOCLONIUM
AUDOUINELLA
TOLYPOTHRIX
CHARA
BULBOCHAETE
LYNGBYA
MICROSPORA
COMPSOPOGON
BATRACHOSPERMUM
CYMBELLA
PHYTOCONIS
OEDOGONIUM
DRAPARNALDIA
CHAETOPHORA

- Not all detrimental – Can be used to purify water

"Simplicity is the ultimate sophistication."

Leonardo da Vinci

Minimise the expected problems via a methodical & critical approach of individual situation.

- Your plant environment. (KZN, Mpumalanga!!!).
- For bottling applications use the best systems dependent on the available budget.
- Sanitise according to a controlled, well-maintained programme.
- Consider humans (bottlers) and bottling points back to raw water source.
- Leave nothing to chance!

Council Water Sources

- Expect the worst.
- Montagu April-13
- “Due to unembellished, methodical, systemic & unstoppable incompetence”
- Tian van Heerden – Systems Analyst.

Types and Sources of Pollution

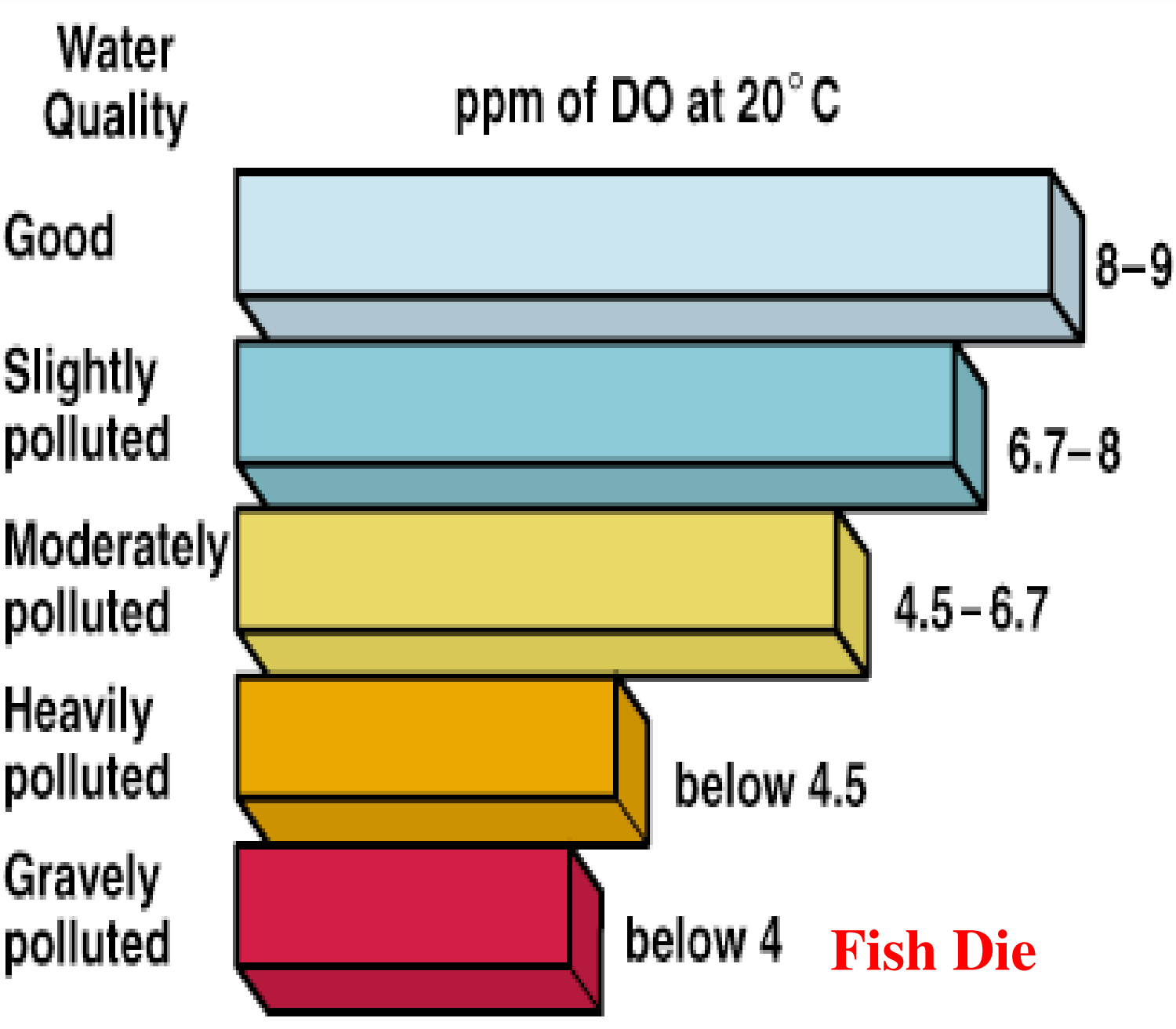
- Unwanted biological activity
- **Oxygen Demanding Agents**
- Water-soluble Inorganic Chemicals
- Inorganic Plant Nutrients
- Organic Chemicals
- Sediment or Suspended Material
- Water-soluble Radioactive Isotopes
- Heat
- Genetic Pollution

Biological Oxygen Demand (BOD)

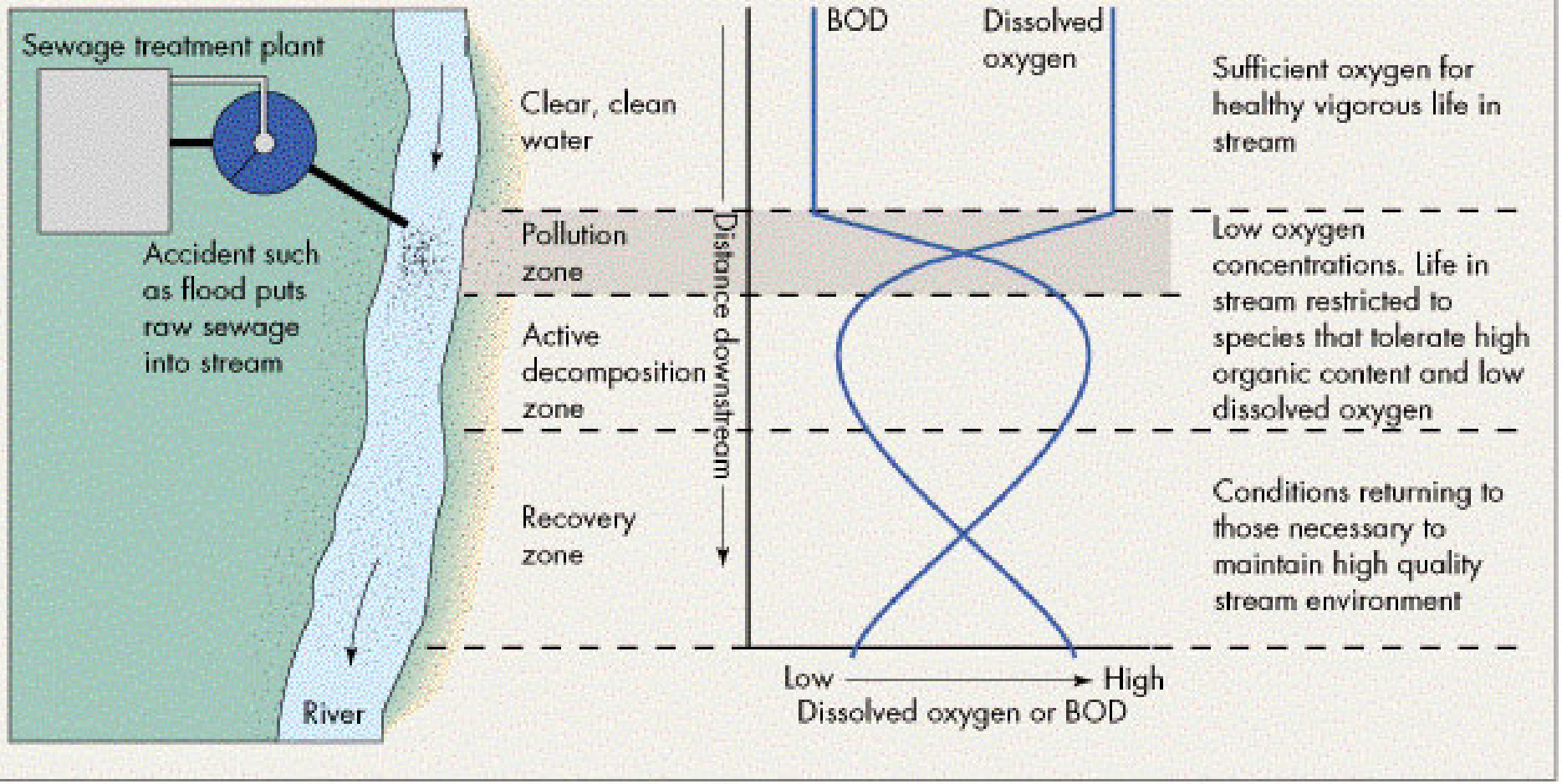
- BOD: Oxygen is removed from water when organic matter is consumed by bacteria.
- Low oxygen conditions may kill fish and other organisms.

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.


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

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.

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Heavy Metals

- Metallic elements having a density greater than 5 g/cm^3
- Most are extremely toxic
  - Water soluble
  - Readily absorbed into plant or animal tissue
    - Bioconcentrate
  - Combine with biomolecules
    - Proteins
    - Nucleic acids

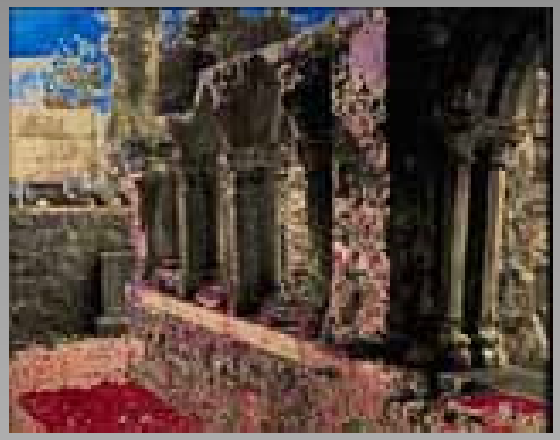
Sources of Heavy Metals

- Natural
  - Redistributed by geologic and biologic cycles
- Industrial
- Burning of fossil fuels
- Environmental pollution

Acid Rain

- Broad term used to describe several ways that acids fall out of the atmosphere

http://www.pacificnet.net/~fastoso/sm_acid.jpg



Dr. Harvey F. Thomas @ Illinois State University

Wet and Dry Acid Rain

- Wet deposition refers to acidic rain, fog, and snow.
- Dry deposition refers to acidic gases and particles.

Causes of Acid Rain

- Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are the primary causes of acid rain.
- In the US, about 2/3 of all SO_2 and 1/4 of all NO_x comes from electric power generation that relies on burning fossil fuels like coal.

Formation of Acid Rain

- Gases react in the atmosphere with water, oxygen, and other chemicals to form a mild solution of sulfuric acid and nitric acid.

Measuring Acid Rain

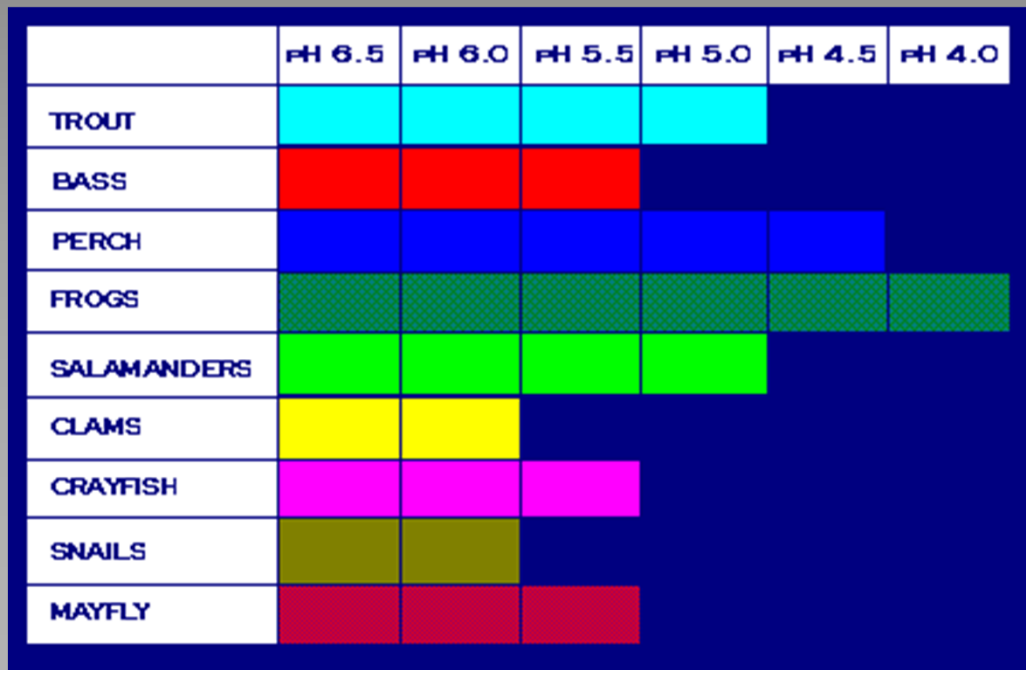
- Acid rain is measured using a "pH" scale.
  - The lower a substance's pH, the more acidic it is.
- Pure water has a pH of 7.0.
  - Normal rain is slightly acidic and has a pH of about 5.5.
- As of the year 2000, the most acidic rain falling in the US has a pH of about 4.3.

Buffering Capacity

- Acid rain primarily affects sensitive bodies of water, which are located in watersheds whose soils have a limited “buffering capacity”
- Lakes and streams become acidic when the water itself and its surrounding soil cannot buffer the acid rain enough to neutralize it
- Some lakes now have a pH value of less than 5

Effects on Wildlife

- Generally, the young of most species are more sensitive to environmental conditions than adults
- At pH 5, most fish eggs cannot hatch
- At lower pH levels, some adult fish die
- Some acid lakes have no fish



Nutrients

- Acidic water dissolves the nutrients and helpful minerals in the soil and then washes them away before trees and other plants can use them to grow.

- Acid rain also causes the release of substances that are toxic to trees and plants, such as aluminum, into the soil.

Types and Sources of Pollution

- Disease-causing Agents - Pathogens
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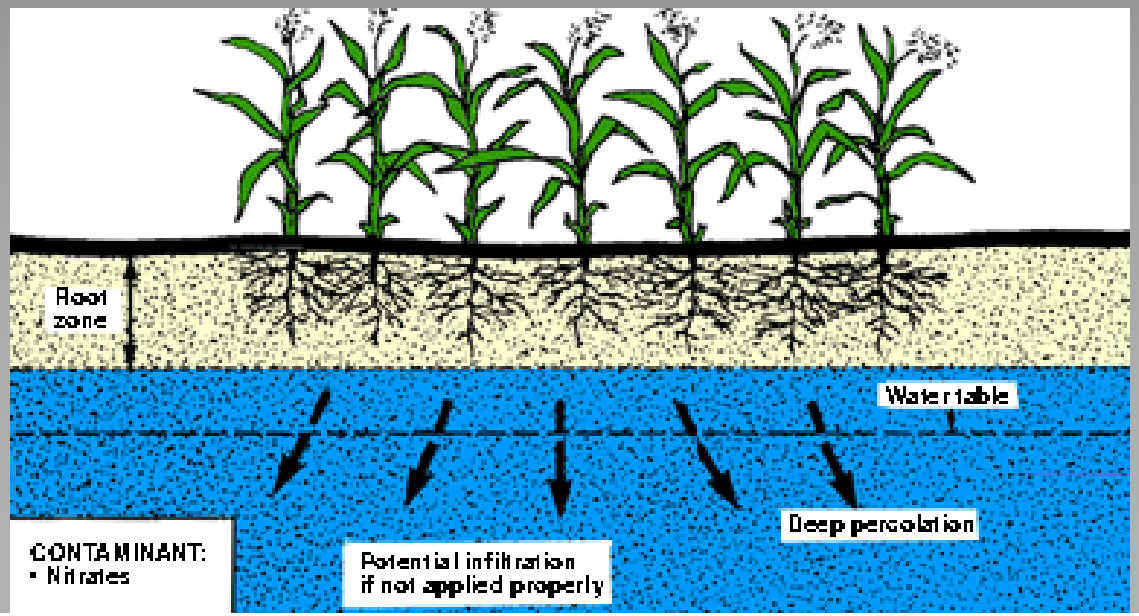
- **Inorganic Plant Nutrients**
- Organic Chemicals
- Sediment or Suspended Material
- Water-soluble Radioactive Isotopes
- Heat
- Genetic Pollution

Selected Pollutants: Nutrients

Phosphorus and nitrogen are the major concerns

Sources:

- Human, animal (e.g., Hog Farms), and industrial waste
- Storm water
- Soil erosion
- Excessive use of fertilizers for crops, lawns, and home gardens



Selected Pollutants: Nutrients

High nutrient concentrations can cause Eutrophication ("well-fed" in Greek) of water bodies

Eutrophication is characterized by rapid increase in plant life. An example is the algae bloom shown here.

- Algae blooms block sunlight so plants below die.
- Decomposition of dead plants consumes oxygen.
- Low oxygen conditions may kill fish etc.
- Aesthetics (color, clarity, smell)
- Uptake and release of toxics

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Biological Magnification

concentrations increase at increasing levels in the food chain – PCBs, DDT, etc.

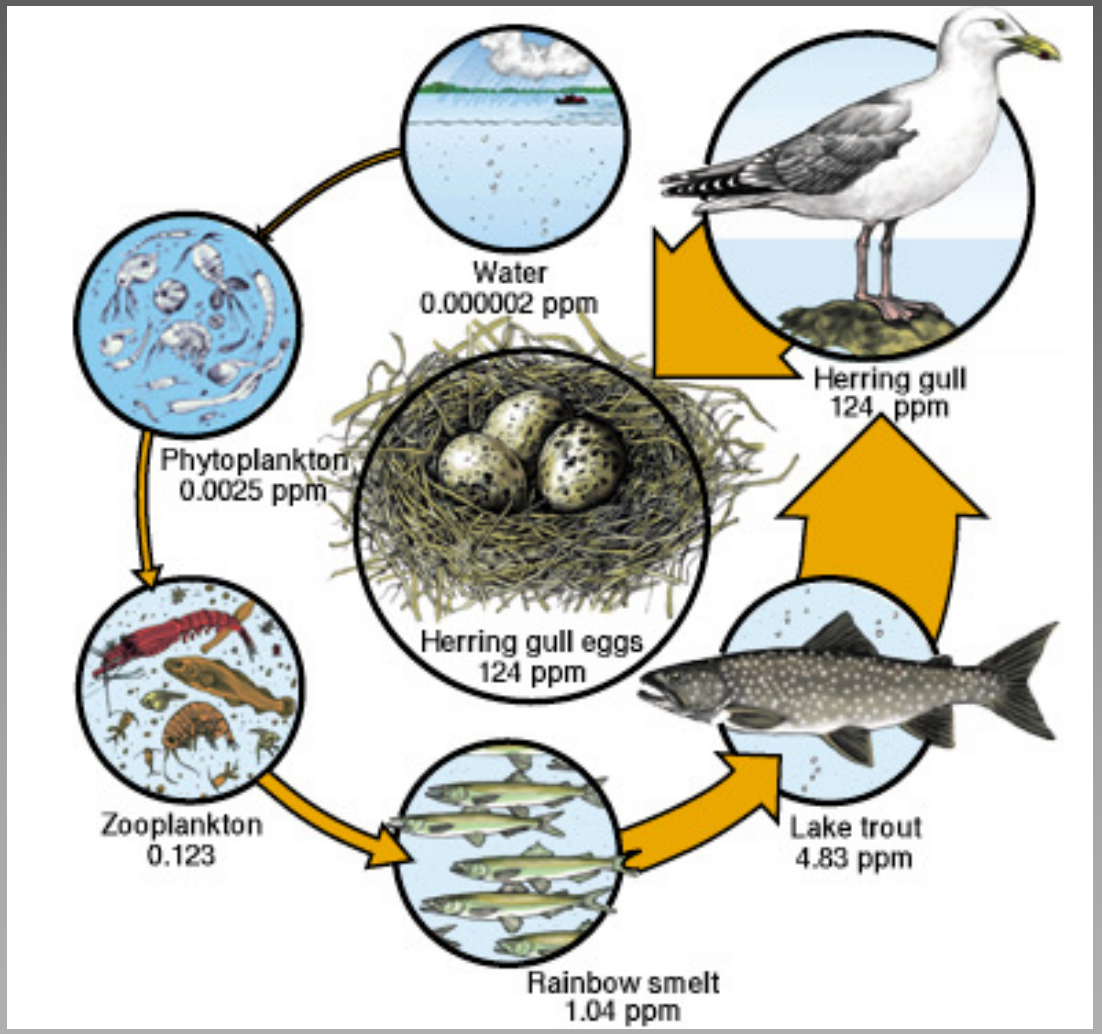

Fig. 12–20

Degradable/Biodegradable

- Degradable: That can be chemically decomposed: *decomposable plastic wastes*
- Photodegradable: that the product is decomposed (broken down) by exposure to light
- Biodegradable: Capable of being decomposed by biological agents, especially bacteria: *a biodegradable detergent*

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

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Erosion

Sediment (clay, silt) is the #1 source of water pollution. Bare soil easily washes into storm drains and streams, clouding the water and suffocating aquatic life.

- Never leave soil exposed! Place straw over newly seeded areas.
- Cover your garden during winter months.
- Sod, seed, grow plants, or build terraces on slopes.
- Rock gardens can also be effective for slowing the flow of water and minimizing erosion.

Effects of Sediment Loading

- Destruction of spawning beds
- Adsorption and transport of other pollutants
- Reduced light penetration, aquatic vegetation
- Greater nutrients loadings, oxygen demand
- Interference with navigation, flood control, recreation, industry

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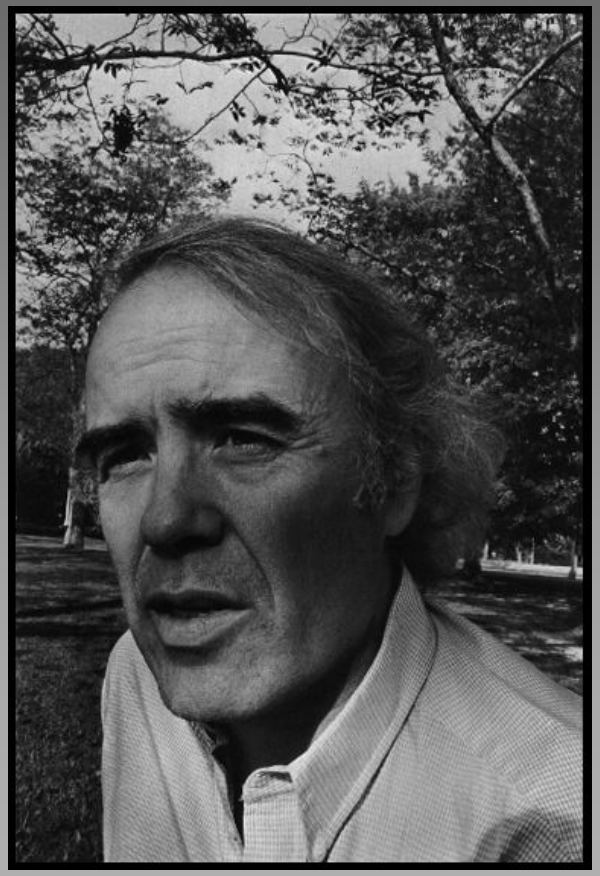
China Syndrome

- In a complete reactor meltdown, the extremely hot (about 2700º Celsius) molten uranium fuel rods would melt through the bottom of the reactor and actually sink about 50 feet into the earth beneath the power plant
- Molten uranium would react with groundwater, producing large explosions of radioactive steam and debris that would affect nearby towns and population centers

William Lawless



- At Savannah River, South Carolina, the US Department of Energy ran plutonium production reactors (to make plutonium for bombs) and a reprocessing plant (to separate plutonium from spent nuclear fuel)
- William Lawless was surprised when -- with no prior experience -- he was put in charge of radioactive waste management at the huge military complex

Whistleblower

- Lawless wanted to do a good job, so he started asking some pointed questions:
  - Why were liquid radioactive wastes being poured into shallow trenches, where they could leak into the soil and enter the surface waters?
  - Why were solid plutonium-contaminated wastes being buried in cardboard boxes and covered with earth?
- He was told to keep quiet
- Instead, he went public, and promptly lost his job

Post Whistle-Blowing

- He was hired to teach mathematics at a local college, which enabled him to make a living while he kept on talking -- to the press, on national radio and TV -- about shoddy waste management practices at Savannah River
- Since then, all plutonium production reactors and reprocessing plants have been shut down not only at Savannah River but throughout the US, and environmental cleanup has become a priority

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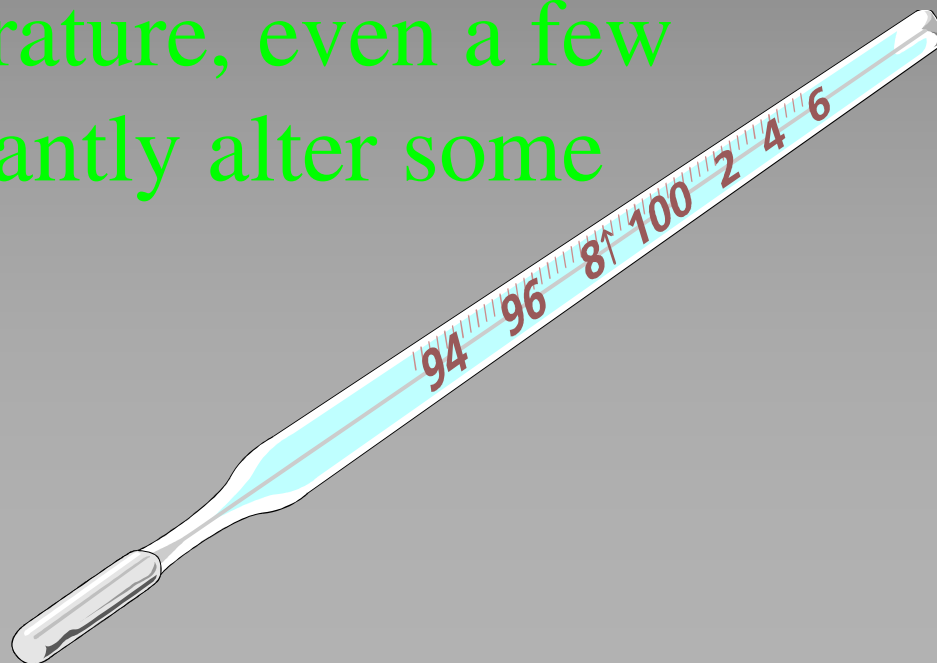
Industrial Water Pollution

- Thermal Pollution occurs when water is withdrawn, used for cooling purposes, and then heated water is returned to its original source
- An increase in temperature, even a few degrees, may significantly alter some aquatic ecosystems



Waste Heat

- **A pollutant as dangerous to waters as more tangible of forms of waste**
- **On national scale, industrial cooling waters is a first-order source of heat**
  - **Electric power generation uses 80% of cooling waters**
  - **Past experience has indicated that thermal pollution has not multiplied as fast as power generation because of improvements in thermal plant efficiency and development of hydropower**
  - **Nuclear plants - waste even higher proportion of heat than fossil-fuel plants**

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Hydrilla: Non-native Aquatic Plant

- Dense mats alter water quality
  - raising pH
  - decreasing oxygen under the mats
  - increasing temperature
  - stagnant water
  - good breeding grounds for mosquitoes
- Hydrilla will grow with less light and fewer nutrients, and can out compete other native and non-native plant
- Fish populations are negatively affected if hydrilla exceeds 30-40% coverage of the lake

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

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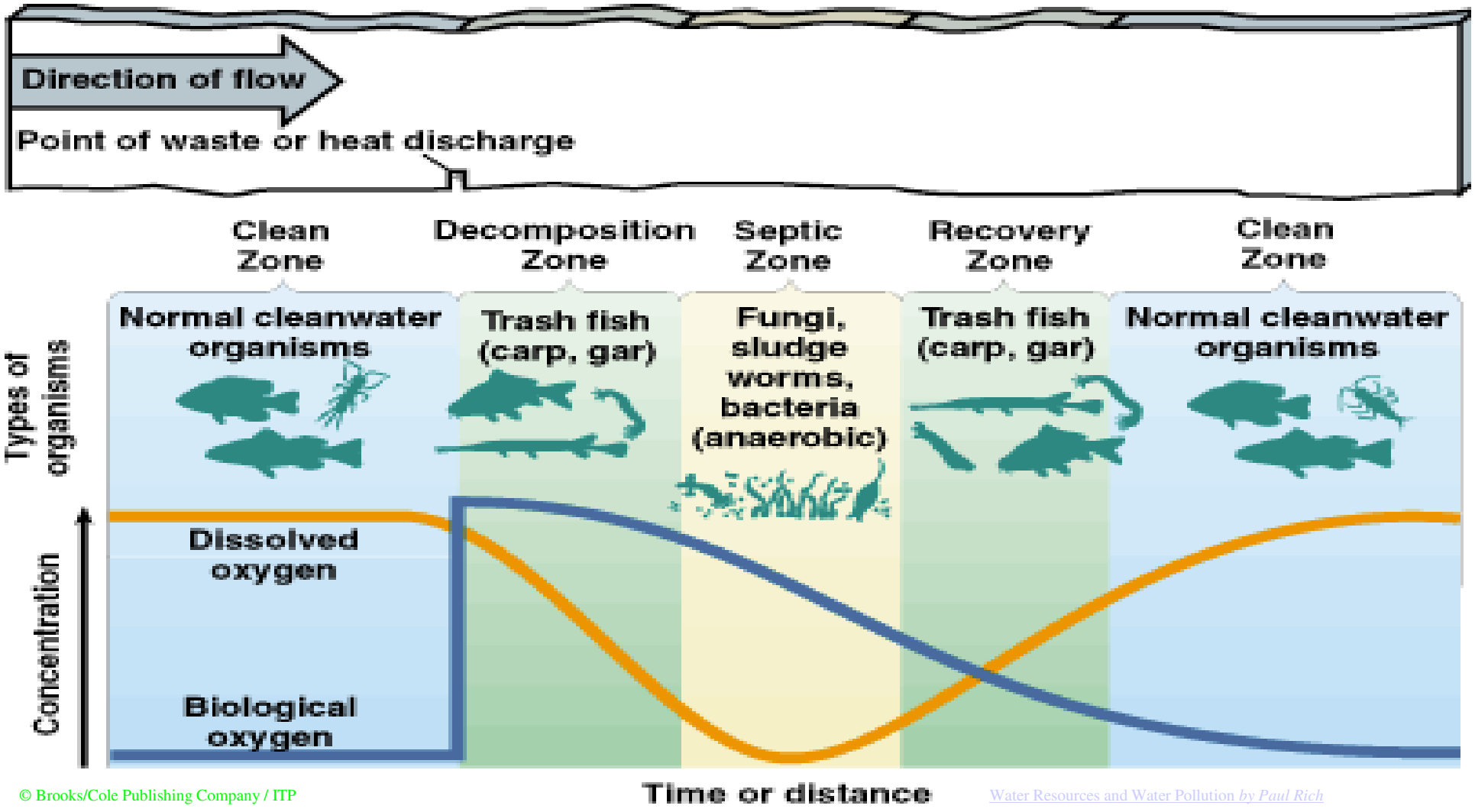
Rivers

- Rivers have been easy targets for dumping of sewage and industrial wastes
- Many rivers that are in industrial areas are so polluted and low in oxygen that very few species can live in them anymore
- The Rhine, Danube, Illinois, Cuyahoga, and Mississippi are the worst examples of polluted rivers

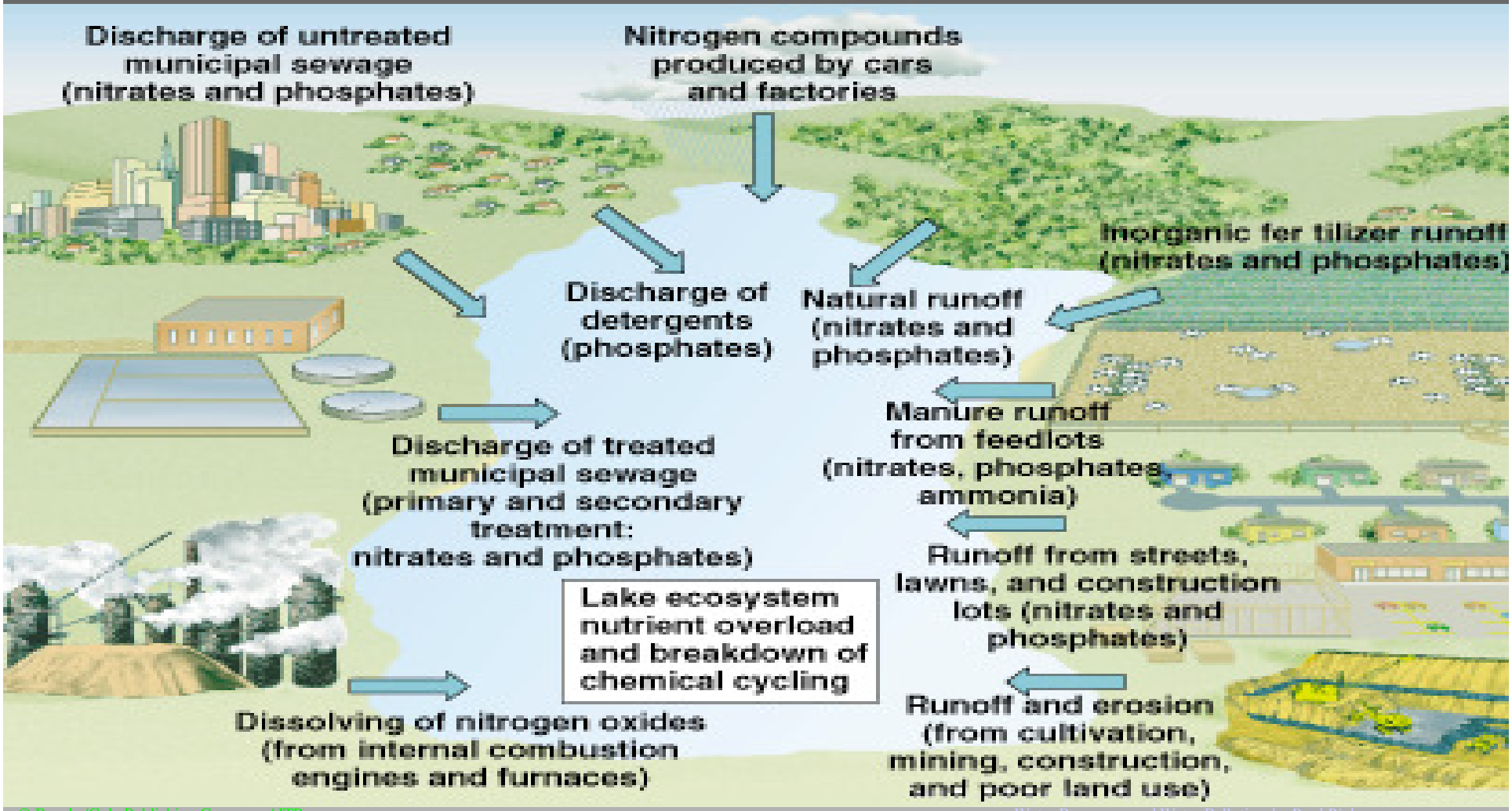
Pollution of Streams and Lakes

flowing water can recover rapidly by dilution and decay



Eutrophication

Accelerated results with human input of nutrients to a lake



Case Study: Great Lakes

- Basin contains >95% of fresh surface water in U.S. and 20% of world
- Severe cultural eutrophication in 1960s (e.g., Lake Erie)
- $20 billion pollution–control program improved water quality since 1972

Fig. 12–22

Pollution of Streams and Lakes

- water pollution laws of 1970s greatly increased number and quality of wastewater treatment plants in U.S.
- also improvements in Canada, Japan, and most western European countries;
- large fish kills and contamination of drinking water still occur, especially in developing countries;
- lakes, reservoirs and ponds more vulnerable to contamination than streams because of less mixing and aeration.

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Ocean Pollution

- Coastal areas most impacted – especially wetlands and estuaries, coral reefs, and mangrove swamps
- Half of world's population lives within 100 km (60 miles) of oceans and 14 of 15 largest cities coastal
- About 35% of U.S. municipal sewage discharged virtually untreated in ocean waters
- Dumping of industrial waste directly into ocean off U.S. coasts stopped, but many countries still dump large quantities of toxic substances
- Ocean is the ultimate repository of waste

Pollution in Coastal Waters

- Coastal waters especially are highly affected by pollution because they are:
  - Heavily used
  - Close to sources of pollution
  - Shallow-water bodies
  - Not as well circulated as the open ocean
- Coastal pollution is made up of ocean pollution and ocean debris

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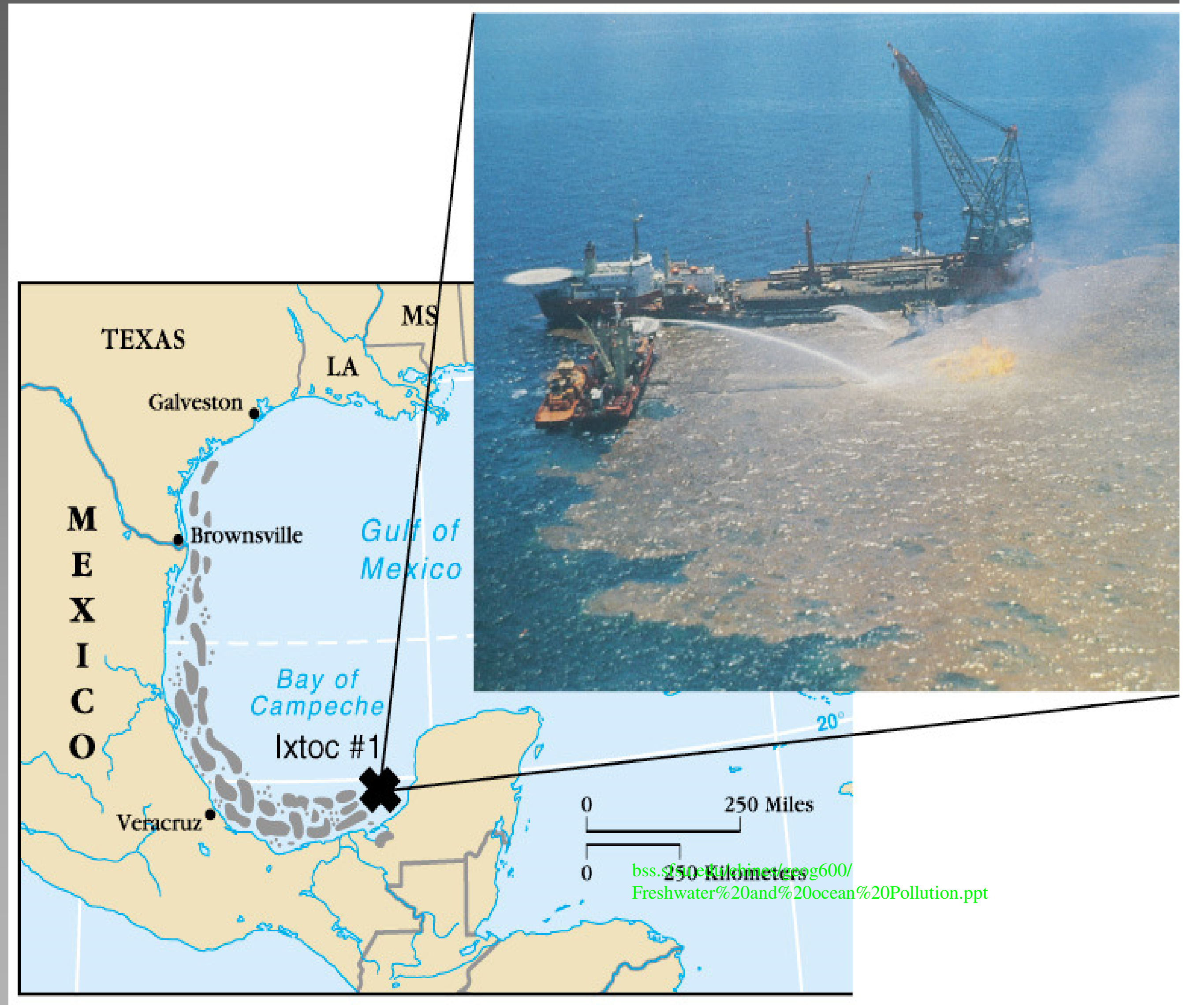
Main Types of Ocean Pollution

- Petroleum (oil)
- Sewage sludge
- DDT and PCBs
- Mercury
- Point source: clearly discernable in terms of origin (municipal sewage outfall, oil tanker spills, offshore oil well blowouts)
- Non-point-source pollution: ill-defined or diffused sources, runoff (harbors and marinas, TBT, powerboat pollution, invasive species, agriculture, forestry, urban runoff, ocean debris, air pollution, noise pollution, dredging

Ocean Pollution: Petroleum

- Oil spills can be caused by:
  - Tanker accidents
  - Intentional dumping
  - Drilling/ pumping operations



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Effects of Oil Spills

- **V**olatile **O**rganics **C**ompounds immediately kill many of the aquatic organisms (especially plankton and larvae) and contaminate fish
- **Floating oil** coats birds and ocean mammal; destroys natural insulation and buoyancy and causes deaths
- **Heavy oil** sinks to ocean bottom and washes into estuaries where it contaminates crabs, oysters, mussels, clams, etc.
- **Oil slicks on beaches** harm intertidal life and cause economic losses to tourism and fishing industries

Ocean Pollution: Petroleum

- When oil washes up at a beach, it can negatively affect the ocean environment
- Oil can coat ocean organisms and render their insulating fur or feathers useless

Oil on the beach from the *Exxon Valdez* oil spill, Alaska

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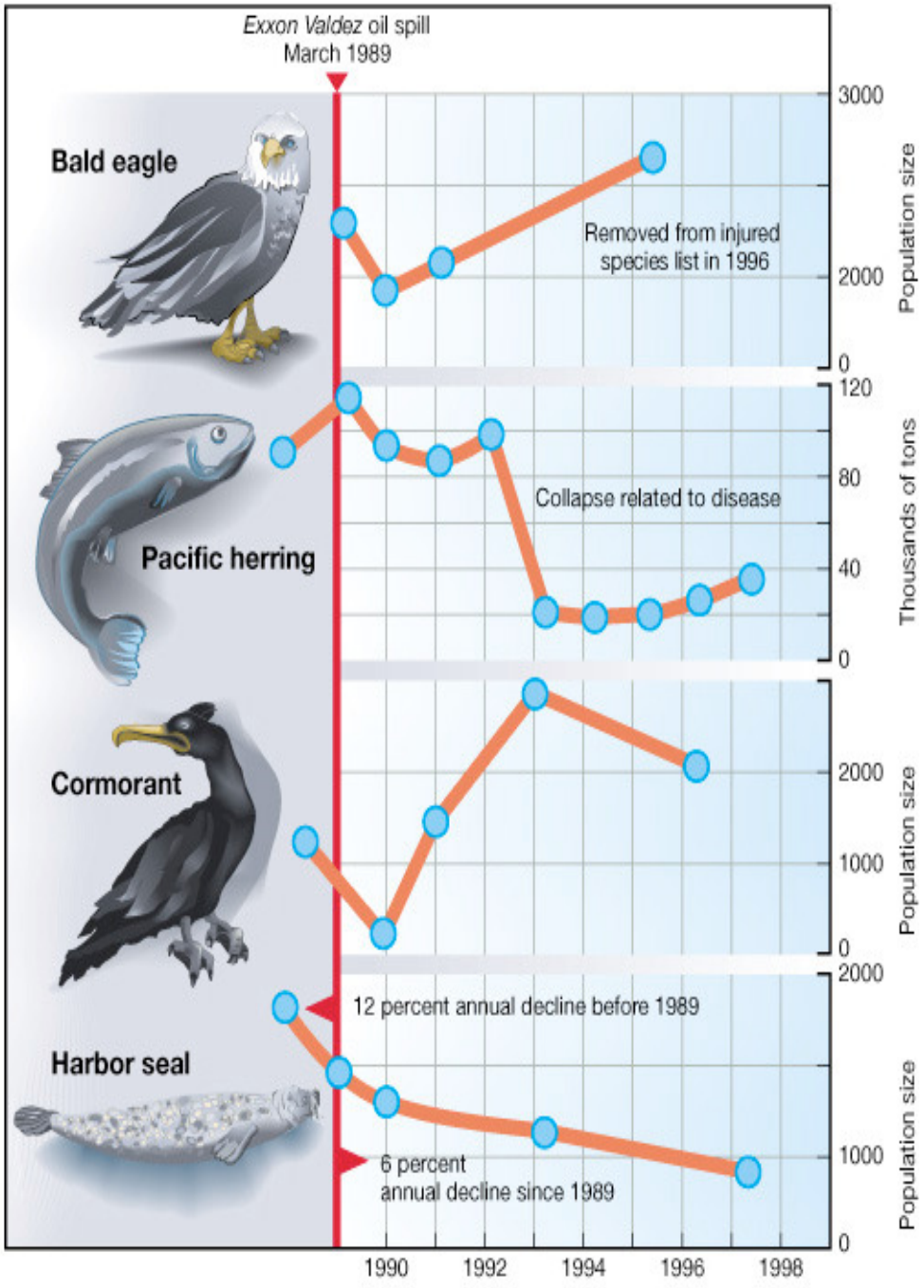
Ocean Pollution: Petroleum

- Petroleum is biodegradable
- Many pollution experts consider oil to be among the least damaging ocean pollutants
- Data from the 1989 *Exxon Valdez* oil spill shows the recovery of key organisms



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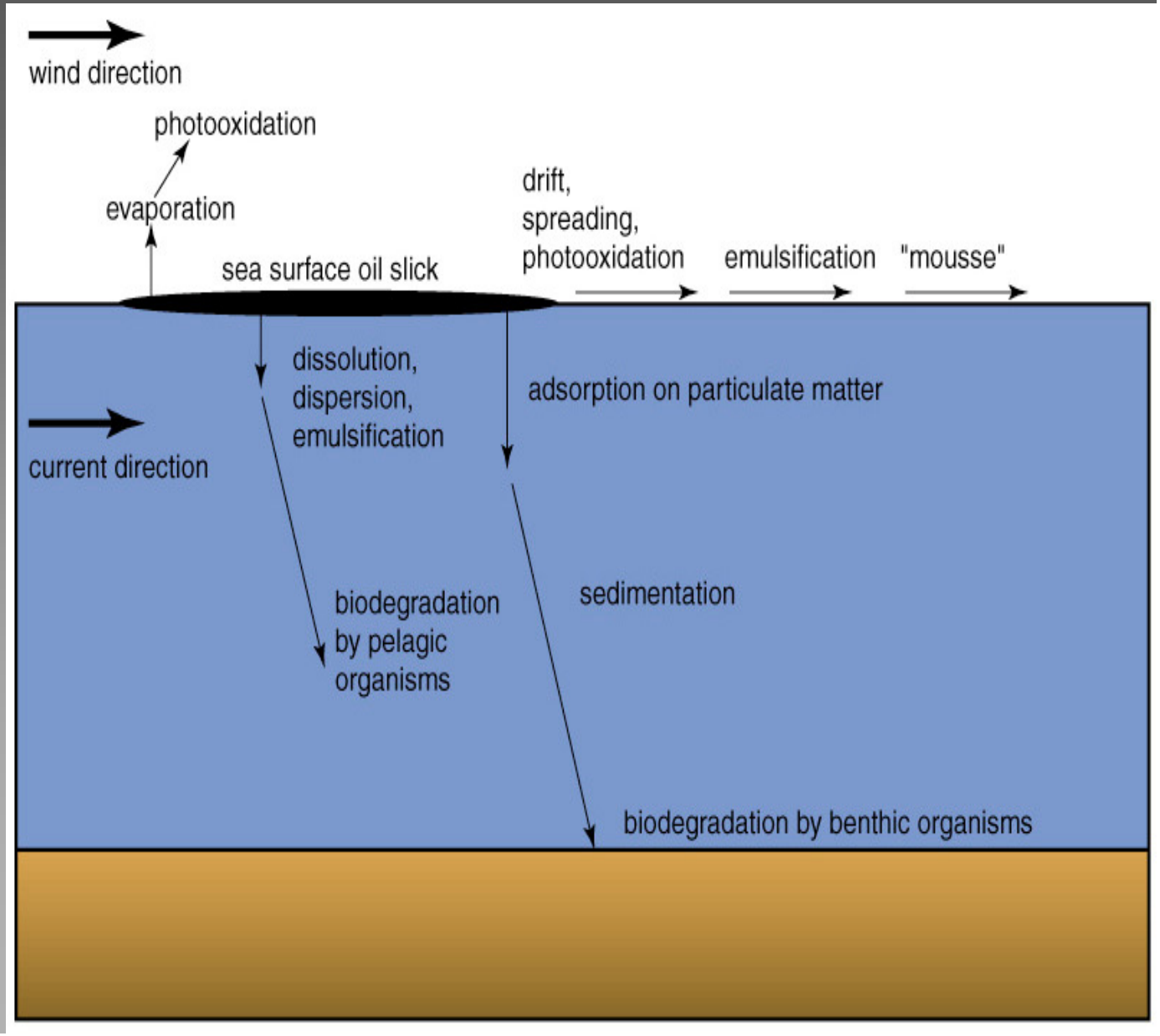
Ocean Pollution: Petroleum

Various processes act to break up and degrade oil in the ocean environment



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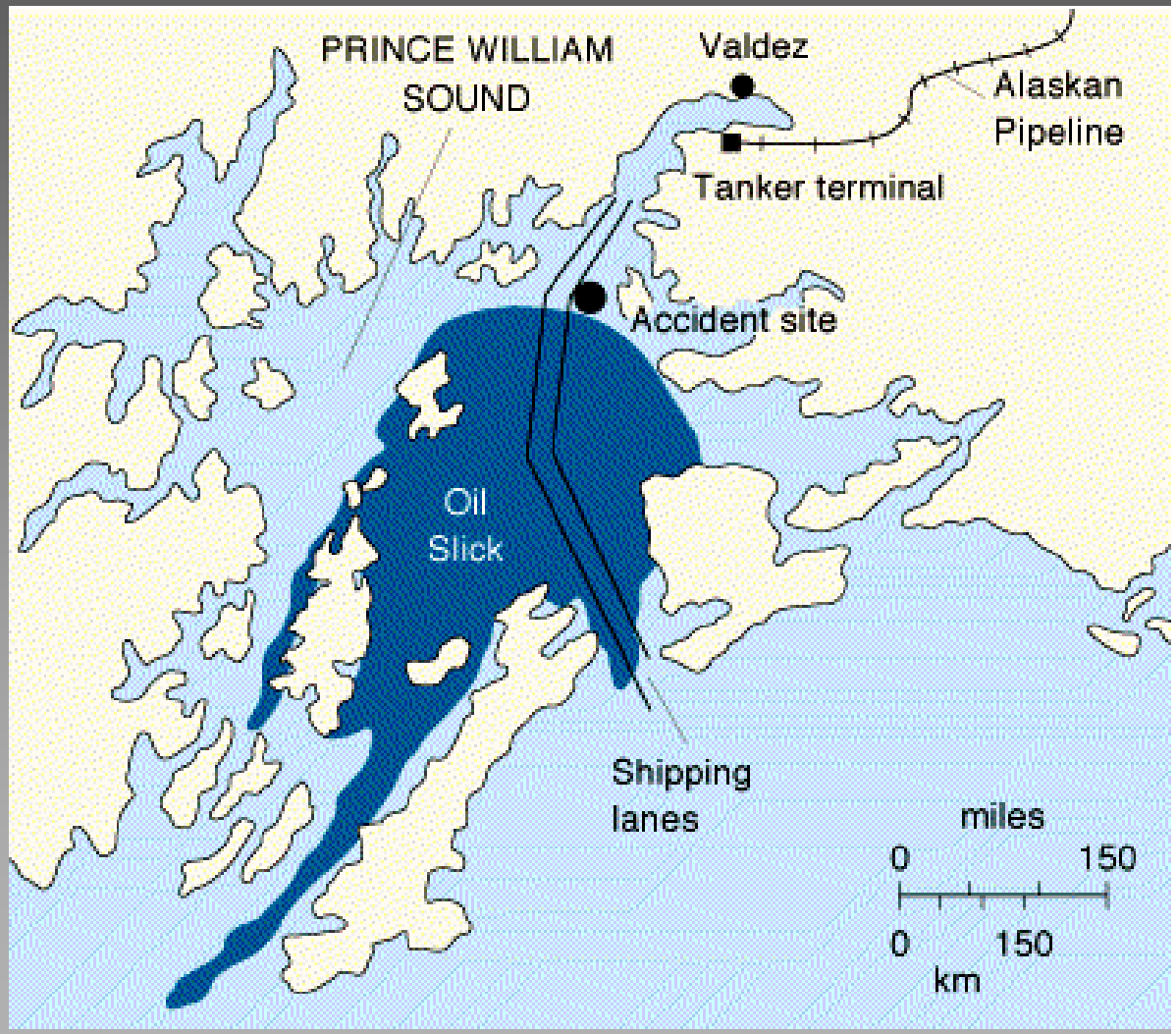
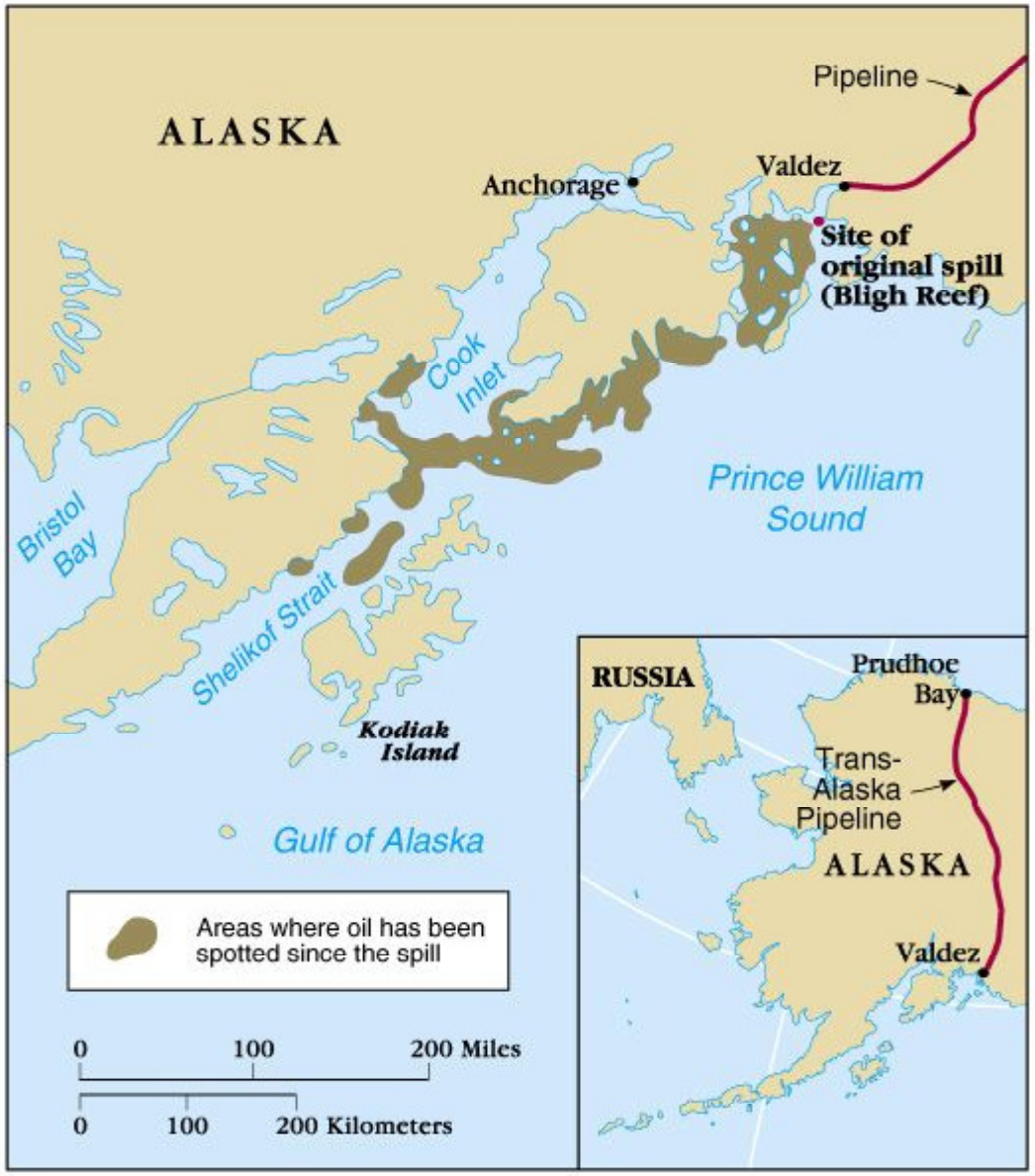
Case Study: Exxon Valdez Oil Spill

- March 24, 1989, tanker in Prince William Sound, Alaska, worst oil spill in U.S. waters
- Coated 1,600 of shoreline, killed wildlife, and caused serious contamination
- Exxon spent $2.2 billion on direct cleanup + $1 billion fines and damages; another $5 billion being appealed





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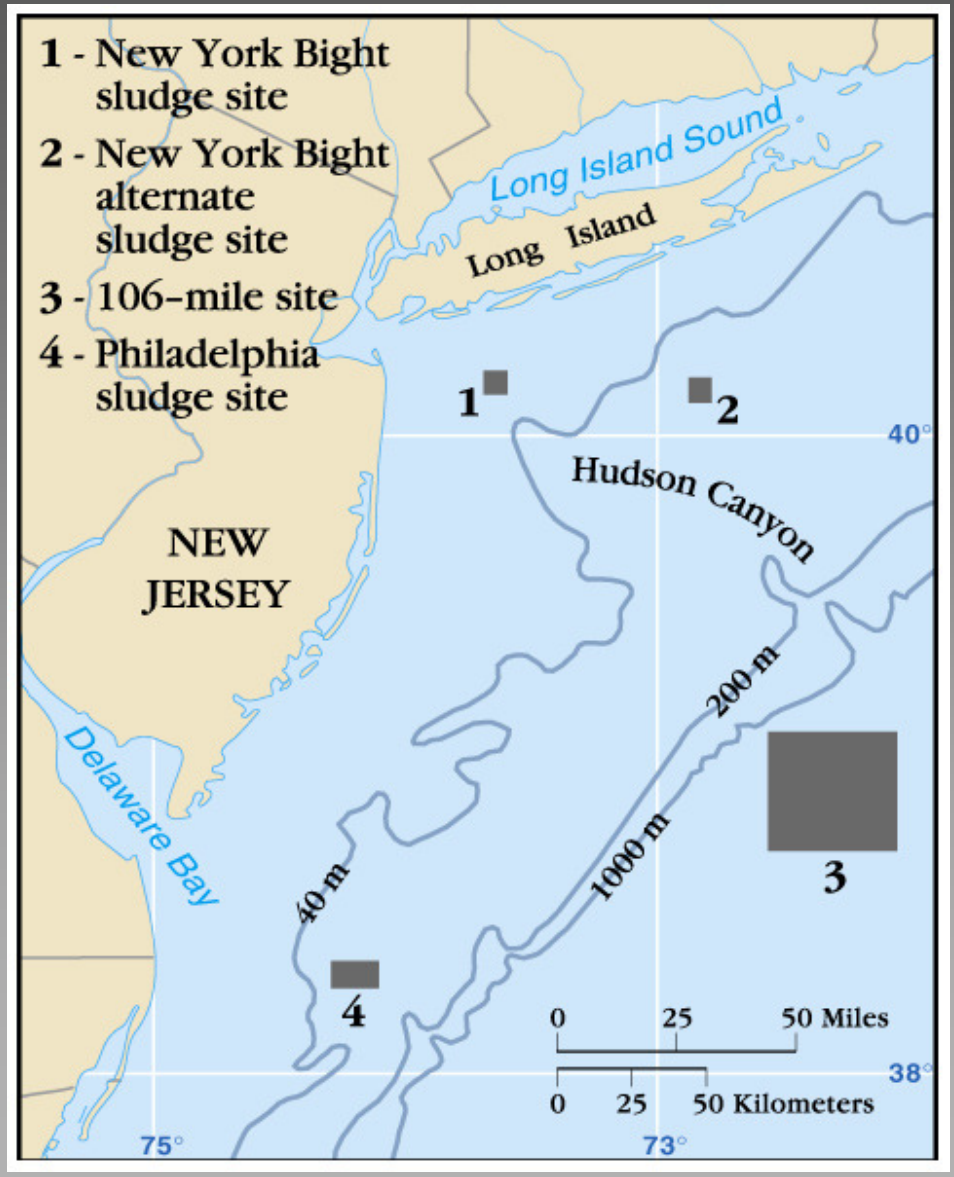
Exxon Valdez only #53????

Table I I A. The world's largest oil spills.

Rank	Date	Location	Source of spill	Size of spill	
				million liters	million gallons
1	1/1991	Kuwait, Saudi Arabia	Oil terminals, tankers	908	240
2	6/1979	Gulf of Mexico	Ixtoc #1 oil well	530	140
3	3/1992	Uzbekistan	Oil well	333	88
4	2/1983	Iran	Oil well	303	80
5	8/1983	Near coast of South Africa	*Castillo de Bellver* tanker	299	79
6	3/1978	Near coast of France	*Amoco Cadiz* tanker	261	69
53	3/1989	Prince William Sound, Alaska	*Exxon Valdez* tanker	44.0	11.6

Ocean Pollution: Sewage Sludge

- Sewage sludge is the semisolid material that remains after sewage treatment
- Much sewage sludge was dumped offshore until laws restricted sewage dumping



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Ocean Pollution: DDT

- DDT was a widely used pesticide that became concentrated in ocean fish
- DDT caused brown pelicans and ospreys to produce thin egg shells
- Worldwide, DDT has been banned from agricultural use but is still found in developing countries…

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Ocean Pollution: PCBs

- PCBs are industrial chemicals used as liquid coolants and insulation in industrial equipment such as power transformers
- PCBs enter the ocean environment through leaks and from discarded equipment
- PCBs can accumulate in animal tissues and affect reproduction

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Ocean Pollution: Mercury and Minamata Disease

- Mercury has many industrial uses but is extremely toxic
- A chemical plant released large quantities of mercury into Minamata Bay, Japan
- Residents who ate highly contaminated fish suffered neurological disease and birth disorders

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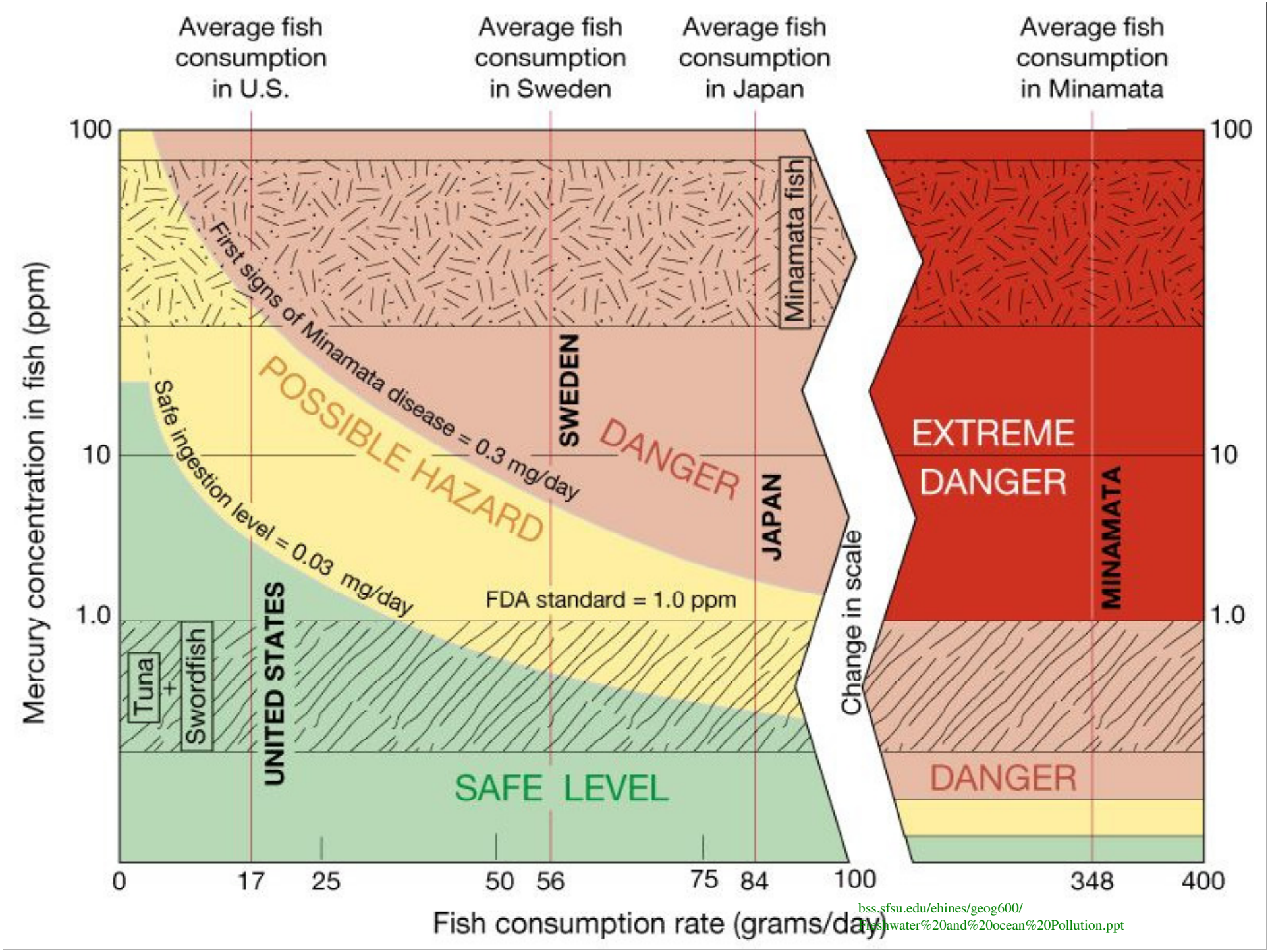

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Case Study: Chesapeake Bay

- Largest estuary in U.S.
- Severely degraded by water pollution from 6 states
- Deposition of air pollutants

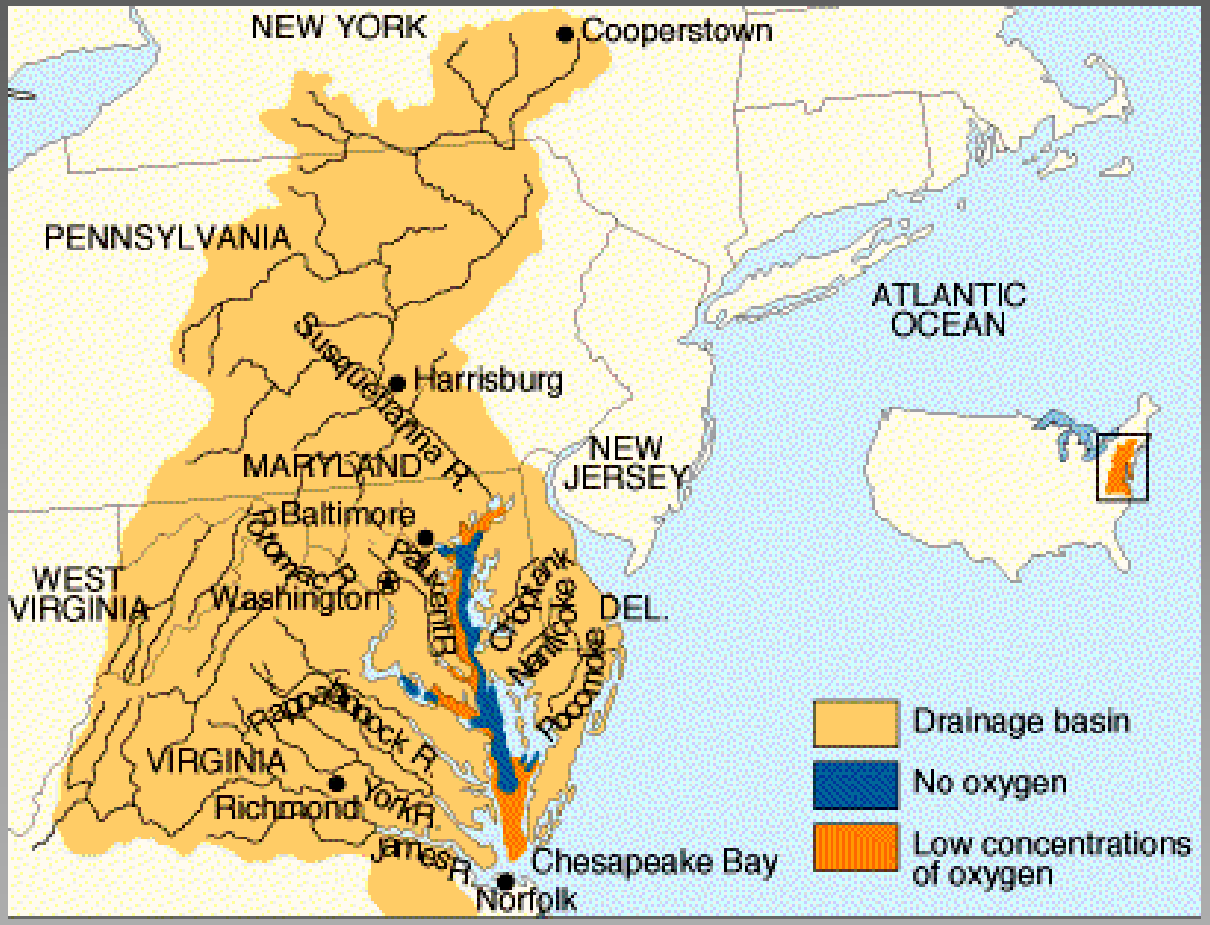

Fig. 12–24

Ocean Pollution: Point Source

- Are clearly discernible in terms of origin
- Originate from municipal and industrial facilities
- Bypasses and overflows from municipal sewage systems
- Oil tanker spills and offshore oil well blowouts

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Ocean Pollution: Non-Point Source

- Non-point-source pollution comes from material washed down storm drains as "poison runoff"
- Includes fertilizers, pesticides, road oil, and trash

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Plastic in the Ocean Environment

- Plastic:
  - Either does not biodegrade or not in human time…
  - Floats
  - Has high strength
  - Is ingested by and entangles ocean animals

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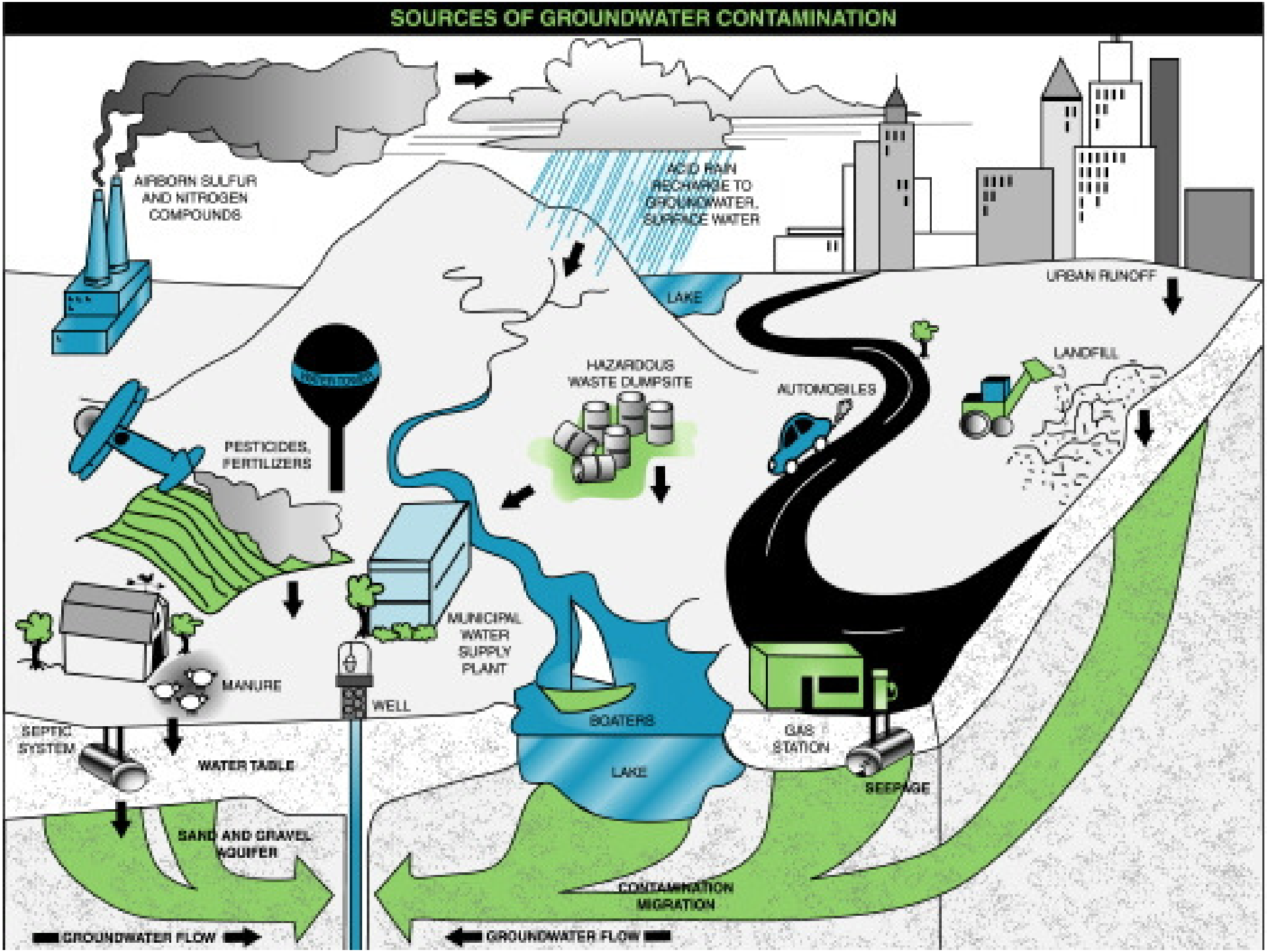
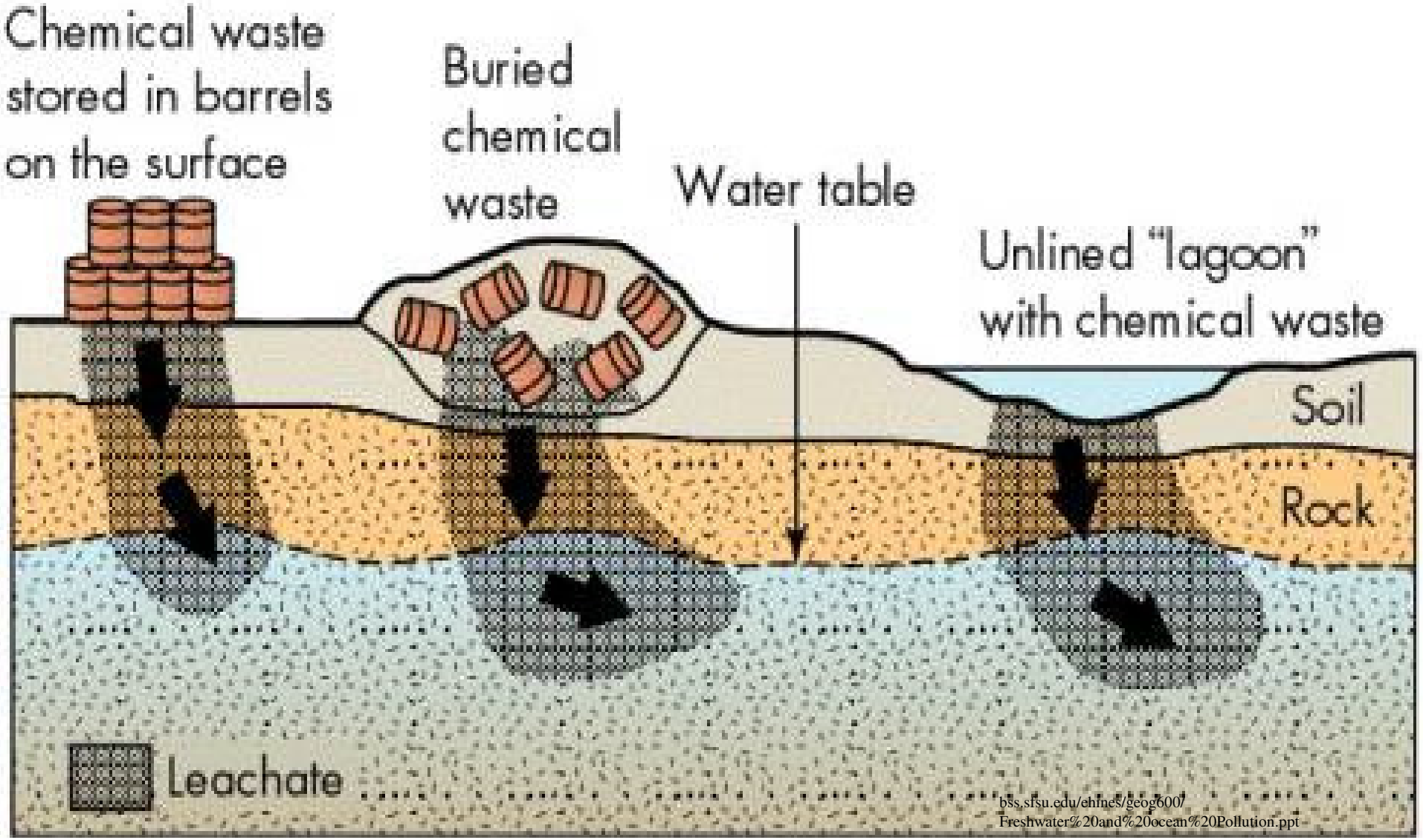
- Types and Sources of Pollution
- Pollution of Streams and Lakes
- Ocean Pollution
- **Groundwater Pollution**
- Drinking Water Quality
- Waste Water Treatment
- Water Legislation

Groundwater Pollution

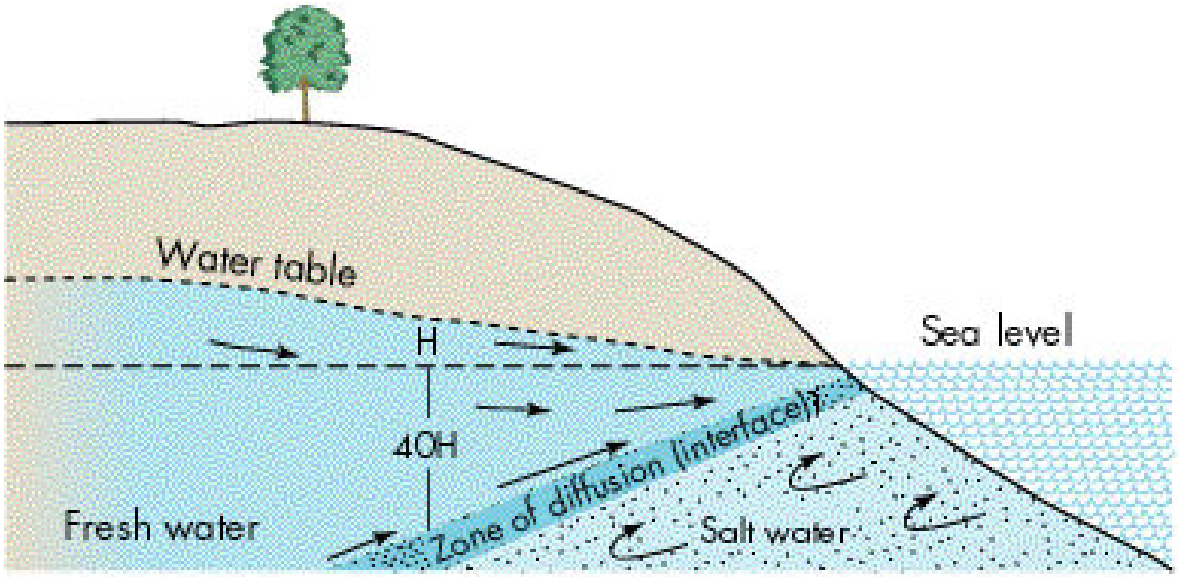
- Greater threat to humans than much of more visible surface water pollution
- Much groundwater renewed slowly, such that pollution lingers for long time
- Crude estimates indicate that up to 25% of usable groundwater in the U.S. contaminated
- Extremely difficult to clean up contaminated groundwater; prevention more effective
- Main approach: pump groundwater to surface, purifying water, and returning to aquifer; costs high

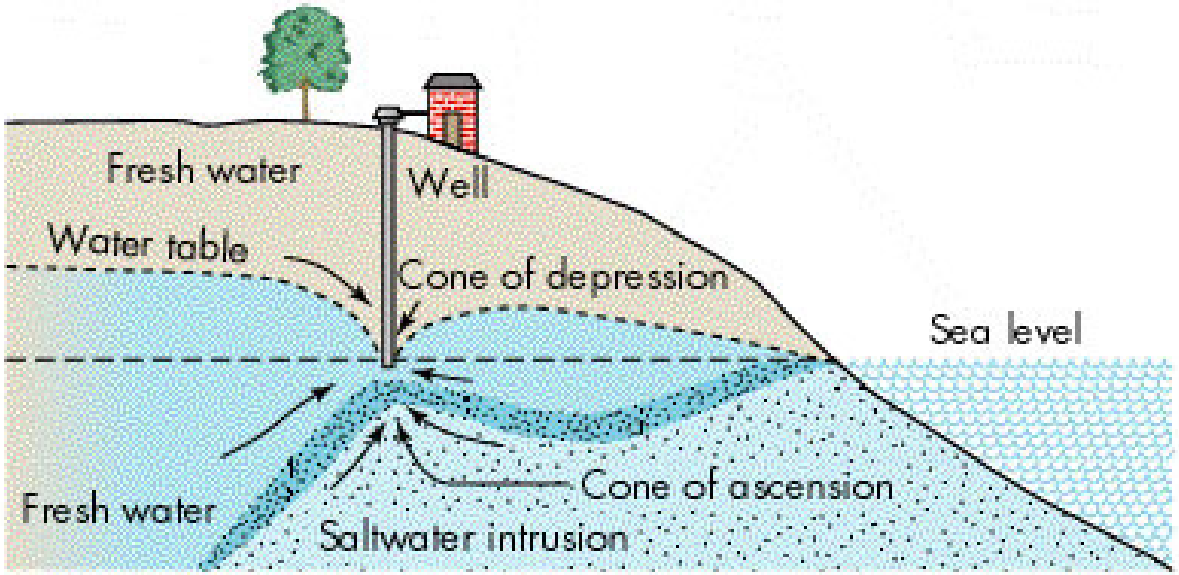

SOURCES OF GROUNDWATER CONTAMINATION
AIRBORN SULFUR AND NITROGEN COMPOUNDS
ACID RAIN RECHARGE TO GROUNDWATER, SURFACE WATER
URBAN RUNOFF
LAKE
HAZARDOUS WASTE DUMPSITE
AUTOMOBILES
LANDFILL
PESTICIDES, FERTILIZERS
MUNICIPAL WATER SUPPLY PLANT
MANURE
WELL
BOATERS
GAS STATION
SEPTIC SYSTEM
WATER TABLE
LAKE
SEEPAGE
SAND AND GRAVEL AQUIFER
CONTAMINATION MIGRATION
GROUNDWATER FLOW
GROUNDWATER FLOW

75% of 175,000 known waste disposal sites in US may be producing hazardous subsurface plumes (contaminated regions of the subsurface)



Groundwater Pollution





Salt Water Intrusion

Extensive pumping in coastal areas can cause salt water to rise into wells, forming a cone of ascension

Prevention

- Reduce sources that feed into the aquifer;
- Monitor aquifers near landfills and underground storage tanks;
- Require leak detection systems and liability insurance for existing and new underground tanks that store hazardous liquids;
- Ban or more strictly regulate disposal of hazardous wastes in deep injection wells and landfills;
- Store hazardous liquids aboveground with more safeguards.

- Types and Sources of Pollution
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- Ocean Pollution
- Groundwater Pollution
- Drinking Water Quality
- Waste Water Treatment
- Water Legislation

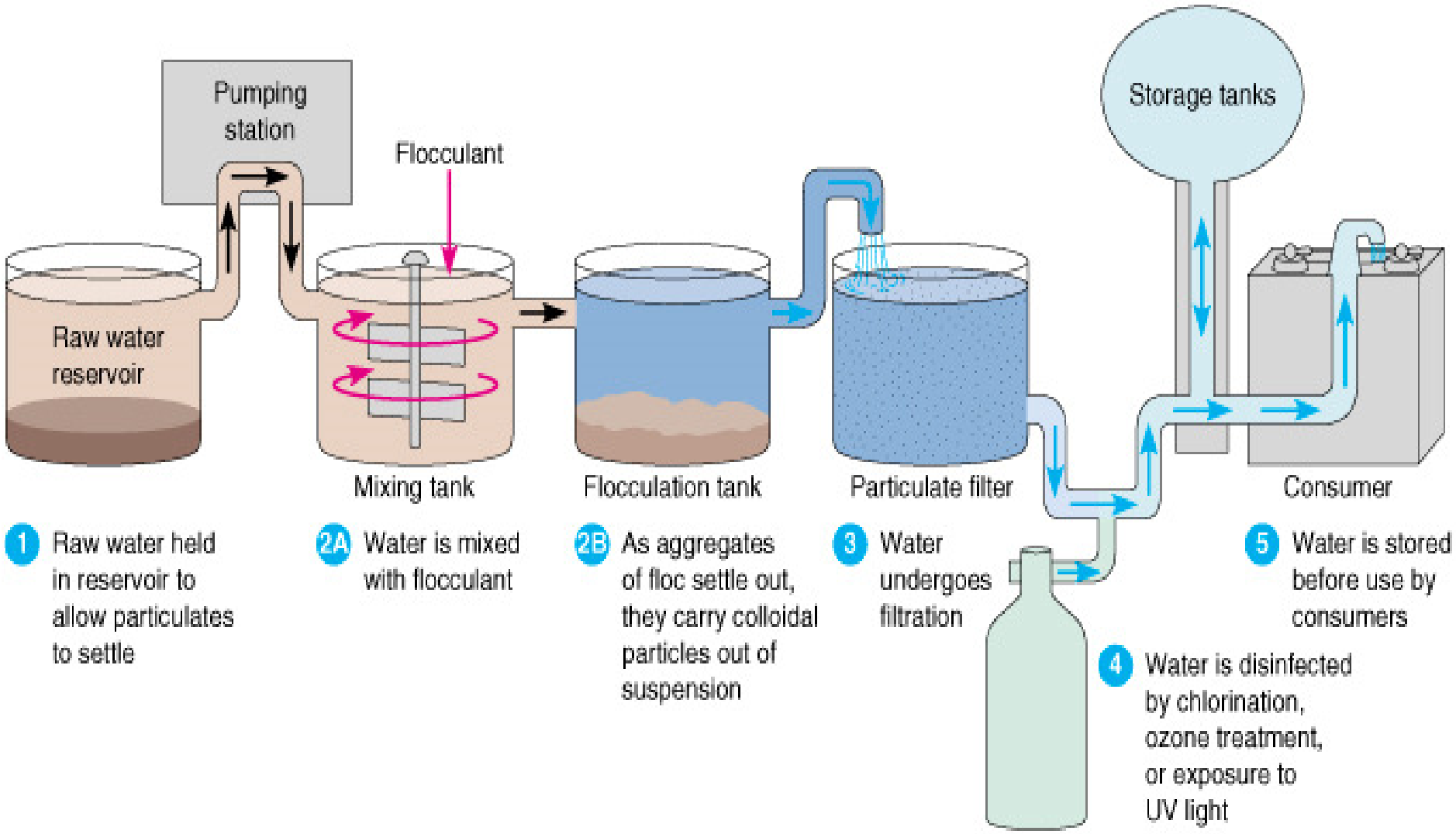
Drinking Water Quality

- 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.

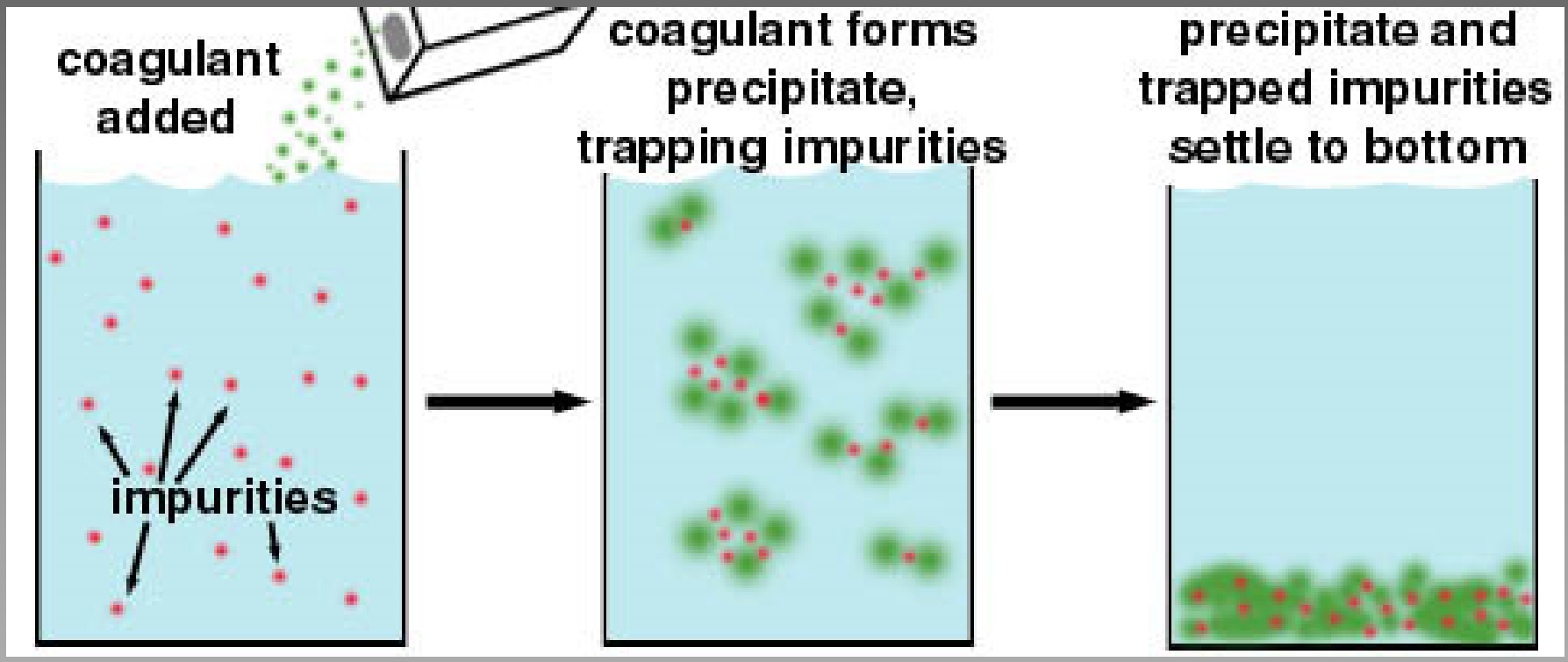
Initial Stages

- **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.

Coagulation



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

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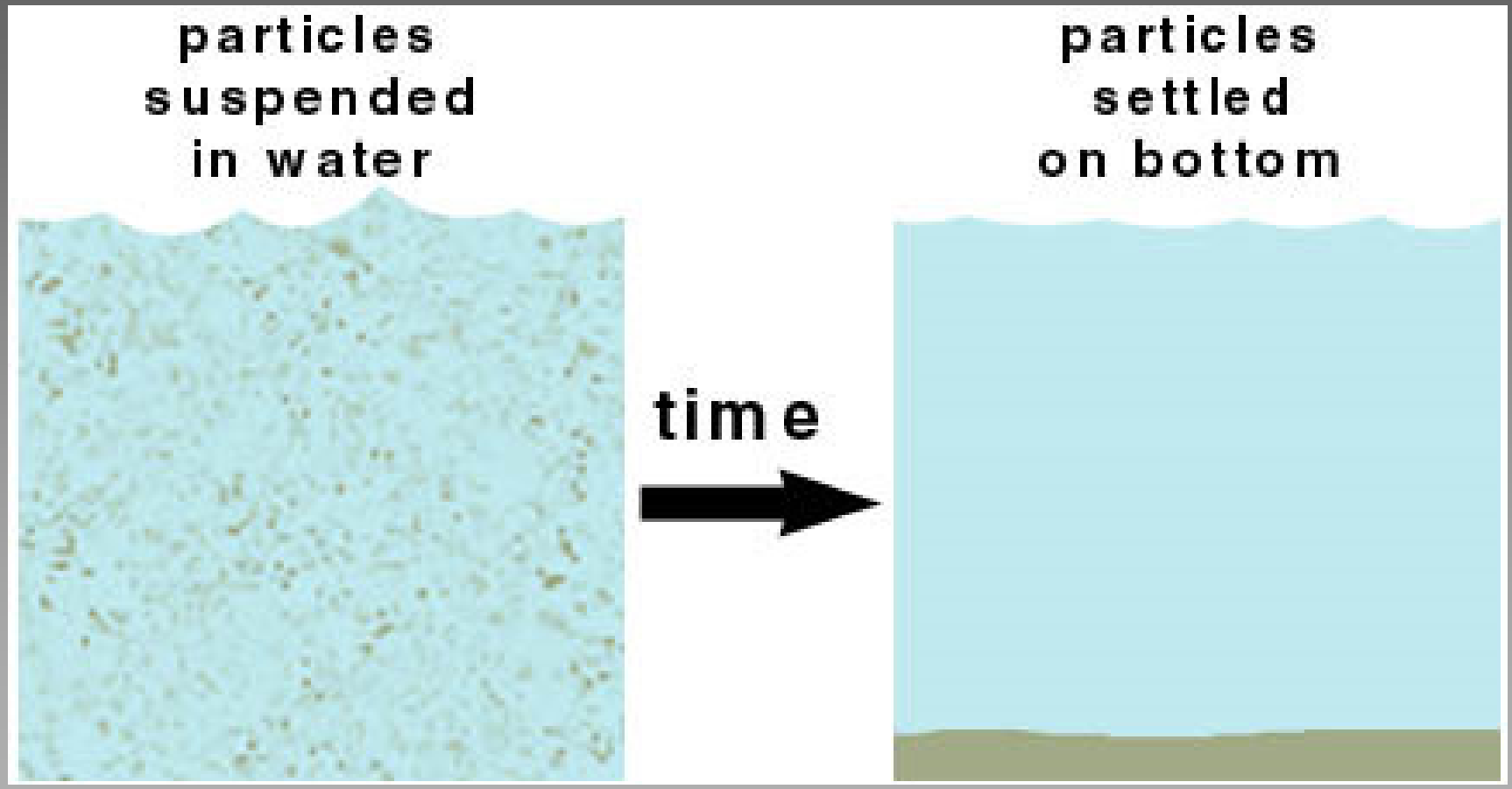
Sedimentation



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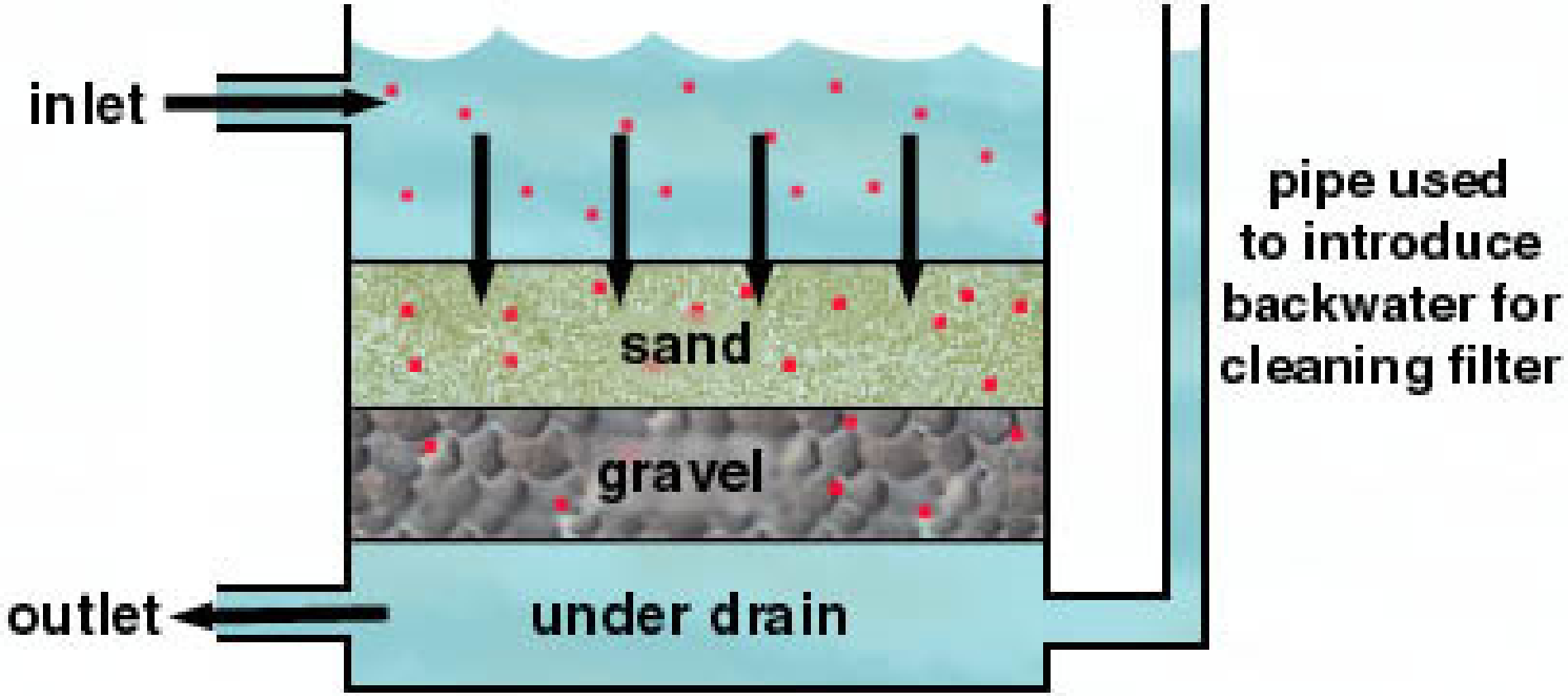
Filtering Out What's Left

- 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



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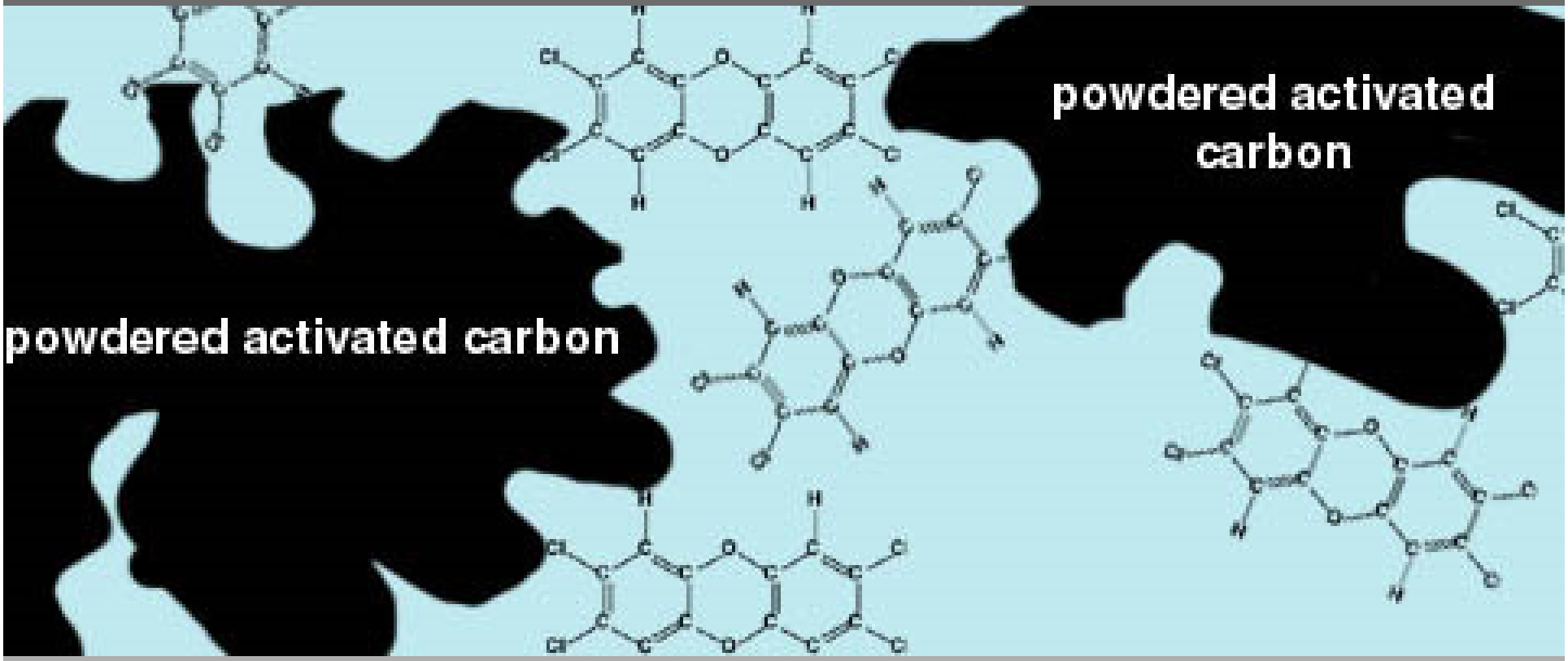
Final Touches

- **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

Adsorption



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

Water Treatment Virtual Tours

- A number of water suppliers have helpful and interesting virtual tours of their facilities on the web:
- The City of Tempe Az: http://www.tempe.gov/water/360/default.htm
- The City of Arlington Tx: http://www.ci.arlington.tx.us/water/virtualtour.html
- Central Coast Water Authority, CA: http://www.ccwa.com/treatment01.htm

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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

Wastewater Treatment

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

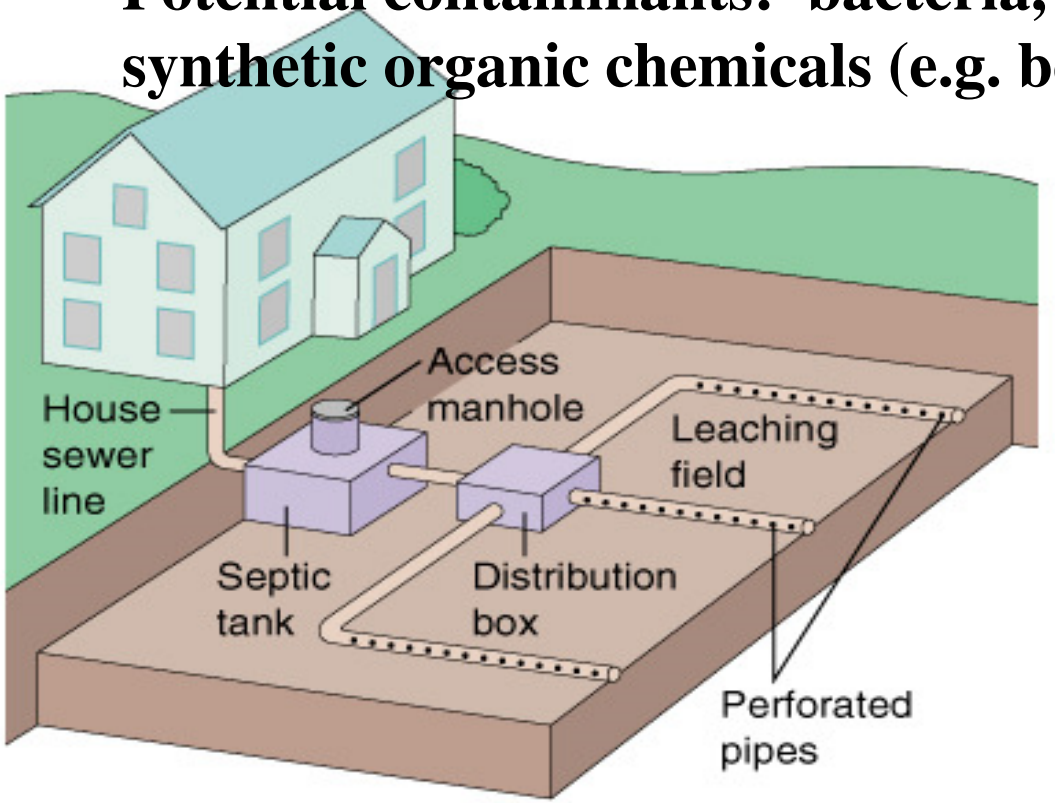
- Septic Tanks typically treat small volumes of waste (e.g., from a single household, small commercial/industral)
- WWTPs typically treat larger volumes of municipal or industrial waste.

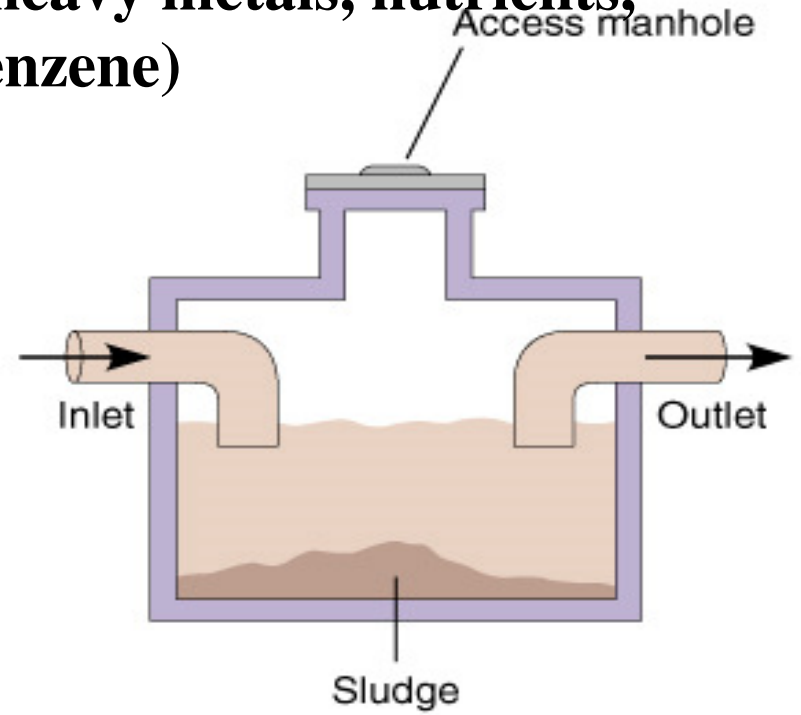
Decentralized Alternatives

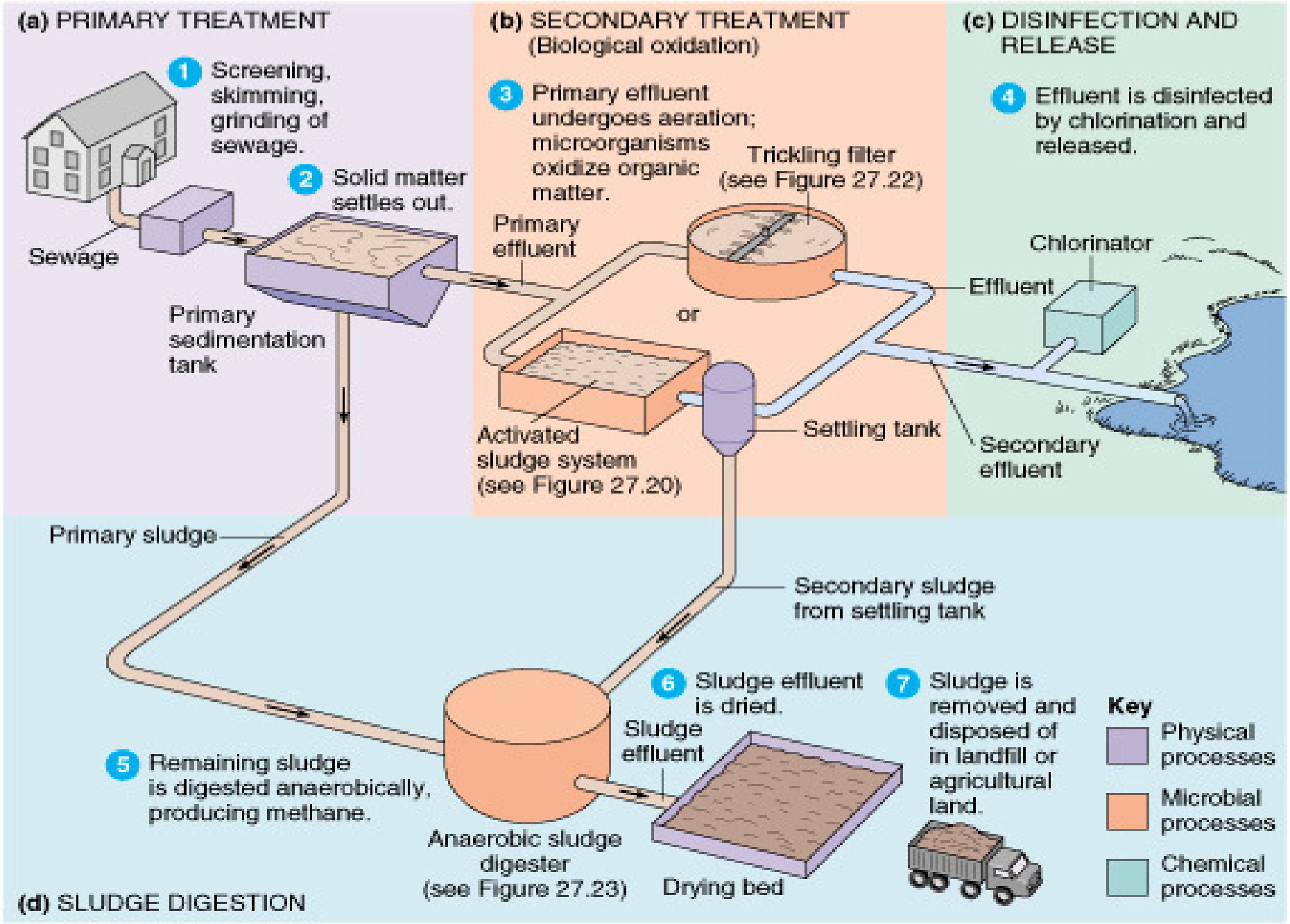
- In rural areas or in particular urban communities in the U.S., human wastewater will be treated through individual septic tank systems (pumped or leachfield varieties)
- Wastewater is filtered, microorganisms killed and chemicals adsorbed and/or diluted in its passage through the soils and rocks of 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)**







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

Sewage Treatment

2. Secondary Treatment (Microbial Process)
   - 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

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

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

Sewage Treatment

3. 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

Reusing Wastewater

- Currently, treated wastewater, no matter how "clean" cannot be directly mixed with treated raw water and supplied as potable (from Latin *potare* = "to drink") water (most places)
- However, if a dual plumbing system is available, wastewater can be piped into facilities for specific, approved uses for which non-potable water is adequate (process water, irrigation, sanitary use, etc.)
- Dual plumbing systems in America are colored purple to distinguish pipes, valves, taps, etc. from potable ones (e.g. Las Positas CC and the adjacent industrial park has this)

Indirect Use of Wastewater

- Increasingly, treated wastewater is being used in Aquifer Recovery and Storage projects, used to recharge and protect groundwater that will ultimately be used for potable supplies.
- In Israel and the Netherlands, treated wastewater is allowed to percolate into and filter through deep sand dunes or permeable sandstone rocks to deep aquifers and is pumped out below and sent to raw water treatment plants.
- In California, many plans exist for recharging groundwater basins with wastewater (Zone 7, Orange County, etc.) as long as the groundwater has adequate residence times.
- Treated wastewater is frequently used as sources of saline intrusion barrier water.

Wastewater Virtual Tours

- The State of South Dakota has a useful generic wastewater treatment plant tour on the web: http://www.state.sd.us/denr/DES/Surfacewater/virtual.htm
- The City of Camarillo, CA has a nice and clear virtual tour of their secondary treatment plant: http://www.ci.camarillo.ca.us/csd/tour.html

CA Tertiary Wastewater Systems

- Irvine Ranch Water District has a very advanced tertiary wastewater treatment system used to supply reclaimed water that you can read about and virtually tour at: http://www.irwd.com/index.html.
- Orange County Water District also has a very sophisticated system used for groundwater recharge and aquifer recovery that you can read about and virtually tours at: http://www.ocwd.com/_html/wf21.htm#Anchor-WF21Overview-49575

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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

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

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
6. MARPOL 73/78 is implemented in the U.S. by the Act to Prevent Pollution from Ships, under the lead of the U.S. Coast Guard

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
- 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

Porter-Cologne Act

- This Act (1969), California Water Code §13000 et seq., provides for aesthetic values, fish and wildlife preservation, water reclamation, and comprehensive planning and regulation to attain the highest "reasonable" water quality in consideration of conflicting demands.

- It is California's Clean Water Act.

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

California Safe Drinking Water and Toxic Enforcement Act

- This 1986 law (Prop 65) had two major provisions:
  1. That no person in the course of doing business shall knowingly discharge or release a chemical known to the state to cause cancer or reproductive toxicity into water or onto or into land where such chemical passes or probably will pass into any source of drinking water, notwithstanding any other provision.
  2. No person in the course of doing business shall knowingly and intentionally expose any individual to a chemical known to the state to cause cancer or reproductive toxicity without first giving clear and reasonable warning.
- It strengthened both the Federal CWA and SDWA.

Environmental Science ENSC 2800 - Pollution in the Bay-Delta

Current Law Regulating Ocean Dumping

- The only substance that is **illegal** to dump anywhere in the ocean is *plastic*

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