APES CHAPTER 14 NOTES (MRS. BAUCK): WATER POLLUTION

MODULE 41: Wastewater from Humans and Livestock

I. Wastewater Problems

A. General terms

1) **pollutant—** something causing unclean and impure conditions which can *pose threats to organisms' health and the environment*

2) **water pollutant**—*any chemical, biological, or physical change in water quality that has a harmful effect on living organisms, making water unsuitable for use* (Miller)

   a) **biodegradable**—can be broken down by detritus feeders and decomposers

   b) **nonbiodegradable**—will not be decomposed naturally

3) sources of water pollution

   a) **point sources**

      i. *specific sites of pollution discharge* (pipes, ditches, sewers)

      ii. fairly easy to locate and monitor

   b) **nonpoint source**s

      i. broad, scattered, diffuse; *can't be traced to one site* (large land areas, runoff, surface flow)

      ii. harder to control

4) **wastewater**— water produced from humans and livestock (sewage, bathing, washwater, etc)

5) types of water pollution

   a) **pathogens** *(disease-causing agents)*

      i. from human and animal waste

      ii. *bacteria, viruses, and parasites*

      iii. examples: *Giardia, fecal coliform bacteria (E. coli)*

   b) **organic wastes**

      i. leaves, grass clippings, trash

      ii. *oxygen-demanding wastes*—organic wastes that can be decomposed by aerobic bacteria which depletes oxygen

      iii. threatens human, animal, and aquatic plant life

   c) **chemical pollutants**

      i) *water-soluble inorganic materials*

      - water-soluble nitrates and phosphates
      - heavy metals (including Pb, Hg, Cd, and Ni)
      - sulfuric acid (H_2SO_4), nitric acid (HNO_3)
      - road salts ($NaCl$, $CaCl_2$)
      - can cause excessive growth of algae and other aquatic plants that die and deplete the O_2 content, killing fish

      ii) *organic materials*— oil, gas, plastic, petroleum products, pesticides, detergents, industrial chemicals

      iii) *water-soluble radioactive isotopes*

      - accumulate in tissues and organs
      - cause birth defects, cancer and genetic damage

      iv) **sediments** or *suspended matter (largest class)*

      - soil, sand, silt, clay, gravel, dust

- particles stay suspended in water, making it cloudy
- **bed load**—*sand and silt gradually washed along the bottom of a body of water*
- reduces photosynthesis and disrupts food webs
- clogs harbors, reservoirs, channels and artificial lakes

d) nutrients – nitrates and phosphates (more later)

e) *TDS (total dissolved salts, total dissolved solids)* a measure of the ions dissolved in a sample of water

i. electrical conductivity (EC) estimates TDS

ii. unit of EC: microSiemens per centimeter (µS/cm)

iii. can be from specific rock types, urban runoff, sewage plant wastewater, septic system wastewater, high evaporation rate, some bacteria

f) *thermal pollution*

i. rise in water temp from heat absorbed to cool power plants

ii. lowers water level and makes organisms more vulnerable to disease

g) *genetic pollution*

i. deliberate or accidental addition of nonnative species

ii. disrupts aquatic systems and crowd out natives

iii. reduces biodiversity

iv. mainly introduced by intake and ballast from ships

B. Oxygen Demand

1) **DO (dissolved oxygen)** http://www.state.ky.us/nrepc/water/wcpdo.htm

a) *a measure of the amount of gaseous oxygen (O_2) dissolved in an aqueous solution*

b) O_2 dissolved by diffusion from air, by water movement, & photosynthesis

c) environmental impact:

"…Fish in waters containing excessive dissolved gases may suffer from 'gas bubble disease'; however, this is a very rare occurrence. The bubbles or emboli block the flow of blood through blood vessels causing death. *External bubbles (emphysema)* can also occur and be seen on fins, on skin and on other tissue. Aquatic invertebrates are also affected by gas bubble disease but at levels higher than those lethal to fish.

Adequate dissolved oxygen is necessary for good water quality. Oxygen is a necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. *As dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1-2 mg/L for a few hours can result in large fish kills.*"

2) **Biochemical (or biological) oxygen demand (BOD)**—*amount of dissolved oxygen needed by aerobic decomposers to break down over 5 day period @ 20ºC (68ºF)*

from http://purdue.edu/

"The first step in measuring BOD is to obtain equal volumes of water from the area to be tested and dilute each specimen with a known volume of distilled water which has been thoroughly shaken to insure oxygen saturation.

After this, an *oxygen meter* is used to determine the concentration of oxygen within one of the vials. The remaining vial is than sealed and placed in darkness and tested five days later. BOD is then determined by subtracting the second meter reading from the first.

The range of possible readings can vary considerably: water from an exceptionally clear lake might show a BOD of less than 2 mg/L of water. Raw sewage may give readings in the hundreds and food processing wastes may be in the thousands."

3) **Chemical Oxygen Demand (COD)**—*a measure of the oxygen consumed when organic matter is broken down chemically rather than naturally*
   a) can be determined much more quickly than BOD
   b) more accurately reflects amount of organic matter in a water sample

4) **hypoxia** ("low oxygen")—**dead zone** *in a body of water due to lack of oxygen*
   a) Gulf of Mexico hypoxia first detected in 1974
   b) causes

nitrogen runoff from fertilizers
large amounts of nitrogen →
growth of phytoplankton →
phytoplankton die and sink →
consumed by bacteria, which use up oxygen

   c) **stratification**—the tendency of fresh water flowing out from the Mississippi river to sit atop the heavier salt water from the Gulf
   d) *human-made changes* to the Mississippi River and its tributaries
      i. "**Channelization** *(*the practice of *dredging the river bottom* to make passage easier and safer for cargo ships)
      ii. Channelization, along with wetland drainage, contributes to hypoxia by increasing the speed of river flow. Faster-moving waters spend less time subjected to biological processes in which nitrogen is metabolized."

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force https://www.epa.gov/ms-htf

C. nutrients: total phosphorus http://www.state.ky.us/nrepc/water/wcparint.htm

1) importance

"Phosphorus is one of the key elements necessary for growth of plants and animals. *Phosphorus in elemental form is very toxic and is subject to bioaccumulation.* Phosphates PO_4^{3-} are formed from this element. Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorous in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boiler waters and in detergents. In water, they change into the ortho form. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. They may exist in solution, as particles, loose fragments, or in the bodies of aquatic organisms."

2) environmental impact

"Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate will stimulate the growth of plankton and aquatic plants which provide food for fish. This increased growth may cause an increase in the fish population and improve the overall water quality. However, *if an excess of phosphate enters the waterway, algae and aquatic plants will grow wildly, choke up the waterway and use up large amounts of oxygen. This* *condition is known as eutrophication or over-fertilization of receiving waters. The rapid growth of aquatic vegetation can cause the death and decay of vegetation and aquatic life because of the decrease in dissolved oxygen levels.* Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate."

D. Nutrients: Nitrate / Nitrite / Nitrogen

1) importance

"Nitrogen is one of the most abundant elements. About 80 percent of the air we breathe is nitrogen. It is found in the cells of all living things and is a major component of proteins. *Inorganic nitrogen may exist in the free state as a gas* N_2*, or as nitrate* NO_3^-*, nitrite* NO_2^- *, or ammonia* NH_3*. Organic nitrogen is found in proteins and is continually recycled by plants and animals."*

2) environmental impact

"Nitrogen-containing compounds act as nutrients in streams and rivers. *Nitrate reactions [*NO_3^-*] in fresh water can cause oxygen depletion. Thus, aquatic organisms depending on the supply of oxygen in the stream will die. The major routes of entry of nitrogen into bodies of water are municipal and industrial wastewater, septic tanks, feed lot discharges, animal wastes (including birds and fish) and discharges from car exhausts. Bacteria in water quickly convert nitrites [*NO_2^-*] to nitrates [*NO_3^-*].*

Nitrites can produce a serious condition in fish called "brown blood disease." Nitrites also react directly with hemoglobin in human blood and other warm-blooded animals to produce methemoglobin. Methemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious in babies under three months of age. It causes a condition known as methemoglobinemia or "blue baby" disease. *Water with nitrite levels exceeding 1.0 mg/L should not be used for feeding babies. Nitrite/nitrogen levels below 90 mg/L and nitrate levels below 0.5 mg/L seem to have no effect on warm water fish."*

E. Nutrients in water can cause eutrophication

1) **eutrophication**—*natural "enrichment" or overfertilization of a body of water* (a harmful process)
    a) natural nutrient enrichment of lakes
    b) **cultural eutrophication**—*human activities which accelerate eutrophication* (sewage treatment plants, runoff of fertilizers, accelerated erosion of topsoil) – *nitrates and phosphates*
    c) *suspended matter such as clay, silt, and organic matter*
    d) *plankton and other microscopic organisms*
    e) *increased turbidity decreases light penetration through water*
    f) general consequences
        i. *leads to excessive algal growth*
        ii. *affects quantity and type of plants*
        iii. *affects water quality*
        iv. *affects water clarity and depth*
        v. *affects fisheries*
        vi. can lead to **hypoxia**
    g) affected by water **turbidity** (*cloudiness)*

2) different kinds of aquatic plants
    a) **benthic plants**—vegetation on the *bottom* of a body of water
    b) **SAV—submerged aquatic vegetation—***usually underwater*
        i. increased turbidity decreases available light

ii. nutrients absorbed through roots

c) **emergent vegetation**—*lower parts submerged, upper parts exposed*

d) *phytoplankton*

i. *microscopic photosynthetic organisms*

ii. they live floating in the water

iii. examples: diatoms, dinoflagellates, coccolithophores, phytoflagellates, photosynthetic bacteria

MAIN CLASSIFICATIONS BY SIZE	
Megaplankton, 20-200 cm	Nanoplankton, 2-20 µm
Macroplankton, 2-20 cm	Picoplankton, 0.2-2 µm, mostly bacteria
Mesoplankton, 0.2 mm-2 cm	Femtoplankton, smaller than 0.2 µm, consisting of marine virus
Microplankton, 2 -200 µm	

3) "trophic states" or "trophic status" of Florida's lakes

a) *oligotrophic – clear, low in nutrients, ample DO, limited phytoplankton*, (~12%)

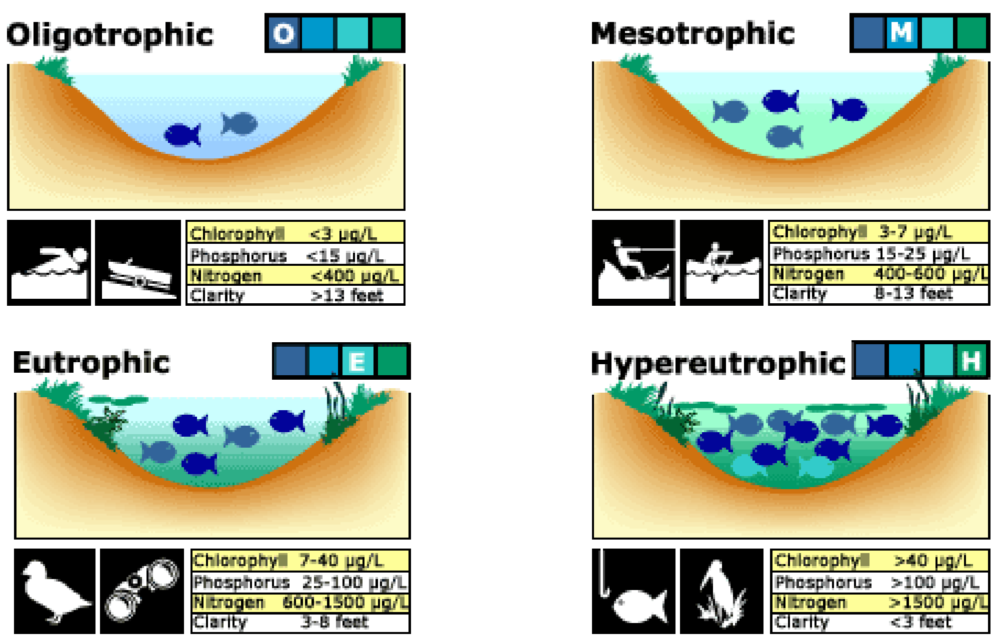
b) *mesotrophic lakes* (~31%)

c) *eutrophic lakes* (~41%)

d) *hypereutrophic lakes* (~16%)

Trophic State Index (TSI) http://www.lake.wateratlas.usf.edu/shared/learnmore.asp?toolsection=lm_tsi

http://www.lake.wateratlas.usf.edu/upload/documents/trophic2.pdf



4) natural vs. cultural eutrophication

a) *natural eutrophication* occurs on its own, over time

b) **cultural eutrophication** is caused by human activities

5) eutrophication – main steps

nutrient enrichment →
growth of phytoplankton →
death of phytoplankton →
accumulation of detritus →
growth of bacteria →
depletion of DO →
suffocation of higher organisms

6) eutrophication of shallow lakes and ponds (< 6 ft. deep) – main steps
- impedes boating, fishing, and swimming

nutrient enrichment →
SAV grows high enough to be above the surface →
SAV blocks light from going beneath it →
as SAV dies, the debris sinks (accumulation of detritus) →
growth of bacteria →
depletion of DO →
suffocation of higher organisms

7) combating eutrophication
   a) attacking the symptoms
      i. *herbicides*
         - examples: $CuSO_4$, diquat, 2,4-D, glyphosate
         - can kill fish and aquatic animals
         - can't use water right away for fishing, irrigation, etc.
         - contributes to the "pesticide treadmill"
      ii. *artificial aeration* by plastic tubes with microscopic holes
      iii. *harvesting aquatic weeds* in shallow lakes and ponds
      iv. *drawing water down by damming*
      v. *planting vegetation along streambeds* to slow erosion
      vi. *controlling application & timing of fertilizer*
      vii. *controlling runoff* from feedlots, golf courses, & fields
      viii. *use of biological control agents* such as denitrification
   b) getting at the root causes
      i. control strategies for point sources
         - regulation of sewage-treatment plant wastes
         - upgrading sewage-treatment plant systems
         - restriction or banning use of detergents with phosphates
         - monitoring dishwashing detergent labels for phosphates (these are not regulated)
      ii. control strategies for nonpoint sources
         - responsibility of the individual property owners
   c) recovery through **BMPs (best management practices)**

- agriculture: animal waste management, contour farming, strip cropping, crop rotation, IPM…
- construction: limiting areas of work, runoff retention…

- urban: flood storage, porous pavements, runoff retention, street cleaning…
- forestry: log removal, ground maintenance, pesticide management…
- mining: water diversion, underdrains…
- multicategory: sediment traps, buffer strips, increased infiltration devices…

from http://www.bmpdatabase.org

"In the 1990's as required by the Clean Water Act the U.S. Environmental Protection Agency (USEPA) mandated that *most municipalities in the United States with populations larger than 10,000 obtain a stormwater runoff discharge permit. One of the requirements of this permit program is the use of non-structural and structural best management practices (BMPs) appropriate to reduce pollutants to the Maximum Extent Practicable (MEP).* In response to this program, communities need to know which types of BMPs are appropriate for them (e.g., which BMPs function best in cold climates or in areas of heavy rainfall) and how to monitor the performance of the BMPs they select to ensure they function properly."

D. Pathogens in water – bacteria, protists, viruses

1) *fecal coliform bacteria such as Escherichia coli* (E. coli) serve as **indicator species** for other pathogens associated with contaminated sewage
2) water borne diseases: *cholera, Hepatitis A, Cryptosporidium, malaria, diarrhea and its complications (dehydration etc.*
3) http://www.state.ky.us/nrepc/water/wcparint.htm **-** the importance of testing

"Total coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in the intestines of man and warm- and cold-blooded animals. They aid in the digestion of food. A specific subgroup of this collection is the fecal coliform bacteria, the most common member being *Escherichia coli*. These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and are associated only with the fecal material of warm-blooded animals."

4) environmental impact

"*The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of man or other animals.* At the time this occurred, the source water may have been contaminated by pathogens or disease producing bacteria or viruses which can also exist in fecal material. *Some waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis and hepatitis A.* The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. *Fecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste*."

II. Wastewater Treatment

A. A History of Sewage Management and Treatment http://www.nau.edu

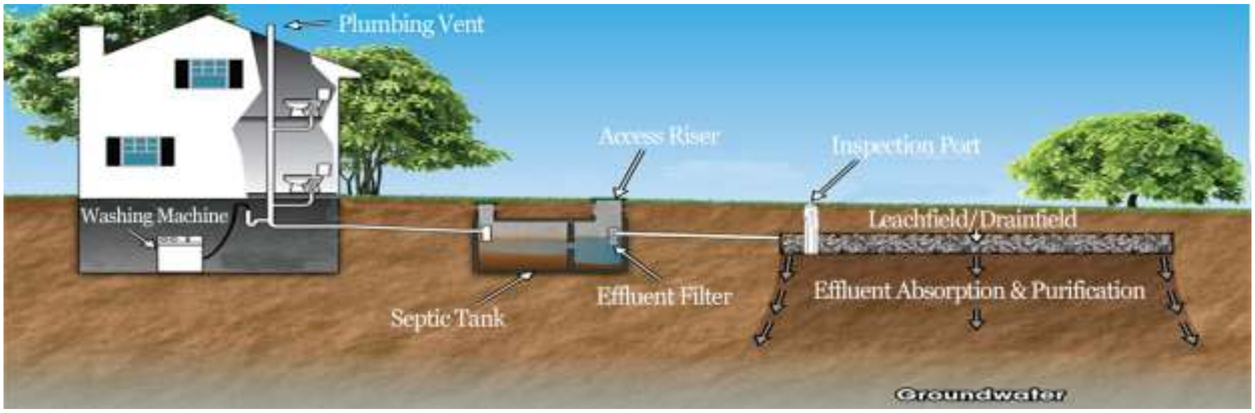
1) nomadic tribes (~10,000 B.C.E.) – the earth received the wastes directly; sometimes wastes were buried
2) Ur (3500 B.C.E.) – sewage was swept into the street
3) Indus Valley (present day Pakistan) – (2500 to 1500 B.C.E.) – refuse bins throughout some cities, home chutes for garbage, simple toilets
4) Jerusalem (~1300 B.C.E.) – some streets were washed daily
5) Crete (1500-1700 B.C.E.) – advanced plumbing, organic waste disposal sites, capital city courtyard with baths

6) Greeks (~500 B.C.E.) – first dumps established in Athens
7) *Western Roman Empire* (31 B.C.E. – C.E. 476) – *very advanced technology, focused on efficiency and purity*
   a) *aqueducts* (some still being used)
   b) water used for baths, fountains, cleaning sewers, etc.
   c) sewage disposal to nearby rivers and dumping wastes outside the city still caused health concerns
8) *Middle Ages* (500 C.E. to 1500 C.E.)
   a) *reverting to more primitive methods*
   b) *outhouses, chamber pots, open trench disposal…*
   c) improper drainage, widespread mudholes of wastes
   d) *rats, ticks, flea infestations*
   e) examples of diseases: "*dysentery, typhus* (which comes from bad sanitation and is highly contagious), and *typhoid fever* (from human feces and urine)"
   f) post-Black Plague (1349) reforms
      - "scavenger system" of people removing carcasses and refuse from streets
      - banning of throwing waste products into bodies of water
9) Renaissance (1400 – 1600)
   a) cesspools invented
   b) water issues, health issues more important
   c) slaughterhouse regulations
10) more modern times…
   a) 1800s – major changes in waste disposal
   b) 1860 – Louis Moureas invented the *septic tank*
   c) 1868 – Edward Frankland developed trickling sand filter technology
   d) *cholera* pushed improvements in technology and practices

B. Septic Systems http://www.nesc.wvu.edu/subpages/septic.cfm
1) **septic system**—*a simple, small sewage treatment system on the site of a home, made up of a* **septic tank** *and* **leach field (drain field)**
2) individual septic systems
   a) treat household wastewater onsite
   b) less disruptive to the environment than sewer systems
   c) parts of a *septic tank*
      i. *fiberglass or concrete watertight box*
      ii. inlet and outlet pipes
      iii. *tank holds wastewater so the layers separate*
         - oils on top
         - **septage** wastewater
         - solid **sludge** on bottom
      iv. *bacteria break down sludge* (what isn't broken down remains until the tank is pumped periodically)
      v. clarified wastewater flows to the leach field, often through a distribution setup
   d) **leach field** (*drain field, disposal field, soil absorption system*)
      i. *trenches*
      ii. *gravel or sand-lined bed*
      iii. *1-3 ft. below surface*
      iv. *underground, perforated pipes for distribution*
      v. *lawn cover*

"The drain field treats the wastewater by allowing it to slowly trickle from the pipes out into the gravel and down through the soil. The gravel and soil act as biological filters."

3) pros and cons
   a) PRO: runs on gravity – no electricity needed
   b) CON: tank must be cleaned every 5-10 years or back-up can occur; regular inoculation of the tank with bacterial cultures needed



Source: silverbulletseptic.com

SEPTIC TIPS from http://www.nesc.wvu.edu/subpages/septic.cfm
1) "Do not drive over the absorption field with cars, trucks, or heavy equipment. 2) Do not plant trees or shrubbery in the absorption field area, because the roots can get into the lines and plug them. 3) Do not cover the absorption field with hard surfaces, such as concrete or asphalt. Grass is the best cover, because it will help prevent erosion and help remove excess water. 4) Divert surface runoff water from roofs, patios, driveways, and other areas away from the absorption field.
Take care not to flush the following: hair combings, coffee grounds, dental floss, disposable diapers, kitty litter, sanitary napkins and tampons, cigarette butts, paper towels, gauze bandages, fat, grease, or oil… and <u>never</u> flush chemicals that could contaminate surface and groundwater, such as paints, varnishes, thinners, waste oils, photographic solutions, and pesticides."

C. Sewage Treatment Plants
   1) general terms
      a) **raw sewage (raw wastewater)**—completely *untreated* sewage
      b) **storm drain**—*collection* and draining of waste
      c) **sanitary sewer**—*destination* for the wastewater
      d) **effluent**— *water that is not reused after flowing out of any wastewater treatment facility or other works used for the purpose of treating, stabilizing, or holding wastes*
      e) **potable water**— *water fit for consumption by humans and animals; "drinking water"*
   2) pollutants in raw sewage
      a) general components
         i. *debris/grit*
         ii. *particulate organic material*
         iii. *colloidal/dissolved organic material*
         iv. *dissolved inorganic material*

b) more specific components
   i. *beneficial or neutral organisms* (bacteria, protozoa, worms)
   ii. *pathogens* (bacteria, protozoa, worms)
   iii. *organic matter* (from plants, animals, or synthetic organic compounds)
   iv. *"FOG" – fats, oil, and grease*
   v. *inorganic materials* (inorganic minerals, metals, and compounds; examples: Na, K, Ca, Mg, Cd, Cu, Pb, Ni, Zn)
   vi. *nutrients* (nitrate and phosphate)
   vii. *solids* (settlable, suspended, dissolved)
   viii. *gases* (CH_4, NH_3, H_2S)

Removing pollutants from raw sewage (extra info: http://ohioline.osu.edu/)

3) **preliminary treatment** – *removal of debris and grit*
   a) *screening out debris*
      i. purpose: *to protect the pumping and other equipment*
      ii. parts
         - **bar screen**
         - comminutor or *sewage grinder*, a large version of a garbage disposal
      iii. destination: debris is usually deposited in a *landfill*
   b) *settling of grit*
      i. purpose: *to protect the pumping and other equipment*
      ii. main part = **grit chamber**, a *large pool* with slow-moving wastewater
      iii. destination: grit is usually deposited in a *landfill*

4) **primary treatment** – *removal of particulate organic material*
   a) purpose: *to separate suspended solids and grease from wastewater*
   b) procedure
      i. wastewater is held in a **primary clarifier** (quiet tank) for several hours
      ii. *particles will sink and grease will float*
      iii. "the solids drawn off the bottom and skimmed off the top receive further treatment as **raw sludge**
      iv. *clarified wastewater* flows on to the next stage of wastewater treatment
      v. *clarifiers* and *septic tanks* are usually used to provide primary treatment"

5) **secondary treatment (biological treatment)** – *removal of colloidal and dissolved organic material*
   a) purpose: *to break down raw sludge further*
   b) procedure
      i. sewage *microorganisms* (*natural detritus feeders/decomposers*) are cultivated and added to the wastewater
      ii. microorganisms use organic matter from sewage as food, producing CO_2 and H_2O
      iii. O_2 is added
   c) types of systems
      i. *fixed film systems*

“Fixed film systems grow *microorganisms on substrates* such as rocks, sand or plastic. The wastewater is spread over the substrate, allowing the wastewater to flow past the film of microorganisms fixed to the substrate. As organic matter and nutrients are absorbed from the wastewater, the film of microorganisms grows and thickens. **Trickling filters**, rotating biological contactors, and sand filters are examples of fixed film systems.”

ii. *suspended film systems*

“Suspended film systems *stir and suspend microorganisms in wastewater*. As the microorganisms absorb organic matter and nutrients from the wastewater they grow in size and number. After the microorganisms have been suspended in the wastewater for several hours, they are settled out as a sludge (and clumps called *floc*). Some of the sludge is pumped back into the incoming wastewater to provide "seed" microorganisms. The remainder is wasted and sent on to a sludge treatment process. **Activated sludge**, extended aeration, oxidation ditch, and sequential batch reactor systems are all examples of suspended film systems.” **Activated sludge systems** use an *aeration tank* and a **clarifier tank.**

iii. *lagoon systems*

“Lagoon systems are *shallow basins which hold the waste-water for several months to allow for the natural degradation of sewage*. These systems take advantage of natural aeration and microorganisms in the wastewater to renovate sewage.”

6) **biological nutrient removal (BNR)** – *removal of dissolved inorganic material*
   a) sometimes called **tertiary treatment**
   b) natural **denitrification** uses *denitrifying bacteria*
   c) setup
      i. intake (from primary treatment, or sent back through the cycle)
      ii. zone 1: *anaerobic (no oxygen) zone*
         - *anaerobic bacteria fermentation*
         - organic acids and $(NH_4)^+$ formed
      iii. zone 2: *anoxic (highly oxygen-deficient) zone*
         - *$(NO_3)^-$ recycled from zone 3 →→ N_2 gas*
         - $(PO_4)^{3-}$ and more $(NH_4)^+$ formed
      iv. zone 3: *oxygen-rich zone*
         - $(PO_4)^{3-}$ absorbed by bacteria
         - removed with excess sludge
      v. secondary clarifier
      vi. output of clarified water

7) final cleansing and disinfection
   a) purpose: *to remove pathogens from wastewater*
   b) examples
      i. *adding chlorine (Cl_2 gas or NaClO)*
      ii. *uv treatment*

“High levels of chlorine may be harmful to aquatic life in receiving streams. Treatment systems often add a chlorine-neutralizing chemical to the treated wastewater before stream discharge.”

8) *advanced treatment*
   a) purpose: *to remove nutrients from wastewater*
   b) procedures
      i. chemical addition
      ii. coagulant addition to remove P
      iii. air stripping to remove NH_3

Processing the sludge (extra info: http://ohioline.osu.edu/)

9) sludge treatment
   a) *primary sludge*
      i. "material that settles out during primary treatment
      ii. often has a strong odor
      iii. requires treatment prior to disposal"
      iv. ~97% water
   b) *secondary sludge*—"extra microorganisms from the biological treatment processes"
   c) sludge treatment goals
      i. *"to stabilize the sludge and reduce odors*
      ii. *to remove some of the water and reduce volume*
      iii. *to decompose some of the organic matter and reduce volume*
      iv. *to kill disease causing organisms*
      v. *to disinfect the sludge"*
   d) types of treatment
      i. **anaerobic digestion**—*bacteria breaking down detritus in the absence of oxygen*
         - raw sludge is placed into tanks called **sludge digesters**
         - products = *CO_2, H_2O, CH_4 (methane)…* **biogas**
         - process takes 4-6 weeks
         - **treated sludge (biosolids)—**mixture of organic material and water
            - similar to humus; good fertilizer; water squeezed out to form a **sludge cake**
            - sludge cakes can be used as manure
      ii. **composting** *(aerobic digestion)*
         - raw sludge mixed with wood shavings to absorb water
         - placed in **windrows**—*long, narrow piles*
         - *organic matter is broken down by naturally-occurring bacteria and fungi*
         - aeration is all the microorganisms need to thrive
      iii. *removal of excess water* (target: 50-80% water)

settling and decanting, drying bed, vacuum filter, filter press, centrifuge

> "Wastewater treatment processes require careful management to ensure the protection of the water body that receives the discharge. Trained and certified treatment plant operators measure and monitor the incoming sewage, the treatment process and the final effluent."

SEWAGE TREATMENT PLANT Source: Louksengineering.com

D. Legal Sewage Dumping

1) when *older* sewage treatment plants are overwhelmed with stormwater, they can dump raw sewage into nearby bodies of water
2) environmental impacts https://www.miamiwaterkeeper.org

"Sewage pollution can cause severe environmental damage and negatively impact human health and safety. Sewage dumping is caused by outdated and ineffective infrastructure, leaking septic tanks, and the destruction of natural areas and the wetlands that naturally absorb stormwater. Sewage introduces pathogens, heavy metals, excess nutrients, and other pollutants into our waterways that enact a heavy toll on water quality. These toxins can cause destructive algal blooms, fish kills, and the die-off of aquatic life. Pathogens into swimming areas and our water supply can cause illness, disease outbreaks, and increased risk of chronic, long-term illnesses."

3) remedy: modernization of older sewage treatment plants

E. Feed Lots and Manure Lagoons

1) **manure lagoon**—*human-made pond with a rubber liner used to hold livestock manure*
2) aerobic bacterial action to break down organic material
3) possible issues: liner leaks, overflow

Source: sustainableagriculture.net

MODULE 42: Heavy Metals and Other Chemicals

I. Heavy Metals

A. **toxic heavy metal**— *any relatively dense metal or metalloid that is noted for its potential toxicity, especially in environmental contexts*

B. Mainly *cadmium (Cd), mercury (Hg), lead (Pb), arsenic (As)*

C. Others: manganese (Mn), chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), selenium (Se), silver (Ag), antimony (Sb) and thallium (Tl)

D. *methods of intake: inhalation, physical contact, old plumbing (Pb), cheap imported plastics (Pb), food/drink, root uptake, vehicular emissions* (As, Cd, Co, Ni, Pb, Sb, V, Zn, Pt, Pd, Rh).

E. *methods of environmental distribution: leaching from industrial and consumer waste into water bodies; acid deposition releases heavy metals trapped in soils; natural dissolving in water from minerals in the crust (As); burning fossil fuels/coal (Hg), cement processing (Hg); petroleum drilling (Pb, Hg); shellfish consumption (methylmercury ion* CH_3Hg^+*)*

F. Bioaccumulation and biomagnification occur

HEALTH EFFECTS OF HEAVY METAL EXPOSURE

Element	Acute exposure – *usually a day or less*	Chronic exposure – *often months or years*
Cadmium	Pneumonitis (lung inflammation)	Lung cancer Osteomalacia (softening of bones) Proteinuria (excess protein in urine; possible kidney damage)
Mercury	Diarrhea Fever Vomiting	Stomatitis (inflammation of gums and mouth) Nausea Nephrotic syndrome (nonspecific kidney disorder) Neurasthenia (neurotic disorder) Parageusia (metallic taste) Pink Disease (pain and pink discoloration of hands and feet) Tremor
Lead	Encephalopathy (brain dysfunction) Nausea Vomiting	Anemia Encephalopathy Foot drop/wrist drop (palsy) Nephropathy (kidney disease)
Chromium	Gastrointestinal hemorrhage Hemolysis (red blood cell destruction) Acute renal failure	Pulmonary fibrosis (lung scarring) Lung cancer
Arsenic	Nausea Vomiting Diarrhea Encephalopathy Multi-organ effects Arrhythmia Painful neuropathy	Diabetes Hypopigmentation/Hyperkeratosis Cancer

Source: Aggrawal et.al.

II. pH issues: Acid Deposition and Acid Mine Drainage (more later)

A. **acid deposition**—*wet (rain, snow, sleet, fog, cloudwater, and dew) and dry (acidifying particles and gases) acidic components settling on the surface of Earth*

1) *acid rain*— acids falling out of the atmosphere
2) **acid precipitation**—precipitation with a pH of 5.6 or less
3) **acid deposition**
   a) *wet deposition*: acidic rain, fog, and snow etc.
   b) *dry deposition*: acidic gases and particles
4) Normal rain is slightly acidic because CO_2 dissolves into it, so it has a pH of about 5.6. $\mathbf{CO_2\,(g) + H_2O\,(l) \rightleftharpoons H_2CO_3\,(aq)}$
5) The most acidic rain falling in the U.S. has a pH of about 4.3. (http://www.epa.gov/acidrain/measure/index.html)
6) prevailing winds can blow acidic compounds over hundreds of miles

B. Chemical causes: **NONMETAL OXIDE + WATER → ACID**

1) *sulfur dioxide (SO_2)* → *forms* **H_2SO_4 (sulfuric acid)**

$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ oxidation to form sulfur trioxide

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4\,(aq)$ formation of sulfuric acid

$SO_2\,(g) + H_2O\,(l) \rightleftharpoons H_2SO_3\,(aq)$ formation of sulfurous acid

2) *nitrogen oxides (NO_x)* → *forms* **HNO_3 (nitric acid)**

$2NO_2\,(g) + H_2O\,(l) \rightarrow HNO_2\,(aq) + HNO_3\,(aq)$ formation of nitrous and nitric acids

3) *carbon dioxide (CO_2)* → *forms* **H_2CO_3 (carbonic acid)**

$CO_2\,(g) + H_2O\,(l) \rightleftharpoons H_2CO_3\,(aq)$

- In the U.S., ~ 2/3 of all SO_2 and ~ 1/4 of all NO_x comes from electric power generation that relies on burning fossil fuel

C. pH importance http://www.state.ky.us/nrepc/water/wcparint.htm

"**pH** *is a measure of the acidic or basic (alkaline) nature of a solution.* The concentration of the hydrogen ion [H^+] activity in a solution determines the pH… *pH = - log [H^+]*

A pH range of 6.0 to 9.0 appears to provide protection for the life of freshwater fish and bottom dwelling invertebrates."

0	7	14
strongest acid	neutral	strongest base

D. environmental impact

"*The most significant environmental impact of pH involves synergistic effects*. Synergy involves the combination of two or more substances which produce effects greater than their sum. *This process is important in surface waters*. Runoff from agricultural, domestic, and industrial areas may contain iron, aluminum, ammonia, mercury or other elements. The pH of the water will determine the toxic effects, if any, of these substances. For example, 4 mg/L of iron would not present a toxic effect at a pH of 4.8. However, as little as 0.9 mg/L of iron at a pH of 5.5 can cause fish to die.

Synergy has special significance when considering water and wastewater treatment. The steps involved in water and wastewater treatment require specific pH levels. In order for coagulation (a treatment process) to occur, pH and alkalinity must fall within a limited range. Chlorination, a disinfecting process for drinking water, requires a pH range that is temperature dependent."

Limiting pH Values

Minimum	Maximum	Effects
3.8	10.0	Fish eggs could be hatched, but deformed young are often produced
4.0	10.1	Limits for the most resistant fish species
4.1	9.5	Range tolerated by trout
---	4.3	Carp die in five days
4.5	9.0	Trout eggs and larvae develop normally
4.6	9.5	Limits for perch
---	5.0	Limits for stickleback fish
5.0	9.0	Tolerable range for most fish
---	8.7	Upper limit for good fishing waters
5.4	11.4	Fish avoid waters beyond these limits

6.0	7.2	Optimum range for fish eggs
---	1.0	Mosquito larvae are destroyed at this pH value
3.3	4.7	Mosquito larvae live within this range
7.5	8.4	Best range for the growth of algae

III. Synthetic Organic Chemicals

A. *Pesticides and inert ingredients/formulants* (review Ch. 11 extension)

B. *Pharmaceuticals and hormones*

1) antibiotics
2) reproductive hormones
3) steroid medications
4) misc. OTC medicines
5) misc. prescription medicines

C. Military chemicals

1) **perchlorates** $(ClO_4)^-$ from rocket fuel
2) exposure through contaminated food/drink
3) can cause thyroid and hormone dysfunction

D. Industrial compounds (review **PCBs** in plastics)

IV. Chlorides (Cl^-) http://www.state.ky.us/nrepc/water/wcparint.htm

A. importance

"'*Chloride' is a salt compound resulting from the combination of the gas chlorine and a metal. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Chlorine alone as Cl_2 is highly toxic*, and it is often used as a disinfectant. In combination with a metal such as sodium it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life."

B. environmental impact

"Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Sodium chloride may impart a salty taste at 250 mg/L; however, calcium or magnesium chloride are not usually detected by taste until levels of 1000 mg/L are reached. *Public drinking water standards require chloride levels not to exceed 250 mg/L*."

"Chlorides can corrode metals and affect the taste of food products. Therefore, water that is used in industry or processed for any use has a recommended maximum chloride level. Chlorides can contaminate freshwater streams and lakes. Fish and aquatic communities cannot survive in high levels of chlorides."

C. sources

1) rocks containing chlorides
2) agricultural runoff
3) wastewater from industries
4) oil well wastes
5) effluent wastewater from wastewater treatment plants

V. Total iron (Fe^{2+}, Fe^{3+}) http://www.state.ky.us/nrepc/water/wcparint.htm

A. importance

"Iron is the fourth most abundant element, by weight, in the earth's crust. Natural waters contain variable amounts of iron despite its universal distribution and abundance. Iron in groundwater is normally present in the *ferrous or bivalent form [*Fe^{++}*]* which is a soluble state. It is easily oxidized to *ferric iron [Fe+++]* or insoluble iron upon exposure to air. Iron is a trace element required by both plants and animals. *It is a vital oxygen transport mechanism in the blood of all vertebrate and some invertebrate animals*."

B. environmental impact

"Iron in water may be present in varying quantities depending upon the geological area and other chemical components of the waterway. Ferrous (Fe^{++}) and ferric (Fe^{+++}) ions are the primary forms of concern in the aquatic environment. Other forms may be in either organic or inorganic wastewater streams. *The ferrous form Fe++ can persist in water void of dissolved oxygen and usually originates from groundwater or mines that are pumped or drained. Iron in domestic water supply systems stains laundry and porcelain. It appears to be more of a nuisance than a potential health hazard. Taste thresholds of iron in water are 0.1 mg/L for ferrous iron and 0.2 mg/L ferric iron, giving a bitter or an astringent taste*. Water used in industrial processes usually contains less than 0.2 mg/L iron. Black or brown swamp waters may contain iron concentrations of several mg/L in the presence or absence of dissolved oxygen, but this iron form has little effect on aquatic life. *The current aquatic life standard is 1.0 mg/L based on toxic effects."*

VI. Water temperature http://www.state.ky.us/nrepc/water/wcparint.htm

"Human activities should not change water temperatures beyond natural seasonal fluctuations. To do so could disrupt aquatic ecosystems. Good temperatures are dependent on the type of stream you are monitoring. Lowland streams, known as "warmwater" streams, are different from mountain or spring fed streams that are normally cool.

In a warmwater stream temperatures should not exceed 89 degrees (Fahrenheit). Cold water streams should not exceed 68 degrees (Fahrenheit). Often summer heat can cause fish kills in ponds because high temperatures reduce available oxygen in the water."

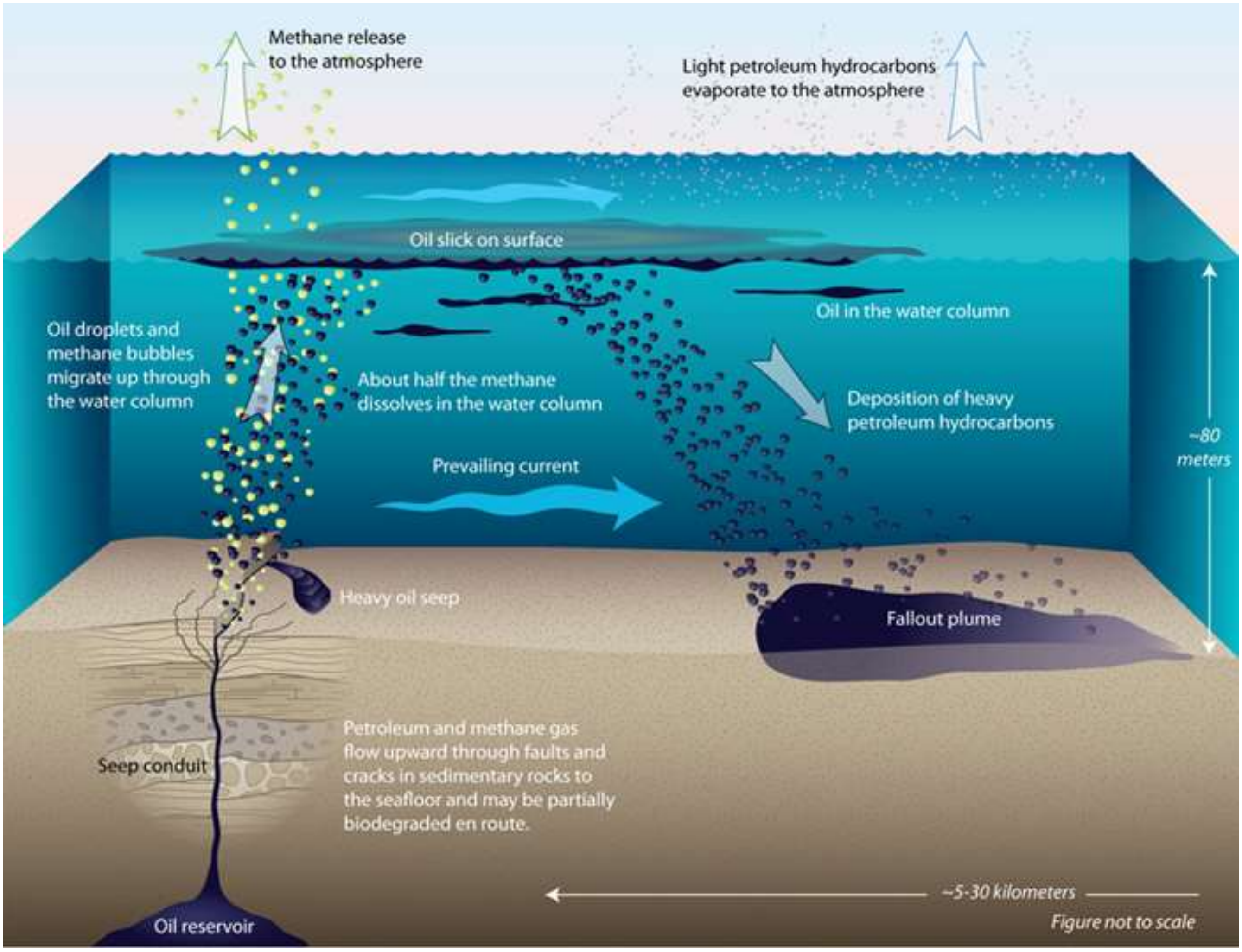
MODULE 43: Oil Pollution

I. Sources of Oil Pollution

A. oil tanker accidents (*Exxon Valdez* ran aground and spilled oil on Alaska shore, 1989)
http://www.evostc.state.ak.us/?FA=facts.QA

B. offshore oil drilling (*Deepwater Horizon*, explosion pipe rupture on floor of Gulf of Mexico, 2010)
https://darrp.noaa.gov/oil-spills/deepwater-horizon

C. natural oil seepage …
http://www.whoi.edu/oilinocean/page.do?pid=51880&tid=441&cid=139413&ct=61&article=97109



II. Oil spill remediation

A. for wildlife – they must be cleaned by hand

B. for oil on surface of open water

1) *containment booms* made of plastic barriers; vacuum oil

2) *surfactant chemicals* used to break up the oil

C. for oil in shallow areas or on shoreline – absorbent materials used

D. genetically engineered bacteria

https://www.marineinsight.com/environment/10-methods-for-oil-spill-cleanup-at-sea/

I. Summary of Water Treatment Methods

***** SUMMARY OF METHODS AND CONTAMINANTS:**
http://kwanga.net/apesnotes/water-treatment-grid.pdf ***

II. General water purification and treatment methods
(www.hawaii.edu, www.corrosion-doctors.org, www.gewater.com, www.excelwater.com)

A. **settling**
1) *letting water sit still, and/or adding Al^{3+} from $Al_2(SO_4)_3$ ("alum")*
2) *the Al^{3+} ion promotes precipitation*

B. **filtration**—commonly through a layer of sand
1) *mechanical filters (or microfiltration)*
2) *activated charcoal (carbon) filters*
   - **adsorption—**binding and retention of undesired materials
3) *oxidizing filters (***ion exchange***; water softeners)*
   a) soften hard water by removing minerals that cause hardness
   b) hard water is pumped through a tank containing an exchange resin or plastic beads
   c) sodium ion on the resin replaces the hardness minerals
   d) sodium ion remains in a soluble form in the softened water
   e) contaminants removed: Fe, Mg, Ca, Mn
4) *neutralizing filter—treats acidic water*
5) **reverse osmosis** or **RO –** (*hyperfiltration*)
   a) *can reject bacteria, salts, sugars, proteins, particles, dyes*
   b) uses a membrane that is semi-permeable
   c) usually uses a process known as *crossflow* to allow the membrane to continually clean itself, preventing algae growth
   d) *requires a driving force (pump) to push the fluid through the membrane*

C. **biological oxidation--***organic material removed by detritus feeders and decomposers*

D. **distillation**—*evaporating and re-condensing the water*
1) *separation of substances due to boiling point differences*
2) uses substantial amount of energy
3) re-condensed water is pure (left impurities behind)

E. **disinfection**
1) *chlorination*
   a) elimination of undesirable matter from the water by oxidation
   b) *permanent protection of the hygienic and sanitary quality of the water throughout the distribution phase*
   c) *active, immediate disinfection in cases of accidental pollution*
   d) continuous monitoring of chlorine demand to warn of pollution
2) *pasteurization*
   a) solar cookers
   b) flow-through heat exchangers
   c) solar puddle
3) *ultraviolet light*
4) *boiling*

MODULE 44: Water Pollution Laws

I. **CWA: Clean Water Act of 1972**
https://www.epa.gov/laws-regulations/summary-clean-water-act
   A. history
      a) amendments to the Federal Water Pollution Control Act of 1948
      b) revised multiple times
      c) affected by newer laws
      d) provisions

- established the basic structure for regulating discharges of pollutants into U.S. waters
- gave the EPA authority to implement pollution control programs
- continued requirements to set water quality standards for all contaminants in surface waters
- made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions
- funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution
- Revisions in 1981 streamlined the municipal construction grants process, improving the capabilities of treatment plants built under the program
- Changes in 1987 phased out the construction grants program, replacing it with the State Water Pollution Control Revolving Fund, more commonly known as the Clean Water State Revolving Fund. This new funding strategy addressed water quality needs by building on EPA-State partnerships.

II. **Safe Drinking Water Act of 1974** https://www.epa.gov/sdwa

> "The Safe Drinking Water Act (SDWA) is the federal law that protects public drinking water supplies throughout the nation. Under the SDWA, EPA sets standards for drinking water quality and with its partners implements various technical and financial programs to ensure drinking water safety."

   A. **MCL – maximum contaminant levels** – *safety standards established for 77 substances in groundwater and surface water*
   B. list of contaminants: https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

Search current legislation on http://thomas.loc.gov/