Conductivity

- Measures the ability of water to carry an electric current
- Measures the ions such as Na^+, Cl^- in the water
- Differences in conductivity are usually due to the concentration of charged ions in solution (and ionic composition, temp.)
- Reported as microsiemens per cm

Salinity

- The total amount of solid material in grams contained in 1kg of seawater when all the carbonate has been converted to oxide (66 elements).
- Measured by hydrometer (density) or conductivity.
- Only present in freshwater if groundwater comes from limestone, NaCl, or CaCl rich soils. Freshwater fish tolerate up to 10 ppt. Freshwater diseases can tolerate no more than 2 ppt.
- Osmolality (total dissolved particles/unit volume); increases as salinity increases.
- Fish plasma osmolality = 320 mosm/kg; adjusting water's salinity to match fish plasma decreases osmotic gradient & stress.
- Saltwater is 35 ppt.

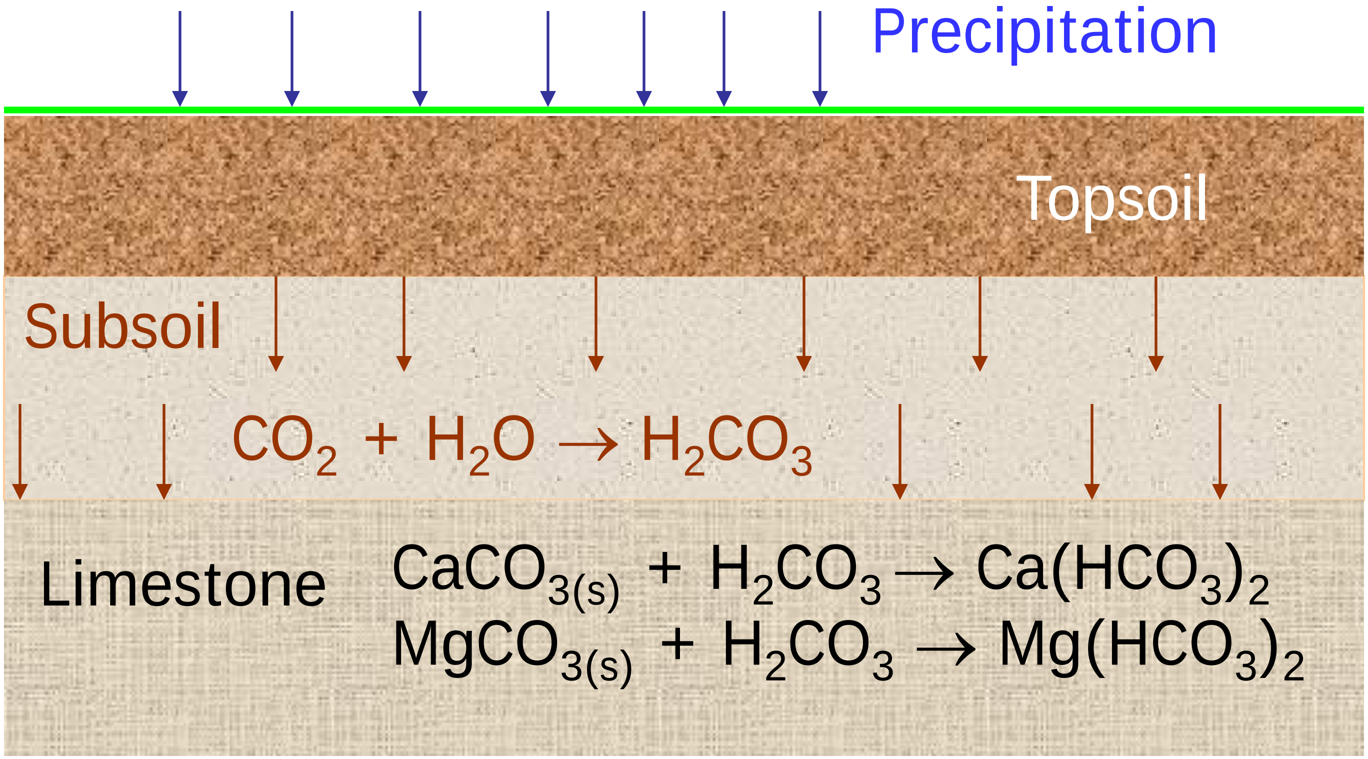
Solubility of oxygen in water (mg/L) at 1 atm with varying temperature and salinity

	Salinity (ppt)		
Temperature (°C)	**0**	**10**	**20**
10	11.3	10.6	9.9
12	10.7	10.1	9.5
14	10.3	9.7	9.1
16	9.9	9.3	8.7
18	9.5	8.9	8.4
20	9.1	8.6	8.1
22	8.7	8.2	7.8
24	8.4	7.9	7.5
26	8.1	7.7	7.2
28	7.8	7.4	7.0
30	7.6	7.1	6.8
32	7.3	6.9	6.5

Hardness

- Amount of dissolved minerals in water
  - Commonly calcium, magnesium, and iron that groundwater picks up as it moves through rock
- Hard water (high mineral content) causes build up of *scale* in pipes and hot water heaters
- Soft water (low mineral content) doesn't rinse off soap well
- If household water comes from ground water it tends to harder (higher mineral content)
- Limestone = hard water, granite= not hard water

Formation of Hardness



Hardness

- Soft water can be a problem: in soft water, heavy metals are more poisonous, some chemicals are more toxic, drinking soft water over long periods can increase chance of heart attack

- Hardness and alkalinity are related

Water Hardness

- Water hardness affects fish because it influences osmoregulation.
- Each species has an optimum range.

Water Type	**$CaCO_3$ (mg/L)**
Soft	0 - 75
Moderately hard	75 - 150
Hard	150 - 300
Very hard	>300

Alkalinity

- A measure of the substances in water that can neutralize acid and resist changes in pH
- Natural source = rocks
- Ideal water for fish and aquatic organisms has a total alkalinity of 100-120 mg/L
- Groundwater has higher alkalinity than surface water

Alkalinity/Hardness

- $CO_2 + H_2O \rightarrow H_2CO_3 \leftrightarrow HCO^- + H^+ \leftrightarrow CO_3^{-2}$ (solid) $+ 2H^+$
- Carbon dioxide (excreted by animals & plants) dissolves in water to form carbonic acid.
- If pH increases, carbonic acid dissociates to form bicarbonate & hydrogen ions.
- Since hydrogen ions are acid-forming, they counteract the alkalinity increase.
- If pH continues to increase, bicarbonate will dissociate to form carbonate (solid) and more hydrogen ions.
- If pH decreases, the process reverses.
- At pH = 7-8, bicarbonate dominates.
- At pH$\geq$9, carbonate dominates.

TABLE 4.5 PROCESSES AFFECTING ALKALINITY

Process	Alkalinity Change for Forward Reaction
Photosynthesis and Respiration:	
(1*a*) $n\mathrm{CO_2} + n\mathrm{H_2O} \underset{\text{respir}}{\overset{\text{photos.}}{\rightleftharpoons}} (\mathrm{CH_2O})_n + n\mathrm{O_2}$	No change
(1*b*) $106\mathrm{CO_2} + 16\mathrm{NO_3^-} + \mathrm{HPO_4^{2-}} + 122\mathrm{H_2O} + 18\mathrm{H^+} \underset{\text{respir.}}{\overset{\text{photos.}}{\rightleftharpoons}} \underset{\text{"algae"}}{\{\mathrm{C_{106}H_{263}O_{110}N_{16}P_1}\}} + 138\mathrm{O_2}$	Increase
(1*c*) $106\mathrm{CO_2} + 16\mathrm{NH_4^+} + \mathrm{HPO_4^{2-}} + 108\mathrm{H_2O} \underset{\text{respir.}}{\overset{\text{photos.}}{\rightleftharpoons}} \{\mathrm{C_{106}H_{263}O_{110}N_{16}P_1}\} + 107\mathrm{O_2} + 14\mathrm{H^+}$	Decrease
Nitrification:	
(2) $\mathrm{NH_4^+} + 2\mathrm{O_2} \longrightarrow \mathrm{NO_3^-} + \mathrm{H_2O} + 2\mathrm{H^+}$	Decrease
Denitrification:	
(3) $5\mathrm{CH_2O} + 4\mathrm{NO_3^-} + 4\mathrm{H^+} \longrightarrow 5\mathrm{CO_2} + 2\mathrm{N_2} + 7\mathrm{H_2O}$	Increase
Sulfide Oxidation:	
(4*a*) $\mathrm{HS^-} + 2\mathrm{O_2} \longrightarrow \mathrm{SO_4^{2-}} + \mathrm{H^+}$	Decrease
(4*b*) $\underset{\text{pyrite}}{\mathrm{FeS_2(s)}} + \frac{15}{4}\mathrm{O_2} + 3\frac{1}{2}\mathrm{H_2O} \longrightarrow \mathrm{Fe(OH)_3(s)} + 4\mathrm{H^+} + 2\mathrm{SO_4^{2-}}$	Decrease
Sulfate Reduction:	
(5) $\mathrm{SO_4^{2-}} + 2\mathrm{CH_2O} + \mathrm{H^+} \longrightarrow 2\mathrm{CO_2} + \mathrm{HS^-} + \mathrm{H_2O}$	Increase
$CaCO_3$ Dissolution:	
(6) $\mathrm{CaCO_3} + \mathrm{CO_2} + \mathrm{H_2O} \rightleftharpoons \mathrm{Ca^{2+}} + 2\mathrm{HCO_3^-}$	Increase

Lecture Headings

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

Inorganic Chemicals

- Compounds that do not contain carbon (C)
- Originally defined as compounds that do not originate in plants or animals
- Metals, minerals, and nutrients

Metals

- Lead
  - Used in electrical conductors, pipes (soldering), and a by-product of mining
  - *Lead poisoning c*auses toxic reactions, brain damage, death
- Arsenic
  - Found naturally in some rocks, in banned pesticides, wood preservatives, and as an industrial by-product
  - Causes neurological damage and cancers
  - Drinking water standard of < 50 ppb (in 2006 <10)

Mining

Can kill fish & make water undrinkable

Pyrite
Iron sulfide, or FeS_2
AKA "fool's gold"

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{+2} + 2SO_4^{-2} + 2H^{+}$$

Acid!

Acid dissolves metals in the rock, and they get into water

Like Hg, Fe, Zn, Cu, Pb

Heavy Metal Contaminants

- Water quality is important
- Heavy metals - Cd, Cu, Zn, Hg, must be all < .1 mg/L.
- Al,As,Cd,Cr,Co,Cu,Fe,Hg,Pb,Mn,Ni,Zn
  - Naturally low
  - Increase with acidification or land use change
- Soft water makes a difference in toxicity of metals

Nutrients

- Major minerals important in animal and plant nutrition:
  - Nitrogen, phosphorus, potassium, calcium
- Trace elements also required in
  - Iron, zinc, manganese, etc.
- At high concentrations in streams and lakes they can cause problems

Nutrients

- Nitrogen and phosphorus are considered pollutants when too much present in high conc.
- High levels of nutrients cause disturbances in the food web
- Major sources of nutrients (N, P):
  - Phosphorus-based detergent
  - Fertilizer and agricultural runoff
  - Food-processing wastes
  - Animal and human waste

Nutrients: Nitrogen

- Nitrogen (N) an important plant nutrient
- Nitrogen is a major component of Amino Acids, which are the building blocks of protein
- Takes several forms in nature
  - Nitrogen gas (N_2)
  - Nitrate (NO_3^-)
  - Ammonia gas (NH_3)
  - Ammonium (NH_4^+)
  - Organic forms

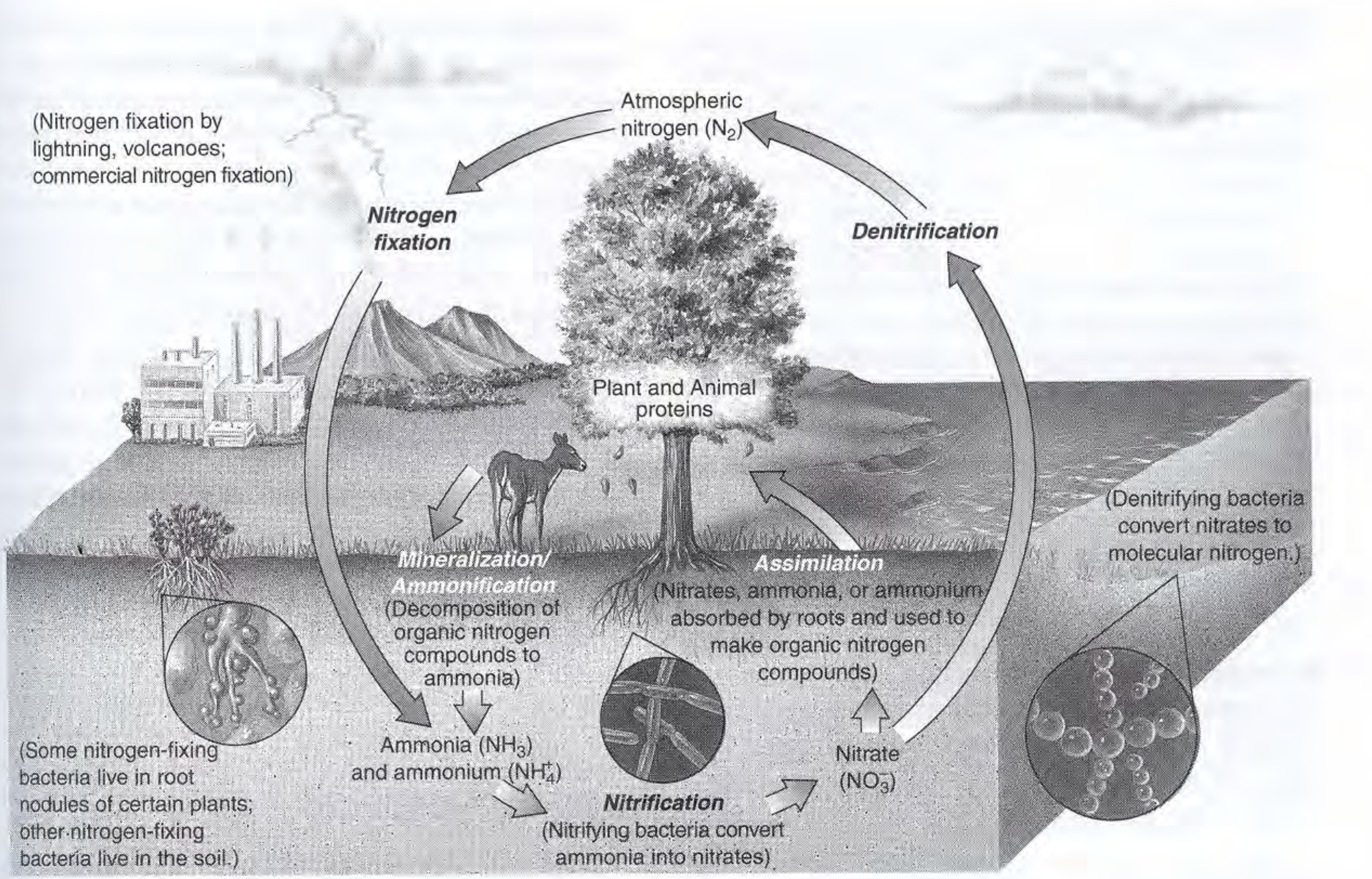


FIG. 5.6. The Nitrogen Cycle.

Nitrogen

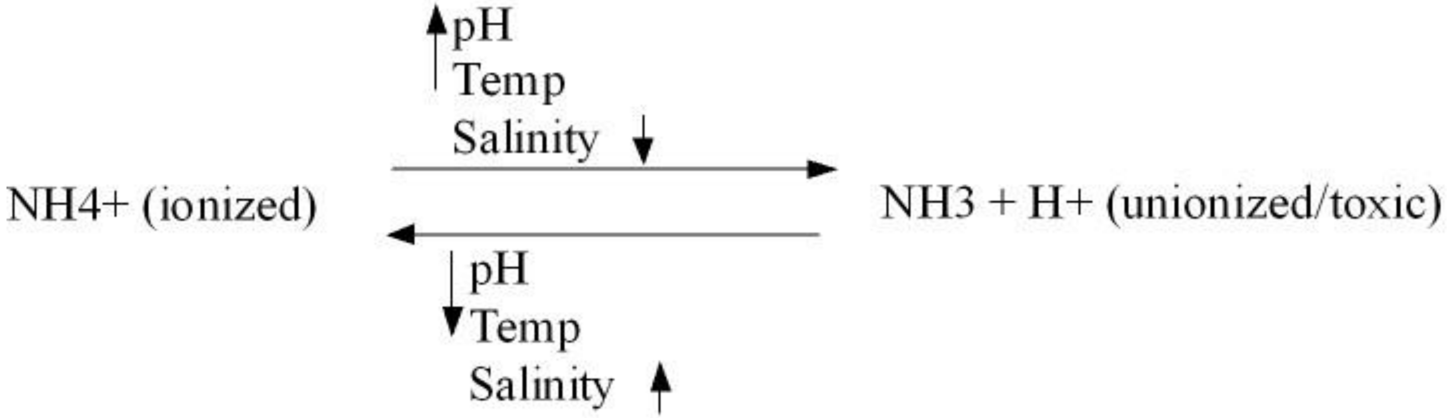
- Source: The decomposition of dead plants & animals and the excretions of fish.
  - Excess nitrogen
    - Increases plant growth & decay
    - Promotes bacterial decomposition
    - Decreases available oxygen

Ammonia

- Product of protein metabolism; major waste product of fish; excreted by gills as NH_3 (unionized) + NH_4 (ionized) = TAN.
- Present as ammonia (NH_3) and ammonium (NH_4^+)
- pH and temperature determines the proportion of each.
- Alkaline pH → more NH_3 (toxic)
- Acidic pH → more NH_4 (less toxic)
- Ammonia poisoning more common at alkaline pH.

Ammonia Poisoning

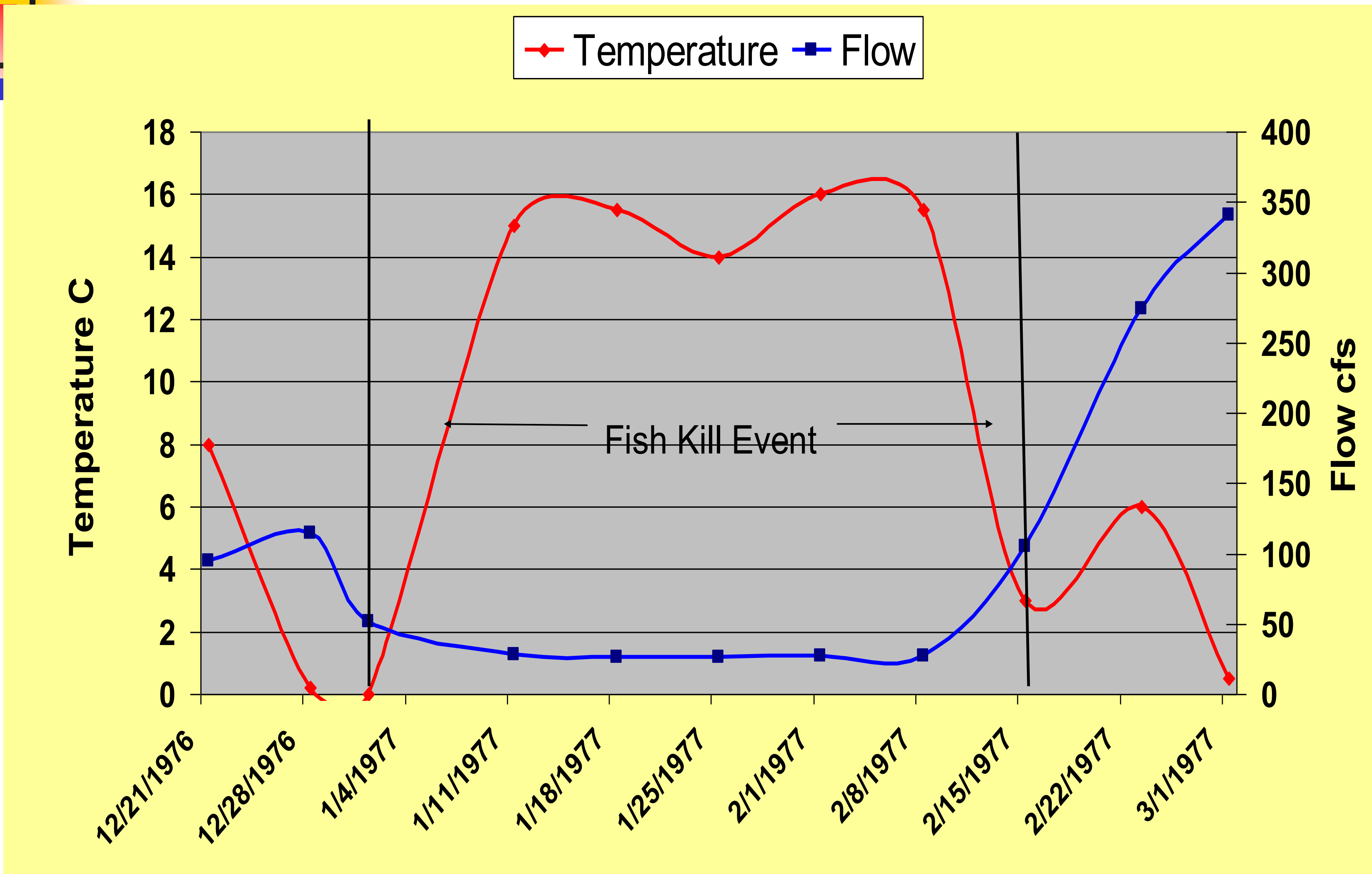
- Can occur at levels of only 0.1 ppm
- Results in hemorrhaging & destruction of mucus membranes; noticeable around the gills; fish gasp for air & show rapid gill movement.
- Ammonia is controlled by adjusting feeding levels & turnover of water.



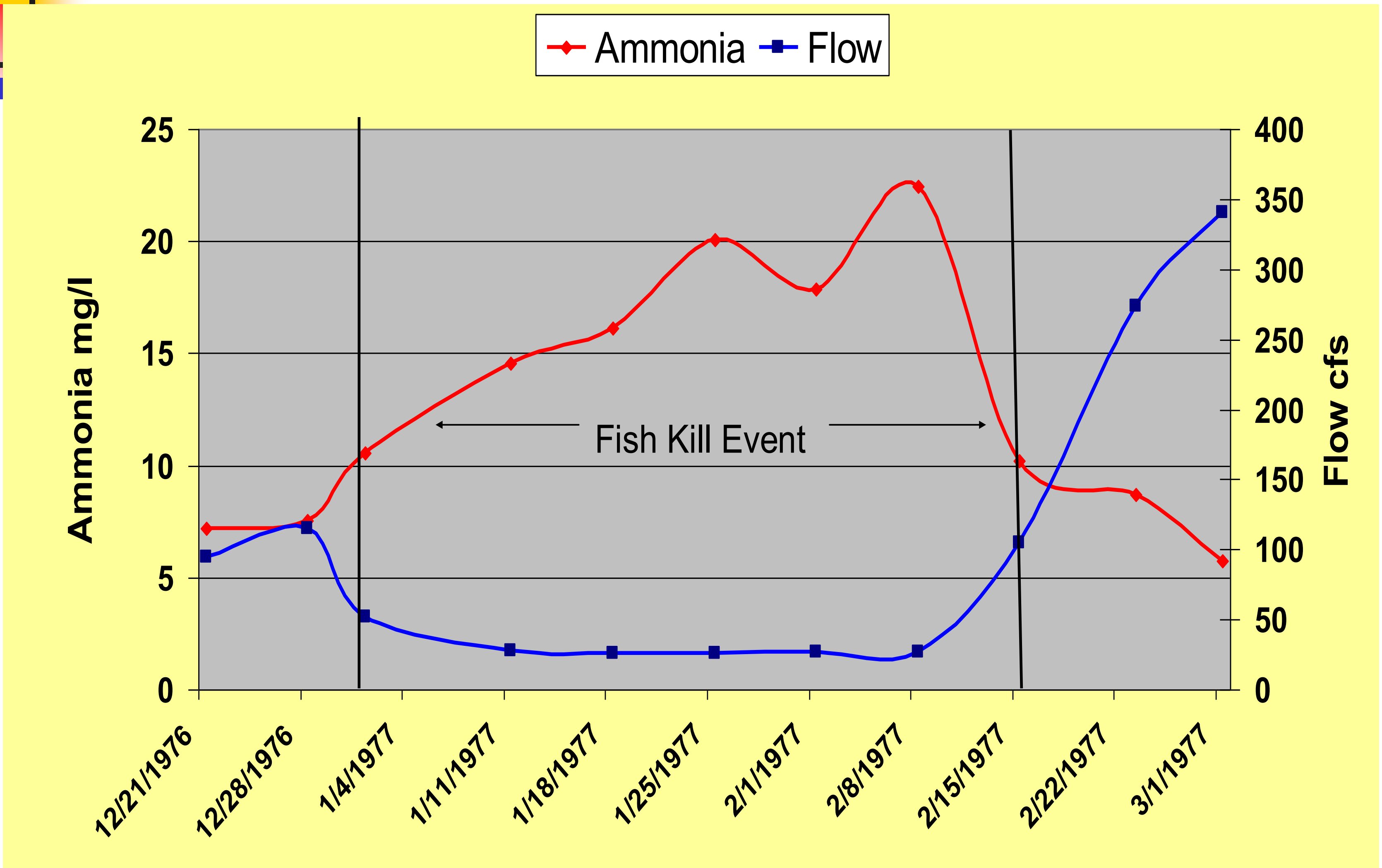
Ammonia toxicity (96 hr LC_{50})

Species	**Lethal level (mg/L)**
Cyprinus carpio (Carp)	1.84
Ictalurus punctatus (Catfish)	1.5 - 3.1
Micropterus salmoides (Largemouth bass)	0.7 - 1.2
Oncorhynchus mykiss (Rainbow trout)	0.44

Point Source Event 1977



Point Source Event 1977



Nitrogen Conversion

- Bacteria convert ammonia to nitrate.
- *Nitrosomonas*

$$55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57H_2O + 104H_2CO_3$$

- Ammonium is combined with oxygen & hydrogen carbonate to produce nitrite, water & carbonic acid.

Nitrogen Conversion

- *Nitrobacter*

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 \rightarrow C_5H_7O_2N + 3H_2O + 400NO_3^-$$

- Nitrite is combined with ammonium, carbonic acid, hydrogen carbonate & oxygen to produce water & nitrate (nitrification).

Results of Conversion

- Approximately 4.3mg of O_2 are consumed per mg NH_3-N oxidized to NO_3-N.
- Conversion is an alkaline and acidic process.
- Nitrate must still be converted to N_2 (gas) for removal from the system (denitrification).

Nitrification

$$NH_3 \xrightarrow[\textit{nitrosomonas}]{1\frac{1}{2}\,O_2} NO_2^- \xrightarrow[\textit{nitrobacter}]{1\frac{1}{2}\,O_2} NO_3^-$$

- Requires 3 moles oxygen to convert one mole of ammonia to nitrate
- Nitrification is an acidifying reaction

Nitrite (NO_2)

- Fish are sensitive at levels of 1-5 ppm
- Nitrite is produced by the bacterial-mediated oxidation of ammonia.
- Symptoms include:
  - Gasping for air at surface
  - Rapid gill movement
- Can cause suffocation because nitrite binds to hemoglobin (hemolytic anemia); also liver hypoxia, & gill hypertrophy.
- Brown blood disease (Methemoglobinemia)
    - Blood appears dark in color
- Nitrite is pumped into fish by the chloride uptake mechanism, therefore, the addition of chloride (calcium chloride) will competitively exclude nitrite from entering the fish.

Nitrite Water Chemistry

- Nitrite, like ammonia, exists in a pH-dependent equilibrium with nitrous acid (HNO_2).
- Nitrous acid is freely diffusable across the gill membrane, therefore, more toxic to fish.
- However, nitrous acid is rarely present at pH values acceptable to fish.
- Nitrite is not freely diffusable across the gill, but can be pumped by the chloride uptake mechanism.

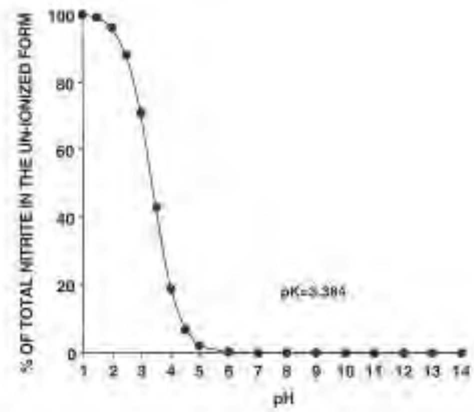


Figure 9. The percent of total nitrite in the un-ionized form (nitrous acid) as a function of pH. Calculations assume a pK of 3.384 at 20°C (Colt and Tchobanoglous 1976).

Nitrates

- Formed by the process of nitrification (addition of O_2 to NH_3 by bacteria)
- Used by plants and algae
- Large amounts (leaking sewer pipes, fertilizer runoff, etc.) can lead to algal blooms, which can alter community structure, trophic interactions and DO regimes)
- Below 90 mg/L seems to have no effect on warm water fish, but cold water fish are sensitive

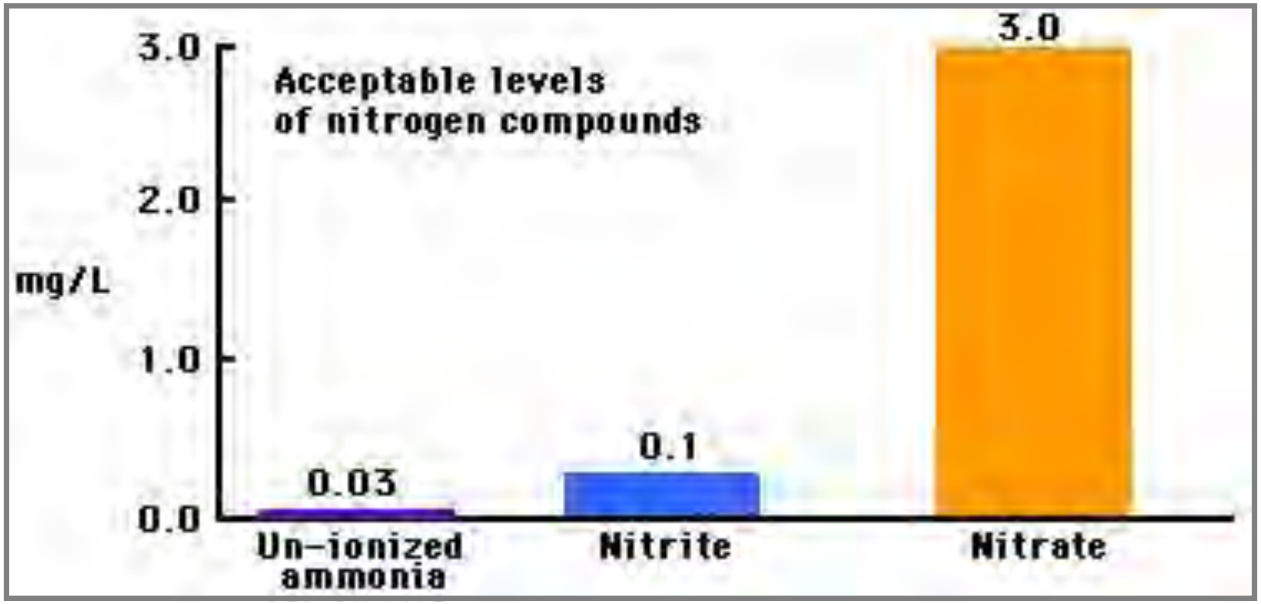
Nitrate

- Is mildly toxic,fatal to fish at high levels (1,000 ppm).
- Effects of long-term exposure unknown.
- Could possibly affect health, growth, & breeding.
- Generally, not a toxic factor in fish production.

Nitrate

- Nitrate in drinking water is a pollutant
- When ingested by babies in milk formula
  - Causes *methemoglobinemia* or *blue baby syndrome*
  - Converts to nitrite (NO_2^-) which interferes with oxygen transport in the blood
  - Baby suffocates
- Drinking water standard is <10 ppm nitrate
- Very mobile in soil and leaches easily to groundwater
- Sources: manures, fertilizers, sewage

Relationships



Phosphorus

- Phosphorus (P) an important plant and animal nutrient
- Can cause excessive algal growth in lakes
  - A little bit of algal growth is good
    - Source of food for fish
  - Too much is bad
    - Microbes that decompose dead algae use oxygen and lower DO
    - Low DO stresses fish, forcing them to the surface, selecting against species such as trout, and even causing fish kills

Phosphorus

- Sources: manures, fertilizers, sewage, detergents
- Not very mobile in soils
  - Usually doesn’t leach to groundwater
- Instead it runs off into streams
  - Dissolved in runoff or
  - Attached to eroded sediment particles
- Not harmful to humans directly
- P was banned from detergents in 1990’s (in west)

Phosphorus

- Limiting factor in fresh water
- Stimulates plant growth, algae, etc.
- Causes eutrophication when plant material decays and causes dissolved oxygen levels to drop.
- EPA *suggests* no more than 0.1 mg/l for streams that do not empty into a reservoirs, 0.05 for streams discharging into a reservoir, and 0.025 mg/l for reservoirs.

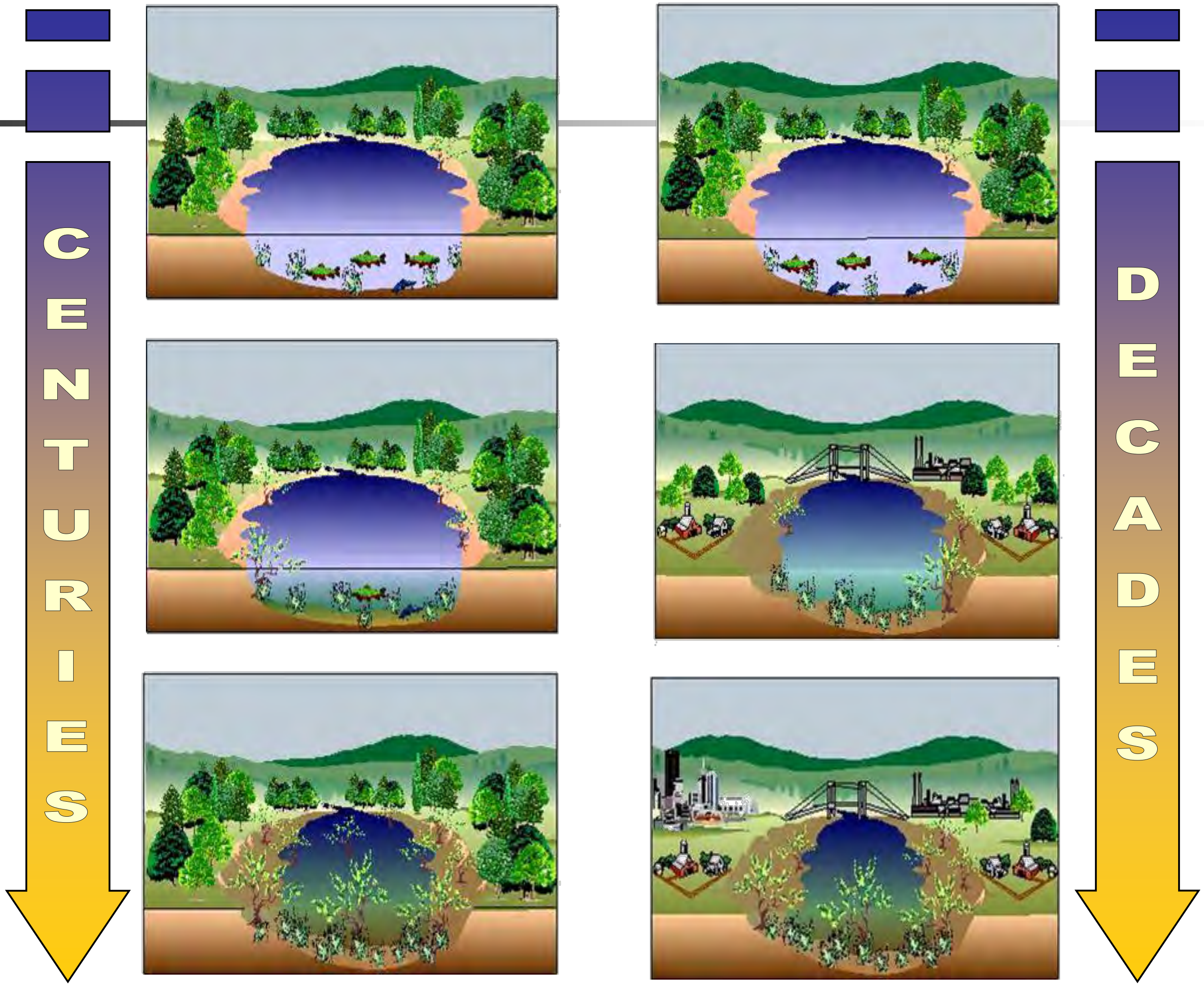
Phosphorus

- Over time, lakes lose depth and naturally evolve from low nutrient to high nutrient status
  - Oligotrophic => mesoptrophic => eutrophic => hypereutrophic
  - Happens over 100's of years
- Excessive inputs of P speed up the process
  - Call this *accelerated eutrophication*
  - Happens over 10's of years
  - Concentrations as low as 0.01 ppm stimulate algae

Lake Aging

Natural Process

Accelerated by land use



Nutrients (summary)

- Common Forms of Nitrogen:
  - Ammonium NH^{+}_{4}
  - Nitrate NO_3^-
  - Nitrite NO_2^-
- Phosphate PO_4^{-3}, HPO_4^{-2}

- Ratio of Uptake of Nutrients (typical):

$$C:N:P \quad 100:16:1$$

- Limiting Nutrient

Lecture Headings

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

Organic Chemicals

- Compounds that <u>do</u> contain carbon (C)
- Often large complex molecules
- May be natural or man-made (synthetic)
- Synthetic compounds may last for a long time in the environment
  - Natural decomposing processes are unable to break down these complex molecules

Organic Chemicals

- Many synthetic organic chemicals are carcinogens:
  - *Benzene* (C_6H_6), commercial solvent
  - *Carbon tetrachloride* (CCl_4), in fire extinguishers, solvents, and cleaning agents
  - *Polychorinated Biphenyls* (PCBs), used as a coolant in electrical transformers

Toxic Organic Chemicals (TOC)

Usually synthetic chemicals

- **Pesticides, herbicides**
- **Polychlorinated biphenyls (PCBs)**
- **Polycyclic aromatic hydrocarbons (PAHs)**
- **Dioxins**
- **DDT**

Characteristics

- **Bioavailable – readily assimilated**
- **Lipid soluble – incorporated into lipid deposits**
- **Bioaccumulate – concentrations increase with time and exposure**
- **Biomagnify – concentrations increase through food web**

Tend to be resistant to degradation

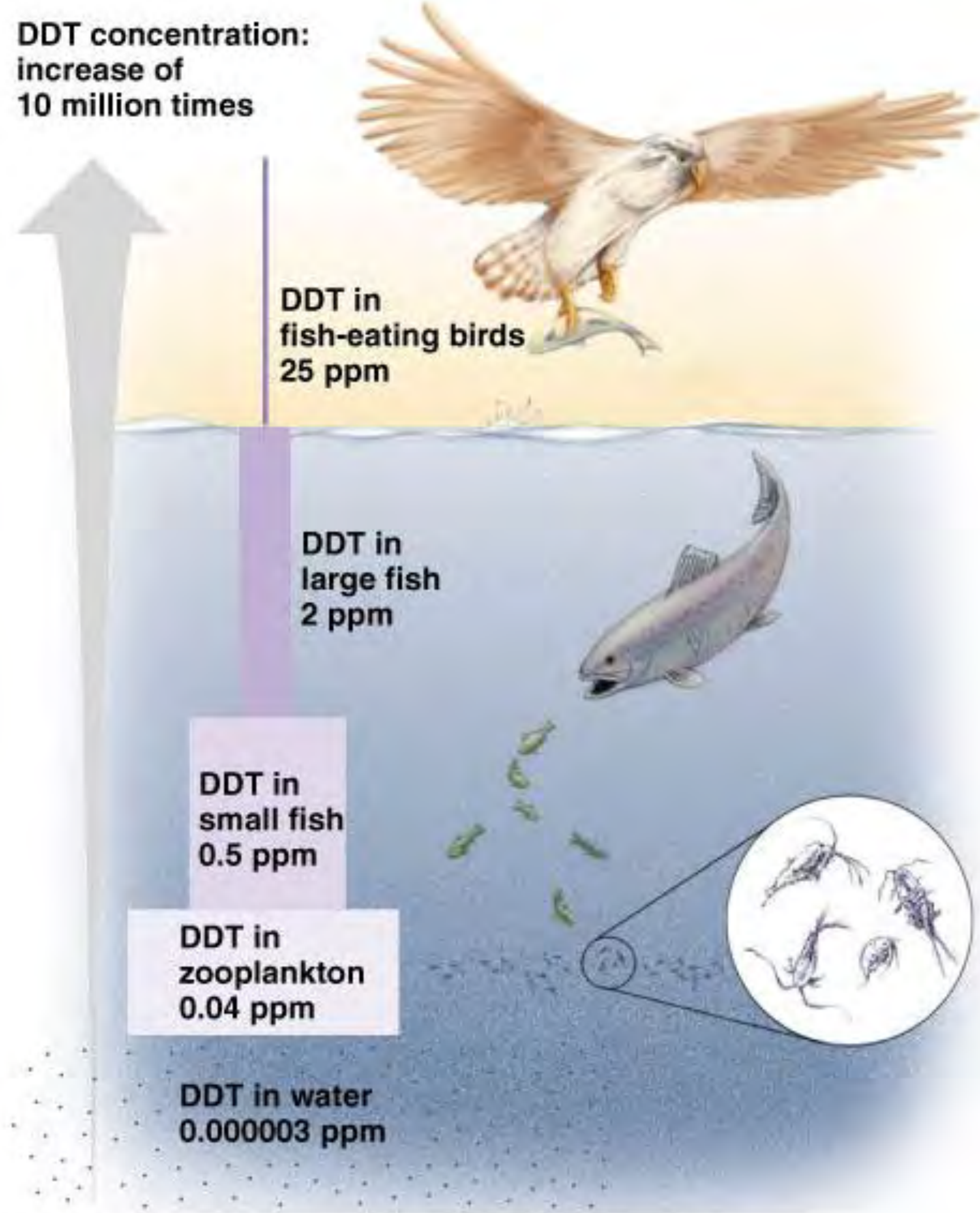
- **Facilitates wide dispersal**
- **Long residence times (persistence)**

Effects – Poorly understood for most compounds

- **CNS damage**
- **Liver damage**
- **Birth defects**

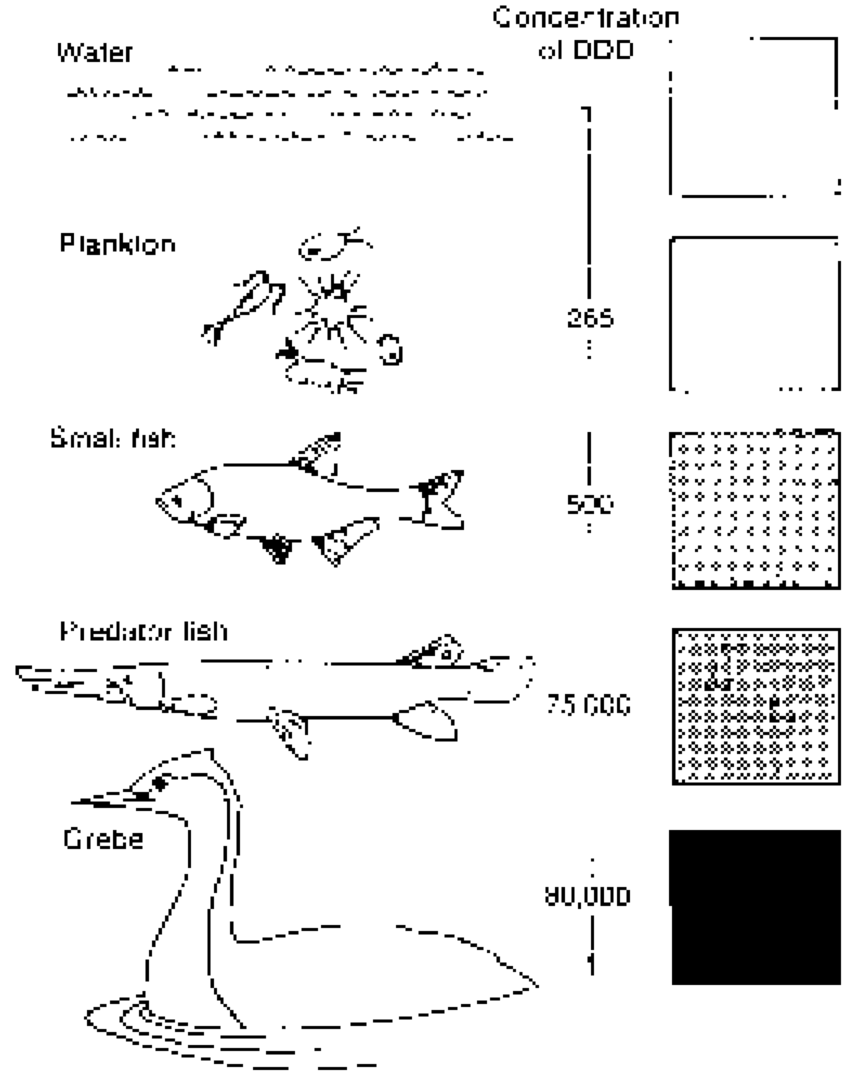
Organic Chemicals: Pesticides

- Pesticides are synthetic organic chemicals used to kill unwanted pests
  - *Insecticides* for control of insects
  - *Herbicides* for control of weeds
- Silent Spring by Rachel Carson published in 1962
  - Showed that pesticides such as DDT spread in the environment and had unintended victims
  - DDT caused thinning of egg shells of eagles
  - Resulted in the banning of DDT


DDT concentration: increase of 10 million times
DDT in fish-eating birds 25 ppm
DDT in large fish 2 ppm
DDT in small fish 0.5 ppm
DDT in zooplankton 0.04 ppm
DDT in water 0.000003 ppm

Biomagnification of DDD in the Food Chain at Clear Lake, California.

Numbers are times amount in water.



(Flint and van den Bosch, 1977) (Ref. 6-1C)

Environmental quality standard for water quality for human health

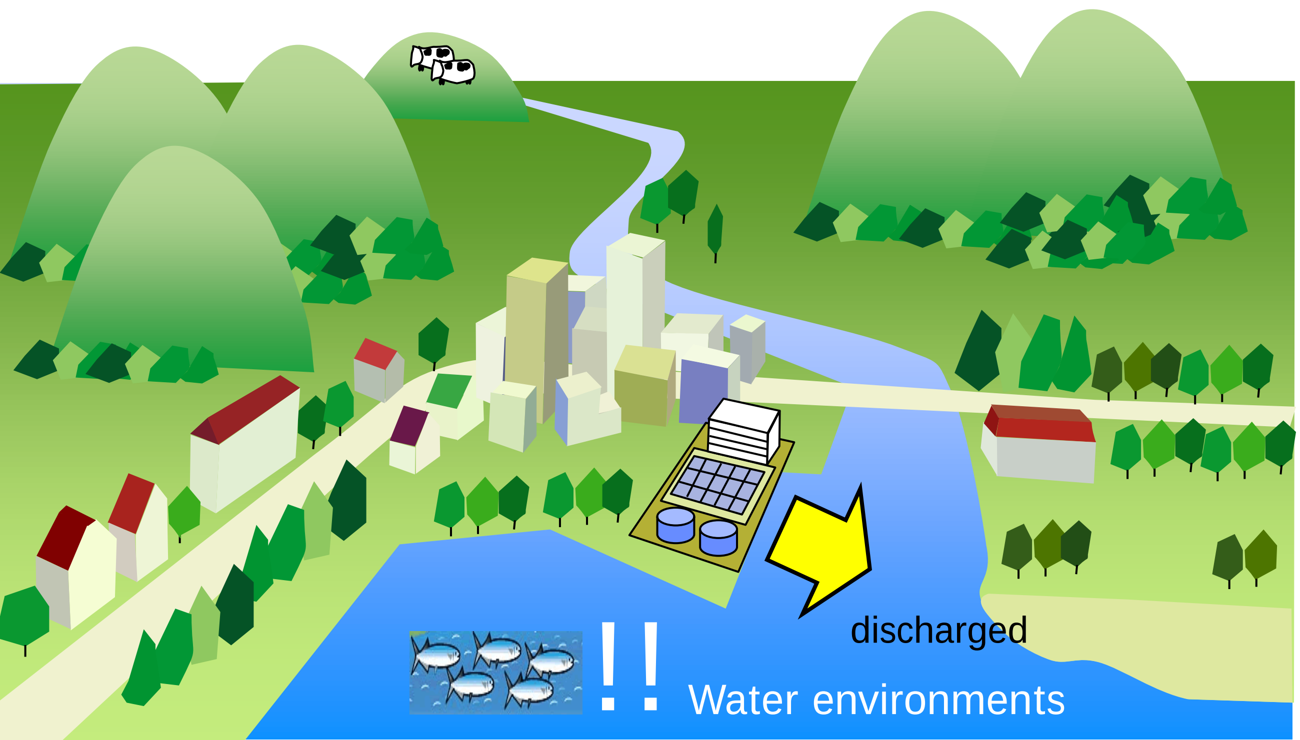
Parameters	Standard		Parameters	Standard
Cd	0.01mg/L		1,1,1-Trichloroethane	1mg/L
Cyanide	ND		1,1,2-Trichloroethane	0.006mg/L
Pb	0.01mg/L		Trichloroethylene	0.03mg/L
Cr(VI)	0.05mg/L		Tetrachloroethylene	0.01mg/L
As	0.01mg/L		1,3-Dichloropropene	0.002mg/L
Hg	0.0005mg/L		Thiuram	0.006mg/L
Alkyl Hg	ND		Simazine	0.003mg/L
PCB	ND		Thiobencarb	0.02mg/L
Dichloromethane	0.02mg/L		Benzene	0.01mg/L
Carbon tetrachloride	0.002mg/L		Se	0.01mg/L
1,2-Dichloroethane	0.004mg/L		Nitrate and Nitrite	10mg/L
1,1-Dichloroethylene	0.02mg/L		F	0.8mg/L
Cis-1,2-Dichloroethylene	0.04mg/L		B	1mg/L

Estrogens, Pharmaceuticals

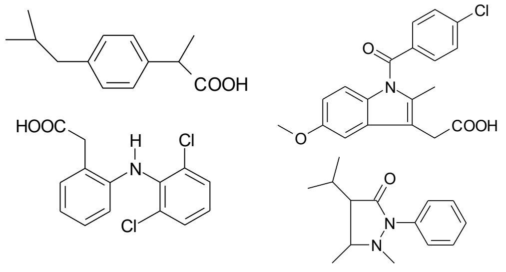
New unregulated contaminants

Originating from Human

Most of pharmaceuticals are by nature biologically active, hydrophilic and persistent



Drugs and Medicines



Lecture Headings

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

Bacteriological Measurements

- Microbiology – study of organisms that can not be seen with the naked eye
  - Recall, before the late 1800's no one knew that they existed. Louis Pasteur
  - Range in size from 1 mm to 10^{-5} mm
  - From an environmental standpoint they are important in every compartment, Air, Water and Soil
  - Most of the organic carbon available for life is in the form of microbes

Bacteriological Measurements

- It is really their world, from a population standpoint
  - 1 gram of rich soil contains:
    - 2.5 billion bacteria
    - 0.5 million fungi
    - 50,000 algae
    - 30,000 protozoa

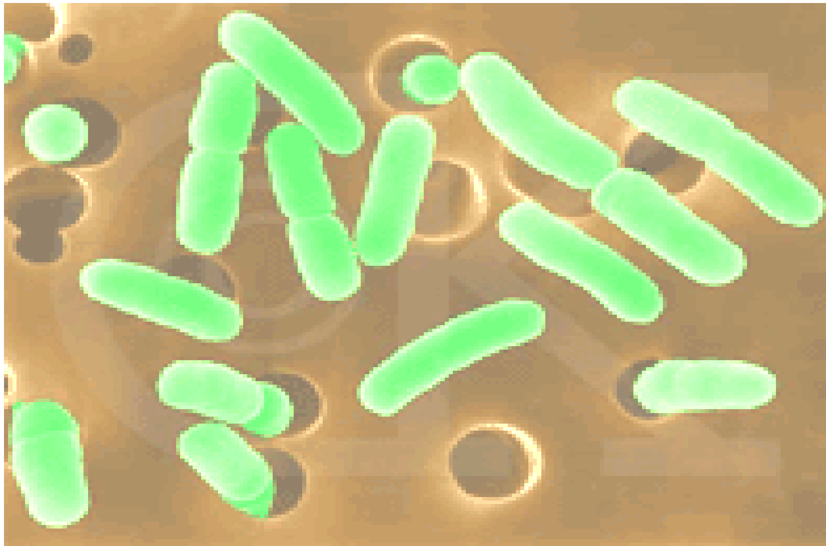
Bacteriological Measurements

- Only a small fraction cause disease
  - Pathogens
    - Typhoid and cholera killed millions around the turn of the century
    - These two waterborne diseases drove technology advancement
    - Today, Salmonella, Shigella, Hepatitis, Entamoeba, Giardia, Cryptosporidium are the main concerns

Pathogenic Organisms

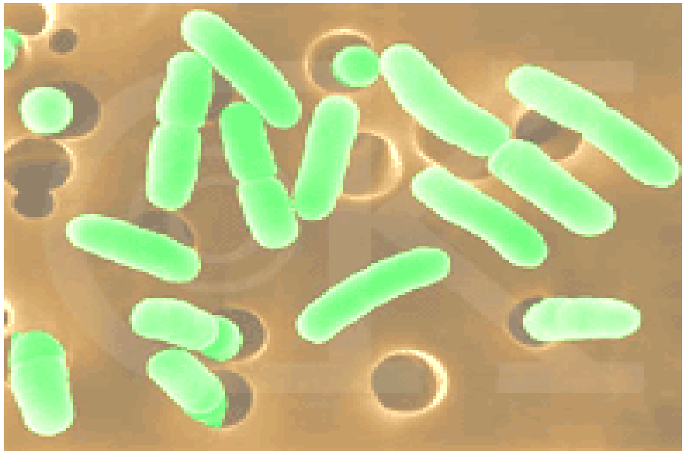
Serious Outbreaks of these cause great suffering

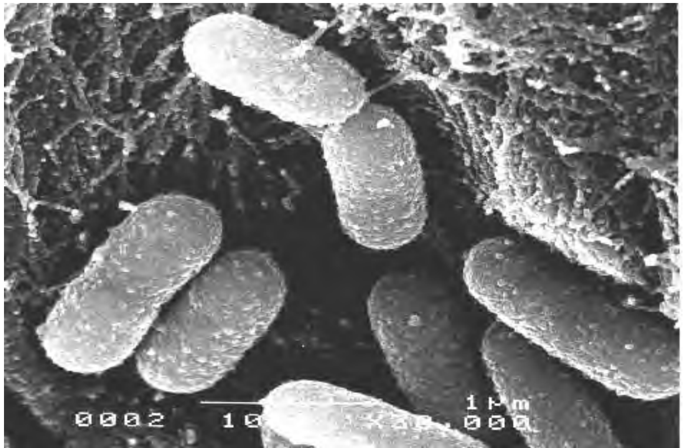
- E. Coli - indicator of fecal coliform bacteria
- Salmonella (typhoid fever)
- Shigella (dysentery)
- Cryptosporidium - protozoa
- Giardia- protozoa



Infectious Agents

- Main source of waterborne pathogens is untreated and improperly treated human waste.
  - Animal wastes from feedlots and fields is also an important source of pathogens.





Typical Pathogens in Human Waste

Pathogen Group and Name	Associated Diseases
Virus	
Adenoviruses	Respiratory, eye infections
Enteroviruses	
Polioviruses	Aseptic meningitis, poliomyelitis
Echoviruses	Aseptic meningitis, diarrhea, respiratory infections
Coxsackie viruses	Aseptic meningitis, herpangina, myocarditis
Hepatitis A virus	Infectious hepatitis
Reoviruses	Not well known
Other viruses	Gastroenteritis, diarrhea
Bacterium	
Salmonella typhi	Typhoid fever
Salmonella paratyphi	Paratyphoid fever
Other salmonellae	Gastroenteritis
Shigella species	Bacillary dysentery
Vibrio cholerae	Cholera
Other vibrios	Diarrhea
Yersinia enterocolitica	Gastroenteritis
Protozoan	
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia	Diarrhea
Cryptosporidium species	Diarrhea
Helminth	
Ancylostoma duodenale (hookworm)	Hookworm
Ascaris lumbricoides (roundworm)	Ascariasis
Hymenolepis nana (dwarf tapeworm)	Hymenolepiasis
Necator americanus (hookworm)	Hookworm
Strongyloides stercoralis (threadworm)	Strongyloidiasis
Trichuris trichiura (whipworm)	Trichuriasis

Source: Hammer and Hammer, 1996.

Lecture Headings

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

Water Quality Management

- We try to manage water quality so that waters don’t become contaminated (*pollution prevention*)
  - Costly and risky to rely only on treatment of drinking water (*cryptosporidum* oocysts unaffected)
  - Reduce impact on wildlife
- Some Books calls this *Fate and Transport*
  - The movement and ultimate disposition of pollutants
- Water quality management programs focus on ground water and surface water

Pergamon

Wat. Sci. Tech. Vol. 31, No. 8, pp. 249–259, 1995.

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WATER QUALITY MANAGEMENT: CAN WE IMPROVE INTEGRATION TO FACE FUTURE PROBLEMS?

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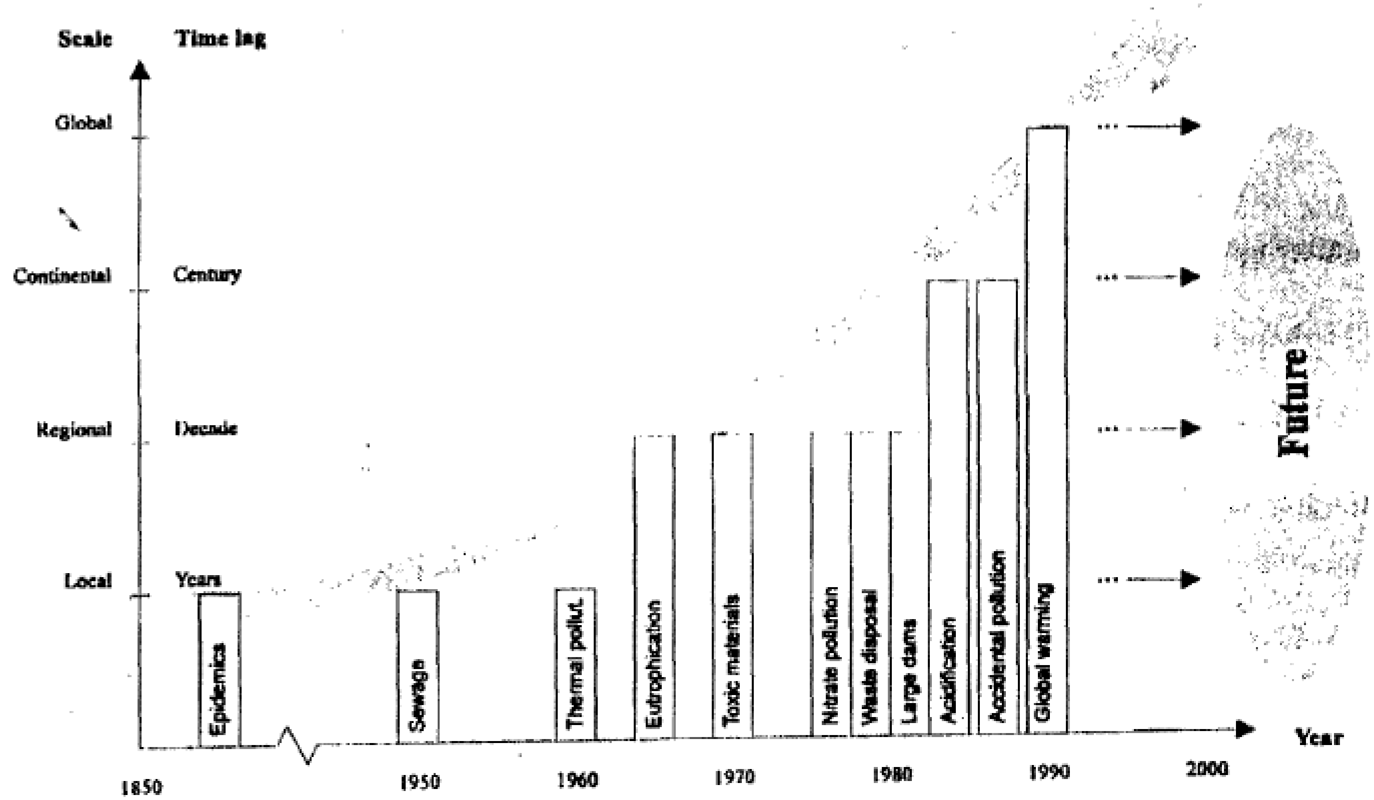


Figure 1. Trends in pollution problems.

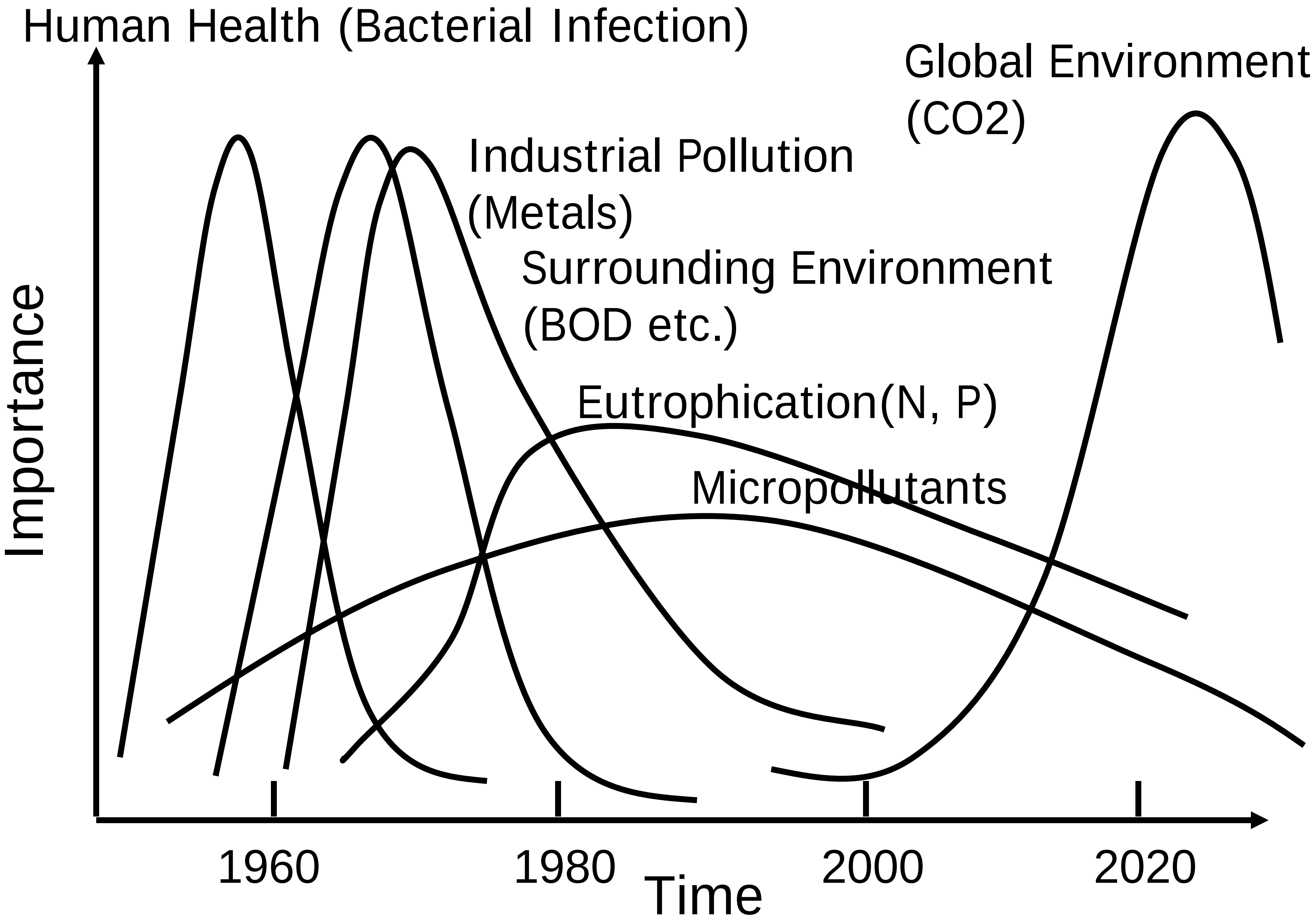
Table 1. Trends in water quality management

PAST	FUTURE
(1) Control Type	
"End of the pipe"	Source control, closing material cycles, land use management, concern on large scale projects
Technical	Non-technical elements
(2) Treatment	
"Traditional technology"	Reuse and recycling
	Special treatment methods (biological-chemical treatment, upgrading, natural treatment, small-scale treatment) and emerging new traditions
(3) Monitoring	
Local measurements	Networks, remote sensing, continuous measurements
Conventional parameters	Special parameters (eco-toxicology, biomonitoring, etc.)
Monitoring of water	Integration of effluent and ambient monitoring and environmental monitoring
Poor data availability	Improved availability (data bases, digital maps, telecommunication)
(4) Modeling	
Individual issues (processes, control, operations, planning, etc.)	Integration (model library, DSS, GIS, expert systems, etc.)
Use by experts	Use in administration, meetings, etc.
(5) Planning and Project Evaluation	
Poor/narrow definition of objectives	"Sensible" definition
Short-term view	Long-term view
Cost evaluation	EIA, risk and multiobjective evaluation, social and political impacts
Little concern on failures and adjustment needs	The future is never certain: reliability, resiliency, robustness, and vulnerability
(6) Science and Engineering	
Science does not drive actions	"Science for Action"
Problem isolation and engineering solutions	Improved planning
Interdisciplinary gaps and barriers	Integration of quantity, quality, hydrology, and management
(7) Legislation, Decision Making Institutions and Development	
General rules and rigidity	Specific rules and flexibility
Fast implementation (a misbelief)	Process view
Little enforcement	Improved enforcement
Command and control	Polluter (and user) pays
Confusing institutional settings	Clearer structures and less barriers
Decisions by politicians and administration	Public awareness and participation, NGOs, and enhanced communication
National policies	International policies
	Sustainable development: how to proceed?

Global Environmental Issues

From http://www.pref.kyoto.jp/intro/21cent/kankyo/contents_e/globe_prob/index.html

- Global Warming
- Ozone Layer Depletion
- Acid Rain
- Deforestation
- Loss of Biodiversity
- Water Pollution
- Desertification
- Waste disposal



Japanese Experiences

Conclusion

- Fundament strategies to combat water quality problems that can form the basis of policy solutions for improving water quality:
  - Prevention of pollution
  - Treatment of polluted water
  - Safe use of wastewater
  - Restoration and protection of ecosystem