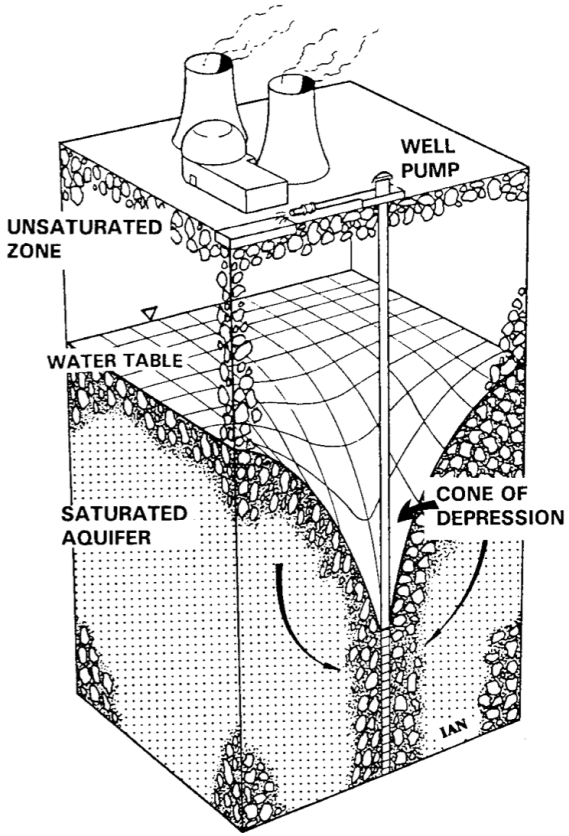
Overview of Water Pollution

Structure and Composition of the Hydrosphere



Outline of Topics

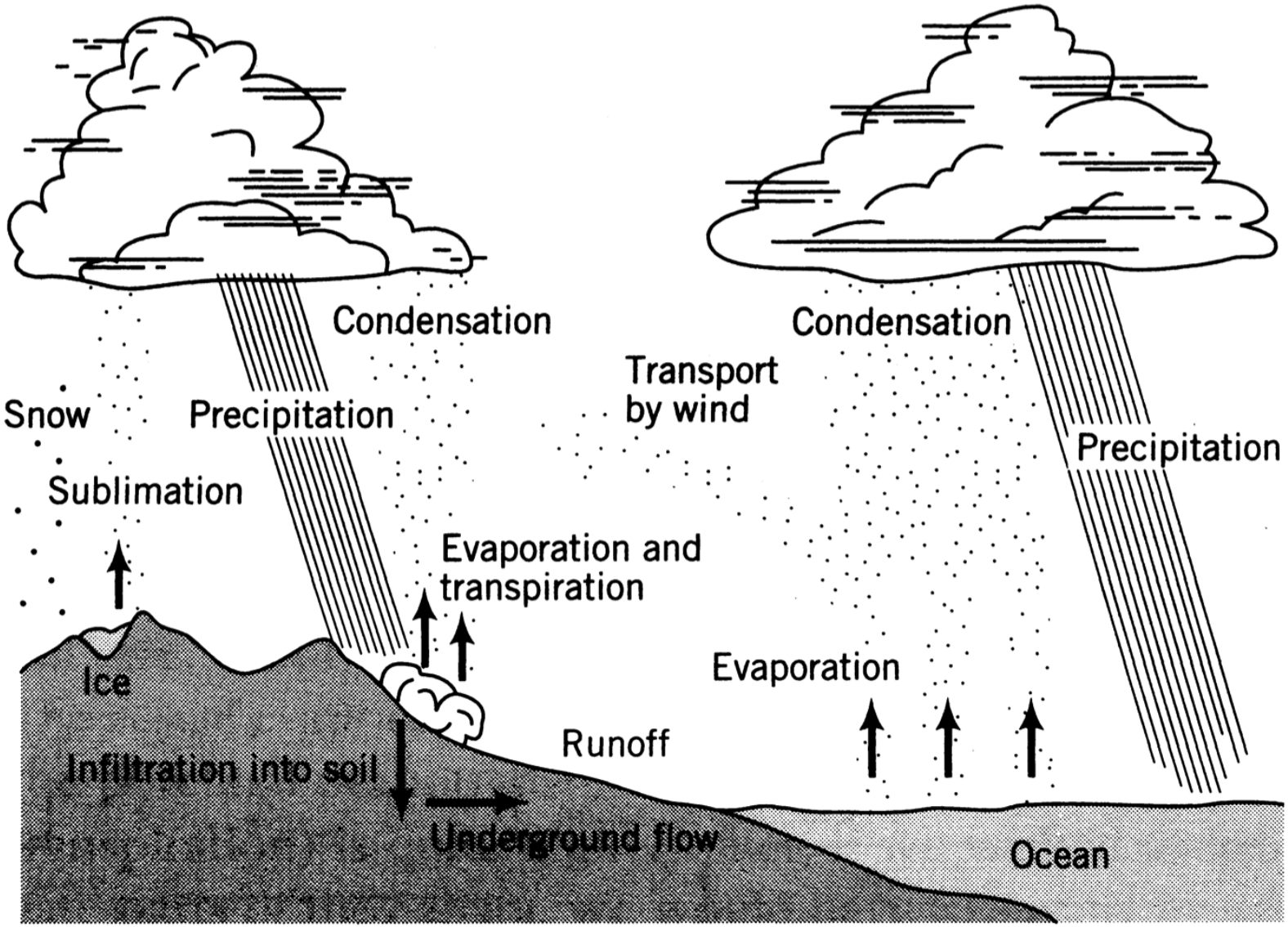
The Hydrosphere

List the major water reservoirs on Earth (the *hydrosphere*) from largest to smallest.

Reservoir	**Volume, km^3**	**%**	**Turnover Time**
Oceans	1.34×10^9	96.54	2640 y
Cryosphere	2.31×10^7	1.74	8900 y
Groundwater/permafrost	2.37×10^7	1.71	515 y
Lakes/Rivers	1.90×10^5	0.01	4.3 y
Soil Moisture	1.65×10^4	0.0012	52 d
Atmosphere	1.29×10^4	0.0009	8.2 d
Biomass	1.12×10^3	0.0001	5.6 d

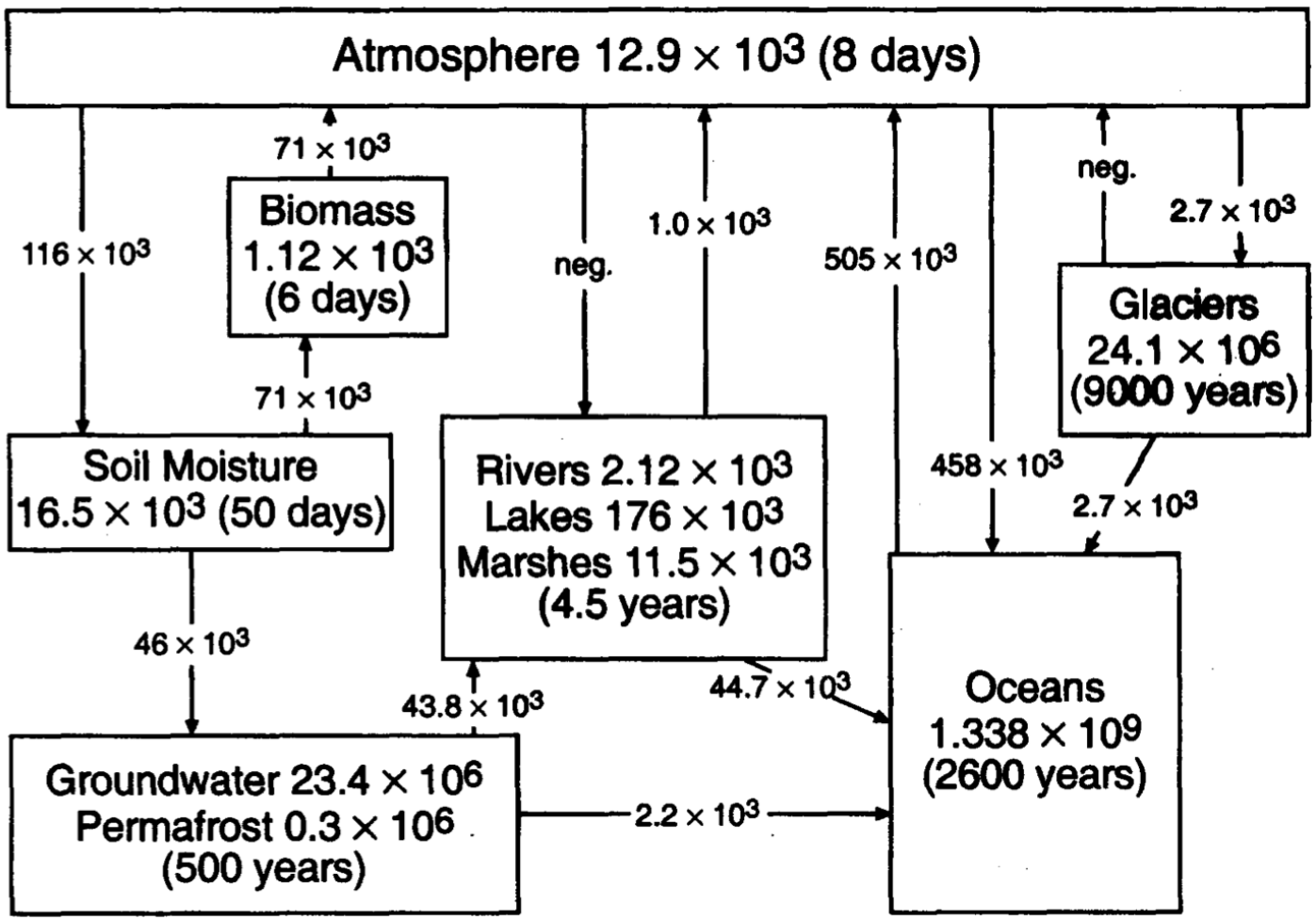
The Hydrologic Cycle

What is the hydrologic cycle? Describe the major processes.



Global Circulation of Water

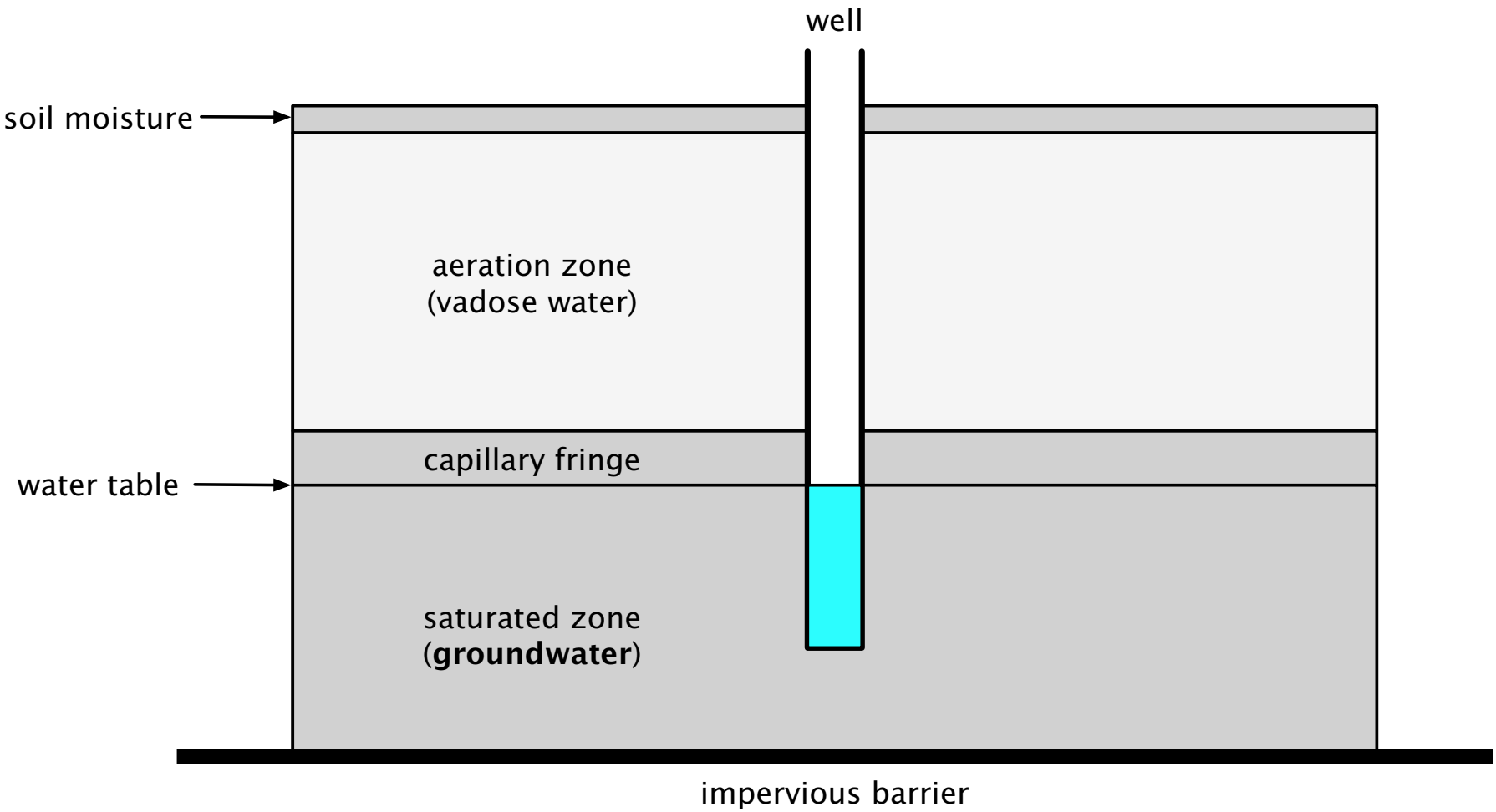
Why are the oceans salty? Describe the circulation of water on a global scale.



- Giant distillation: ocean $\rightarrow$ air $\rightarrow$ land $\rightarrow$ oceans
- Rivers/lakes get most of their water from groundwater

Groundwater

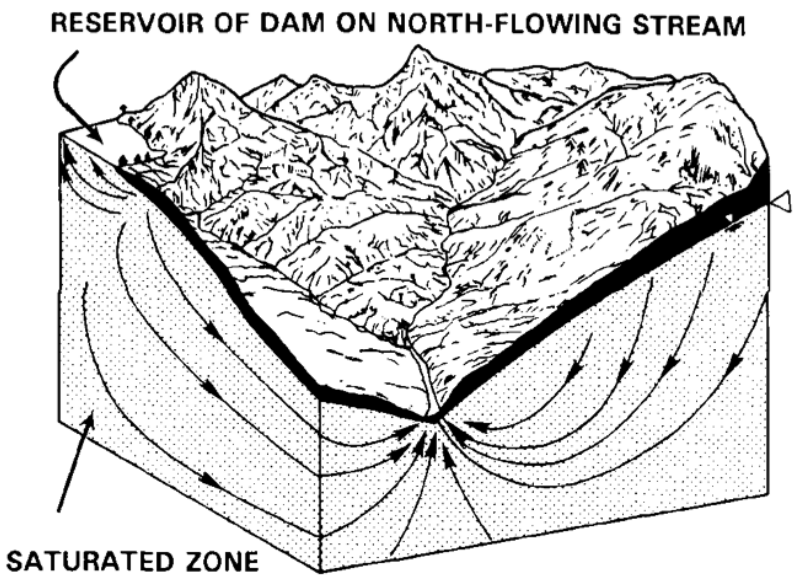
What the heck is groundwater?

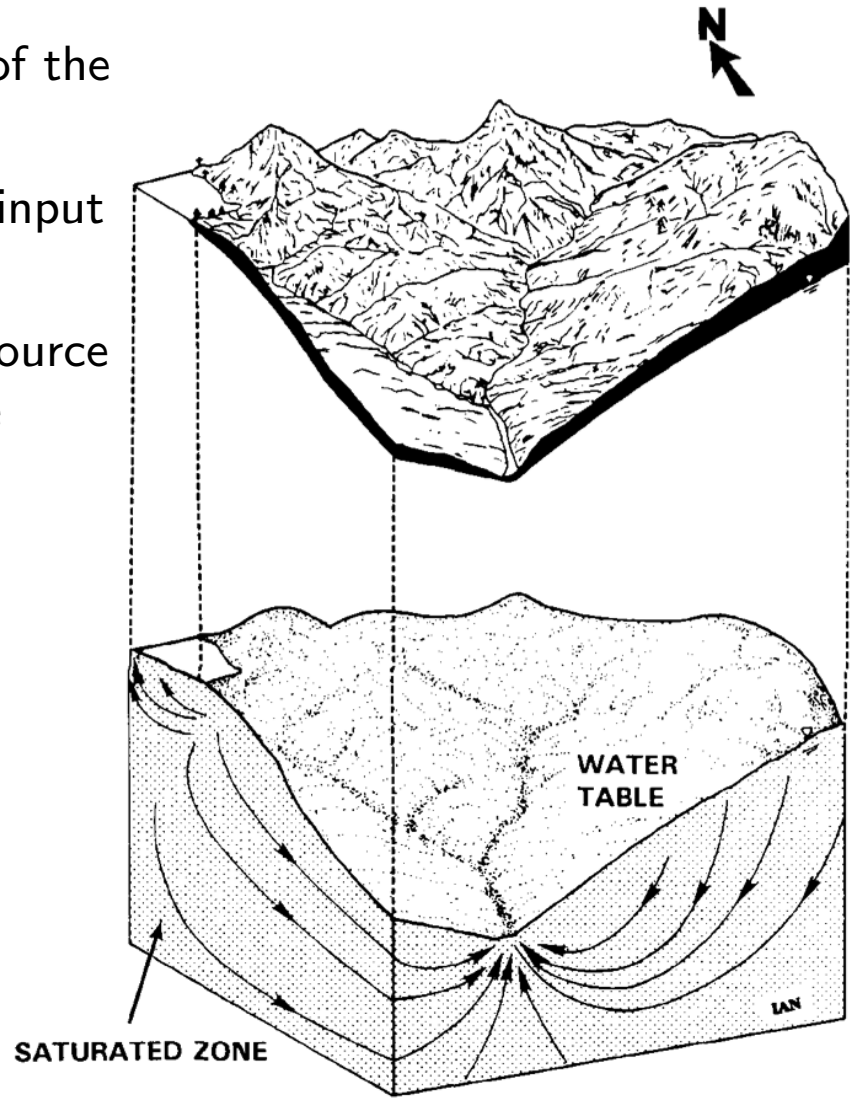


Basin Groundwater Flow

What might the local water table look like?

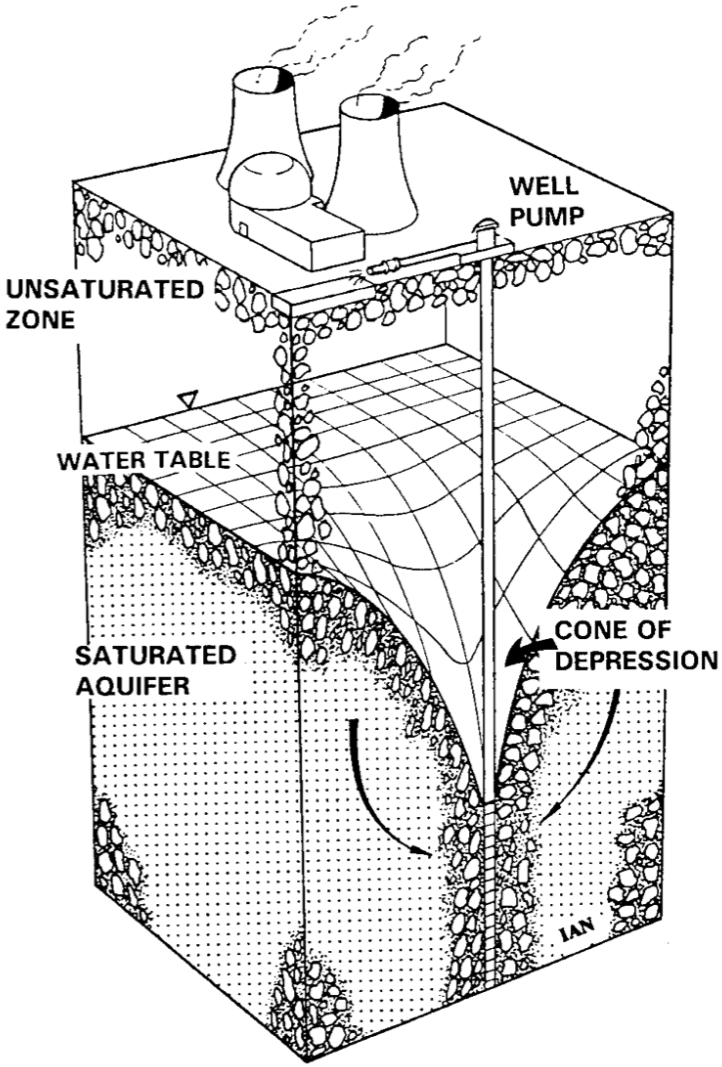
- Local water table often follows topography of the land
- The baseflow is usually the most important input of water into rivers and streams
- Baseflow usually less important as a water source into lakes due to the low permeability of the sediment (there are exceptions)





Cone of Depression

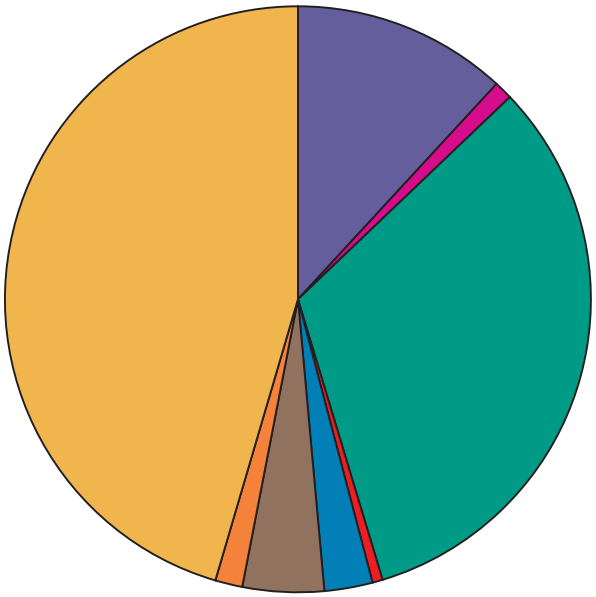
How might well water beome polluted?



- Pumping in an unconfined aquifer creates a *cone of depression* near the well
- Chemicals dumped on the land within a cone of depression can get into the well water
- Spills within the *recharge area* of an aquifer can eventually pollute the groundwater
- Recharge areas do not always lay directly above an aquifer

Water Use in the US

What are the main uses of water in the US?



2010 withdrawals by category, in million gallons per day

Public supply	42,000
Self-supplied domestic	3,600
Irrigation	115,000
Livestock	2,000
Aquaculture	9,420
Self-supplied industrial	15,900
Mining	5,320
Thermoelectric power	161,000

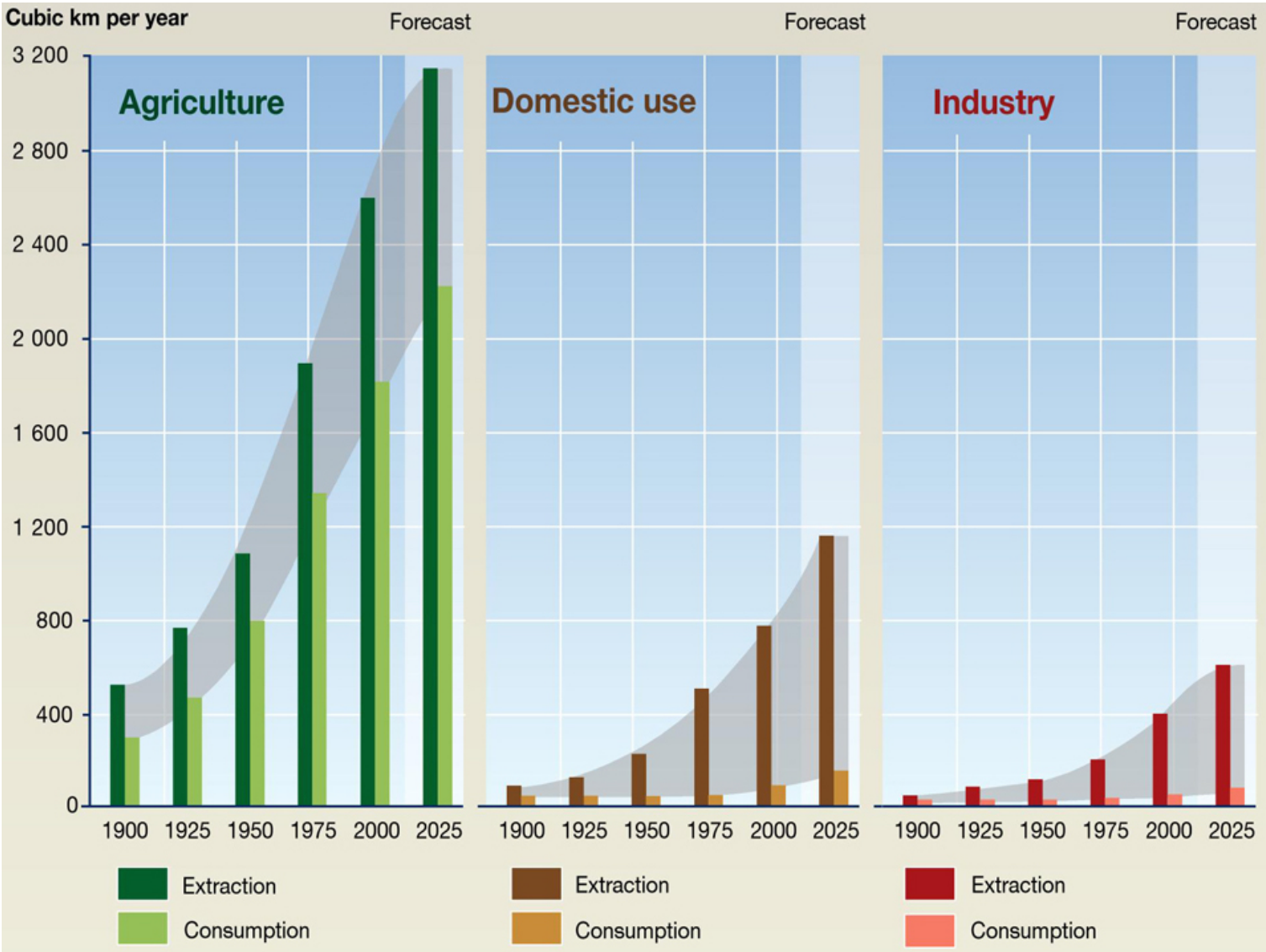
Values do not sum to 355,000 Mgal/d because of independent rounding

1. Thermoelectric: 45%
2. Irrigation: 32%
3. Public supply: 12%
4. All others: 10%

- USGS 2010 report: 355,000 million gallons withdrawn per day
  - Down 13% from 2005
- 86% freshwater, 14% saline
- 78% surface water, 22% groundwater
  - Groundwater: irrigation (70%), public supply (20%)

Global Water Use

What is meant by ‘consumptive’ use of water?

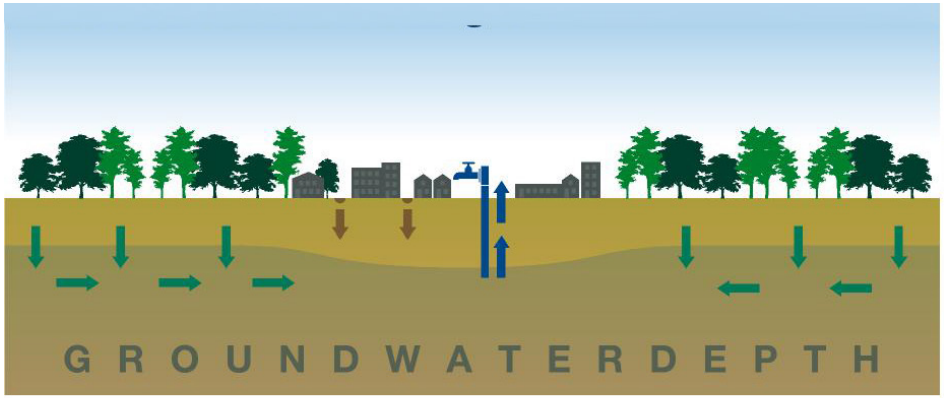


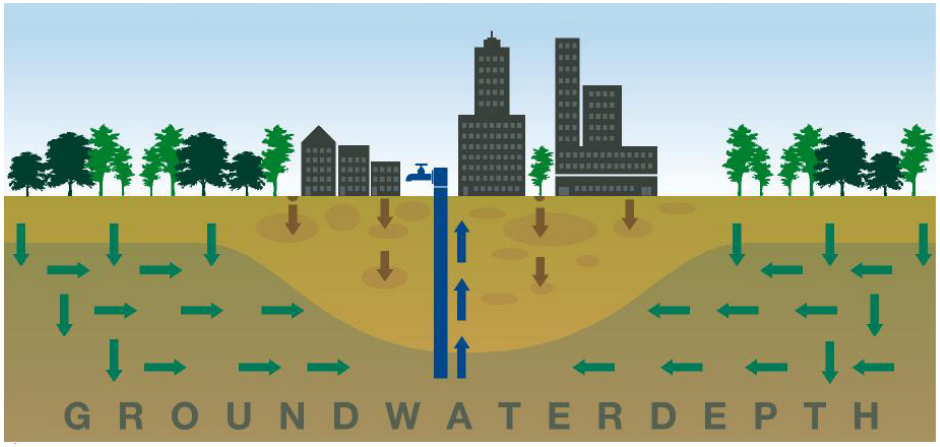
- Data from UNEP describing trends/predictic in global water use
- Consumptive use removes water from local re-use
- Grey area represents water that is available for re-use

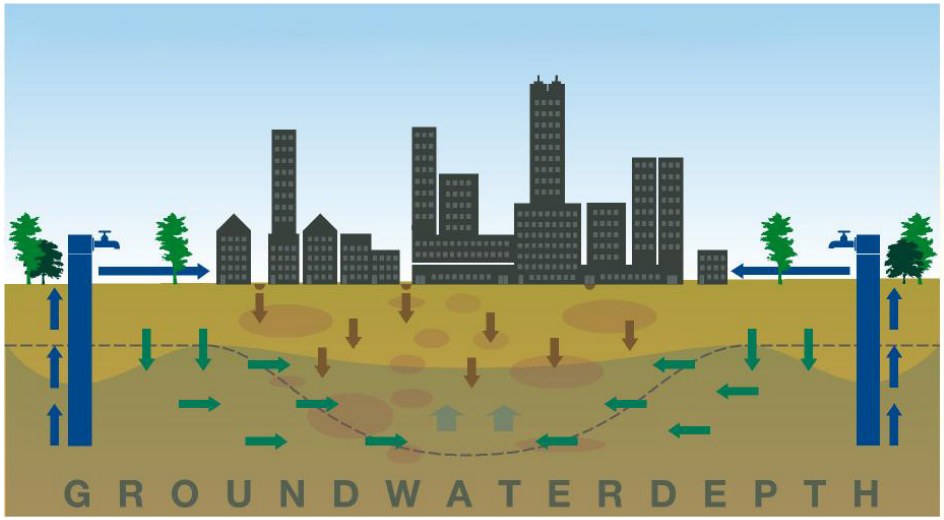
Urban vs Rural Competition for Water

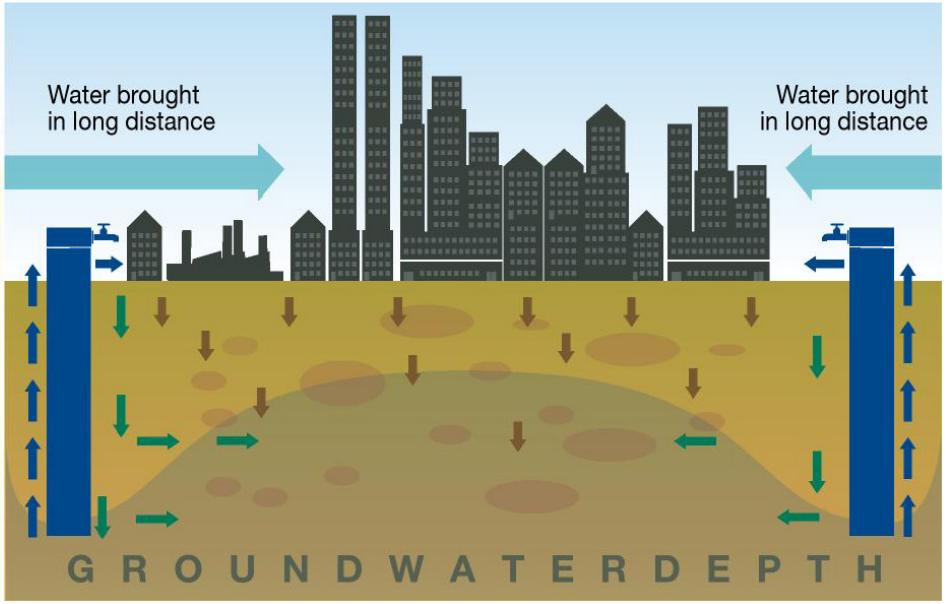
Is there a connection between water quality and quantity?

Panels below show the effects a developing city have on the local groundwater.



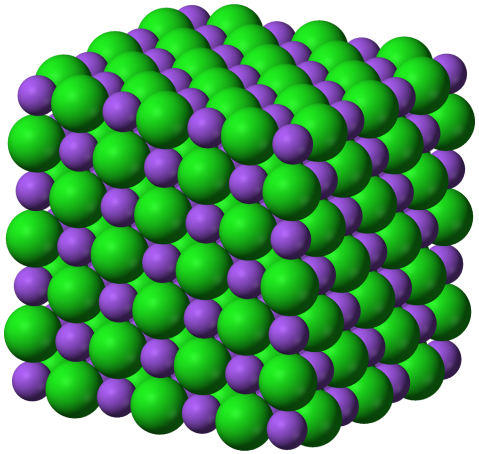




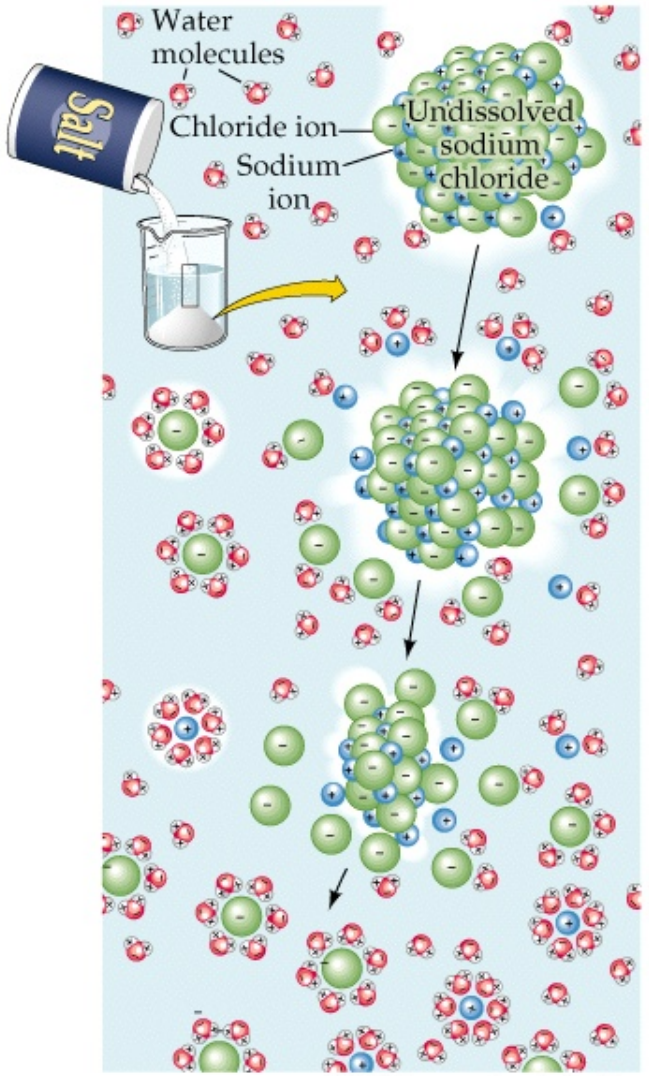


Dissolution of Solids

What is a solution? How is it formed?



Ionic solids exist as 3-d lattices, such as this one for NaCl



Define the following terms:

- solution, solute, solvent
- concentration (including units)
- ionic compound, cation and anion
- electrolyte and non-electrolyte

Composition of Natural Waters

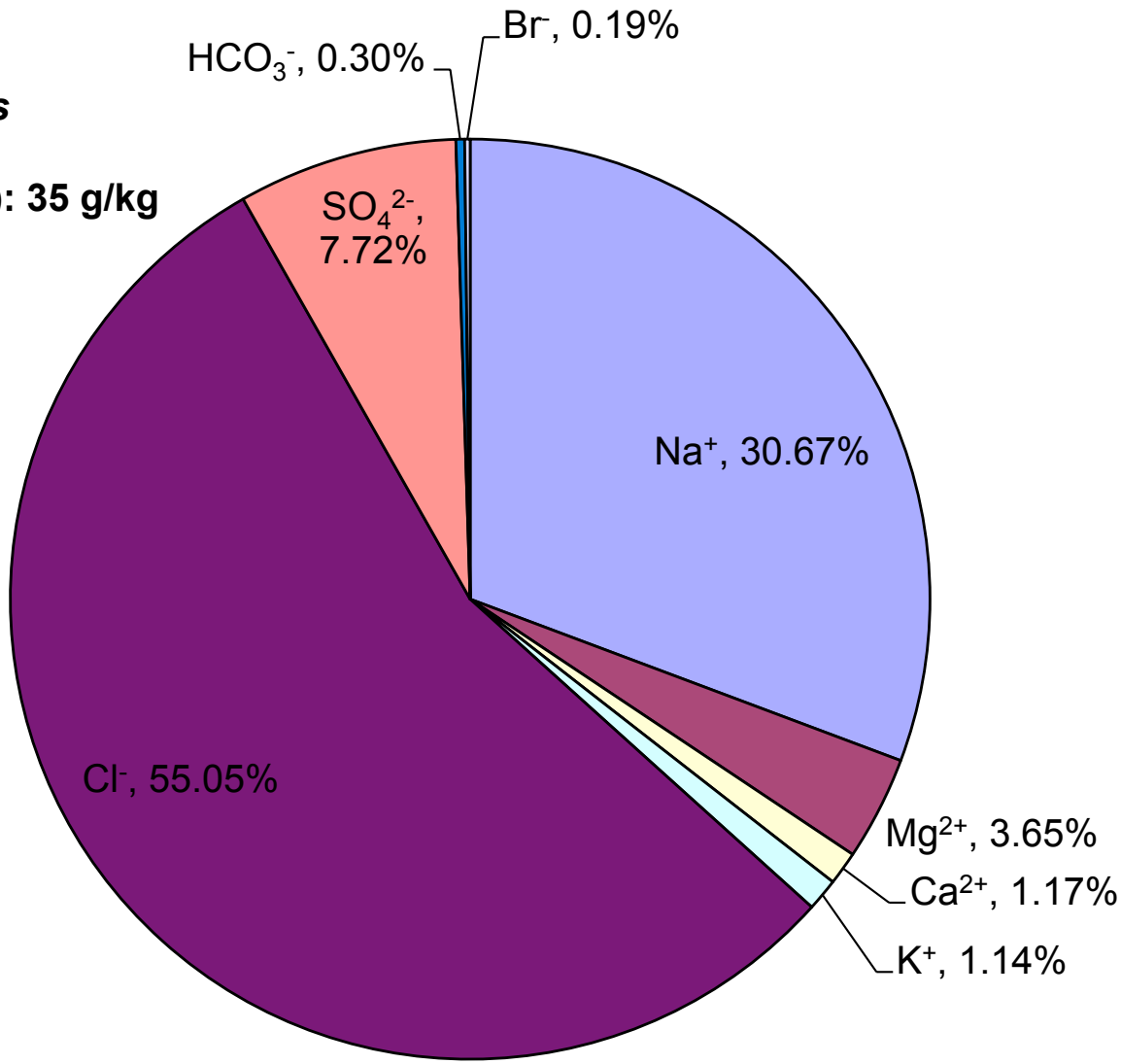
What are the most concentrated solutes in the hydrosphere?

- Cations: Na^+, K^+, Ca^{2+}, Mg^{2+}
- Anions: Cl^-, SO_4^{2-}, HCO_3^-
- Neutral: $Si(OH)_4$

Seawater Composition

Describe the composition of seawater, including typical salinity and pH values.

typical values
pH: 8.1
TDS (salinity): 35 g/kg

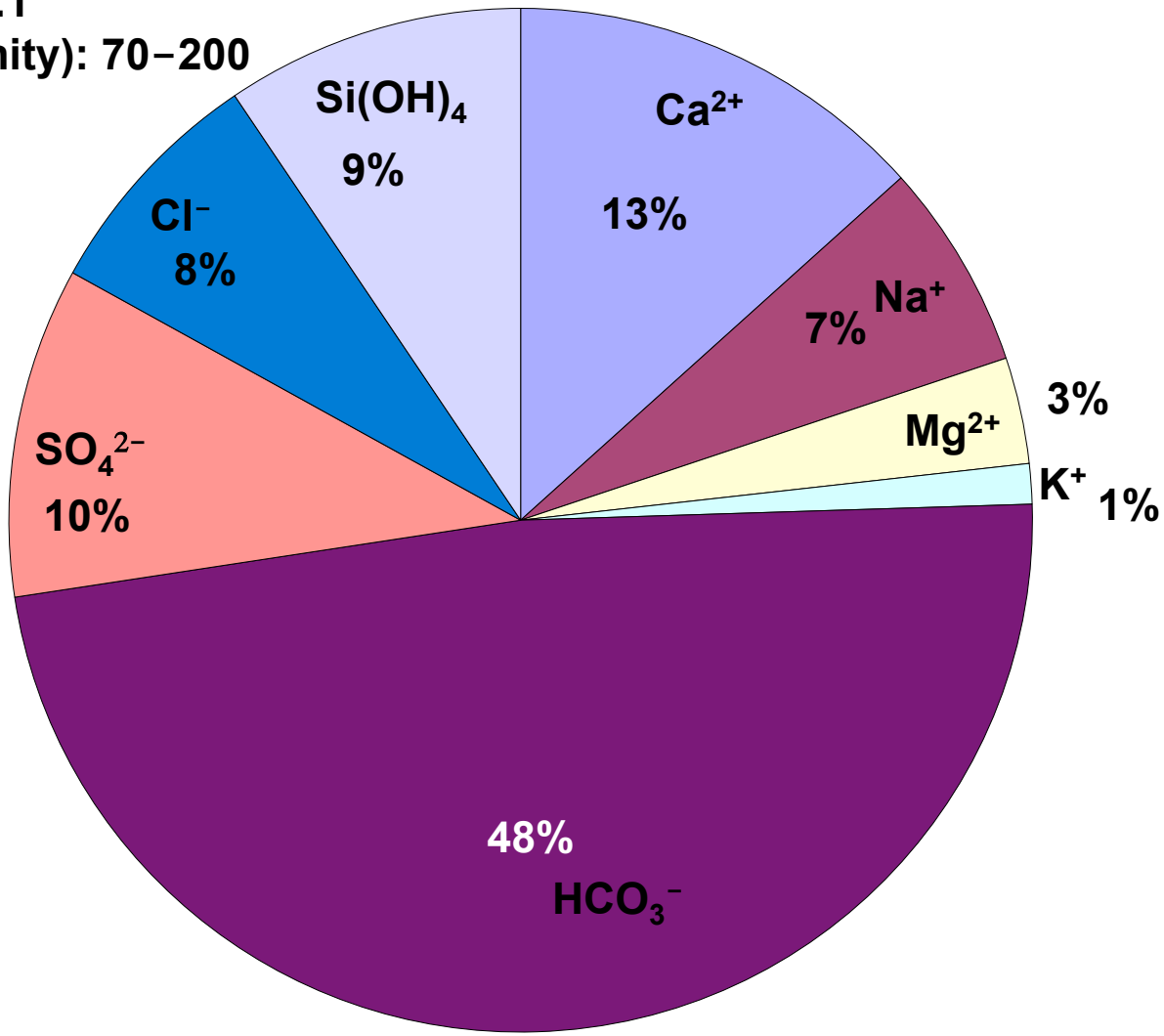


- Concs are mass fractions
- Proportions fairly constant but salinity varies, 33–37 g/kg

Freshwater Composition

What is the average composition of the world's rivers?

typical values
pH: 7.3–8.1
TDS (salinity): 70–200



- TDS units are mg/L
- Values from 1980 average of rivers

Is river composition very variable?

	Africa		*Asia*		*S. America*		*N. America*	
	conc, mg/L	fraction	conc, mg/L	fraction	conc, mg/L	fraction	conc, mg/L	fraction
Ca^{2+}	5.7	9.4%	17.8	13.3%	6.3	11.5%	21.2	14.9%
Na^{+}	4.4	7.2%	8.7	6.5%	3.3	6.0%	8.4	5.9%
Mg^{2+}	2.2	3.6%	4.6	3.4%	1.4	2.6%	4.9	3.4%
K^{+}	1.4	2.3%	1.7	1.3%	1.0	1.8%	1.5	1.1%
HCO_3^{-}	26.9	44.2%	67.1	50.0%	24.4	44.7%	72.3	50.7%
SO_4^{2-}	4.2	6.9%	13.3	9.9%	3.8	7.0%	18.0	12.6%
Cl^{-}	4.1	6.7%	10.0	7.5%	4.1	7.5%	9.2	6.4%
$Si(OH)_4$	12.0	19.7%	11.0	8.2%	10.3	18.9%	7.2	5.0%
TDS	60.9		134.2		54.6		142.7	

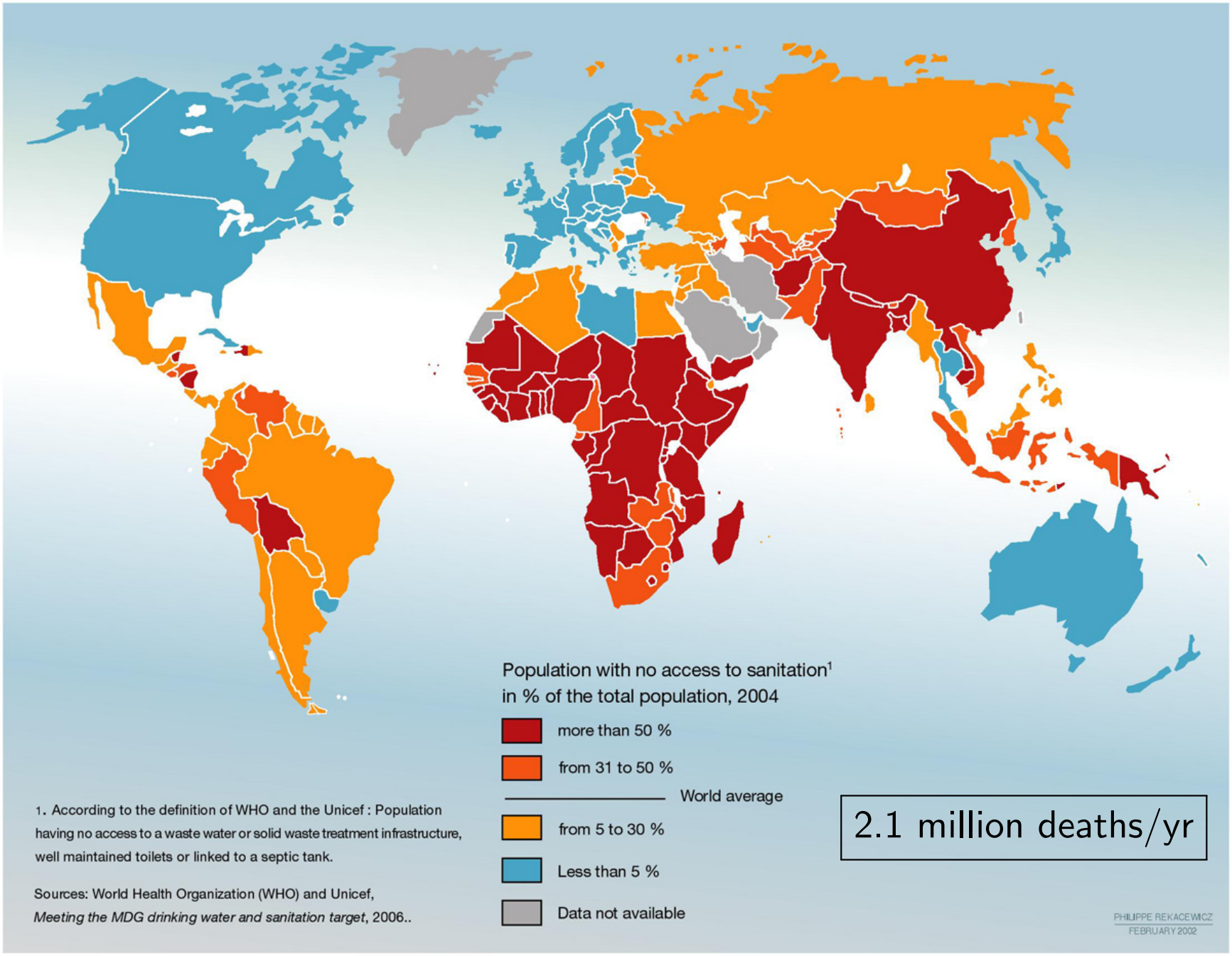
	Europe		*Oceania*		*World Average*	
	conc, mg/L	fraction	conc, mg/L	fraction	conc, mg/L	fraction
Ca^{2+}	31.7	15.5%	15.2	12.2%	**14.7**	**13.3%**
Na^{+}	16.5	8.0%	7.6	6.1%	**7.2**	**6.5%**
Mg^{2+}	6.7	3.3%	3.8	3.1%	**3.7**	**3.4%**
K^{+}	1.8	0.9%	1.1	0.9%	**1.4**	**1.3%**
HCO_3^{-}	86.0	42.0%	65.6	52.9%	**53.0**	**48.1%**
SO_4^{2-}	35.5	17.3%	7.7	6.2%	**11.5**	**10.4%**
Cl^{-}	20.0	9.8%	6.8	5.5%	**8.3**	**7.5%**
$Si(OH)_4$	6.8	3.3%	16.3	13.1%	**10.4**	**9.4%**
TDS	205.0		124.1		**110.2**	

Water Pollution

Why aren't you allowed to swim in Westhampton Lake? And what is the purpose of the aerators?

- High (human fecal) coliform count.
  Globally, poor sanitation of drinking water is the single worst water pollution problem, mostly affecting less developed countries (but obviously still an issue even in industrialized countries).
- Aerators have two purposes:
  - to oxygenate the lake, countering the effects of eutrophication due to nutrient pollution
  - to mix the lake when it stratifies (summer months), helping keep the bottom layer oxygenated

What are some of the world's worst water pollution problems?



US Water Quality

How is water quality regulated in the US?

- Two important laws (there are others): Clean Water Act for natural water bodies, and the Safe Drinking Water Act for drinking water reservoirs and water treatment plants
  - Quantitative **water quality standards** exist for natural water bodies
  - Under the CWA, the appropriate standards depend on the intended use of a water body
- Classification of water bodies
  - *Good*: water quality is sufficient to meet all designated uses
  - *Impaired*: water quality is insufficient to meet at least one designated use. State obliged to develop 'TMDL' rules for impaired water bodies
- Examples of designated uses of water bodies (varies by state)
  - Food supply: fish consumption, shellfish consumption
  - Water supply: public drinking water, agricultural (irrigation)
  - Recreation: swimming (primary contact), boating (secondary contact)
  - Ecosystem health: aquatic life support, wildlife support

Class Exercise: Pollution Sources

What are the major human activities that pollute the hydrosphere?

- **Industrial discharges**: paper and pulp mills, chemical manufacturers, steel plants, textile manufacturers, food processing plants, others
- **Sewage discharges**: discharges of treated sewage from treatment plants; combined sewer overflows (CSOs)
- **Urban runoff**: runoff from impervious surfaces (streets, etc)
- **Agricultural operations**: crop production, livestock operations (esp CAFOS)
- **Silvicultural operations**: forest management, tree harvesting, logging road construction
- **Resource extraction**: mining, petroleum drilling, runoff from mine tailing sites
- **Waste disposal**: landfill leachate, underground injection, incineration (followed by atmospheric deposition of pollutants)
- **Hydrologic modification**: channelization, dredging, dam construction, removal of riparian vegetation, streambank modification, drainage/filling of wetlands

US Water Quality Overview

What are the most common activities that cause water quality impairment in the US?

Leading Pollutant Sources (US EPA 2009)

Rank	*Rivers*	*Lakes*	*Estuaries*	*Groundwater**
1	*Agriculture*	*Atmospheric Deposition*	*Atmospheric Deposition*	*Leaky USTs*
2	*Hydromodification*	*Unknown*	*Unknown*	*Septic tanks*
3	*Unknown*	*Agriculture*	*Sewage Discharges*	*Landfills*
4	Habitat Alteration	Natural/Wildlife	Unspecified nonpoint source	Fertilizer application
5	Natural/Wildlife	Hydromodification	Other	Industrial
6	Sewage Discharges	Urban Runoff/Stormwater	Industrial	Hazardous Waste Sites
7	Unspecified nonpoint source	Sewage Discharges	Natural/Wildlife	Animal feedlots
8	Atmospheric Deposition	Legacy/Historical Pollutants	Urban Runoff/Stormwater	Pesticides
9	Resource extraction	Resource extraction	Agriculture	Surface impoundments
10	Urban Runoff/Stormwater	Unspecified nonpoint source	Hydromodification	Above-ground STs

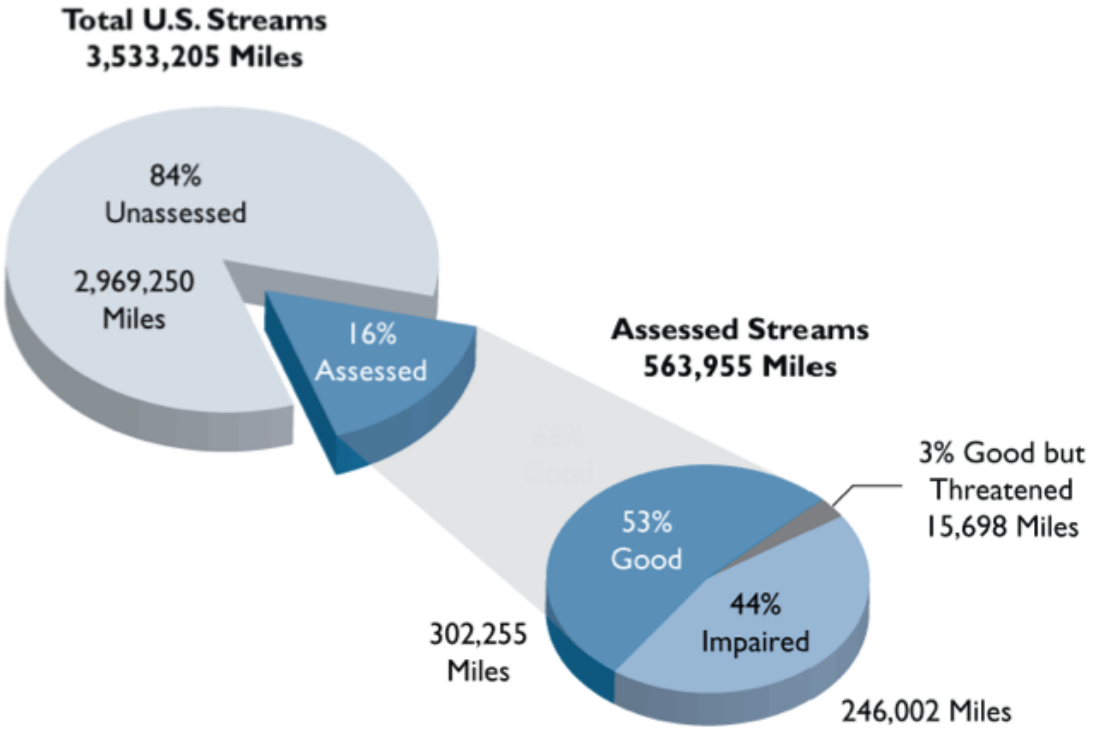
US Water Quality Overview

What are the most common pollutants that cause water quality impairment in the US?

Leading Pollutants/Stressors (US EPA 2009)

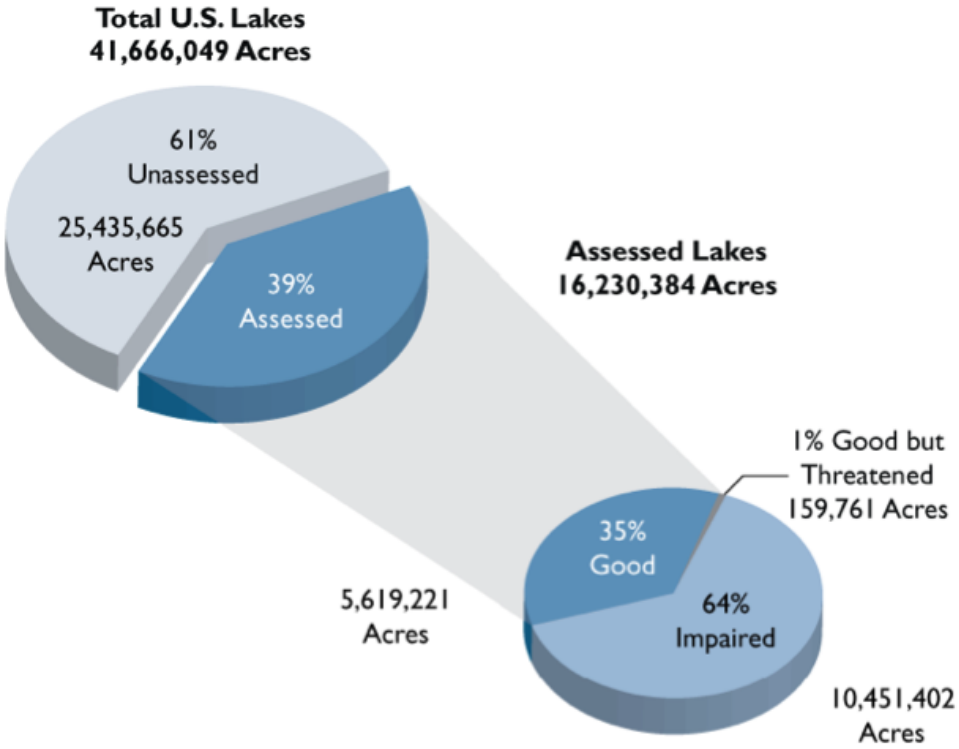
Rank	*Rivers*	*Lakes*	*Estuaries*	*Groundwater**
1	*Pathogens*	*Mercury*	*Pathogens*	*VOCs*
2	*Habitat alteration*	*PCBs*	*Degradable Organic Pollution*	*Petroleum products*
3	*Degradable Organic Pollution*	*Nutrients*	*Mercury*	*Metals*
4	Impaired Biota	Metals	Toxic Organics	Pesticides
5	Nutrients	Degradable Organic Pollution	Nutrients	Nitrate
6	Metals	Nuisance Exotic Species	Pesticides	Pathogens
7	Sediment	Sediment	Habitat alteration	
8	Mercury	Pathogens	PCBs	
9	Flow Alteration	Turbidity	Metals	
10	Turbidity	Other Causes	Turbidity	

What percentage of US rivers and streams are considered impaired?



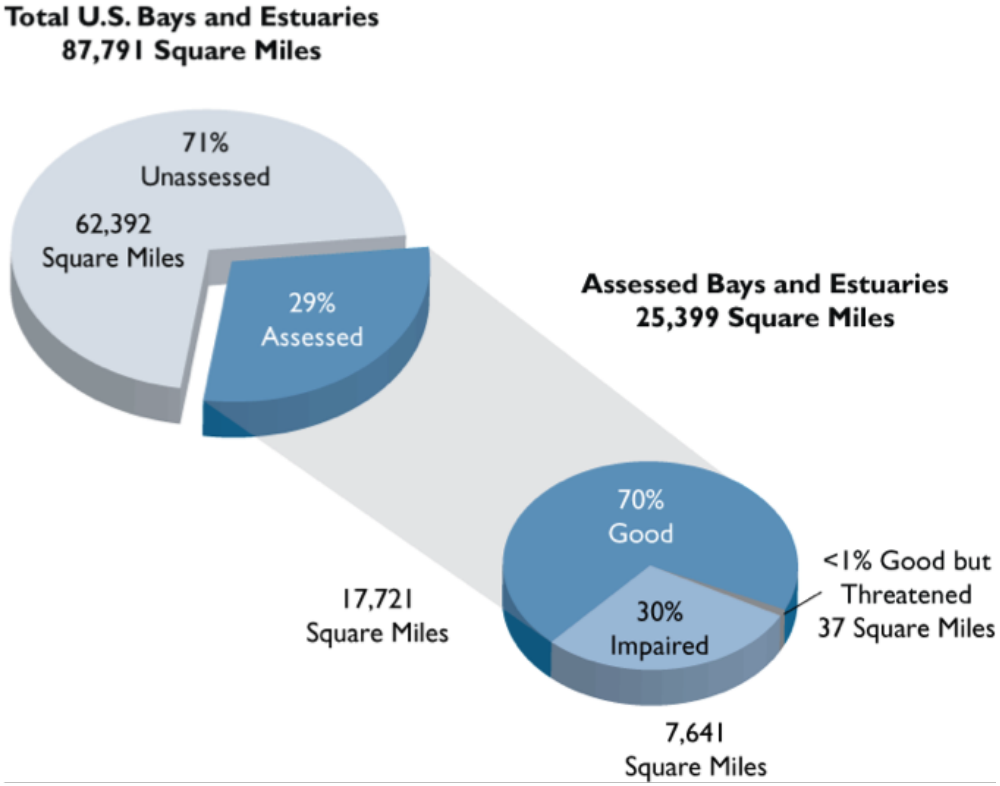
Designated Use	Miles Assessed	Percentage of Total U.S. River Miles	Percentage of Waters Assessed		
			Good	Threatened	Impaired
Fish, Shellfish, and Wildlife Protection/Propagation	466,617	13	61	3	36
Recreation	303,317	9	69	3	28
Agricultural	200,817	6	90	<1	10
Aquatic Life Harvesting	154,746	4	56	4	40
Public Water Supply	144,245	4	79	3	18

What percentage of US lakes are considered impaired?



Designated Use	Acres Assessed	Percentage of Total U.S. Lake Acres	Percentage of Waters Assessed		
			Good	Threatened	Impaired
Fish, Shellfish, and Wildlife Protection/Propagation	11,770,370	28%	66%	4%	30%
Aquatic Life Harvesting	9,390,396	23%	26%	1%	73%
Recreation	8,069,018	19%	70%	4%	26%
Public Water Supply	6,427,687	15%	78%	1%	20%
Industrial	2,848,335	7%	82%	<1%	17%

What percentage of US bays/estuaries are considered impaired?



Designated Use	Square Miles Assessed	Percentage of Total U.S. Estuarine Miles	Percentage of Waters Assessed		
			Good	Threatened	Impaired
Fish, Shellfish, and Wildlife Protection/Propagation	24,338	28%	73%	<1%	27%
Aquatic Life Harvesting	11,004	13%	81%	<1%	19%
Recreation	9,322	11%	87%	<1%	13%

Virginia Water Quality

What about Virginia, are we doing better than the rest of the nation?

Yeah, not so much: data below are from 2014 (draft) report.

Waterbody Type	Total	Assessed	Attained Use	Impaired[1]
Rivers (miles)	100,923	22,480 (22% of total)	6,441 (29% of assessed)	16,039 (71% of assessed)
Lakes (acres)	117,158	114,191 (97% of total)	19,425 (17% of assessed)	94,766 (83% of assessed)
Estuaries (sq. miles)	2,836	2,446 (86% of total)	310 (13% of assessed)	2,136 (87% of assessed)

Causes of Impairment in Virginia

What are the most common causes of water impairment in our fair state?