

CEE 370

Environmental Engineering Principles



Lecture #4

Environmental Chemistry II: Units of Concentration II, Stoichiometry & Chemistry I

[Reading: M&Z: Chapter 2](#)

Other: Davis & Masten, Chapter 2; Mihelcic, Chapt 2



Mass Based Concentration Units

- Solid samples

$$\frac{17.5 \text{ mg Pb}}{1 \text{ kg soil}} = \frac{17.5 \times 10^{-3} \text{ g Pb}}{1 \times 10^3 \text{ g soil}} = 17.5 \text{ g Pb} / 10^6 \text{ g soil}$$
$$= 17.5 \text{ ppm}_m \text{ Pb in soil}$$

$$1 \text{ mg} / \text{kg} = 1 \text{ ppm}_m$$
$$1 \mu\text{g} / \text{kg} = 1 \text{ ppb}_m$$



- Liquid samples

$$\frac{0.35\text{mg Fe}}{1\text{L water}}$$

$$\times \frac{1\text{L water}}{10^3 \text{ g water}}$$

Density of
Water at 5°C

$$= \frac{0.35\text{mg Fe}}{10^3 \text{ g water}} = \frac{0.35 \times 10^{-3} \text{ g Fe}}{10^3 \text{ g water}} = 0.35 \text{ g Fe} / 10^6 \text{ g water}$$

$$= 0.35 \text{ ppm}_m \text{ Fe in water}$$



Orders of magnitude

- Lower as toxicity increases

Mass/Volume Units	Mass/Mass Units	Typical Applications
g/L (grams/liter)	(parts per thousand)	Stock solutions
mg/L (milligrams/liter) 10^{-3} g/L	ppm (parts per million)	Conventional pollutants (DO, nitrate, chloride)
μg/L (micrograms/liter) 10^{-6} g/L	ppb (parts per billion)	Trihalomethanes, Phenols.
ng/L (nanograms/liter) 10^{-9} g/L	ppt (parts per trillion)	PCBs, Dioxins PFAS
pg/L (picograms/liter) 10^{-12} g/L		Pheromones



Molarity

- One mole of any substance contains 6.02×10^{23} (Avogadro's number) elementary chemical units (e.g., molecules).
- It is very convenient to measure concentrations in moles, since reactions conform to the law of definite proportions where integer ratios of reactants are consumed (e.g., 1:1, 1:2, etc.) on both a molecular and molar basis.

- It is calculated by:

$$\text{Molarity} = \frac{\text{mass} / L}{\text{GFW}}$$

- Often use M, mM, μM (molar, millimolar, micromolar)
 - To represent: moles/L, 10^{-3} moles/L, 10^{-6} moles/L *Try examples 2.8 & 2.9, on pg. 48 of Mihelcic & Zimmerman*



Normality

- Like molarity, but takes into account the stoichiometric ratios of reactants and products
- Measured in equivalents per liter

$$\text{Normality} = \frac{\text{mass} / L}{GEW}$$

- And Z is an integer related to the number of exchangeable hydrogen ions, or electrons the chemical has, or its overall charge

$$GEW = GFW / Z$$

Try examples 2.10-2.11, on pg. 49-50 of Mihelcic & Zimmerman

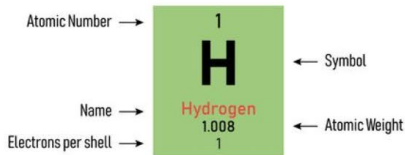


“Complete” water analysis

<i>Species</i>	<i>mg/L</i>	<i>meq/L</i>
Bicarbonate	153	2.5
Chloride	53	1.5
Sulfate	19.2	0.4
Calcium	44	2.2
Magnesium	10.9	0.9
Sodium	25.3	1.1
Potassium	7.8	0.2

Periodic Table of the Elements

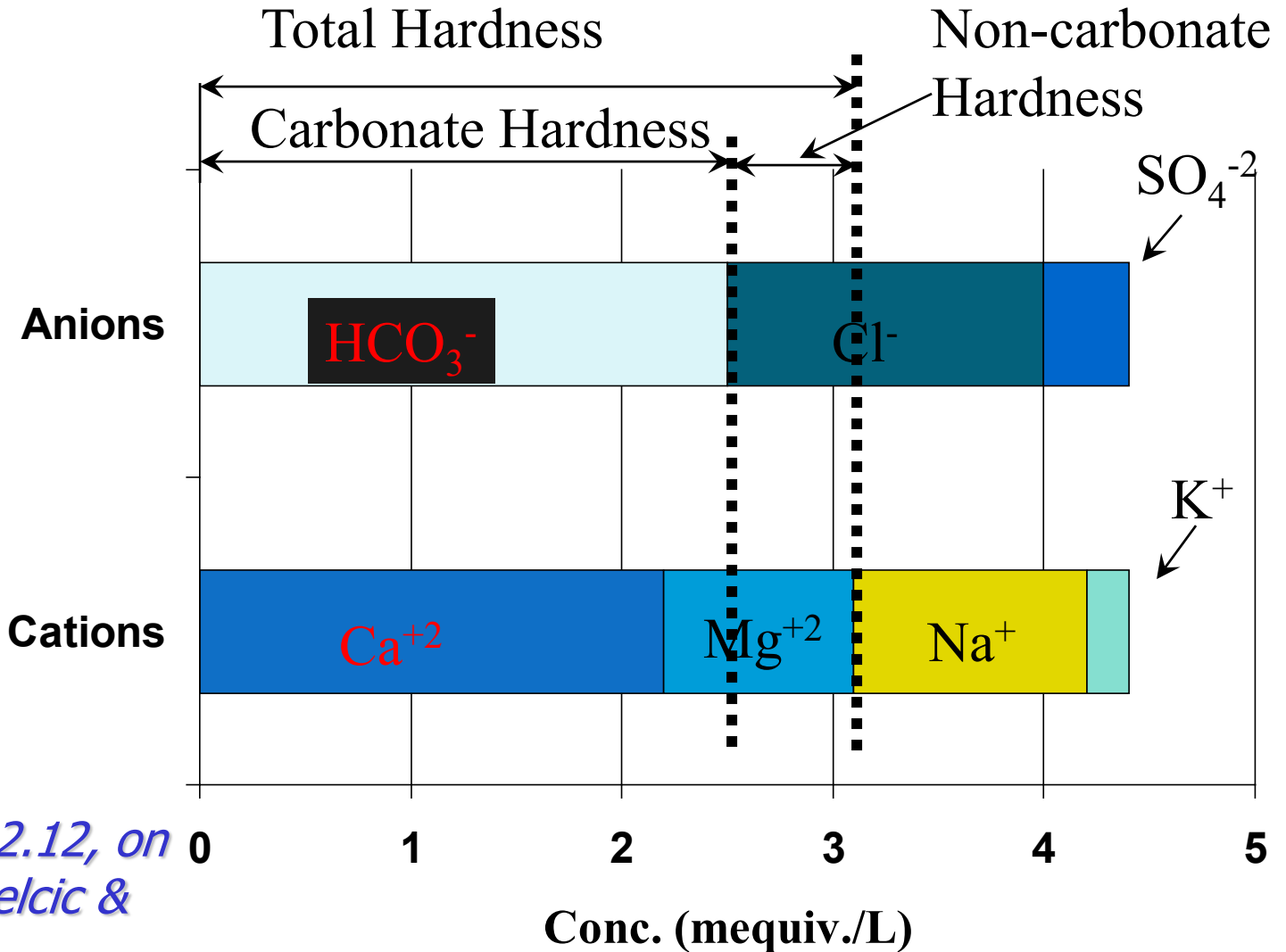
1 IA H Hydrogen 1.008 1																	18 VIIIA He Helium 4.0026 2
3 Li Lithium 6.94 2-1	4 IIA Be Beryllium 9.0122 1-2											13 IIIA B Boron 10.81 2-3	14 IVA C Carbon 12.011 2-4	15 VA N Nitrogen 14.007 2-5	16 VIA O Oxygen 15.999 2-6	17 VIIA F Fluorine 18.998 2-7	10 Ne Neon 20.180 2-8
11 Na Sodium 22.98976928 2-8-1	12 Mg Magnesium 24.305 2-8-2	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 Al Aluminium 26.982 2-8-3	14 Si Silicon 28.085 2-8-4	15 P Phosphorus 30.974 2-8-5	16 S Sulfur 32.06 2-8-6	17 Cl Chlorine 35.45 2-8-7	18 Ar Argon 39.948 2-8-8
19 K Potassium 39.0983 2-8-8-1	20 Ca Calcium 40.078 2-8-8-2	21 Sc Scandium 44.955908 2-8-9-2	22 Ti Titanium 47.867 2-8-9-2	23 V Vanadium 50.9415 2-8-9-2	24 Cr Chromium 51.9961 2-8-10-1	25 Mn Manganese 54.938044 2-8-10-2	26 Fe Iron 55.845 2-8-10-2	27 Co Cobalt 58.933 2-8-10-2	28 Ni Nickel 58.693 2-8-10-2	29 Cu Copper 63.546 2-8-10-1	30 Zn Zinc 65.38 2-8-10-2	31 Ga Gallium 69.723 2-8-10-3	32 Ge Germanium 72.630 2-8-10-4	33 As Arsenic 74.922 2-8-10-5	34 Se Selenium 78.971 2-8-10-6	35 Br Bromine 79.904 2-8-10-7	36 Kr Krypton 83.798 2-8-10-8
37 Rb Rubidium 85.4678 2-8-18-8-1	38 Sr Strontium 87.62 2-8-18-8-2	39 Y Yttrium 88.90584 2-8-18-9-2	40 Zr Zirconium 91.224 2-8-18-10-2	41 Nb Niobium 92.90637 2-8-18-10-1	42 Mo Molybdenum 95.95 2-8-18-10-1	43 Tc Technetium (98) 2-8-18-10-2	44 Ru Ruthenium 101.07 2-8-18-10-1	45 Rh Rhodium 102.91 2-8-18-10-1	46 Pd Palladium 106.42 2-8-18-10-1	47 Ag Silver 107.87 2-8-18-10-1	48 Cd Cadmium 112.41 2-8-18-10-2	49 In Indium 114.82 2-8-18-10-3	50 Sn Tin 118.71 2-8-18-10-4	51 Sb Antimony 121.76 2-8-18-10-5	52 Te Tellurium 127.60 2-8-18-10-6	53 I Iodine 126.90 2-8-18-10-7	54 Xe Xenon 131.29 2-8-18-10-8
55 Cs Cesium 132.90545196 2-8-18-32-8-1	56 Ba Barium 137.327 2-8-18-32-8-2	57-71 Lanthanides	72 Hf Hafnium 178.49 2-8-18-32-10-2	73 Ta Tantalum 180.94788 2-8-18-32-11-2	74 W Tungsten 183.84 2-8-18-32-12-2	75 Re Rhenium 186.21 2-8-18-32-13-2	76 Os Osmium 190.23 2-8-18-32-14-2	77 Ir Iridium 192.22 2-8-18-32-15-2	78 Pt Platinum 195.08 2-8-18-32-17-1	79 Au Gold 196.97 2-8-18-32-18-1	80 Hg Mercury 200.59 2-8-18-32-18-2	81 Tl Thallium 204.38 2-8-18-32-18-3	82 Pb Lead 207.2 2-8-18-32-18-4	83 Bi Bismuth 208.98 2-8-18-32-18-5	84 Po Polonium 209 2-8-18-32-18-6	85 At Astatine 210 2-8-18-32-18-7	86 Rn Radon 222 2-8-18-32-18-8
87 Fr Francium (223) 2-8-18-32-18-8-1	88 Ra Radium (226) 2-8-18-32-18-8-2	89-103 Actinides	104 Rf Rutherfordium (267) 2-8-18-32-32-10-2	105 Db Dubnium (268) 2-8-18-32-32-11-2	106 Sg Seaborgium (269) 2-8-18-32-32-12-2	107 Bh Bohrium (270) 2-8-18-32-32-13-2	108 Hs Hassium (277) 2-8-18-32-32-14-2	109 Mt Meitnerium (278) 2-8-18-32-32-15-2	110 Ds Darmstadtium (281) 2-8-18-32-32-17-1	111 Rg Roentgenium (282) 2-8-18-32-32-17-2	112 Cn Copernicium (285) 2-8-18-32-32-18-2	113 Nh Nihonium (286) 2-8-18-32-32-18-3	114 Fl Flerovium (289) 2-8-18-32-32-18-4	115 Mc Moscovium (290) 2-8-18-32-32-18-5	116 Lv Livermorium (293) 2-8-18-32-32-18-6	117 Ts Tennessine (294) 2-8-18-32-32-18-7	118 Og Oganesson (294) 2-8-18-32-32-18-8
57 La Lanthanum 138.91 2-8-18-32-18-9-2	58 Ce Cerium 140.12 2-8-18-32-18-9-2	59 Pr Praseodymium 140.91 2-8-18-32-18-9-2	60 Nd Neodymium 144.24 2-8-18-32-18-9-2	61 Pm Promethium (145) 2-8-18-32-18-9-2	62 Sm Samarium 150.36 2-8-18-32-18-9-2	63 Eu Europium 151.96 2-8-18-32-18-9-2	64 Gd Gadolinium 157.25 2-8-18-32-18-9-2	65 Tb Terbium 158.93 2-8-18-32-18-9-2	66 Dy Dysprosium 162.50 2-8-18-32-18-9-2	67 Ho Holmium 164.93 2-8-18-32-18-9-2	68 Er Erbium 167.26 2-8-18-32-18-9-2	69 Tm Thulium 168.93 2-8-18-32-18-9-2	70 Yb Ytterbium 173.05 2-8-18-32-18-9-2	71 Lu Lutetium 174.97 2-8-18-32-18-9-2			
89 Ac Actinium (227) 2-8-18-32-18-9-2	90 Th Thorium 232.04 2-8-18-32-18-9-2	91 Pa Protactinium 231.04 2-8-18-32-20-9-2	92 U Uranium 238.03 2-8-18-32-71-9-2	93 Np Neptunium (237) 2-8-18-32-72-9-2	94 Pu Plutonium (244) 2-8-18-32-74-9-2	95 Am Americium (243) 2-8-18-32-75-9-2	96 Cm Curium (247) 2-8-18-32-75-9-2	97 Bk Berkelium (247) 2-8-18-32-77-9-2	98 Cf Californium (251) 2-8-18-32-78-9-2	99 Es Einsteinium (252) 2-8-18-32-79-9-2	100 Fm Fermium (257) 2-8-18-32-80-9-2	101 Md Mendelevium (258) 2-8-18-32-81-9-2	102 No Nobelium (259) 2-8-18-32-82-9-2	103 Lr Lawrencium (266) 2-8-18-32-83-9-2			



State of matter (color of name)
GAS **LIQUID** **SOLID** **UNKNOWN**

Subcategory in the metal-metalloid-nonmetal trend (color of background)
■ Alkali metals ■ Lanthanides ■ Metalloids ■ Unknown chemical properties
■ Alkaline earth metals ■ Actinides ■ Reactive nonmetals
■ Transition metals ■ Post-transition metals ■ Noble gases

Anion-Cation Balance



See example 2.12, on
pg. 50 of Mihelcic &
Zimmerman

David Reckhow

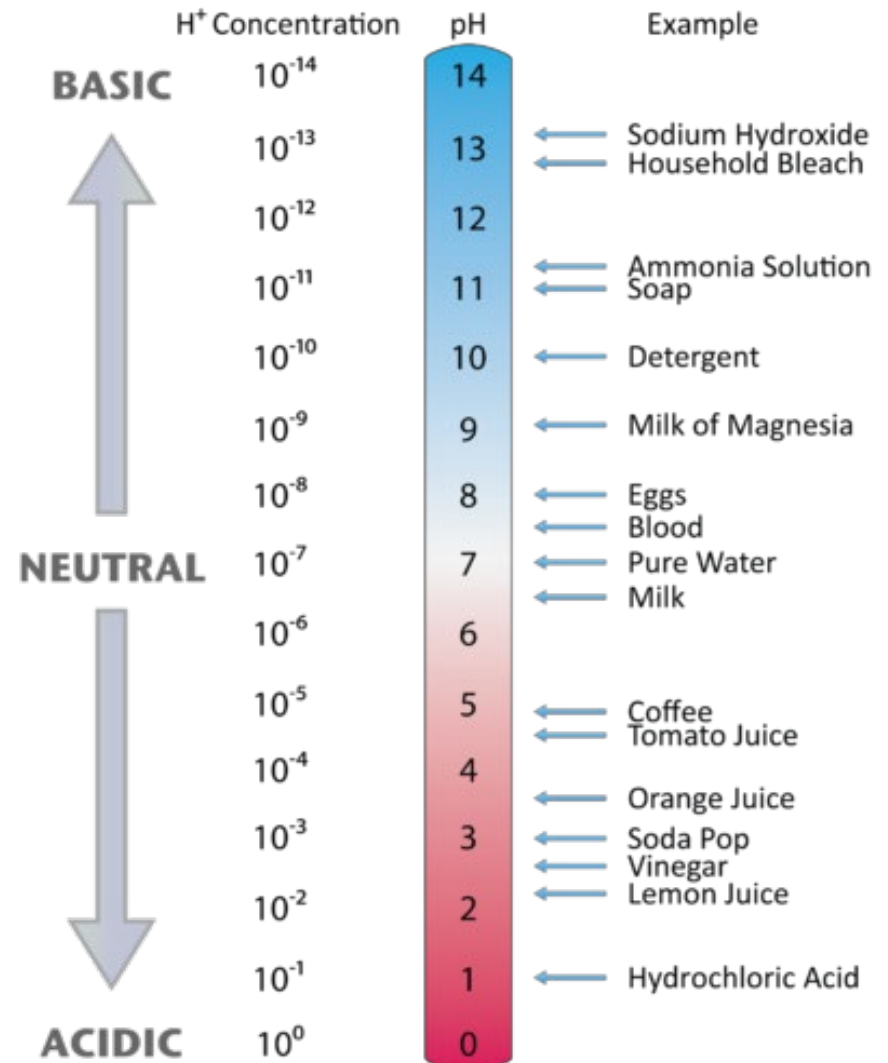


pH

- Definition
 - $\text{pH} = -\log\{\text{H}^+\} \sim -\log[\text{H}^+]$
- Significance
 - treatment systems
 - coagulation, softening, ppt of metals, disinfection, biological processes
 - natural systems
 - mineral formation, sorption
 - research

pH

- Where is coke?

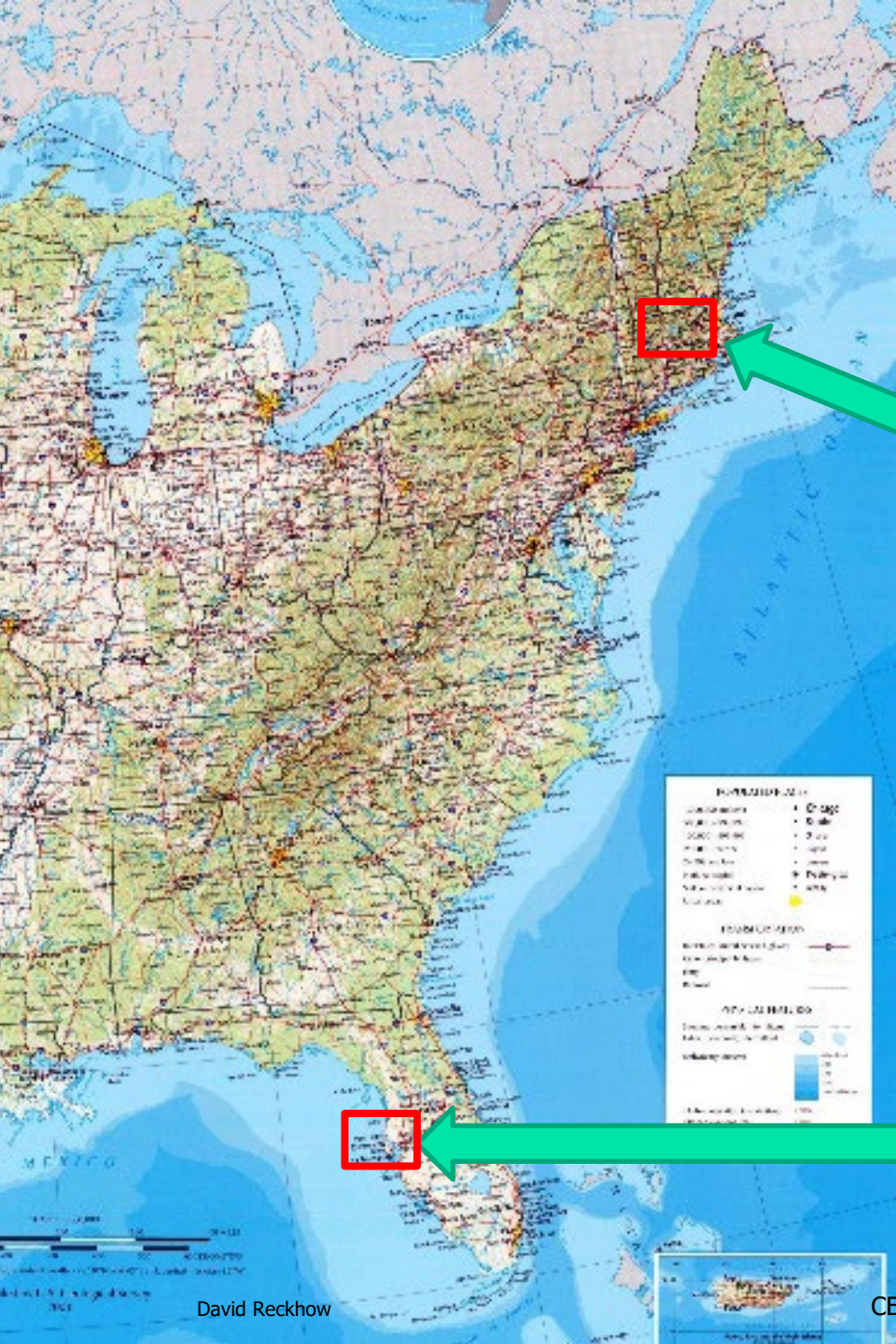


Example 2: two raw waters

**Quabbin Reservoir,
MA**

- What happens when you add 0.001 moles of HCl to each?

Tampa Bay, FL



Both waters start at pH 7

Tampa Bay, FL

- Alkalinity = 200 mg/L
- pH drops to 6.8

Quabbin Reservoir, MA

- Alkalinity = 5 mg/L
- pH drops to 3.1



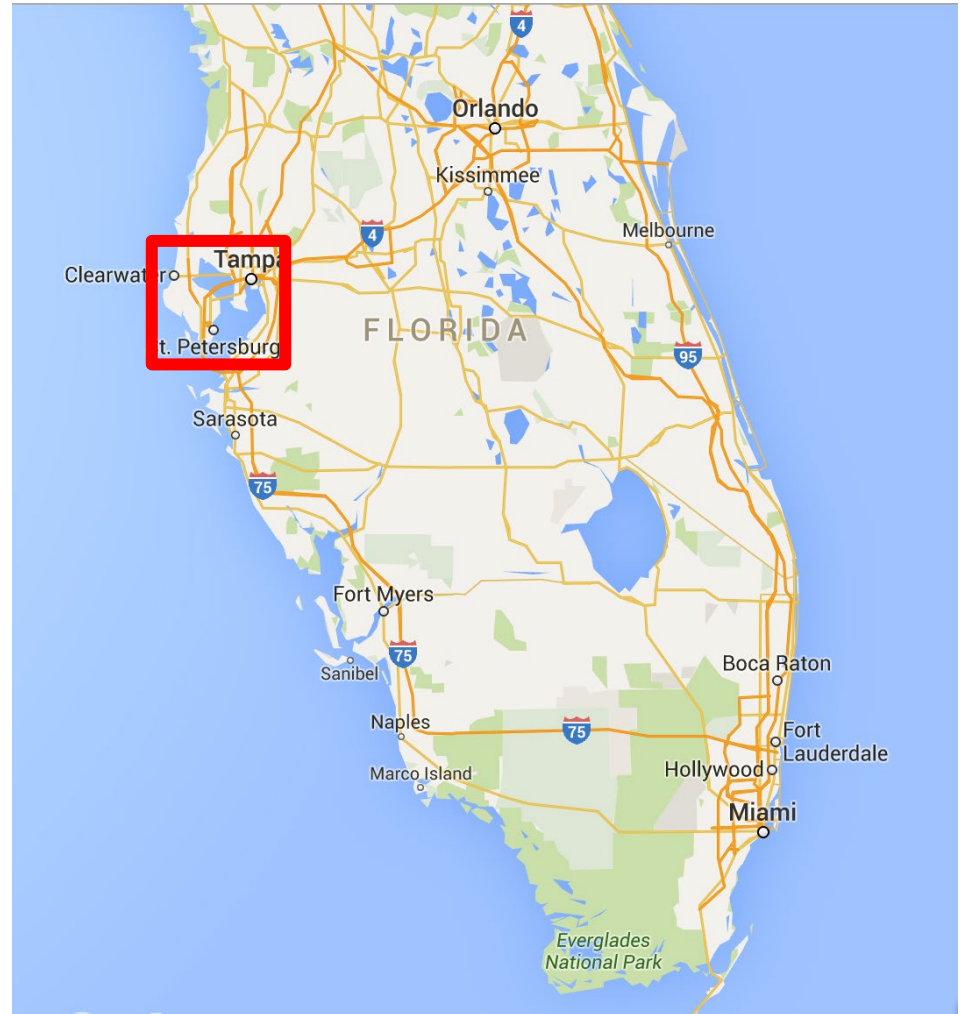
Add 0.001
moles/L of
Hydrochloric
Acid (HCl) to
each



Example 3: differing water quality

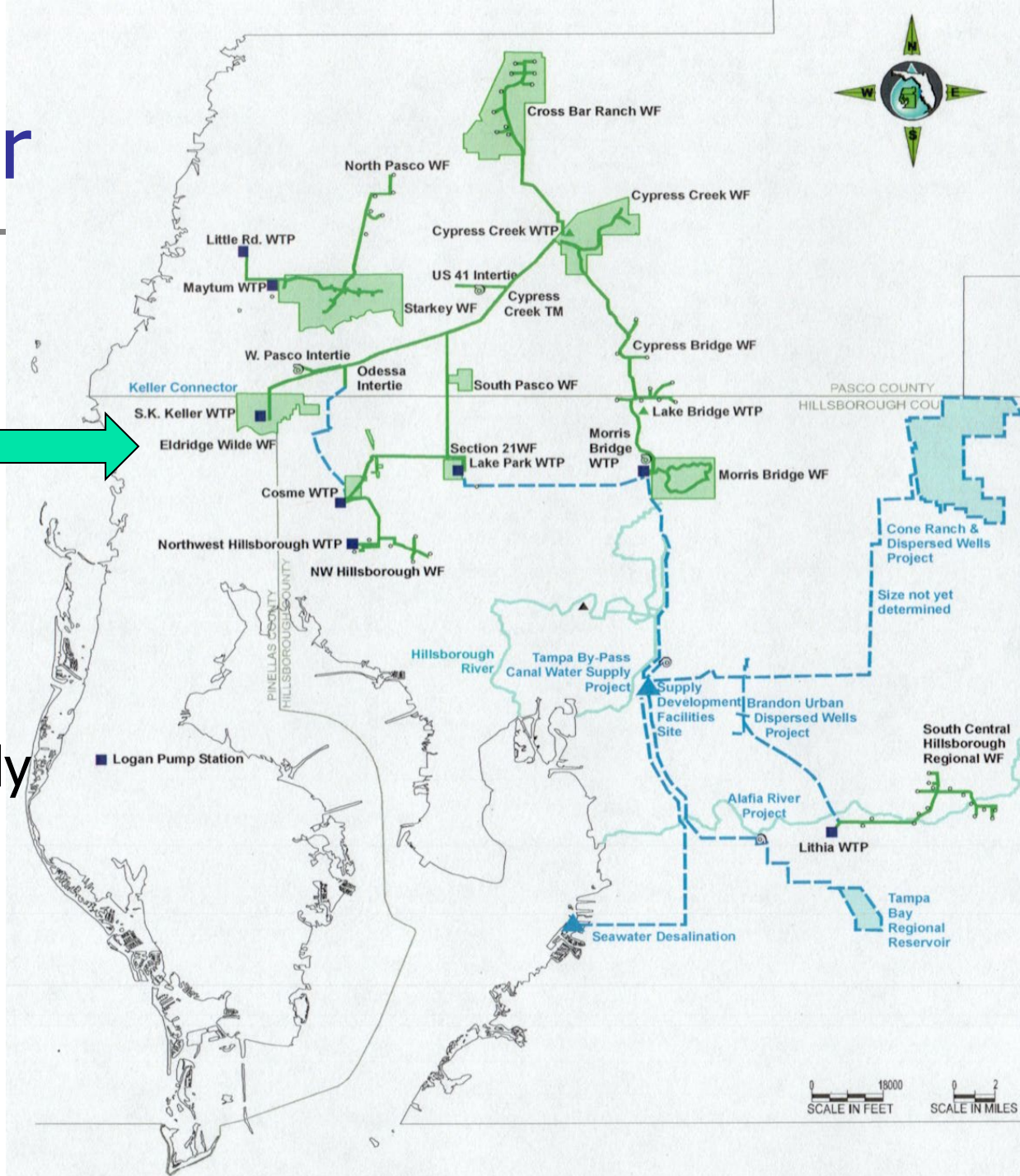
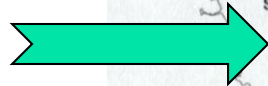
- Many, perhaps most, drinking water utilities have multiple sources
- Often those sources have contrasting water quality
- Especially

David Reckhow



Groundwater and surface water

- Tampa Bay area and regional supply
 - Groundwater
 - River water
 - Ocean water: desal



Keller 2

Groundwater source: Eldridge Wilde Well field

40 MGD

WQ Challenge

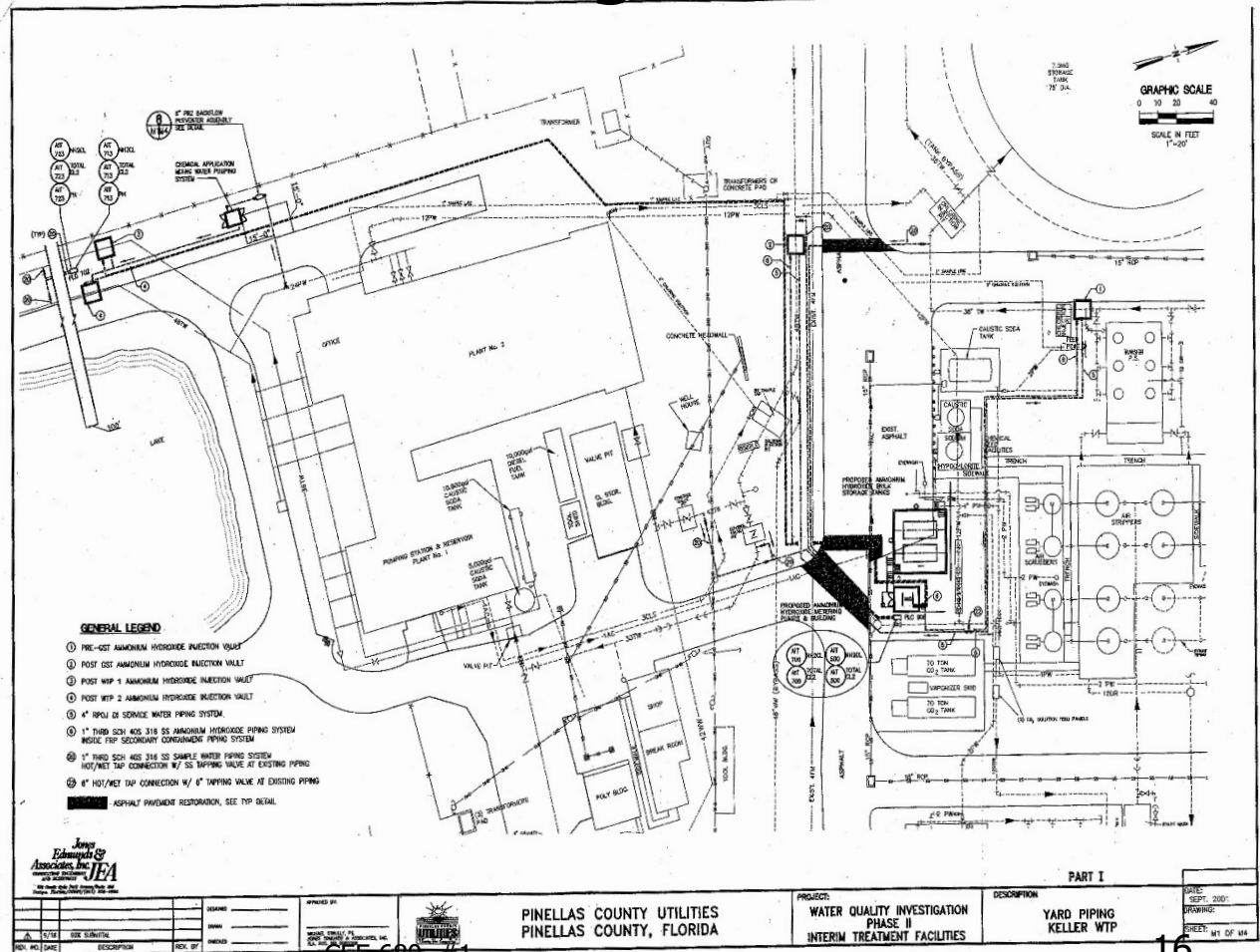
- 1-1.5 ppm H₂S, VOCs

Water Treatment

- Air Stripping with CO₂
- Chlorination
- Ammoniation
- Polyphosphate

Air treatment

- Water scrubbing with caustic & chlorine



Majors – mostly inorganics

■ Keller Plant 2 Sample Station: Aug 9, 2010

Parameter	Value	Units	Parameter	Value	Units
Calcium	77.7	mg/L	Sulfate	4	mg/L
Iron	0.018	mg/L	Phosphorus, Total (as P)	0.23	mg/L
Magnesium	5.08	mg/L	Alkalinity as CaCO ₃	209	mg/L
Arsenic	0.0002	mg/L	Total Hardness	215	mg/L
Copper	0.0013	mg/L	Total Dissolved Solids	316	mg/L
Lead	0.0001	mg/L	Ammonia as N	0.84	mg/L
Bromide	0.05	mg/L	Free Ammonia as N	0.16	mg/L
Chloride	22	mg/L	Total Organic Carbon	3.7	mg/L
Nitrate as N	0.04	mg/L	UV 254	0.117	cm - 1
Nitrite as N	0.02	mg/L	Heterotrophic Plate Count	3	CFU/ml
Orthophosphate as P	0.12	mg/L	E. coli	1	MPN/100ml
Orthophosphate as PO ₄	0.37	mg/L	Total Coliforms	1	MPN/100ml

Trace Organics above MDL

■ Keller Plant 2 Sample Station: Aug 9, 2010

Parameter	Value	Units	Parameter	Value	Units
Bromodichloromethane	8.3	ug/L	Dibromoacetonitrile	0.77	ug/L
Chloroform	45	ug/L	Dichloroacetonitrile	10.7	ug/L
Dibromochloromethane	0.9	ug/L	Total Haloacetonitriles	13.3	ug/L
Total Trihalomethanes	54.2	ug/L	Trichloroacetonitrile	0.12	ug/L
1,1,1-Trichloro-2-propanone	3.47	ug/L	Chloral hydrate	5.45	ug/L
1,1-Dichloro-2-propanone	1.36	ug/L	Dichloroacetic acid	12.6	ug/L
Bromochloroacetonitrile	1.73	ug/L	Total Haloacetic Acids (HAA5)	31.8	ug/L
Chloropicrin	0.21	ug/L	Trichloroacetic acid	19	ug/L



Tampa Bay Questions

- What does the detailed analysis tell you?
- Does it make sense?
- Expressions of concentration?
- Principle of electroneutrality?
- TDS, TH, Alk, TOC, UV – what do these mean



Tampa Bay water analysis

The major
constituents
and some
microbials

Substance	Conc.	units
Calcium		77.7mg/L
Iron		0.018mg/L
Magnesium		5.08mg/L
Arsenic		0.0002mg/L
Copper		0.0013mg/L
Lead		0.0001mg/L
Bromide		0.05mg/L
Chloride		22mg/L
Nitrate as N		0.04mg/L
Nitrite as N		0.02mg/L
Orthophosphate as P		0.12mg/L
Orthophosphate as PO ₄ , calculated		0.37mg/L
Sulfate		4mg/L
Phosphorus, Total (as P)		0.23mg/L
Alkalinity as CaCO ₃		209mg/L
Total Hardness		215mg/L
Total Dissolved Solids		316mg/L
Ammonia as N		0.84mg/L
Free Ammonia as N		0.16mg/L
Total Organic Carbon		3.7mg/L
UV 254		0.117cm - 1
Heterotrophic Plate Count		3CFU/ml
E. coli		1MPN/100ml
Total Coliforms		1MPN/100ml

Tampa Bay Calculations

Substance	Conc. (mg/L)	GFW	mM	charge/M	meq/L	pos	neg
Calcium	77.7	40.078	1.9387	2	3.87744	3.87744	
Iron	0.018	55.845	0.0003	3	0.00097	0.00097	
Magnesium	5.08	24.305	0.2090	2	0.41802	0.41802	
Arsenic	0.0002	74.922	0.0000	-1	0.00000		0.00000
Copper	0.0013	63.546	0.0000	2	0.00004	0.00004	
Lead	0.0001	207.2	0.0000	2	0.00000	0.00000	
Bromide	0.05	79.904	0.0006	-1	-0.00063		-0.00063
Chloride	22	35.453	0.6205	-1	-0.62054		-0.62054
Nitrate as N	0.04	14.007	0.0029	-1	-0.00286		-0.00286
Nitrite as N	0.02	14.007	0.0014	-1	-0.00143		-0.00143
Orthophosphate as P	0.12	30.974	0.0039	-3	-0.01162		-0.01162
Orthophosphate as PO4, calculated	0.37	94.97	0.0039	-3	-0.01169		
Sulfate	4	96.061	0.0416	-2	-0.08328		-0.08328
Phosphorus, Total (as P)	0.23	30.974	0.0074		0.00000		
Alkalinity as CaCO3	209	50.037	4.1769	-1	-4.17691		-4.17691
Total Hardness	215	100.074	2.1484	2	4.29682		
Total Dissolved Solids	316						
Ammonia as N	0.84	14.007	0.0600				
Free Ammonia as N	0.16	14.007	0.0114	1	0.01142	0.01142	
Total Organic Carbon	3.7	12.011	0.3081		0.00000	0.00000	0.00000
Total =	854.33				sum	4.30789	-4.89726
	323.33	exclude TDS, TH			diff		-0.58937
					%		12.0%



Tampa Bay Discussion

- Missing Na, K
 - 13.5 mg/L Na would close the balance



Calcium carbonate units

- Used for major ion concentrations in drinking waters
 - Alkalinity
 - Hardness
- Since CaCO_3 is divalent ($Z=2$) and its GFW is 100 g, its GEW is 50 g
 - 50 g/equivalent or 50 mg/meq
 - 50,000 mg/equivalent

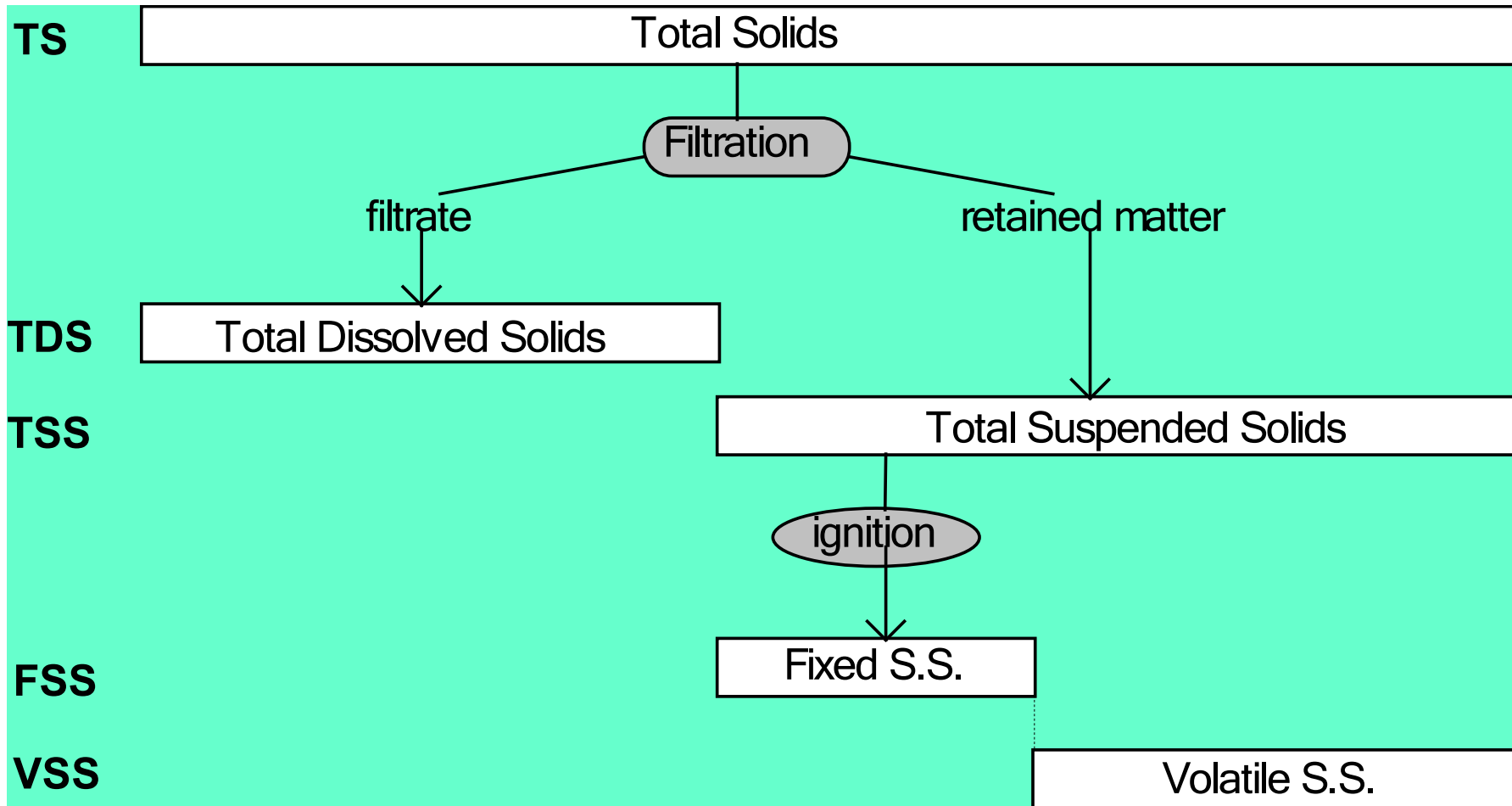
*See also example
2.14, on pg. 52 of
Mihelcic &
Zimmerman*



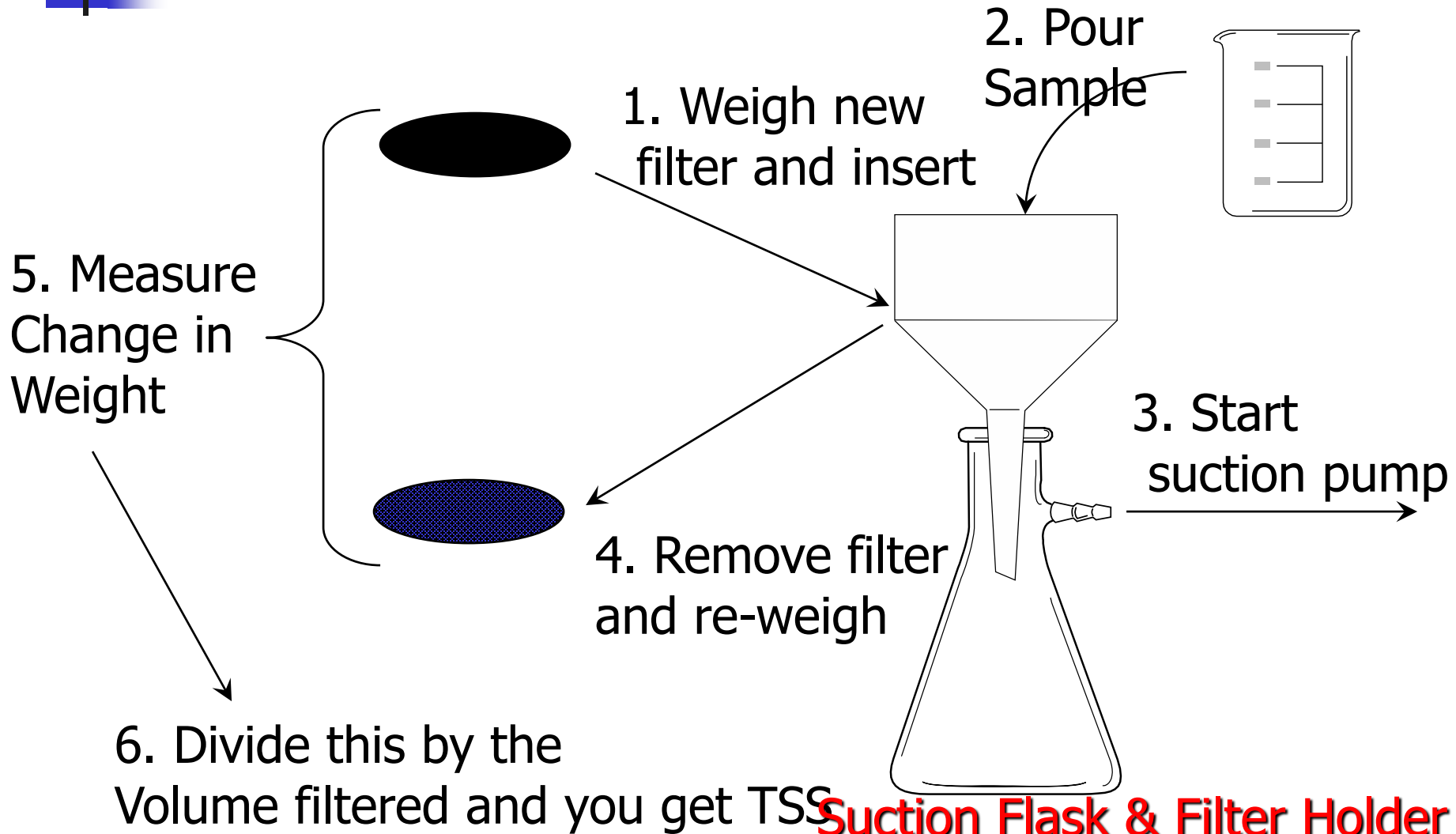
Solids: significance

- TDS: used as a measure of inorganic salt content in drinking waters and natural waters
- TSS: used to assess clarifier performance
- VSS: used to estimate bacterial populations in wastewater treatment systems

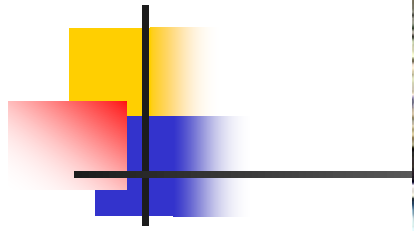
Solids Analysis



Filtration for Solids Analysis







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- To next lecture