# Wastewater 101

## FUNdamentals

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# Objectives

- Understand the history of clean water
- Review and upgrade wastewater vocabulary
- Discuss different sources of wastewater
- Define fundamental treatment classes
- Basic calculation

# Aaron Burke P.E.

- 2003 B.S. in Civil Engineering, Rose-Hulman Institute of Technology
- 2011 M.Eng. in Civil Engineering, Norwich University
- Field Engineering
- Engineering Design
- Project Management
- Entrepreneur/Inventor

# OUTLINE

# Part I: Why Treat Wastewater?

- Public Health
- Environmental Water Quality
- Regulations
  - Federal Water Pollution Control Act
  - → Clean Water Act
- Hydrologic/Pollutant Cycles
- Water Security

# 170 Years of Public Health

- The “Sanitary Idea” starts in Great Britain
- 1842 Sir Edwin Chadwick, *General Report on the Sanitary Conditions*
- 1846 Nuisances Removal Act, Great Britain
- 1848 Public Health Act, General Board of Health, London
- 1849 John Snow, *On the Mode of Communication of Cholera*, London
- 1850’s Epidemiologic Society of London
- 1853, Louis Pasteur, France
- 1873 William Budd, *Typhoid Fever*, Bristol, U.K.

# The “Great Stink” in the U.K.

- Summer 1858, London
- Thames River
- Joseph Bazalgette, Civil Engineer
- 1856 First plan to remedy
- 1875 Completed
- $1.4B in 2020 dollars

Source: Wikimedia

# Public Health in the U.S.

- 1850 Lemuel Shattuck, *Report of the Sanitary Commission of Massachusetts*
- 1890’s Bacteriology and State Laboratories
- Public health becomes a scientific enterprise and a “province of experts”
- “Vital Statistics” as a science
- 1888, W.T. Sedgwick, MIT
- 1912 Public Health Service Act
- 1915-1945 C-E.A. Winslow, Yale Dept. of Public Health

# Cuyahoga River, Cleveland, 1969

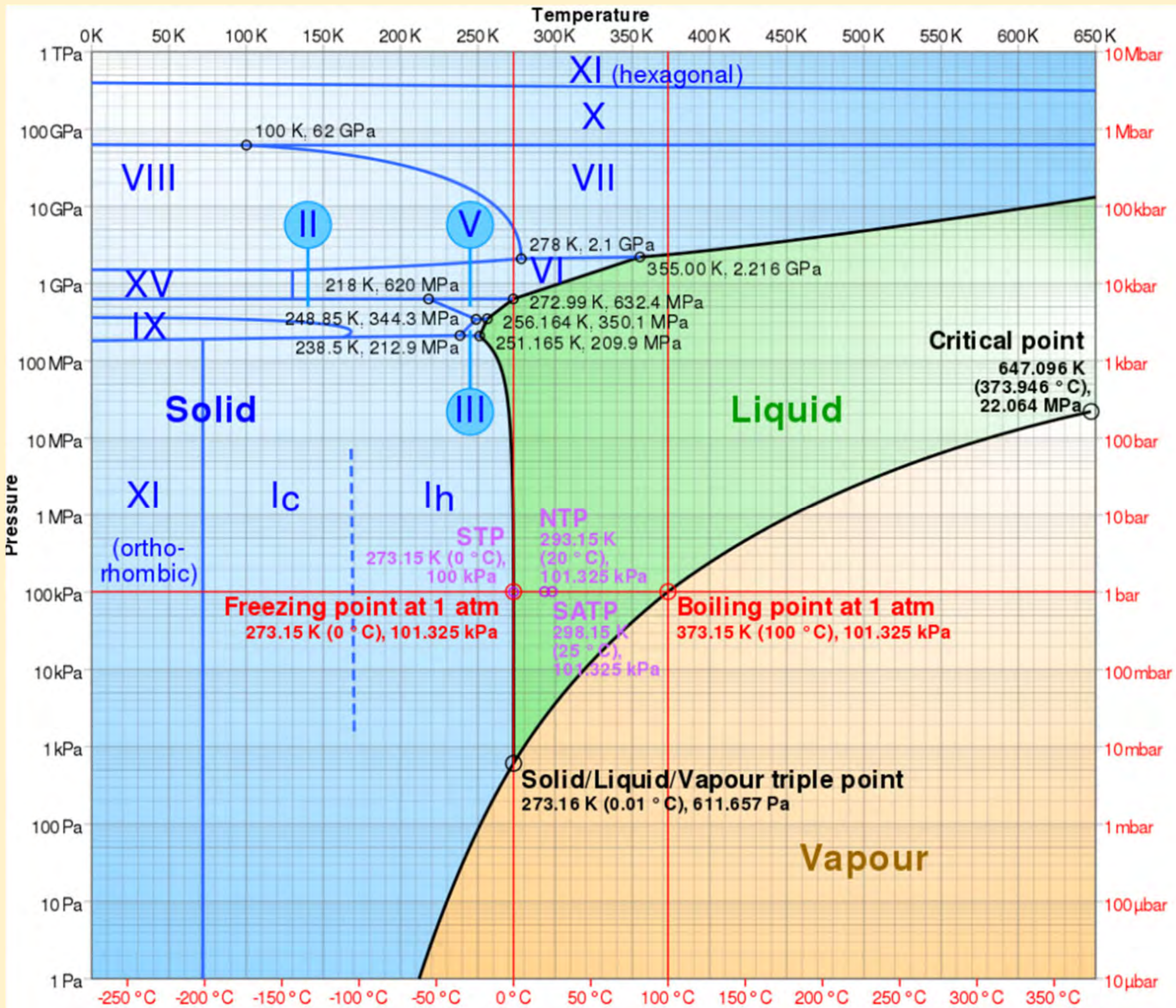
# Regulations in the U.S.

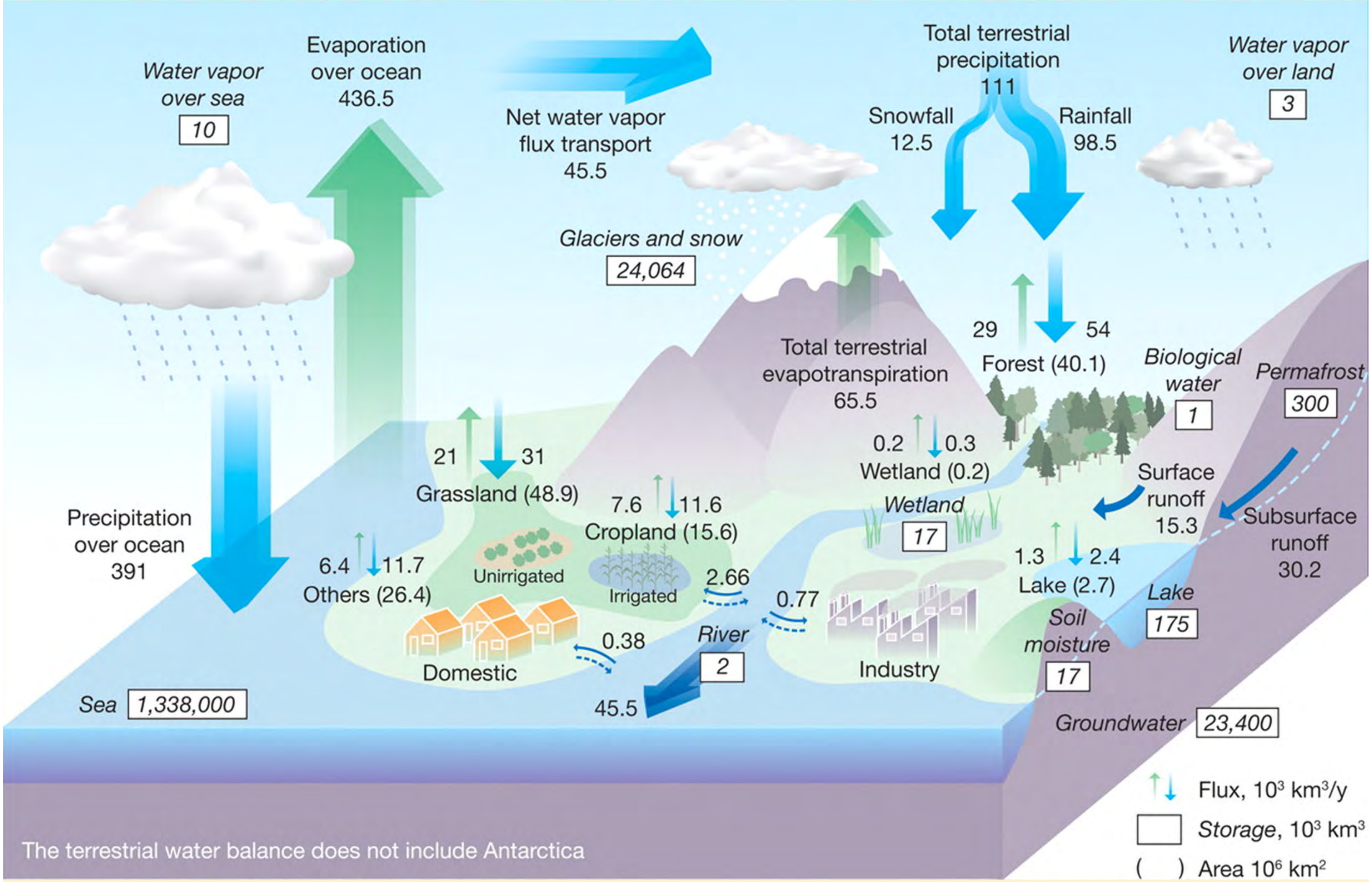
- 1899 Rivers and Harbors Act
- 1942 Water Pollution Control Act
- 1958 Federal Water Pollution Control Act
- 1965 Water Quality Act
- 1972 FWPCA amended to become Clean Water Act
- 1981 Municipal Waste Treatment Construction Grants Amendments
- 1987 State Water Pollution Control Revolving Fund (a.k.a. Clean Water State Revolving Fund, SRF)
- 1990 parts of 1987 Great Lakes Water Quality Agreement with Canada

# Hydrologic Cycle

- All (most) water is connected
- Phases of Water
  - Solid
  - Liquid
  - Gas

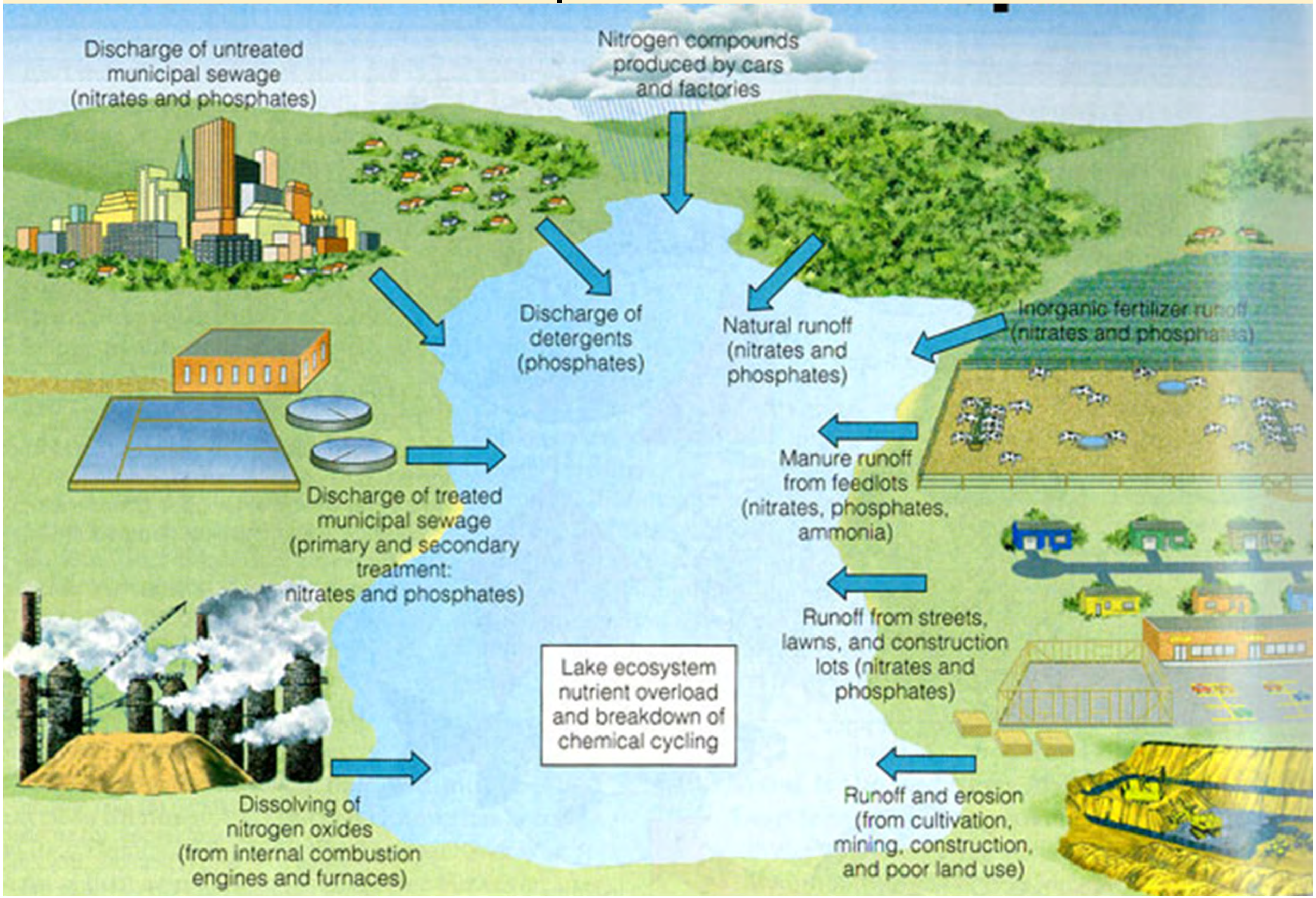
Source: https://en.wikipedia.org/wiki/Phase_diagram#/media/File:Phase_diagram_of_water.svg






Source: https://science.sciencemag.org/content/313/5790/1068.full

# Cultural Eutrophication



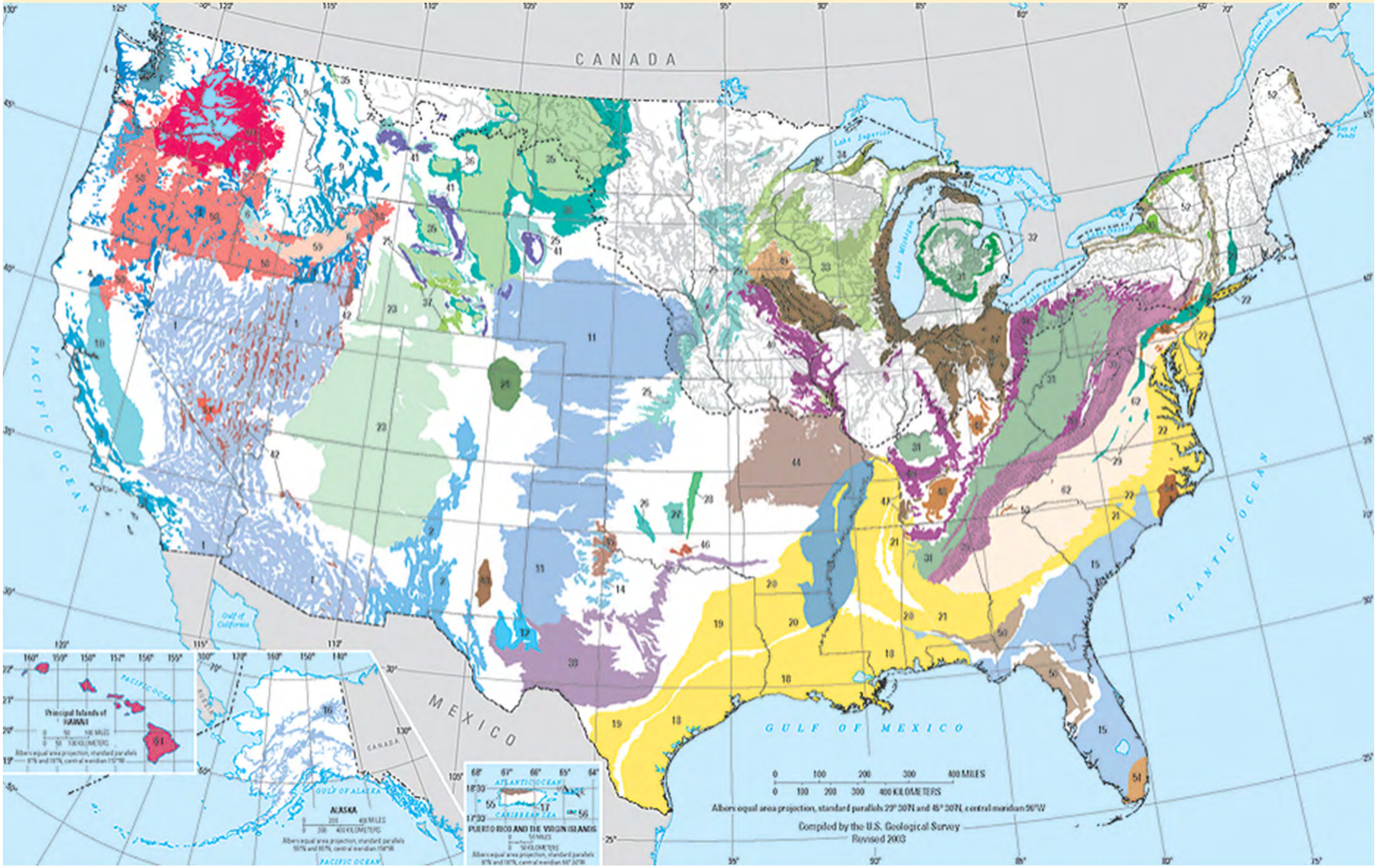
# Environmental Regulation Serves

- Improve public health
- Limit human made pollution in water
- Protect animal life
- Protect water sources

# Water Security

- Complex issue
- Riparian rights
- Climate Change
- Technological Limits

# Groundwater Aquifers in the U.S.



# Part II: Nomenclature

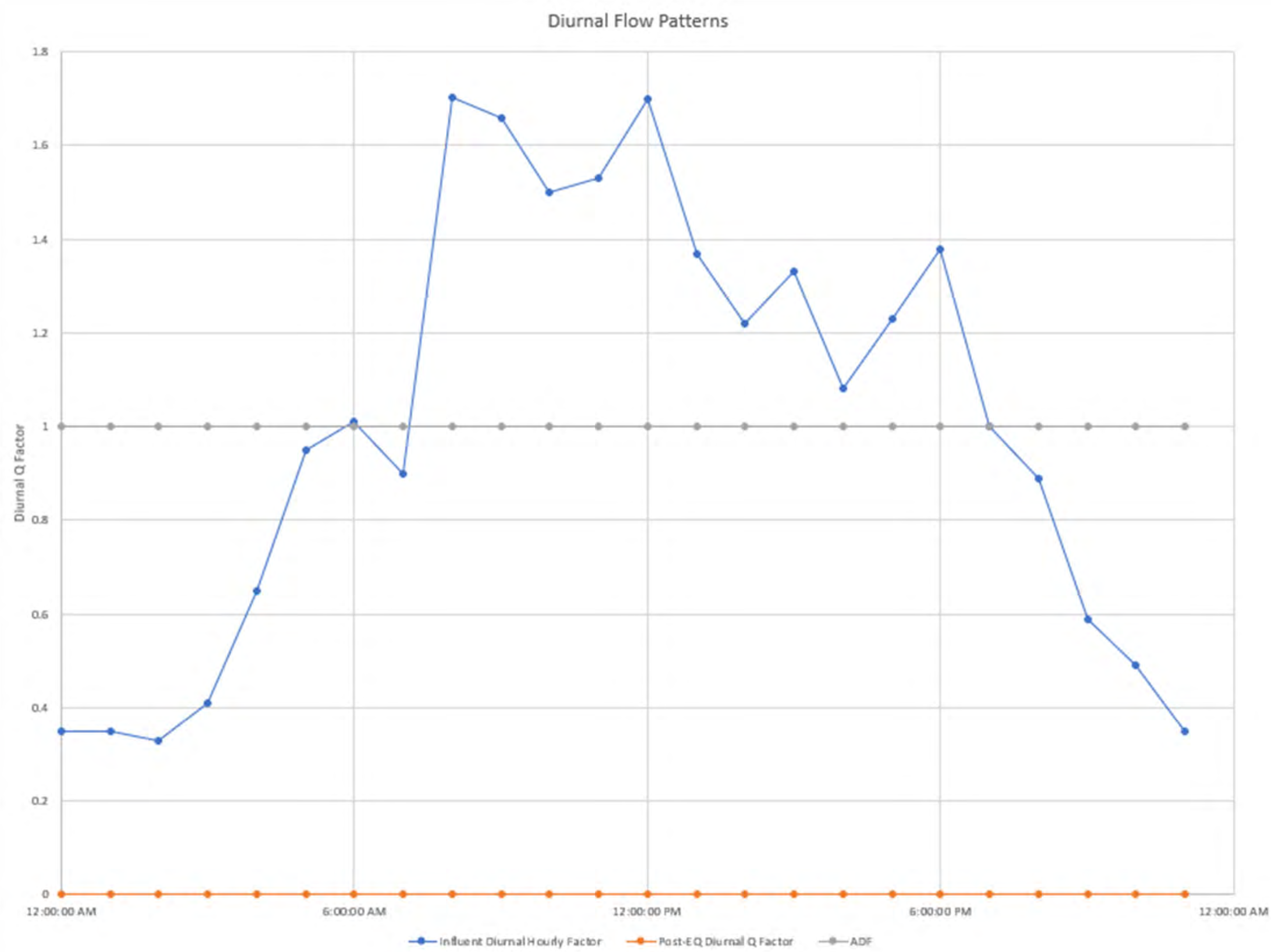
- Definitions
- Wastewater Characterization
- The Magic Wastewater Equation

# Relevant Definitions

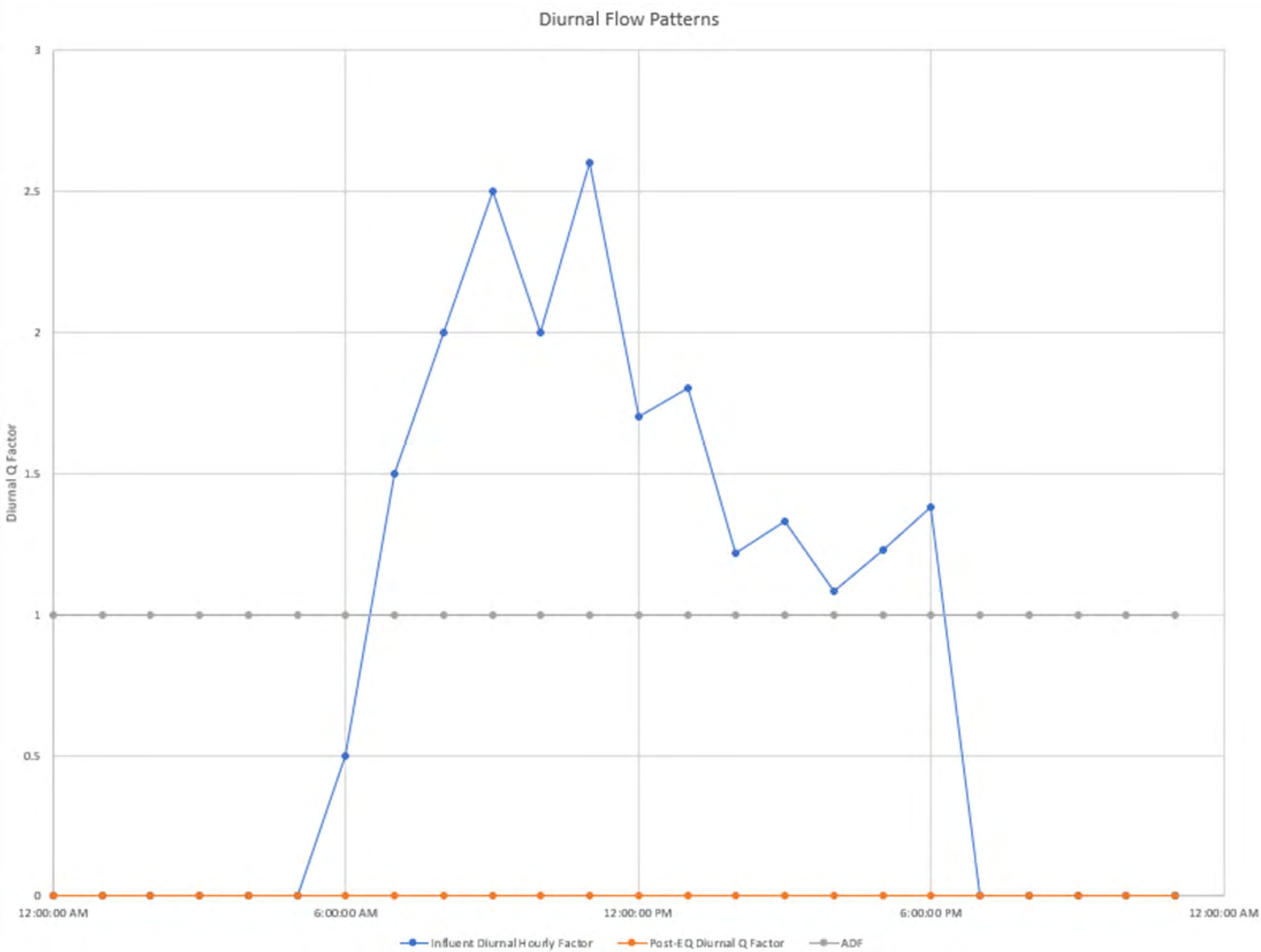
- Wastewater
- Pollutant
- CWA -> NPDES
- Other "Regulations"
- Point Source/Non-point Source
- Discharge Permit
- Industrial/Residential/Municipal
- Certified Operator
- Engineer of Record

# Flow Definitions

- Volume/Time
- Average Daily Flow/Design Average Flow (ADF)
- Peak Daily Flow/Design Maximum Day Flow (PDF)
- Peak Hourly Flow/Design Peak Hourly Flow (PHF)
- Design Peak Instantaneous Flow (PIF)
- Diurnal Flow Pattern



Diurnal Flow Patterns
Diurnal Q Factor
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00:00 AM
6:00:00 AM
12:00:00 PM
6:00:00 PM
12:00:00 AM
Influent Diurnal Hourly Factor
Post-EQ Diurnal Q Factor
ADF



Diurnal Flow Patterns
Diurnal Q Factor
3
2.5
2
1.5
1
0.5
0
12:00:00 AM
6:00:00 AM
12:00:00 PM
6:00:00 PM
12:00:00 AM
Influent Diurnal Hourly Factor
Post-EQ Diurnal Q Factor
ADF

# Typical Flow Rates in Wastewater

- Common:
  - Water: Million Gallons per Day (MGD)
  - Water: Gallons per Day (gpd)
  - Water: Gallons per Minute (gpm)
  - Air: Cubic Feet per Minute (cfm)
  - Chemical: milliLiters per Hour (mL/h)
- Less Common:
  - Water: Gallons per Hour (gph)
  - Water: Cubic Feet per Second (cfs)
  - Water: Cubic Meters per Day ($m^3$/d)

# Characterization: What is in it?

- Inorganic non-metallic
- Metallic
- Aggregate Organics
- Individual Organics
- Microbial
- Radionuclides
- Toxics
- Which parts do we need?

# Organic vs. Inorganic

- Inorganic:
  - pH/Alkalinity
  - Chlorides/Sulfides
  - Nutrients
    - Nitrogen
    - Phosphorus
  - Metals
- Organic:
  - Carbon + Hydrogen + Oxygen, and sometimes Nitrogen
  - 40-60% Protein : 25-50% Carbs : 8-12% Oils & Fats

# Macro Nutrients

- C = Carbon
- N = Nitrogen
- P = Phosphorus
- C:N:P Ratio 100:10:1 or 100:10:5
- Ex: 350 mg/L $BOD_5$ : 35 mg/L TKN : 5 mg/L TP
- Also Macro:

| | |
|---|---|
| Calcium | Magnesium |
| Iron | Potassium |
| Sodium | |

# Micro/Trace Nutrients

- Required, but may also be Inhibitory
- Includes:
  - Chromium*
  - Cobalt
  - Copper*
  - Lead*
  - Magnesium
  - Manganese
  - Nickel*
  - Selenium
  - Tungsten
  - Vanadium
  - Zinc*
  - Molybdenum
- * Also toxic at threshold

# What Happens?

- Stalled Biological Reactions
- Poor Effluent Quality
- Permit Exceedances
- Regulatory Action

# What to Do?

- Add Nutrients!!!
- Dog food = Carbon
- Methanol = Carbon
- Fertilizer = Nitrogen and Phosphorus
- Proprietary Blends
- Proprietary Biology

# Typical Waste Constituents

- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD)
- Total/Volatile Suspended Solids (TSS/VSS)
- Nitrogen (TN, TKN, $NH_3$-N, $NO_2$, $NO_3$)
- Phosphorus (TP)
- pH/Alkalinity
- Dissolved Oxygen (DO)
- Testing Methods per 40 CFR Part 136

# Concentration and Loading

- Concentration = Mass/Volume = mg/L : ppm : g/$m^3$
- Load = Mass/Time = lb/d : kg/d
- Related by Flow and the Magic Equation
- Unit Load = Loading/Volume = lb/d/1,000 $ft^3$

  = Loading/Area = lb/d/$ft^2$

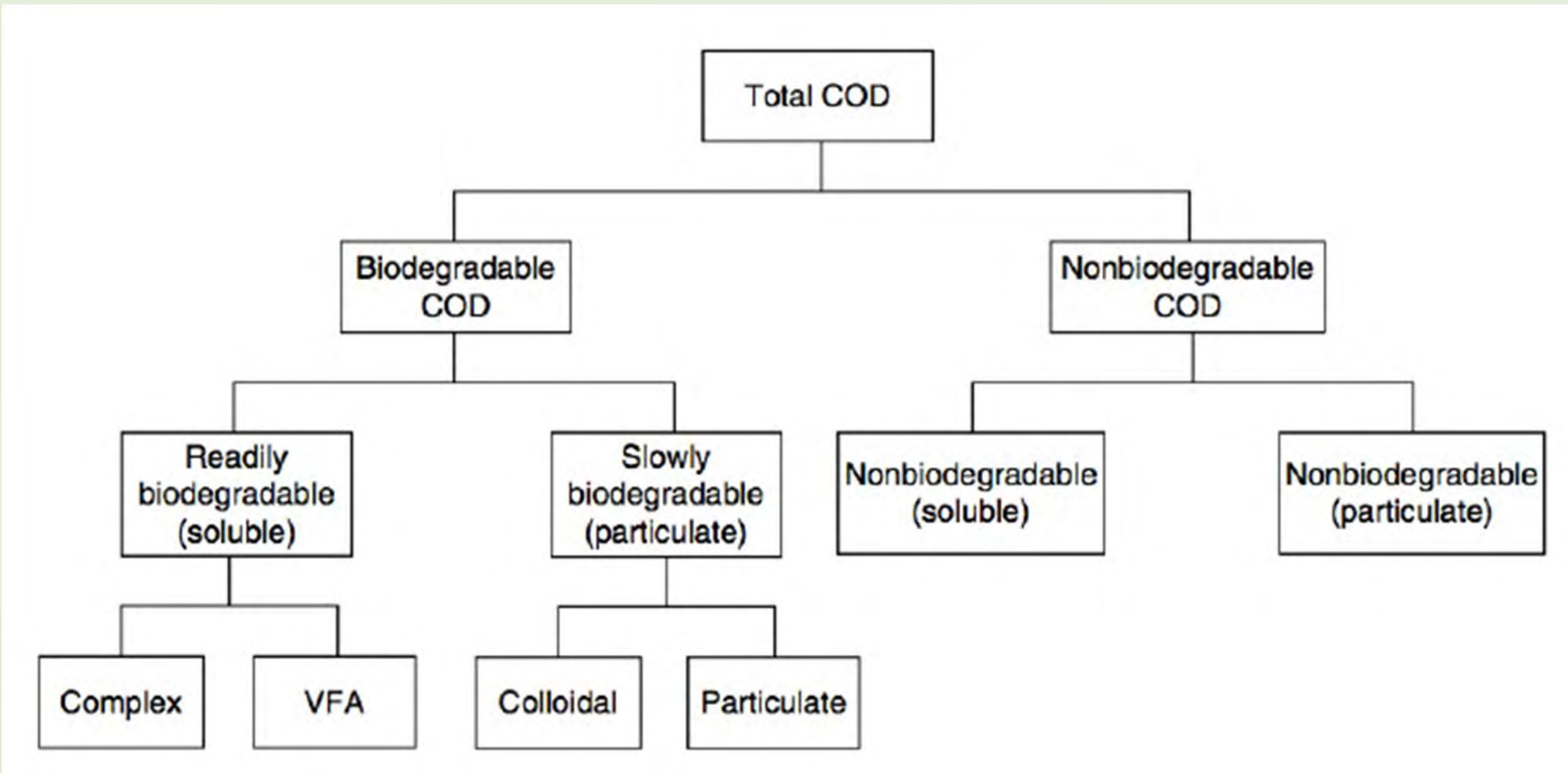
# Additional Characterization

- Biodegradable (b) vs. Nonbiodegradable (nb)
- Soluble (readily (r)) vs. Particulate (slowly(s))
- Soluble (readily):
  - Complex
  - VFA
- Particulate (slowly):
  - Colloidal
  - Particulate
- Example: rbCOD

# (Bio)Chemical Oxygen Demand

- COD and BOD are related
- Long history of BOD
- Up and coming: COD
- Measures oxygen depletion in dilute sample
- Brings Carbon to the party
- Typically only BOD is permitted
- bCOD:BOD  and rbCOD important in advanced BNR

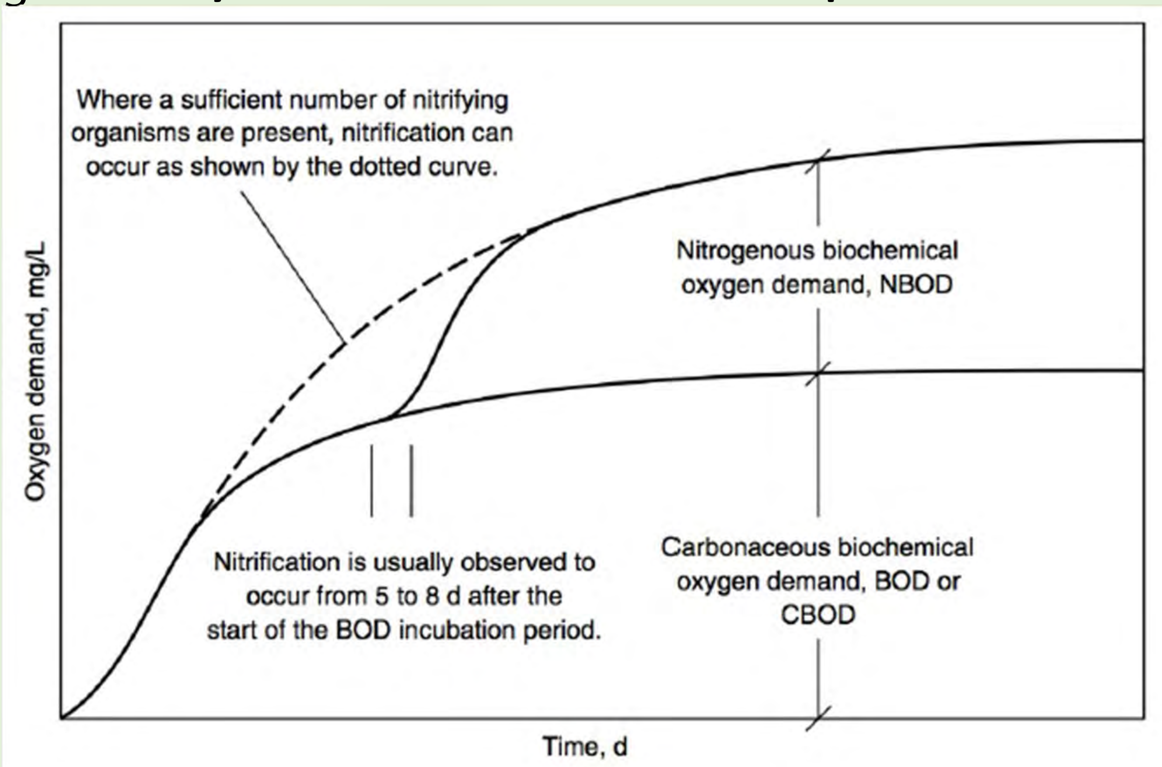
# COD Fractions




Source: Metcalf & Eddy, 5th Ed.

# BOD / $BOD_5$ / $CBOD_5$

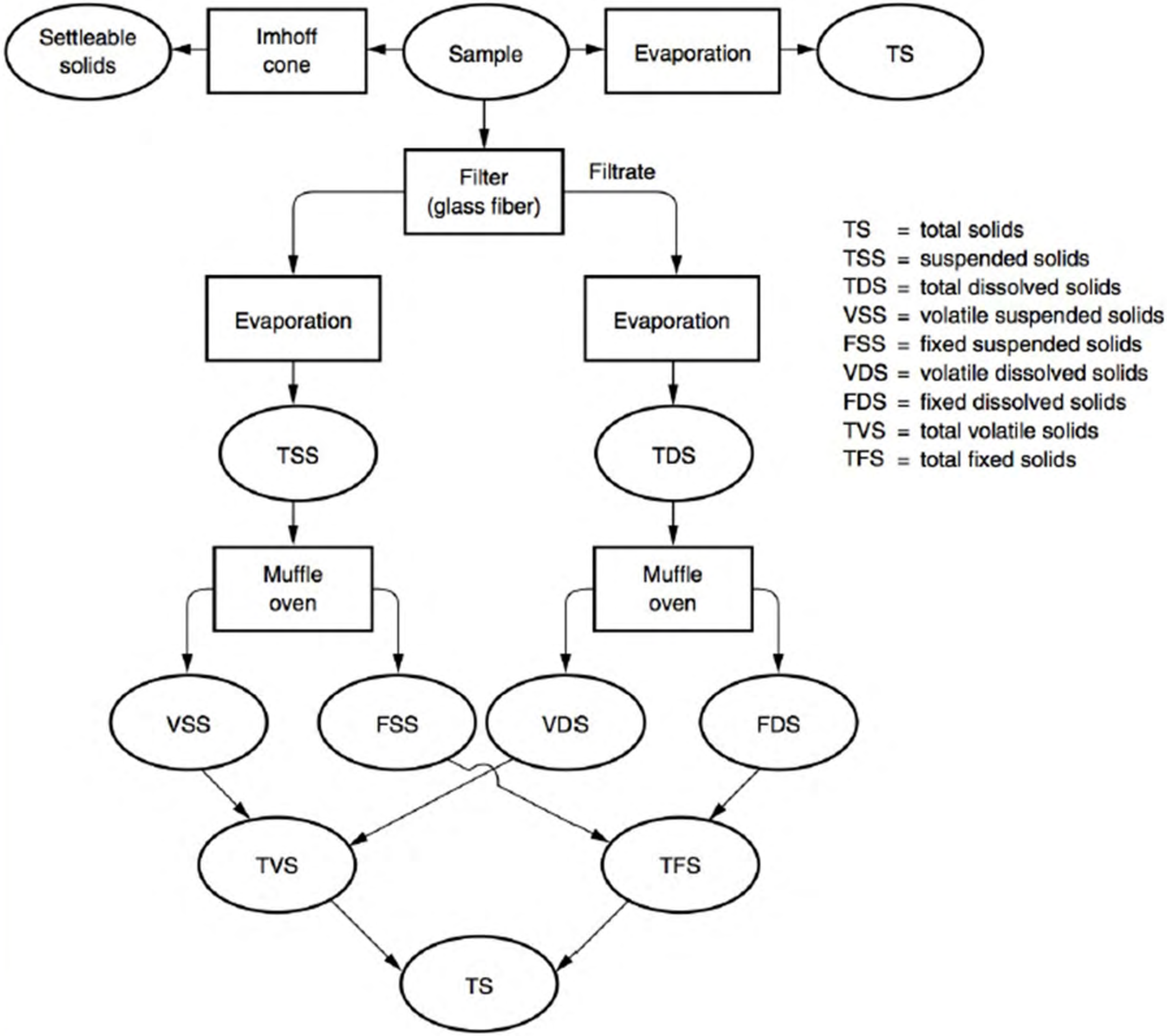
- BOD is the general term
- $BOD_5$ refers to the 5-day standard test method
- $CBOD_5$ is only the Carbonaceous part of BOD




Source: Metcalf & Eddy, 5th Ed.

# Suspended Solids

- Total Suspended Solids
  - TSS = VSS + iTSS
- Almost always permitted
- Removed by Flocculation or Filtration
- VSS:TSS can be used to estimate MLVSS
- Removed by Physical Processes


Settleable solids
Imhoff cone
Sample
Evaporation
TS
Filter (glass fiber)
Filtrate
Evaporation
Evaporation
TSS
TDS
Muffle oven
Muffle oven
VSS
FSS
VDS
FDS
TVS
TFS
TS
TS = total solids
TSS = suspended solids
TDS = total dissolved solids
VSS = volatile suspended solids
FSS = fixed suspended solids
VDS = volatile dissolved solids
FDS = fixed dissolved solids
TVS = total volatile solids
TFS = total fixed solids

# Nitrogen

- Influent:
  - Total Kjeldahl Nitrogen (TKN)
  - Ammonia Nitrogen ($NH_3$-N) (usu. 0.7 x TKN)
  - sometimes Total Nitrogen (TN)
- Effluent:
  - TKN
  - NH3-N
  - TN
  - Nitrate ($NO_3$)
  - Not usually Nitrite ($NO_2$)
- Removed (mostly) by Biological processes

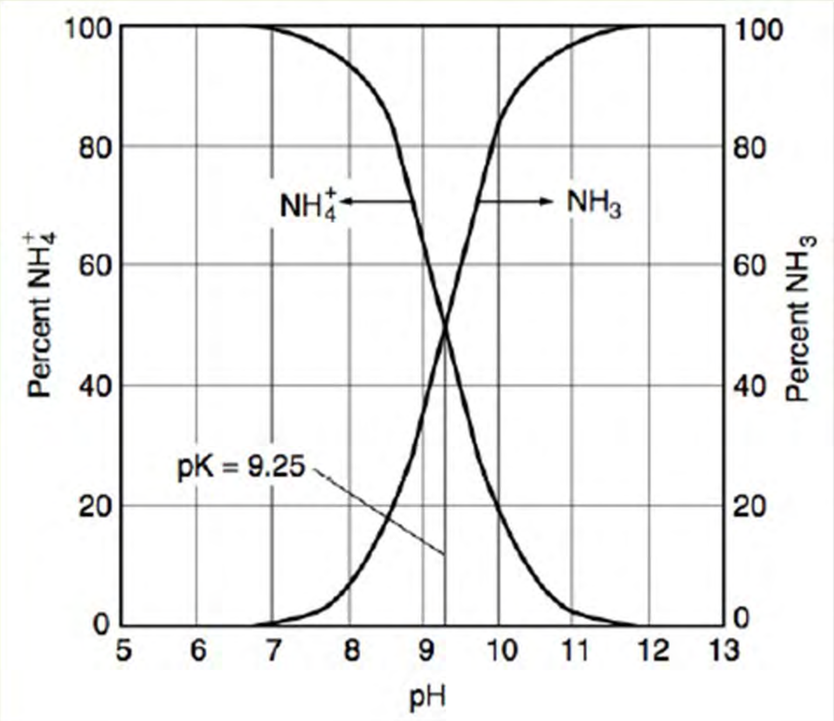
# Forms of Nitrogen

| Form of nitrogen | Abbrev. | Definition |
|---|---|---|
| Ammonia gas | $NH_3$ | $NH_3$ |
| Ammonium ion | $NH_4^+$ | $NH_4^+$ |
| Total ammonia nitrogen | TAN[a] | $NH_3 + NH_4^+$ |
| Nitrite | $NO_2^-$ | $NO_2^-$ |
| Nitrate | $NO_3^-$ | $NO_3^-$ |
| Total inorganic nitrogen | TIN[a] | $NH_3 + NH_4^+ + NO_2^- + NO_3^-$ |
| Total Kjeldahl nitrogen | TKN[a] | Organic N $+ NH_3 + NH_4^+$ |
| Organic nitrogen | Organic N[a] | TKN $- (NH_3 + NH_4^+)$ |
| Total nitrogen | TN[a] | Organic N $+ NH_3 + NH_4^+ + NO_2^- + NO_3^-$ |

[a] All species expressed as N.

Source: Metcalf & Eddy, 5th Ed.

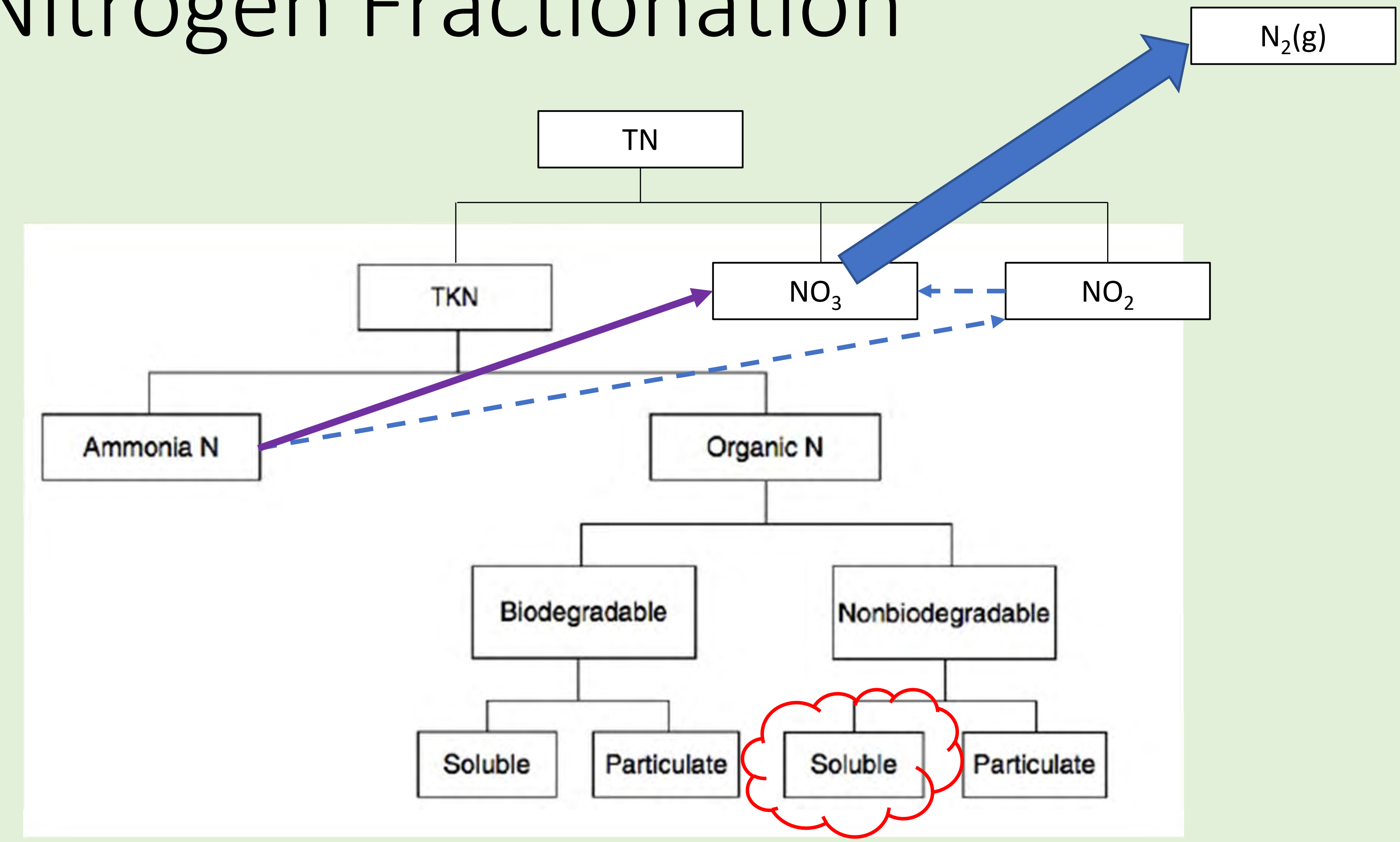
# Ammonia and Ammonium




$$NH_3,\% = \frac{[NH_3] \times 100}{[NH_3] + [NH_4^+]} = \frac{100}{1 + [NH_4^+]/[NH_3]} = \frac{100}{1 + [H^+]/K_a}$$

Source: Metcalf & Eddy, 5th Ed.

# Nitrogen Fractionation




Source: Metcalf & Eddy, 5th Ed.

# Phosphorus

- Usually measured as Total Phosphorus (TP)
- Some consumed naturally during other processes
- Two methods:
  - Chemical (small facilities)
    - Alum
    - Ferric Chloride
  - Biological (large facilities)
    - Anaerobic Selector Reactor
    - VFAs from fermentation

# pH and Alkalinity

- pH affects:
  - Ammonia (NH3) vs Ammonium ($NH_4^+$)
  - Chlorine phases
  - Acid: pH < 7.0 ($H^+$ ions in solution)
  - Base (alkaline): pH > 7.0 ($OH^-$ ions in solution)
- Alkalinity is a solution's ability to neutralize an acid
  - AND resist changes in pH
  - Buffer
  - 7.14 mg/L alkalinity (as $CaCO_3$) consumed per mg/L ammonia converted to nitrate
  - Want 70-80 mg/L as $CaCO_3$ available after nitrification to stabilize pH

# Dissolved Oxygen (DO)

- Used in aerated process control
- Target 2.0 mg/L
- SNDN around 0.5 mg/L
- Becoming common in Effluent Limits

Source: diffusedgas.com


HACH
sc200
LDO000b1-2in
1.22 ppm
24.5 °C
LDO0000b1-1out
1.69 ppm
24.4 °C
1:CLEAN SENSOR
menu
home
back
enter

# Common Units and Conversions

- Volume:
  - 1 cf = 7.48 gal
  - 1 gpm = 1,440 gpd
- Concentration:
  - mg/L = g/m3 = ppm
  - 8.34 = weight of one gallon of water
  - 62.4 lb/cf / 7.48 gal/cf = 8.34 lb/gal
- Load:
  - 1 lb = 0.453 kg

# Other Units

- Specific Weight:
  - Water = 62.42 $lb/ft^3$ at $32^oF$
- Pressure:
  - Head in feet: 1 ft = 12 in = 0.43psi
- Population Equivalents (P.E.):
  - In terms of flow: 100 gpd/capita
  - In terms of load: 0.22 lb $BOD_5$/capita
- Power:
  - 1 hp = 0.746 kW

# Wastewater Magic

Flow x Concentration = Mass :: Q x C = L

$m^3/d \times mg/L = g/d$

OR

MGD x mg/L x 8.34 = lb/d

# Digging Deeper

Metric: $\left(\frac{m^3}{d}\right)\left(\frac{mg}{L}\right)\left(\frac{1{,}000L}{1m^3}\right)\left(\frac{1g}{1{,}000mg}\right) = \left(\frac{g}{d}\right)$

English Engineering: $\left(\frac{MG}{d}\right)\left(\frac{3{,}785m^3}{1MG}\right)\left(\frac{mg}{L}\right)\left(\frac{1{,}000L}{1m^3}\right)\left(\frac{1g}{1{,}000mg}\right)\left(\frac{1lb}{453.59g}\right) = \left(\frac{lb}{d}\right)$

Volume Conversion

Weight Conversion

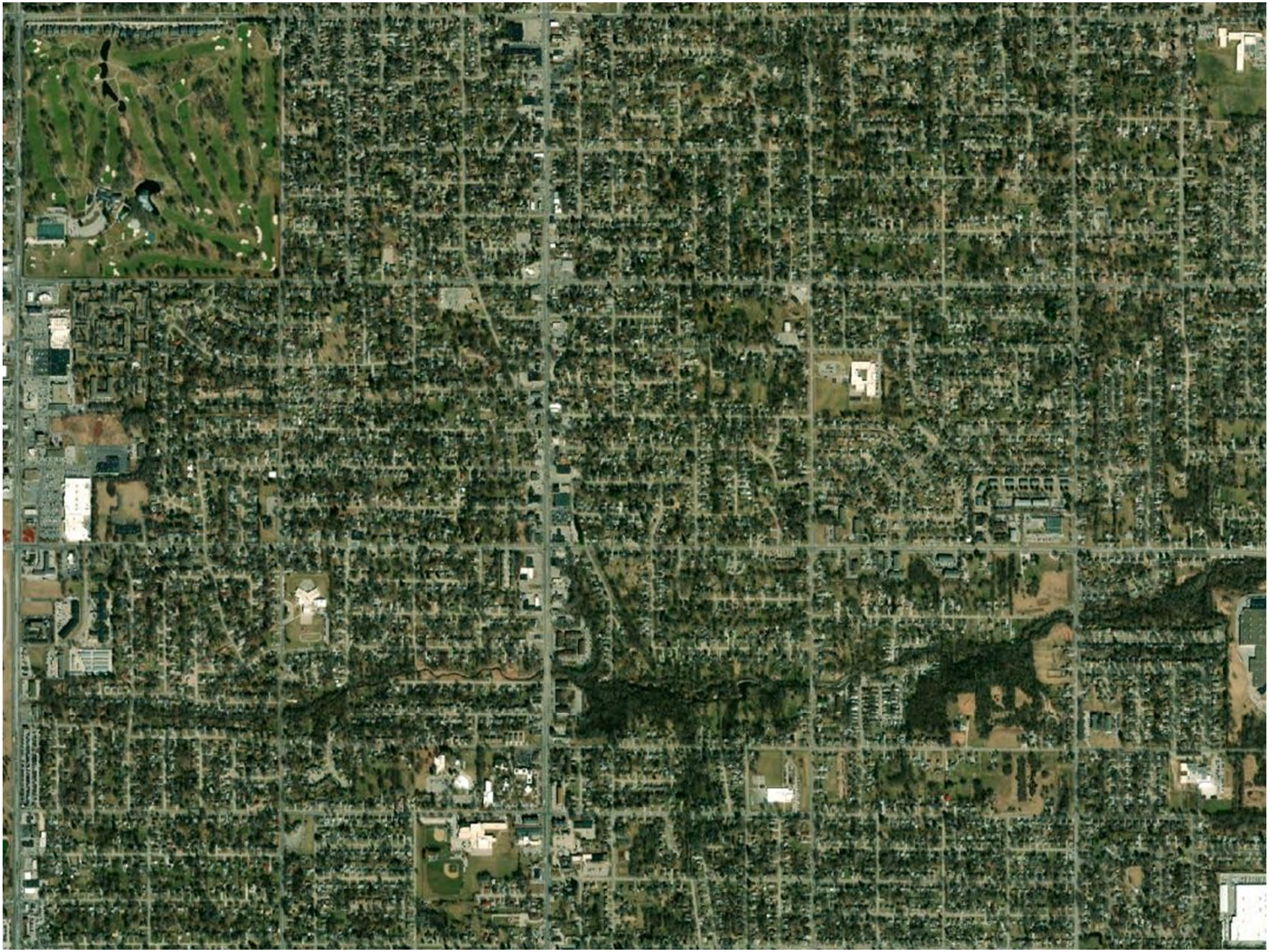
Net Conversion Factor: $\left(\frac{3{,}785m^3}{1MG}\right)\left(\frac{1lb}{453.59g}\right) = 8.34$

# Part III:  Types of Wastewaters

- Residential
- Industrial
- Commercial
- Municipal = R + I + C

# Residential

- Similar to municipal
- More drastic diurnal swings
- Rarely toxic, but varies by household



# Industrial

- Most flows from industrial processes
- Spent/reject water
- Solvents/wash down
- Wide temperature swings
- Often nutrient deficient
- May be toxic
- Very challenging to treat
- Often require pre-treatment prior to municipal discharge

# Commercial

- Most flows from human use
- Similar constituents as residential but can be high strength
- Wider range of flows

# Municipal Wastewater

- Mixture of all sources
- Rarely nutrient deficient
- Typical Values:
  - $BOD_5$ = 200 – 300 mg/L
  - TSS = 100 – 300 mg/L
  - TKN = 30 – 50 mg/L
  - TP = 5 – 10 mg/L
  - pH = 6.5 – 7.5

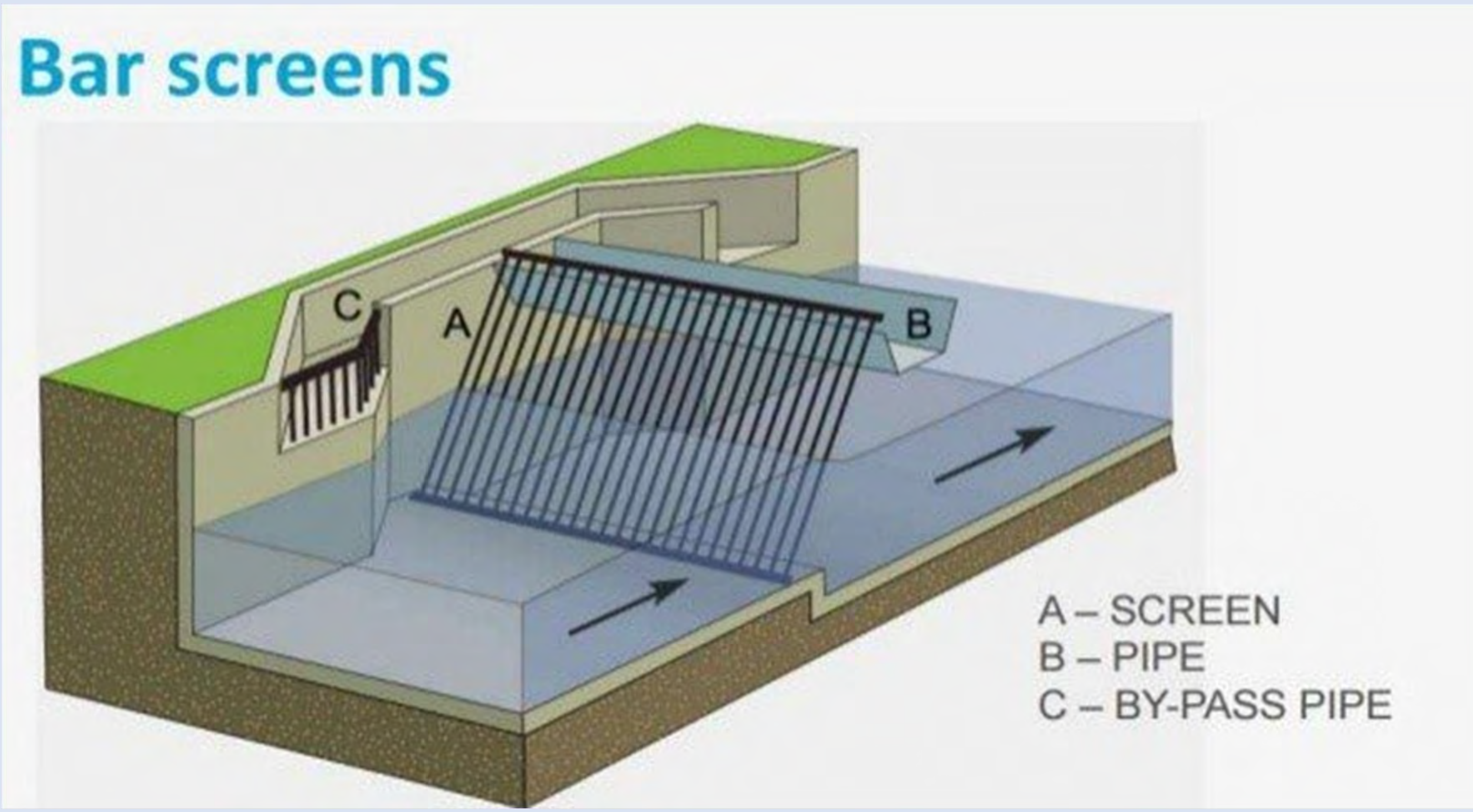
# Part IV: Process Classification

- Physical
- Chemical
- Biological

# Physical Unit Operations

- Screening
- Mixing
- Flocculation
- Sedimentation
- Flotation
- Filtration
- Adsorption

# Physical: Screening

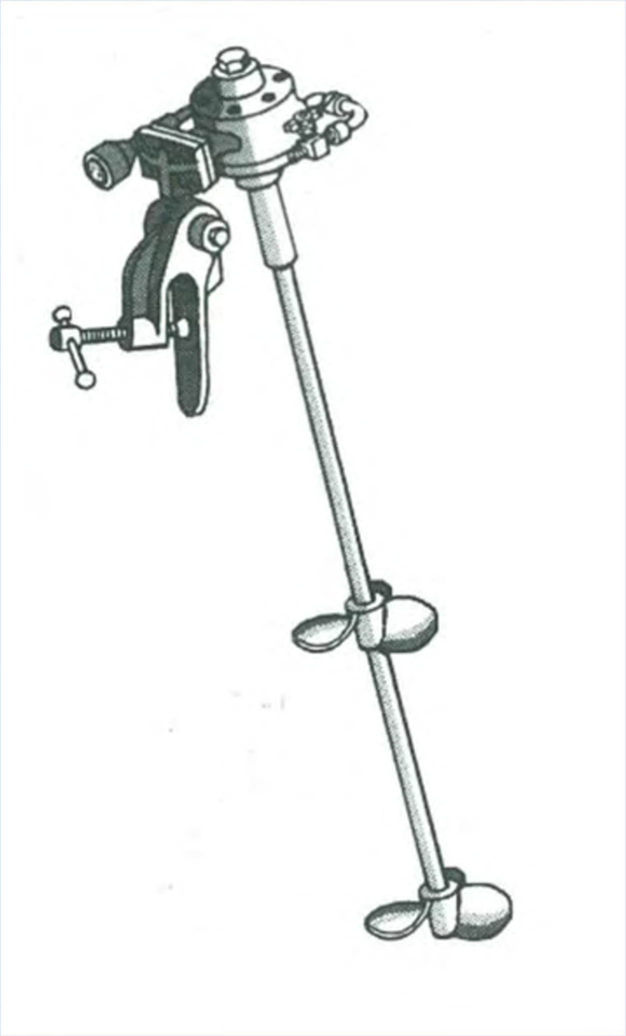



Source: engineeringcivil.org

# Physical: Screening

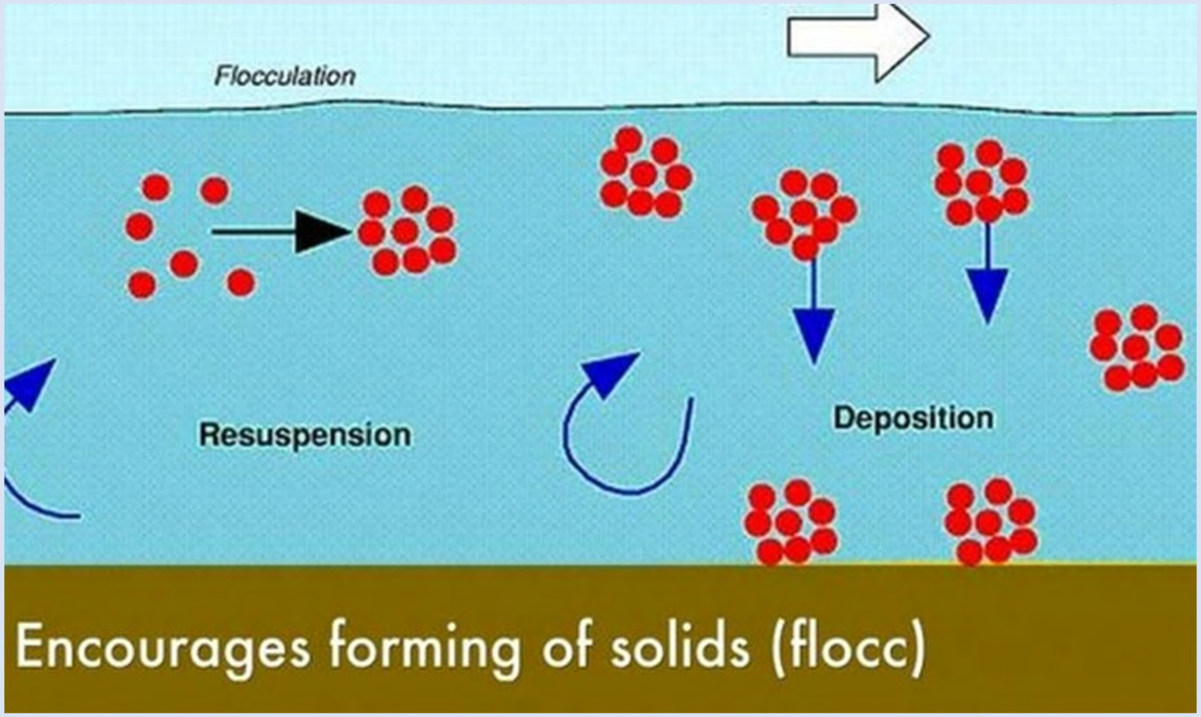

Source: PolyLok, Inc.

# Physical:  Mixing



Source:  thecarycompany.com

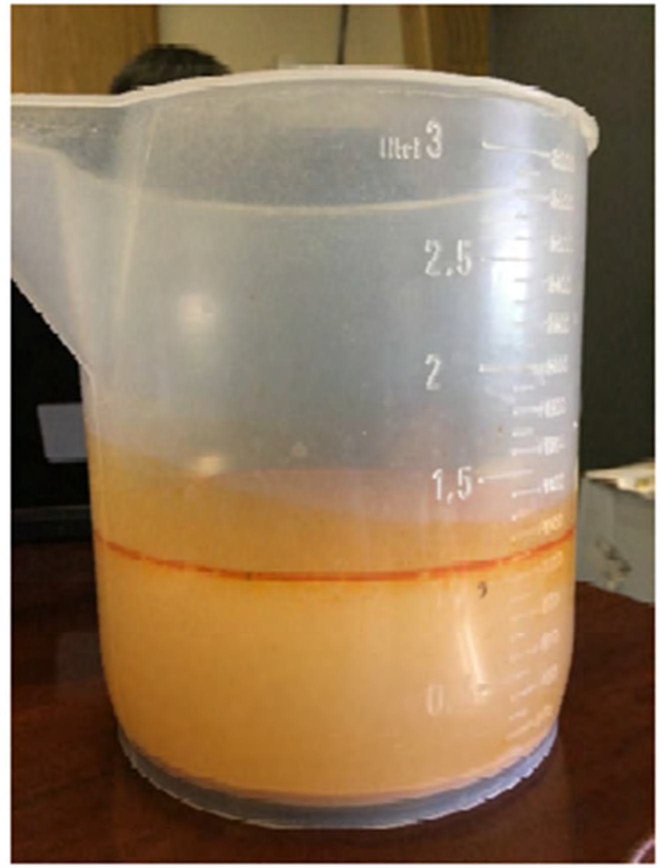
# Physical: Flocculation




Source: quora.com

# Physical:  Sedimentation

6/13/18, Chamber 1



6/13/18, Chamber 2

# Physical: Sedimentation

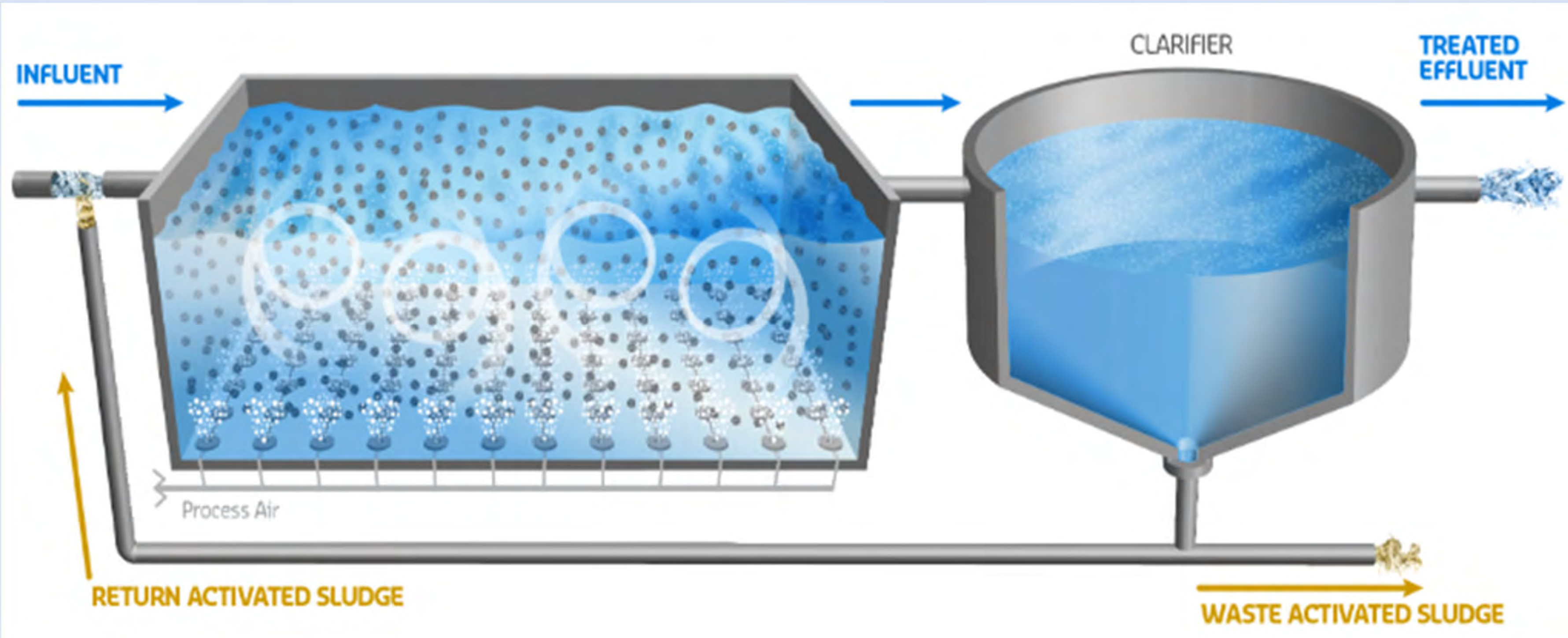
# Chemical Unit Operations

- Precipitation
- Gas Transfer
- Adsorption*
- Disinfection

# Biological Unit Operations

- Colloidal and dissolved biodegradable organics
- Into:
  - Gases that can escape to atmosphere (Chemical)
  - Biological cell tissue that can be removed (Physical)

# Biological: Suspended Growth




Source: camix.com

# Biological:  Attached Growth

Source:  wikipedia.org

Physical: Mixing
Chemical: Gas Transfer
Biological: Activated Sludge

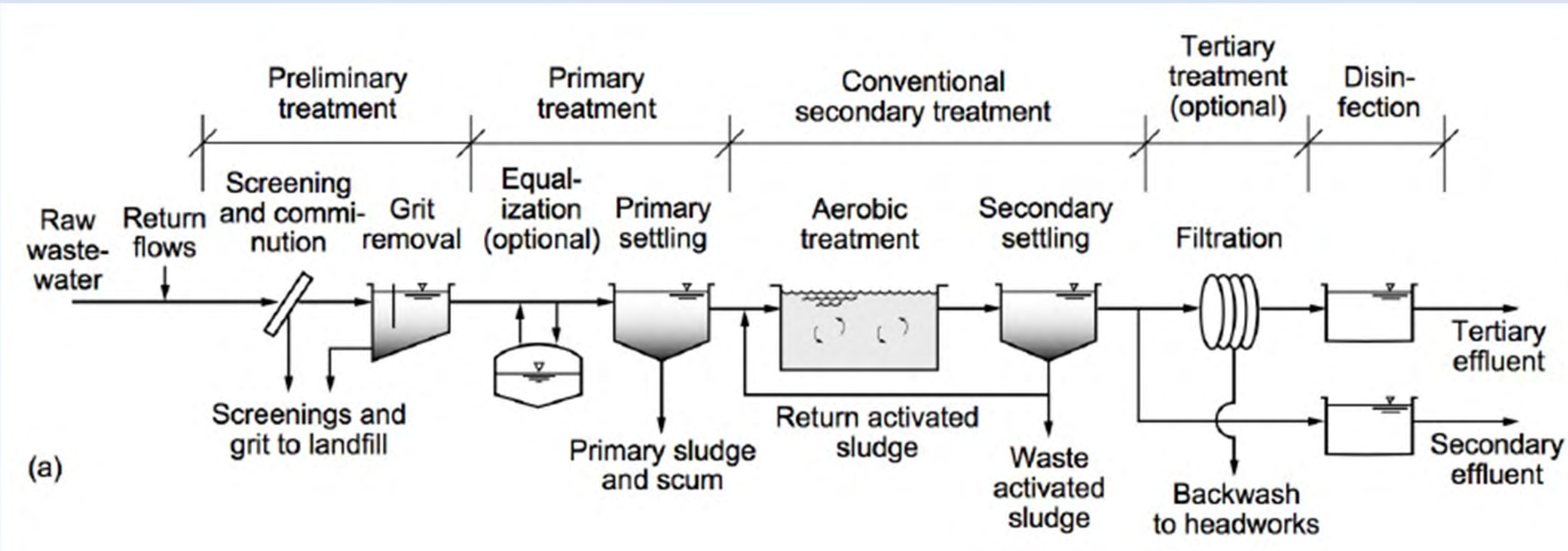
# How Does WW Treatment Work?

- Combination of Unit Operations
- Create favorable environments
- Remove constituents

# 7 Steps to Treatment

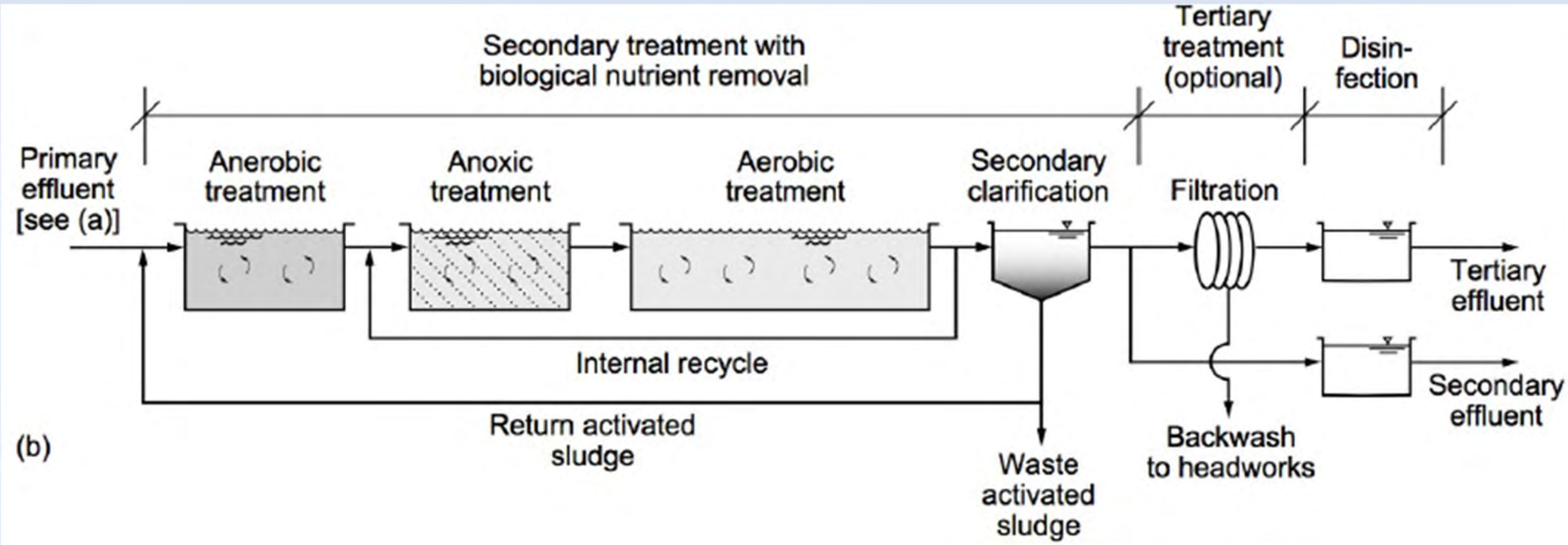
- Preliminary → Screening & Grit
- Primary → Primary Clarifier
- Secondary → Activated Sludge / Secondary Clar.
- Tertiary → Filtration
- Disinfection → Chlorine / UV
- Advanced → Membrane / RO
- Solids Handling → Digestion / Dewatering / Haul

# Conventional



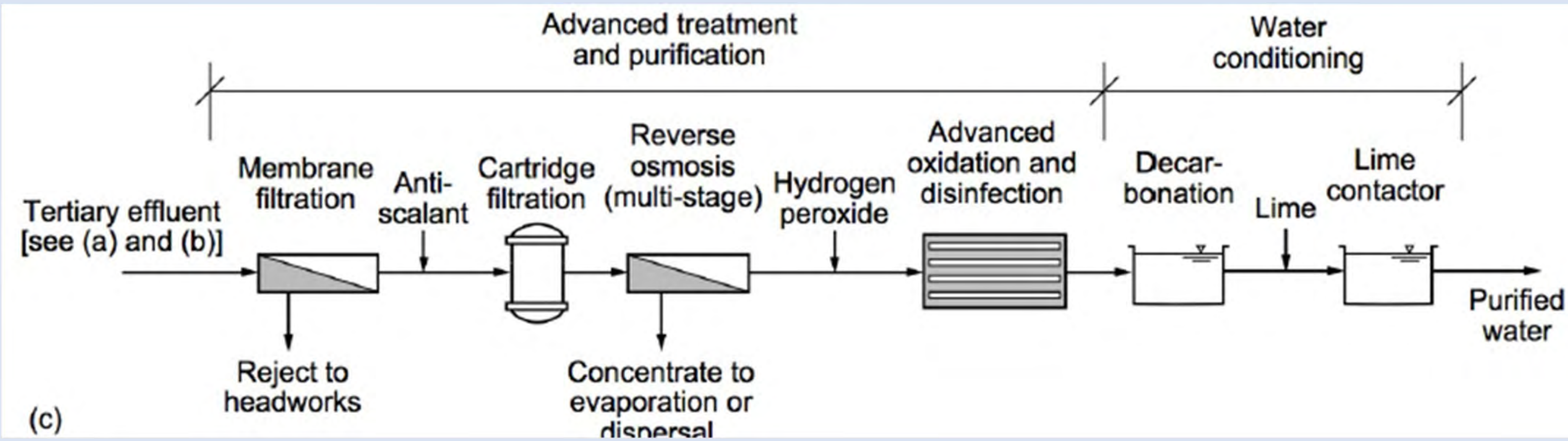

Source: Metcalf & Eddy, 5th Ed.

# Biological Nutrient Removal



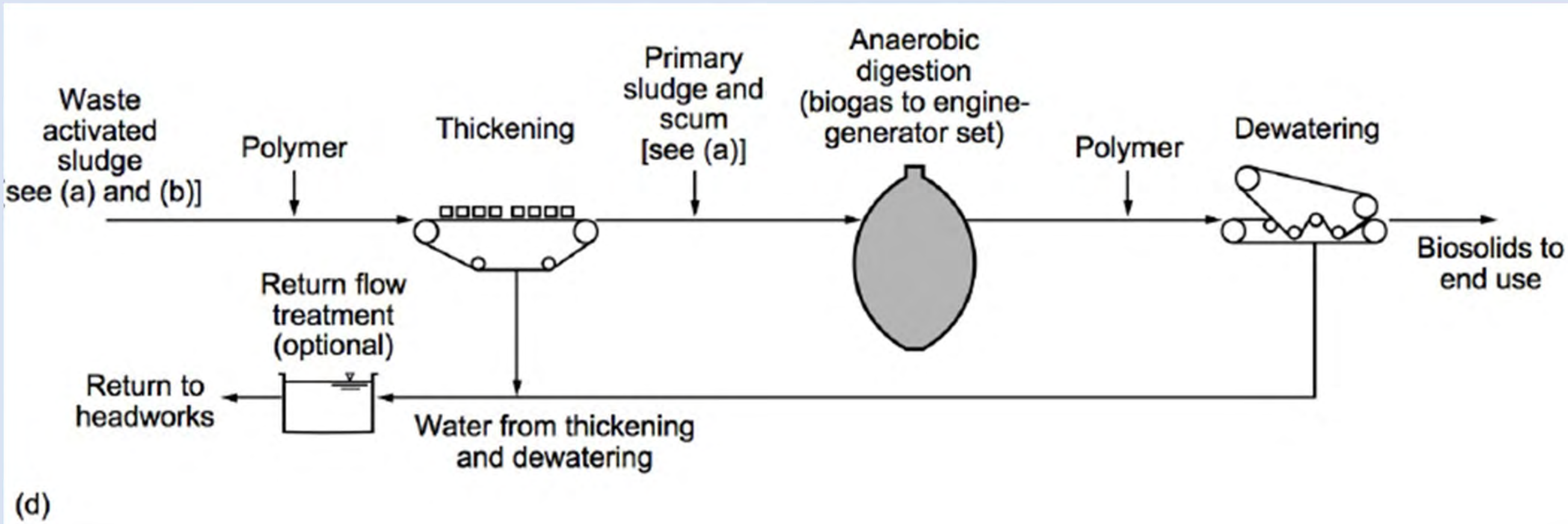

Source: Metcalf & Eddy, 5th Ed.

# Advanced Treatment




Source: Metcalf & Eddy, 5th Ed.

# Solids Processing




Source: Metcalf & Eddy, 5th Ed.

# Part V:  Putting it All Together

NPDES permit requires the following treatment:

25,000 gallons per day capacity

30 mg/L $BOD_5$ effluent or less

Size the Activated Sludge Reactor

# Step 1: Gather Information

- Establish influent BOD5 influent
- Take Samples or Review Data
- Lab → Results

Influent $BOD_5$ concentration is 250 mg/L

Waste stream is determined to be largely residential

Nutrient balance assumed to be acceptable

# Step 2: Use the Magic Wastewater Equation

$Q_i$ = 25,000 gpd (0.025 MGD)

$C_i$ = 250 mg/L $BOD_5$

L = Q x C x 8.34

$L_i$ = 0.025 MGD x 250 mg/L x 8.34 = **52.1 lb $BOD_5$/d**

# Step 3: Size the Aeration Reactor

Regulation requires Organic Load must be less than 15 lb $BOD_5$/day/kcf

1,000 cf = 7,480 gal

1 lb/d/kcf = 1 lb/d/7,480 gal

Therefore

52.1 lb $BOD_5$/d / [15 lb $BOD_5$/d/7,480 gal] = **26,000 gal**

for this BIOLOGICAL Suspended Growth process

# Objectives Recap

- Understand the history of clean water
- Review and upgrade wastewater vocabulary
- Discuss different sources of wastewater
- Define fundamental treatment classes
- Basic calculation

# Questions?

## Wastewater 101:  FUNdamentals

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