Low Cost Nutrient Removal for Wastewater Operators

by Daniel B. Stephens & Associates, Inc.

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About the Trainers

- Michael Alvidrez, AWO
- Jennifer Hill, DBS&A
- Terry Mount, NMSU

Outline for Today

- Morning
  - Regulatory framework
  - Wastewater treatment methods fundamentals of biological treatment
- Afternoon
  - What are nutrients?
  - Review of chemistry and stoichiometry
  - How are nutrients removed?
    - Biological methods
    - Chemical methods

Links

Presentation

https://www.dbstephens.com/services/water-workshops-training/

EPA Case Studies

https://www.epa.gov/sites/default/files/2015-08/documents/case_studies_on_implementing_low-cost_modification_to_improve_potw_nutrient_reduction-combined_508_-_august.pdf

Montana Case Studies

https://deq.mt.gov/files/Water/TFAB/WPCSRF/pdf/Montana-Report-Final-Proof.compressed.pdf

INTRODUCTIONS AND PRE-QUIZ

Pre-Test

1. What does TMDL stand for?
2. What is the recommended range for sludge age in an extended aeration plant?
3. What happens in the activated sludge treatment process when dissolved oxygen (DO) is too low?
4. What does AOB stand for?
5. What is the difference between an anoxic zone and an aerobic zone?
6. What is the limit for nitrogen in WWTP effluent?
7. How does low temperature affect nutrient removal?

WHY ARE WE HERE?

https://deq.mt.gov/files/Water/TFAB/WPCSRF/pdf/Montana-Report-Final-Proof.compressed.pdf

Low Cost Nutrient Removal in Montana

Montana's experience disproves the conventional belief that new infrastructure is required for wastewater treatment plants to significantly reduce nutrients in their effluent.

An investment in wastewater operator training and technical support is sustainably improving the quality of the waters of the State of Montana. The combined efforts and expertise of Montana regulators and municipal wastewater treatment plant operators has given renewed evidence to support the position that operational optimization is an extremely potent and effective alternative to massive capital improvement projects.

The clever use of existing treatment equipment has reduced the wastewater discharge of nutrients by as much as ninety percent. Before and after results from 11 of the 27 participating communities in the Montana Department of Environmental Quality's four year training and technical support effort are summarized below. Total-nitrogen was reduced by an average 59% and total-phosphorus by 33% at facilities not designed to remove nutrients. To achieve similar results through conventional improvements, the cost to each community would typically be several million dollars.

In order to realize the results presented above, Montana expended approximately $1,100 per treatment facility to provide free classroom training and $5,000 for in-plant technical guidance. Since 2012, DEQ has employed an operations consultant to train 70 wastewater treatment plant personnel and make 38 wastewater treatment plant site visits. Montana DEQ and the consultant provided extensive follow-up support in the form of emails and telephone calls.

Montana's experience demonstrates that educated, supported and empowered wastewater operators can remove nutrients using infrastructure not designed to do so.

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Regulatory Framework

- NPDES Permitting
  - Permit limits
  - Required monitoring and reporting
- State TMDL Program
- State Discharge Permits (GWQB)

National Pollutant Discharge Elimination System Program (NPDES)

- The NPDES permit program, created in 1972 by the Clean Water Act (CWA), helps address water pollution by regulating point sources that discharge pollutants to waters of the United States.
- If you discharge from a point source into the waters of the United States, you need an NPDES permit.

NPDES Permit Limits for WWTPs

Loading (lbs/day) = pollutant concentration (mg/l) * 8.345 lbs/gal * design flow (MGD)

30-day average BOD_5/TSS loading = 30 mg/l * 8.345 lbs/gal * 0.02 MGD = 5.0 lbs/day
07-day average BOD_5/TSS loading = 45 mg/l * 8.345 lbs/gal * 0.02 MGD = 7.5 lbs/day

A summary of the technology-based limits based on 0.02 MGD Design Flow

EFFLUENT CHARACTERISTICS	DISCHARGE LIMITATIONS			
Parameter	30-Day Avg.	7-Day Avg.	30-Day Avg.	7-Day Avg.
Flow	N/A	N/A	Measure MGD	Measure MGD
BOD_5	5.0 lbs/Day	7.5 lbs/Day	30 mg/L	45 mg/L
BOD_5, % removal, minimum	≥ 85%	---	---	---
TSS	5.0 lbs/Day	7.5 lbs/Day	30 mg/L	45 mg/L
TSS, % removal, minimum	≥ 85%	---	---	---
pH	NA	NA	6.0 - 9.0 s.u.	

State Discharge Permits

- Groundwater discharge permits are issued pursuant to 20.6.2 NMAC (The New Mexico Ground and Surface Water Protection Regulations), 20.6.6 NMAC (Supplemental Permitting Requirements for Dairy Facilities), and 20.6.7 NMAC (Supplemental Permitting Requirements for Copper Mining Faculties) to ensure that industry, wastewater facilities and other activities that discharge water to the environment do not result in groundwater contamination.
- Any domestic wastewater discharges to a septic system less than 5,000 gallons per day are regulated by the NMED liquid waste program. Domestic wastewater discharges greater than 5,000 gallons per day, from large capacity septic tanks, wastewater treatment plants, sludge and septage disposal, and reclaimed domestic wastewater will require a discharge permit. Other examples of facilities that will likely require a discharge permit include industrial discharges (i.e. power plants, asphalt processing, car washes, and chlorinated solvent remediation) agricultural wastewater discharges (i.e. dairies, chile processing, cheese manufacturing, slaughterhouses, and food processing).
- Permits must be renewed every 5 years.

Discharge Permit Limits

#	Terms and Conditions
	[Subsection A of 20.6.2.3107 NMAC, Subsection C of 20.6.2.3109 NMAC]

Operating Conditions

#	Terms and Conditions
6.	Treated wastewater discharged from the synthetically lined impoundment (Lagoon #2) shall not exceed the following limitations: Test / 30-day Geometric Mean / 30-day Average / Maximum Fecal coliform: / **1,000 CFU/100 mL** / **N/A** / **5,000 CFU/100 mL** [Subsections B and C of 20.6.2.3109 NMAC, NMSA 1978, § 74-6-5.D]
7.	The permittee shall discharge treated wastewater to the surface disposal area such that the amount of total nitrogen discharged does not exceed 200 pounds per acre in any 12-month period. Nitrogen content shall not be adjusted to account for volatilization or mineralization processes. Wastewater shall be distributed evenly throughout the entire disposal area. [Subsection C of 20.6.2.3109 NMAC]
8.	The permittee shall meet the following setbacks and access restrictions for the surface disposal of treated domestic wastewater. a) A minimum 100-foot setback shall be maintained between any dwellings or occupied establishments and the edge of the surface disposal area. b) The permittee shall manage the flood of treated domestic wastewater in a manner that minimizes public contact. c) Public access to the surface disposal area shall be restricted by perimeter fencing using four-strand barbed wire and a locking gate, or other access controls approved by NMED. [Subsections B and C of 20.6.2.3109 NMAC, NMSA 1978, § 74-6-5.D]
9.	The permittee shall maintain 18 to 24-inch berms around the surface disposal area to prevent surface water run-on and run-off. The berms shall be inspected on a regular basis and after any major precipitation event, and repaired as necessary. [Subsection C of 20.6.2.3109 NMAC]
10.	The permittee shall maintain fences around the WWTF to control access by the general public and animals. The fences shall consist of a minimum of six-foot chain link or field fencing and locking gates. Fences shall be maintained throughout the term of this Discharge Permit.

#	Terms and Conditions
	in all surveyed wells, and the data shall be used to develop a groundwater elevation contour map showing the location of all monitoring wells and the direction and gradient of groundwater flow at the facility. The data and groundwater elevation contour map shall be submitted to NMED within 30 days of survey completion. [Subsection A of 20.6.2.3107 NMAC, NMSA 1978, §§ 61-23-1 through 61-23-32]

Groundwater Monitoring Conditions

#	Terms and Conditions
25.	The permittee shall perform quarterly groundwater sampling in the following monitoring wells and analyze the samples for dissolved TKN, NO_3-N, TDS and Cl. a) MW-1a, located 20 to 50 feet hydrologically downgradient and east of abandoned and closed Lagoon#1. b) MW-2a, located 20 to 50 feet hydrologically downgradient and southeast of Lagoon #2. c) MW-3a, located 20 to 50 feet hydrologically upgradient and west of Lagoon #2. d) MW-5, located 20 to 50 feet hydrologically upgradient and northwest of the surface disposal area. e) MW-6, intended to be located 20-50 feet hydrologically downgradient and southeast of the surface disposal area. Groundwater sample collection, preservation, transport, and analysis shall be performed according to the following procedure. a) Measure the depth-to-most-shallow groundwater from the top of the well casing to the nearest hundredth of a foot. b) Purge three well volumes of water from the well prior to sample collection. c) Obtain samples from the well for analysis. d) Properly prepare, preserve, and transport samples. e) Analyze samples in accordance with the methods authorized in this Discharge Permit. Depth-to-most-shallow groundwater measurements, analytical results, including the laboratory QA/QC summary report, and a facility layout map showing the location and number of each well shall be submitted to NMED in the quarterly monitoring reports. [Subsection A of 20.6.2.3107 NMAC]
26.	NMED shall have the option to perform downhole inspections of all monitoring wells identified in this Discharge Permit. NMED shall establish the inspection date and provide at least a 60-day notice to the permittee by certified mail. The permittee shall have any existing dedicated pumps removed at least 48 hours prior to NMED inspection

Water-Quality Based Limitations

- Water quality-based requirements are necessary where effluent limits more stringent than technology-based limits are necessary to maintain or achieve water quality limits. Under Section 301 (b)(1)(C) of the CWA, discharges are subject to effluent limitations based on WQS. Effluent limitations and/or conditions established in the draft permit are in compliance with Tribal WQS to assure that surface WQS of the receiving waters are protected and maintained, or attained. Permit limits will ensure downstream WQS will be met in accordance with 40 CFR §122.4(d).

Total Maximum Daily Loads

- A TMDL is defined as the “calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant. ”
- The New Mexico Environment Department’s Surface Water Quality Bureau is responsible for developing a list of waters that are not supporting their designated uses and established TMDL’s for each segment
- A body of water is “Impaired” if it fails to meet WQ standards

Total Maximum Daily Loads

- A TMDL document is a water quality plan that establishes specific goals to meet water quality standards. It includes:
  - Target loading capacities; and
  - Information potentially leading to 1) permit revisions and implementation, and 2) the development of Watershed Based Plans, which discuss measures to restore the chemical, physical, and biological integrity of the waterbody.

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TMDL Calculation

- A TMDL is the maximum amount of a pollutant that can enter a water body without causing an impairment (exceedance of the water quality standard)
- TMDL = WQS x Critical Flow x CF
  - WQS = Water Quality Standard
  - Flow = based on critical conditions
  - CF = Conversion Factor

TMDL Allocations

TMDL = Σ LA + Σ WLA + MOS

(MOS is a Margin of Safety to account for uncertainty)

Load allocation (LA) is pollution from any non-point source(s) and is addressed through best management practices (BMPs)

Waste Load Allocation (WLA) is from a known point source and is controlled through NPDES permits

Draft TMDL Review Process

- Reviewed by SWQB and EPA Region 6 staff prior to release of the public comment draft
- Released for a 30-day public comment period
- Stakeholders are notified of the draft TMDL and public meeting via GovDelivery (email list)
- SWQB hosts a public meeting
- Stakeholders can submit written comments
- SWQB responds to written comments in the Response to Comments appendix of the Final Draft TMDL

Final TMDL Approval Process

- Final Draft TMDL is presented to the NM Water Quality Control Commission (WQCC)

- The WQCC-approved TMDL is incorporated into the NM Water Quality Management Plan and submitted to EPA Region 6 for final approval

- The EPA-approved TMDL is then posted to the SWQB TMDL website at:

  https://www.env.nm.gov/surface-water-quality/tmdl/

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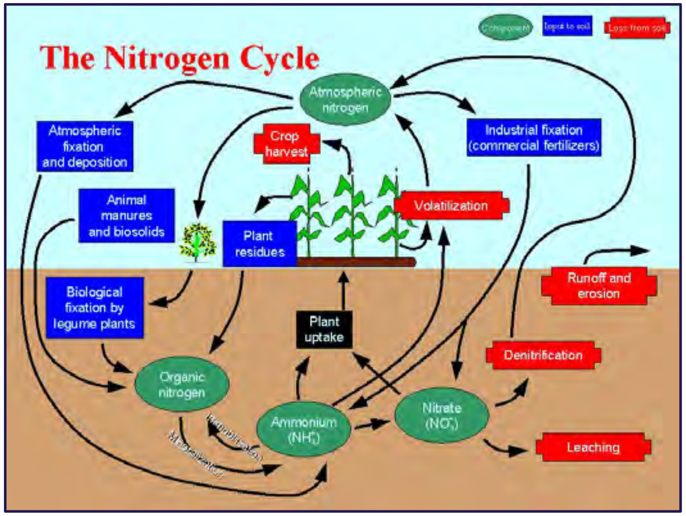
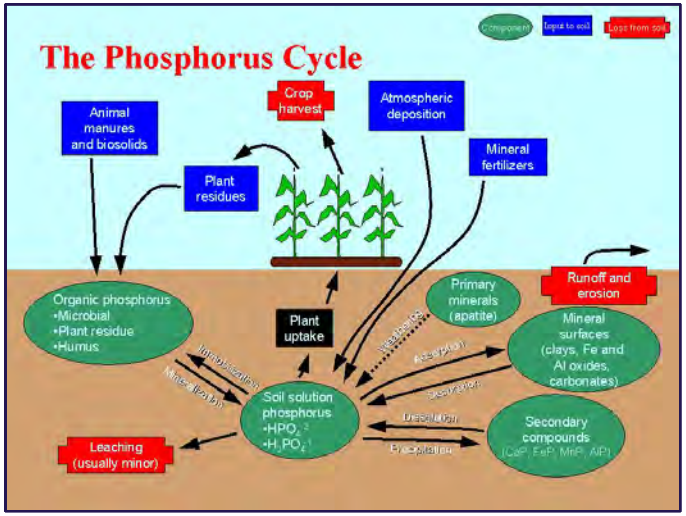
What are plant nutrients?

- Phosphorus and nitrogen are both essential for proper functioning of ecosystems. Some species will thrive in nitrogen limited environments while others thrive in phosphorous limited environments.

- Because of the diversity of nutritional needs amongst organisms, numeric thresholds for both TN and TP are required to preserve the aesthetic and ecologic characteristics along a waterway.





biology.kenyon.edu

What are plant nutrients? (cont.)

- Streams that become overwhelmed with phosphorus can go through a process known as eutrophication resulting in:
  - excessive algal growth
  - reduced light transparency
  - shifts in pH and dissolved oxygen
  - release of toxic levels of ammonia through decay
- Eutrophication can have detrimental effects on recreational opportunities, stream aesthetics, fisheries, aquatic life, and drinking water supply

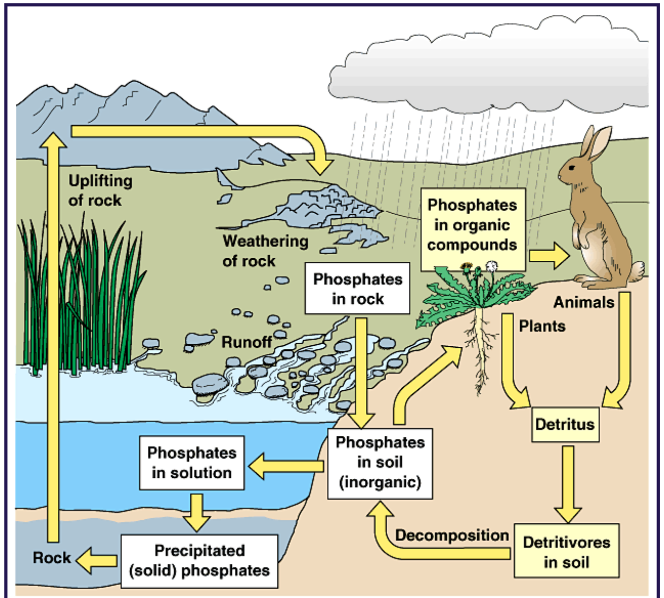

www.siosa.org


www.bucknell.edu

Rio Ruidoso (2003)

Plant Nutrient TMDLs

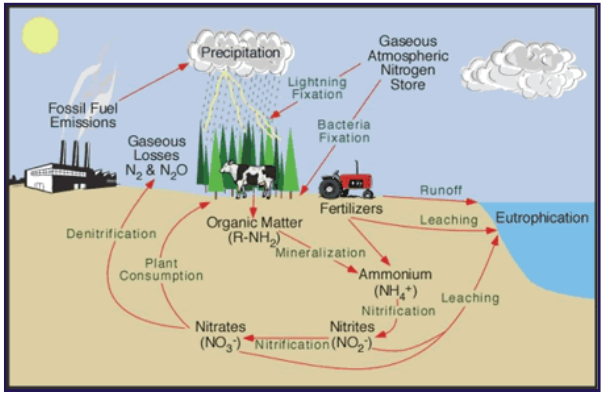
- New Mexico plant nutrient TMDLs include Waste Load Allocations for both total nitrogen and total phosphorus
- Some watersheds (Rio Ruidoso) have a segment-specific total phosphorus criteria, but typically only the narrative plant nutrient standard applies.



The list of nutrient impaired waterbodies in New Mexico is here: https://www.env.nm.gov/surface-water-quality/303d-305b/

Plant Nutrient TMDLs

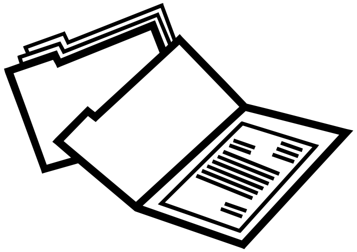
- New Mexico plant nutrient TMDLs are typically developed using the nutrient threshold values listed in the Comprehensive Assessment and Listing Methodology (CALM) and/or a percentage of the concentrations in currently available effluent data. https://www.env.nm.gov/surface-water-quality/calm/
- New Mexico plant nutrient TMDLs are written as phased TMDLs to be implemented in phases by EPA through the NPDES permitting process.



- Recent examples of plant nutrient TMDLs include Raton Creek and Rio Ruidoso. https://www.env.nm.gov/surface-water-quality/tmdl/

TMDL Implementation

A TMDL is not a regulatory document, however, the loading calculations are used for the following:



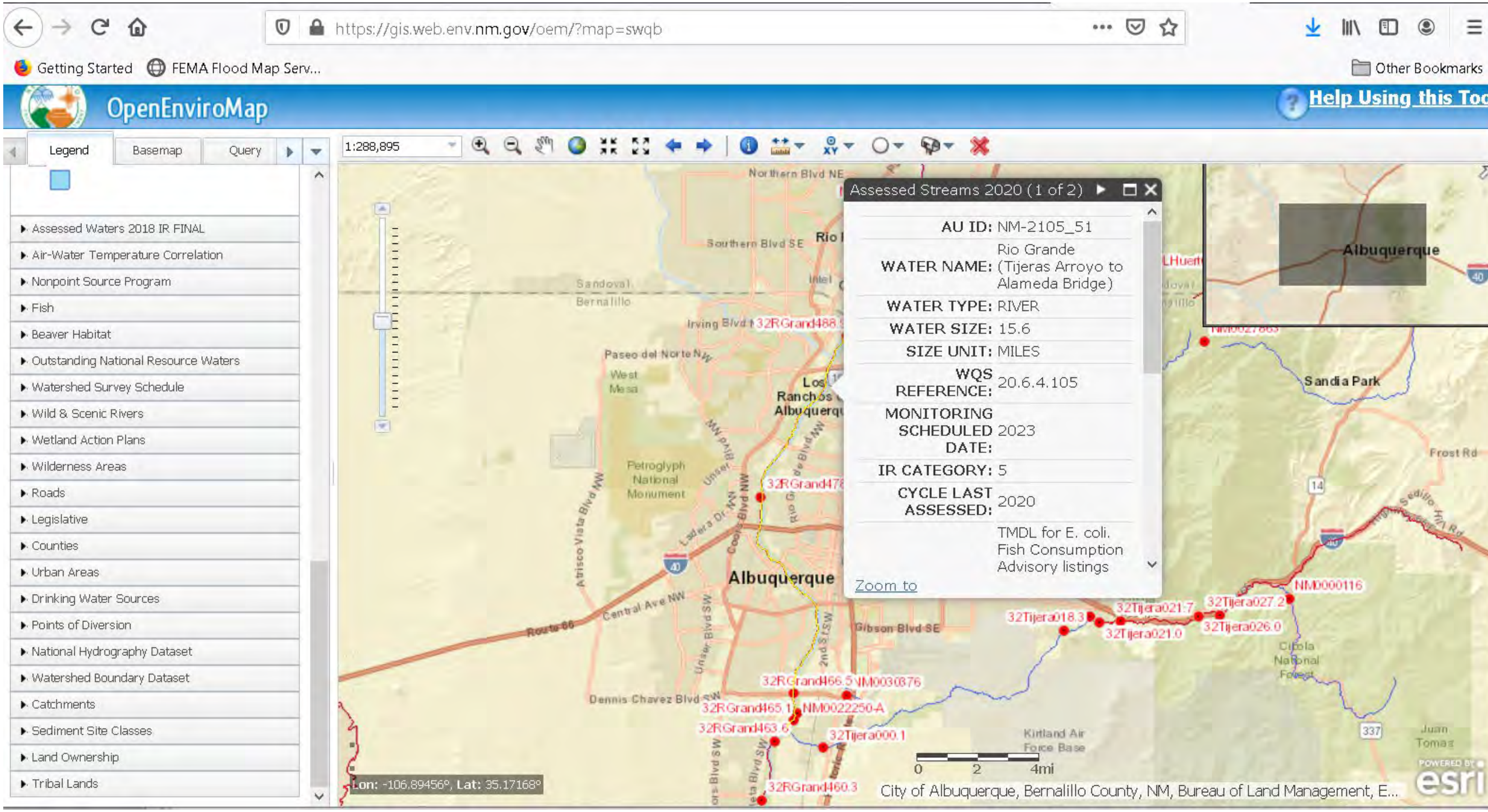
1. Regulatory programs, such as the National Pollutant Discharge Elimination System (NPDES) permitting program administered for NM by EPA Region 6

2. Non-regulatory programs, such as Watershed Protection Programs (WPS) and Water Quality Improvement Projects (WQIP) using CWA §319(h) grants and Clean Water State Revolving Fund loans

Post-TMDL Restoration

- Revise NPDES permits to meet TMDL loading requirements
- Develop a Watershed Based Plan:
  - Outline appropriate steps to achieve the loading defined in the TMDL, including potential solutions, such as BMPs
  - Focus on nonpoint sources of pollution and provide an opportunity for stakeholders to participate in community-based solutions towards improved water quality

NMED's EnviroMap



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https://gis.web.env.nm.gov/oem/?map=swqb

Quiz

- What does NPDES stand for?
- What does TMDL stand for?
- Why do we care about TMDLs?

TRAINING FOR THE OPERATOR OF THE FUTURE

WASTEWATER TREATMENT FUNDAMENTALS I

LIQUID TREATMENT

Water Environment Federation

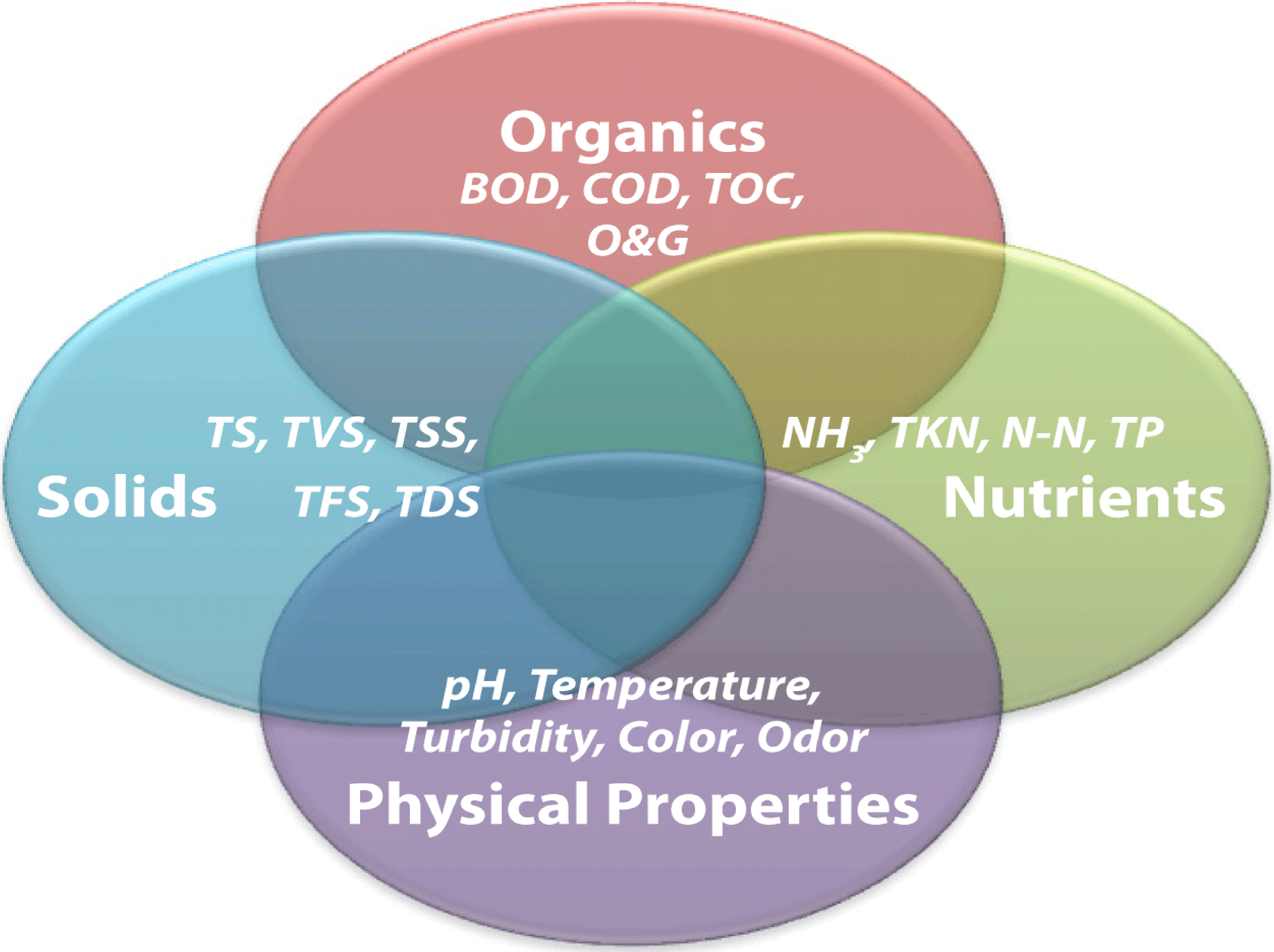
ABC

Wastewater Basics

- What is wastewater?
- How do we treat it?
- Fundamentals of biological treatment

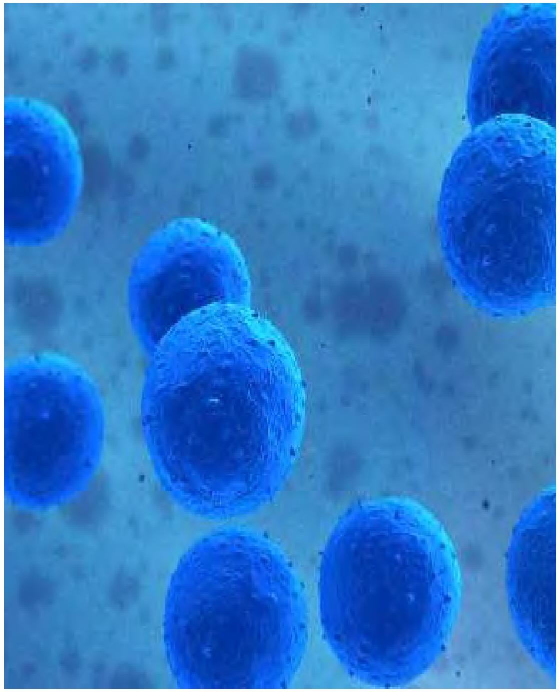
Waste(water)

- Water – 99.94%
- Solids – 0.06%
- Contributors – 100-120 gpd/person
- Infiltration – groundwater through cracks in pipe, manholes
- Inflow – flow into system through drains
- Flows can vary from region to region and seasonal


Organics
BOD, COD, TOC,
O&G
TS, TVS, TSS,
TFS, TDS
Solids
NH3, TKN, N-N, TP
Nutrients
pH, Temperature,
Turbidity, Color, Odor
Physical Properties

Components of Wastewater

- Water
- Solids
- Biochemical oxygen demand
- Nutrients
- Fats, oil and grease
- Bacteria and pathogens



“Typical” Wastewater

Parameter	Units	Sewage in North America[a]			Experimental wetland
		Weak	Medium	Strong	
Total suspended solids (TSS)	mg/l	100	220	350	6–15
Ammonium (NH_4^+)	mg/l	12	25	50	19–27
Nitrate (NO_3^-)	mg/l	0	0	0	4–7
Nitrite (NO_2^-)	mg/l	0	0	0	0.1–0.2
Chemical oxygen demand (COD)	mg/l	250	500	1000	62–90
Dissolved oxygen (DO)	mg/l	–	–	–	1.5–1.9
Hydrogen potential (pH)	pH units	–	–	–	6.9–8.1
Redox potential (Eh)	mV	–	–	–	134–190
Orto phosphate (PO_4^{3-})	mg/l	–	–	–	25–75
Sulfate (SO_4^{2-})	mg/l	20			
Chloride (Cl^-)	mg/l	30			

[a] Metcalf and Eddy (1991).

Variable	Domestic Wastewater[a]	Dairy Wastewater[b]	Dairy Wastewater[c]
COD	1000	2038–4728	2000–10,000
BOD_5	400	1077–2805	1300–1500
TSS	350	438–1224	800–1000
Total P	15	17–29	4.1
NH_4^+–N	50	–	–
Grease	150	240–286	35
Cl^-	100	–	–
Alkalinity ($CaCO_3$)	200	–	1200

[a] Metcalf and Eddy [4]
[b] Typical composition of strong concentration untreated dairy wastewater Tawfik et al. [1]
[c] Koyuncu et al. [3]

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Solids

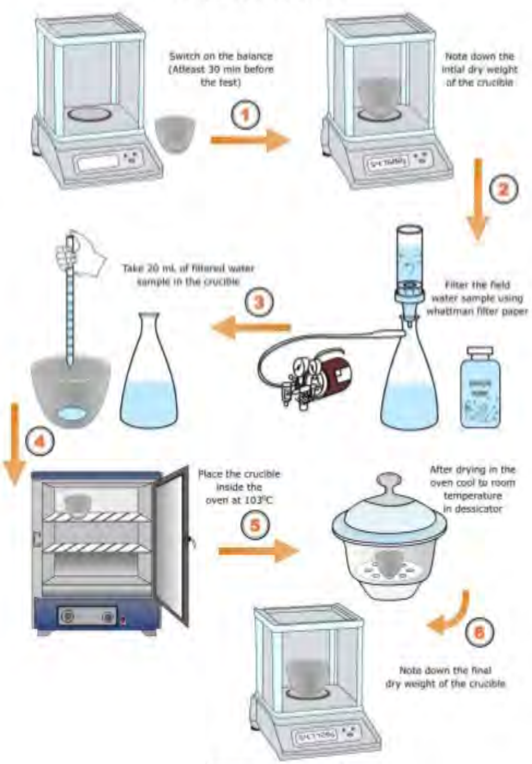
- Debris
- Rags
- Wipes
- Mop heads
- Occasional diamond ring
- Organics
- Inorganics

Types of Solids

- Table 1.1
- TSS – total suspended solids
- TDS – total dissolved solids
- TS – total solids
- TVS – total volatile solids

- Use data of total solids and suspended solids for calculation of total dissolved solids.(appendix)
- Total volatile dissolved solids
- Use the data of total volatile solid and volatile suspended solids for calculation of total volatile solids.(appendix)

PROCEDURE CHART



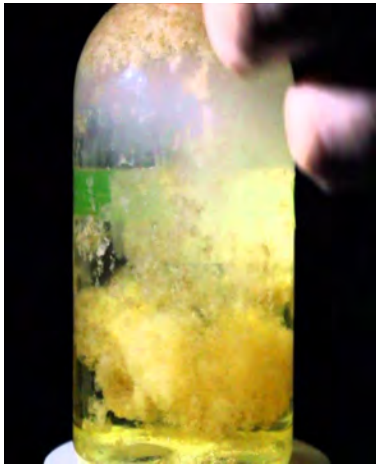
Picture: 3 procedure

Biochemical Oxygen Demand BOD

- Estimate of the organic strength of wastewater
- Expensive and impossible to measure all organic compounds
- BOD measures how much oxygen is needed by the bacteria to stabilize the biodegradable organic material in the wastewater
- Excessive BOD in receiving waters can consume all the available oxygen and kill aquatic life
- Environmental degradation – disintegration of the earth
  - Flow Capacity – Million gallons per day (mgd)
  - Organic material capacity – Pounds per day (lb/d)

BOD

- The more organic material the wastewater contains, the more oxygen the bacteria will consume and stabilize it.
- 1 lb of BOD will consume 1 lb oxygen
- BOD can be solid organic material – food, trash
- Bod can be dissolved organic material – Proteins, fats, oil grease



BOD Test

- A sample of wastewater at a measurable range
- Measure the starting DO
- Incubate the sample @ 20°C (68°F) for fixed period (5 days) in the dark
- Measure the ending DO
- BOD concentration in mg/L is calculated from the amount of oxygen consumed
- 5 days originated from England's Thames River – water flow from river to ocean and the river temperature (18.6-20°C)

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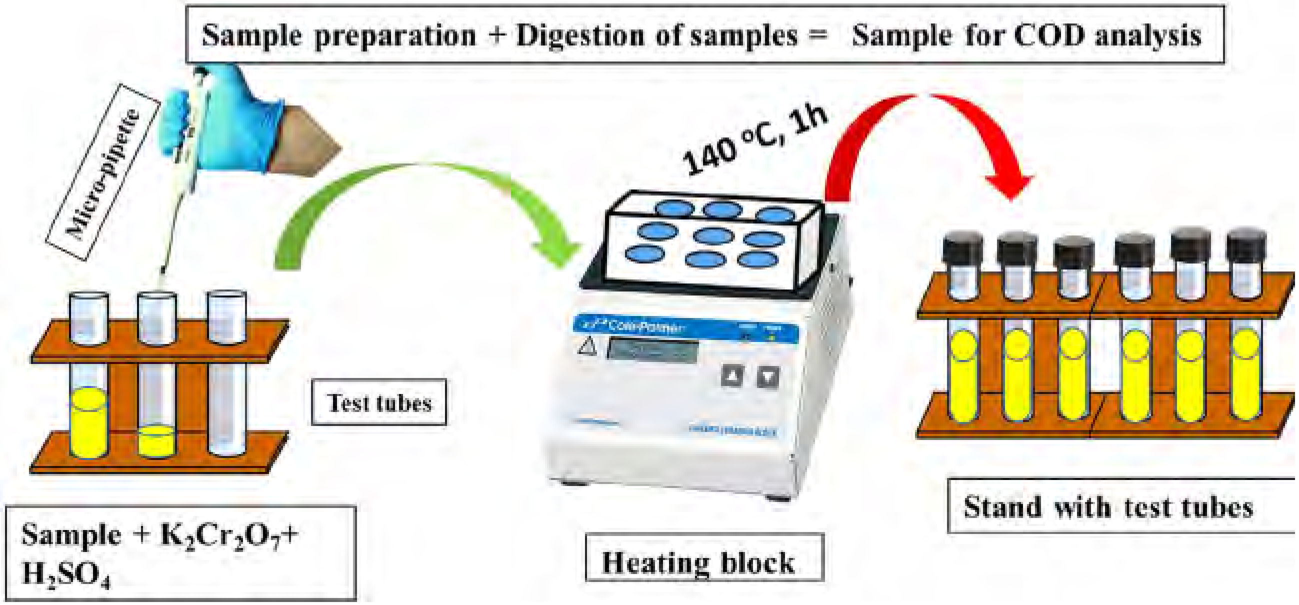
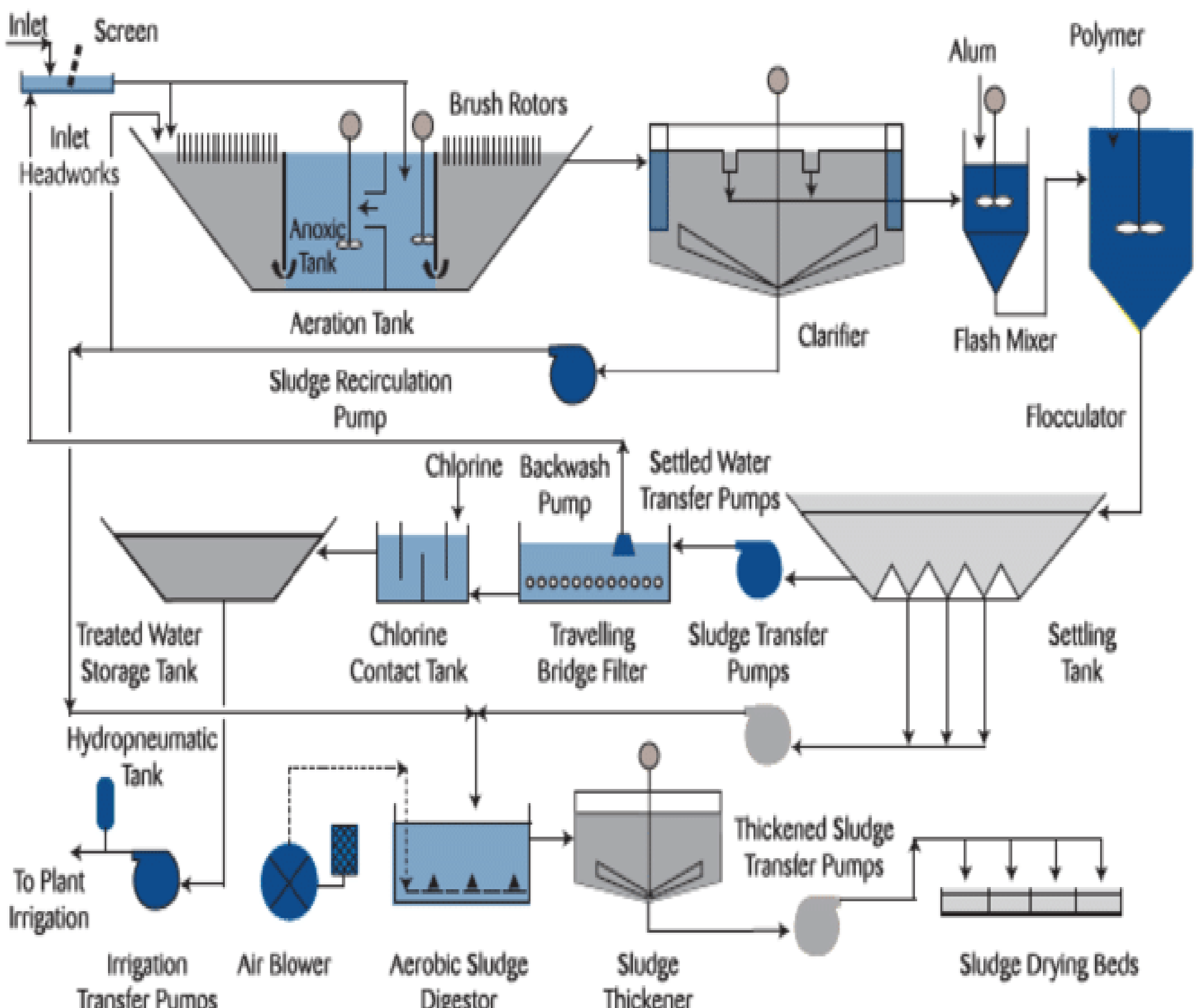
COD testing – 2 hours



Basic Wastewater Treatment Processes

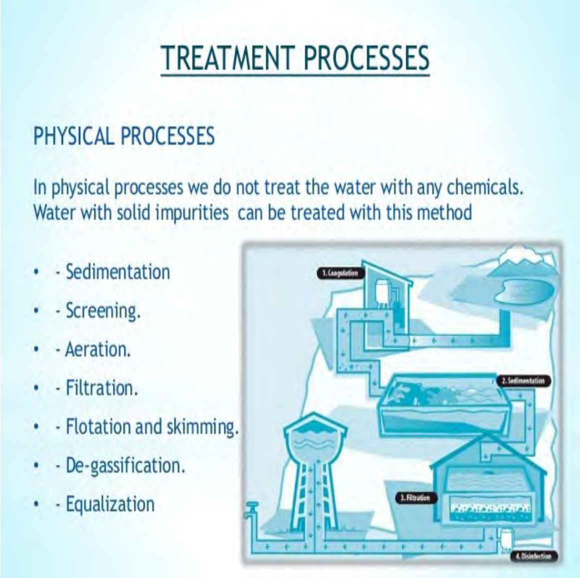
- Physical
- Biological
- Chemical
- *Table 1.4*

Schematic Flow Diagram



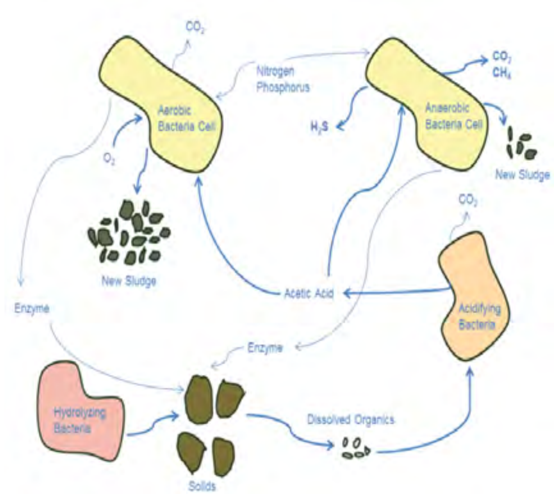
Physical

- Mechanically separate solids from wastewater
- Screening is first separation process
- Particles that are too small to be screened are settled out using gravity
- Bubble curtain of compressed air at the bottom of the tank
- Skimming the surface
- Filtration



Biological

- Organic matter and nutrients became a food source
- Bacteria and other organisms break down waste
- Raising bacteria to do the work



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Chemical

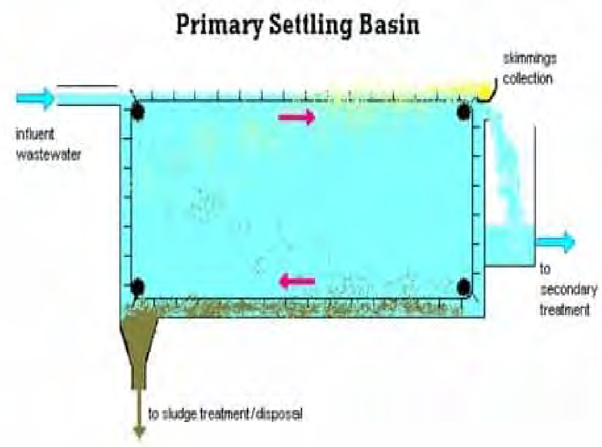
- Sodium hydroxide, sodium carbonate to adjust pH
- Ferric chloride for odor control
- Alum for coagulation
- Chlorine to disinfect
- Sodium bisulfate, sulfur dioxide for dechlorination
- Polymer for dewatering solids

Preliminary Treatment

- Headworks - Remove the larger materials
  - Wood
  - Cardboard
  - Rags
  - Grit
  - FOG
  - Scum

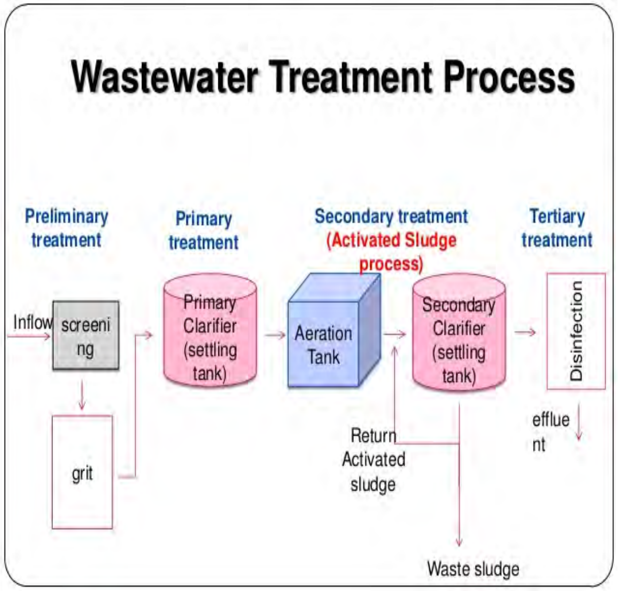
Primary Treatment

- Primary clarifiers
- Slow down the water and remove heavier organic material
- Remove 60-75% of suspended solids
- Remove 20-30% total BOD



Secondary Treatment

- Most large particles are removed
- Colloidal particles remain – they can take 2 years to settle!
- Secondary treatment can efficiently (chemically and biologically) remove 85% of TSS and BOD
- Effluent concentrations of 10-30 mg/L



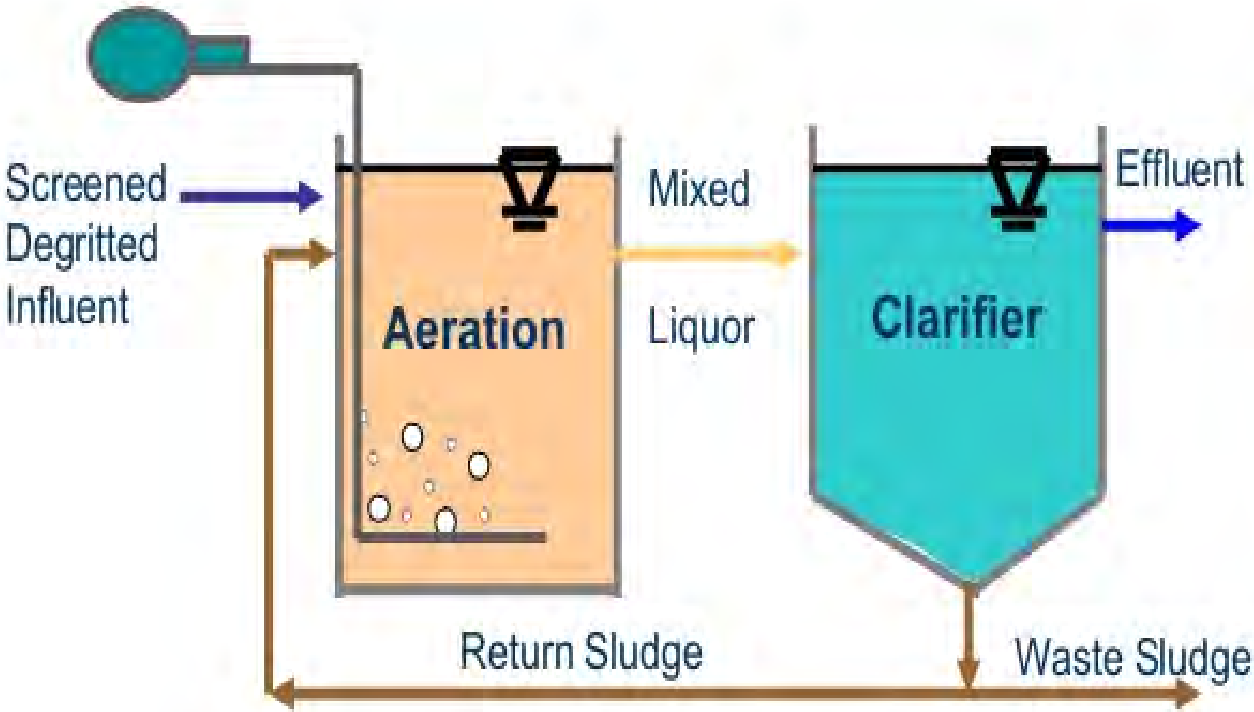
Ponds

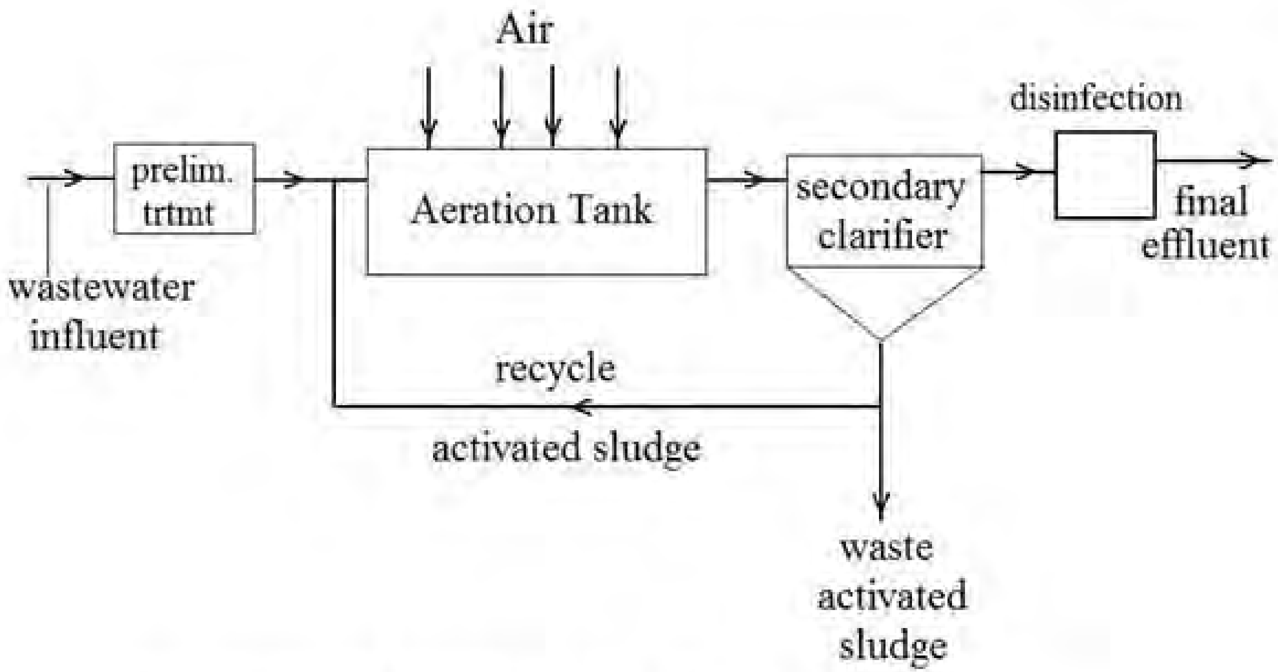
- Lagoons
- Simplest form of wastewater treatment
- Ponds make up 50% of all WRRF in the U.S.
- Large footprint
- Common in rural areas
- Multi-celled

Activated Sludge

- Modification of a pond treatment system
- Water enters the front of the process and passes through to the end of the process
- AS adds a recycle line that returns biological solids that settle out in the clarifier back to the front of the process Figure 1.3 pg. 10
- Biomass/Mixed Liquor Suspended Solids MLSS – BUGS
- Floc / Bio Floc – fibers, bacteria, inert material and other complex microorganisms.
- AS is typically 1200-3500 mg/L

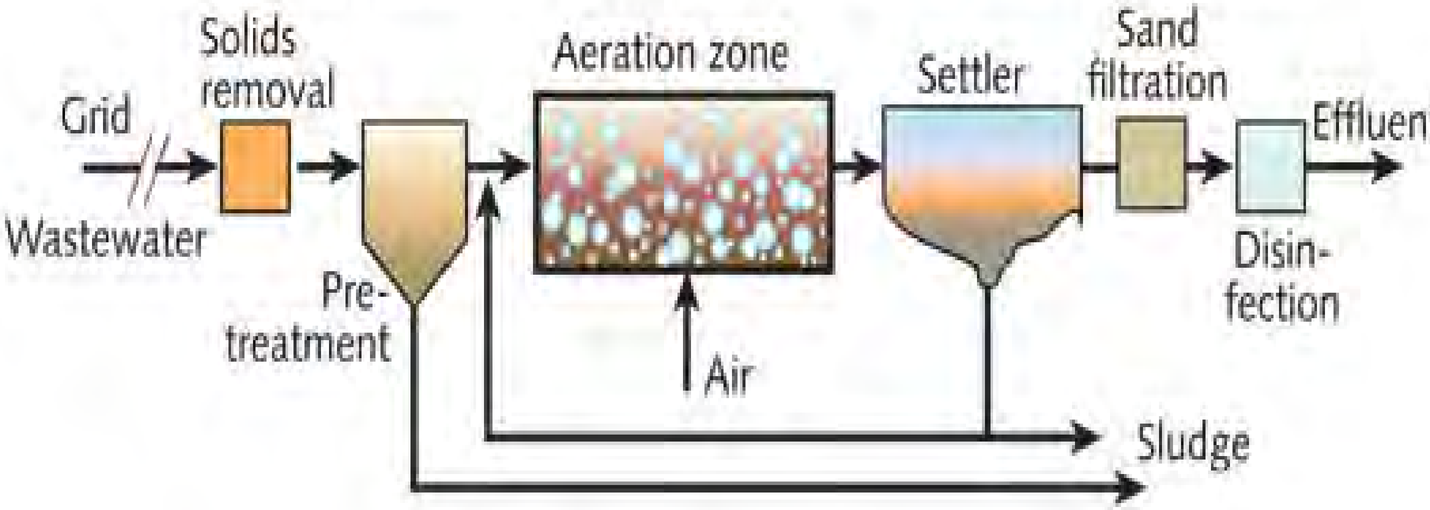
TYPICAL ACTIVATED SLUDGE PROCESS



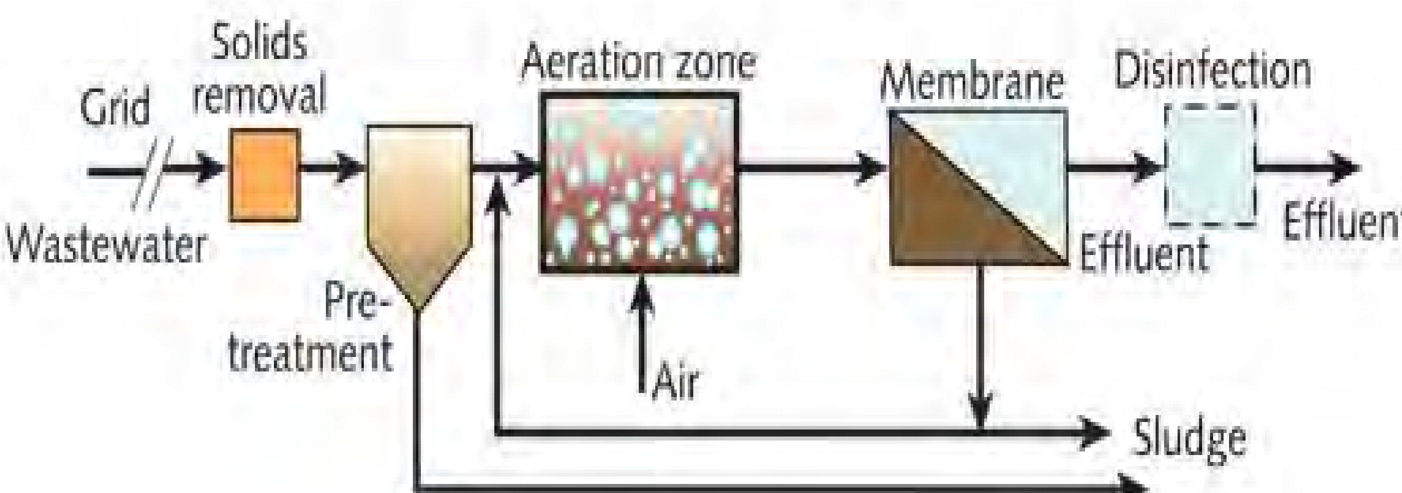


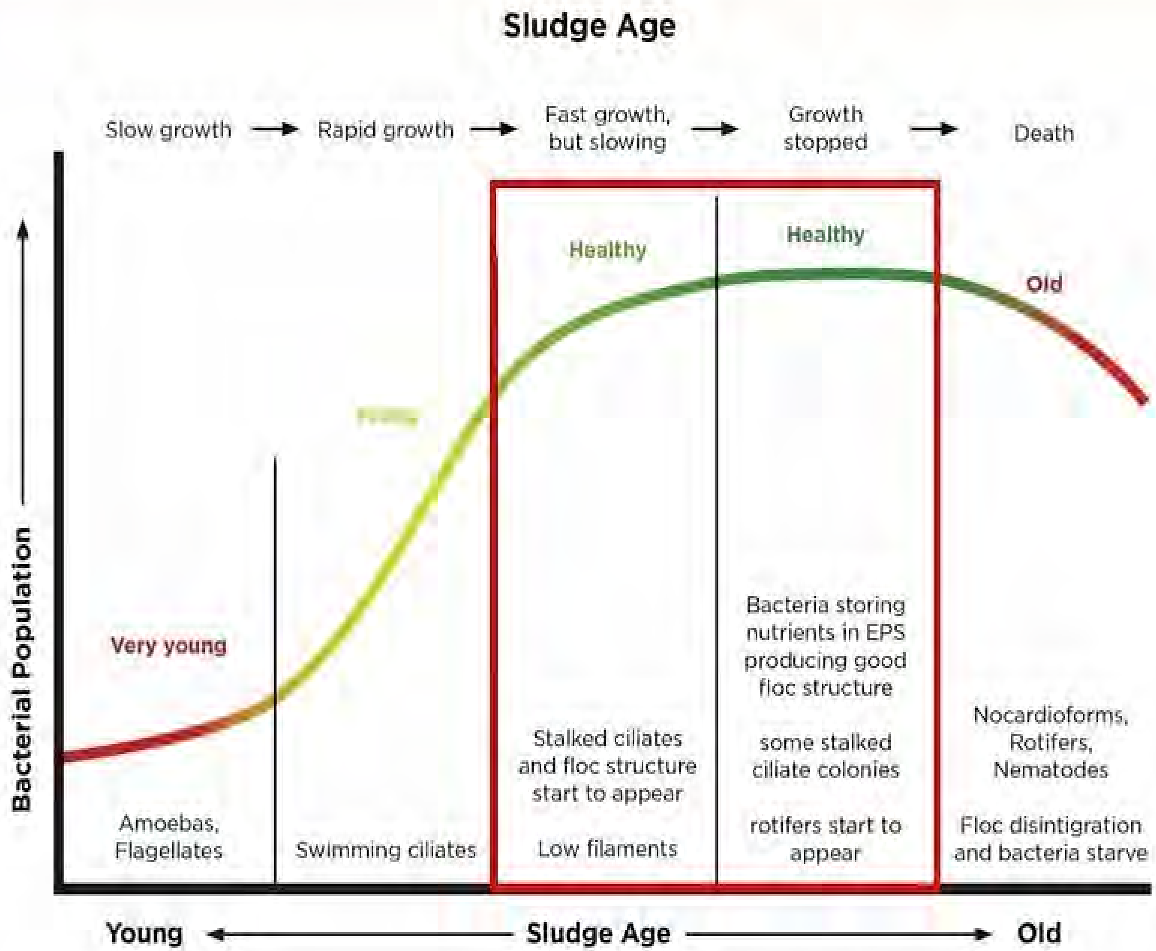
Extended Aeration Activated Sludge
Wastewater Treatment Flow Diagram

(a) Activated Sludge Treatment (AST) Process



(b) Membrane Bioreactor (MBR) process





Healthy Floc Structure

Healthy F:M

Trickling Filters and Rotating Bioreactors

- Same microorganisms as AS
- Wastewater is sprayed on the bacteria that is attached to media
- Media is supported by an underdrain
- Rotating batch reactors (RBC) popular in the 1970s
- Stacked plates or wheels submerged 30-70% in wastewater
- Rotate with microorganisms forming a biofilm

Trickling Filter RBC

Physical-Chemical Treatment

- Screening
- Sedimentation
- Filtration
- Coagulation
- Process is used to remove fats, oil and grease
- Heavy metals
- Activated carbon adsorption to remove organic pollutants
- Chlorination to reduce nitrogen and phosphorous

Advanced Wastewater Treatment

- AWT – further reduction of nutrients (nitrogen and phosphorous)
- More stringent permits
- Microconstituents or Pharmaceuticals and personal care products

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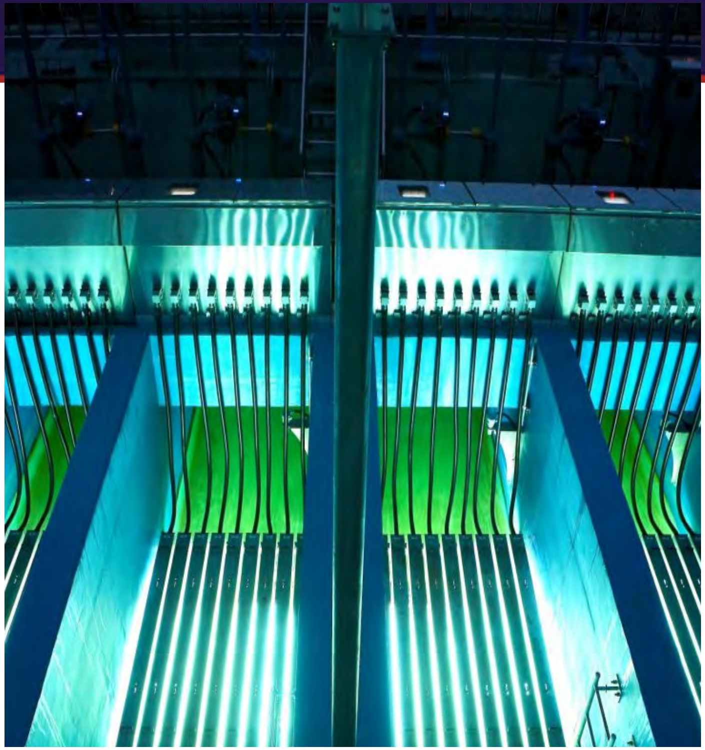
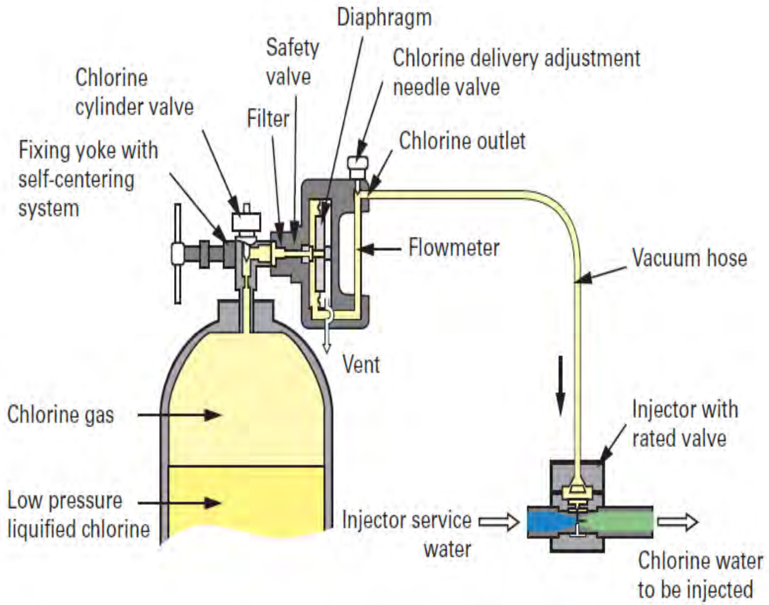
Disinfection

- Destroys pathogens
- Chlorine safety
- Ultraviolet radiation





A chlorine feed system has the rotameter set at 50 lb/day. If chlorine gas is applied for 20 minutes to a 50-foot diameter tank containing water to the 20-foot level, what is the chlorine dose in mg/L?

Step 1

Known

Feed Rate = 50 lb/day

Time = 20 minutes

Tank Diam. = 50 feet

Water Level = 20 feet

Unknown

Dose, mg/L

$\frac{50\ \text{lb}}{\text{day}} \times \frac{1\ \text{day}}{1{,}440\ \text{min}} \times 20\ \text{min}$

Step 2

$$\text{Dose, mg/L} = \frac{\text{lb/day}}{(\text{MGD})\ (8.34)}$$

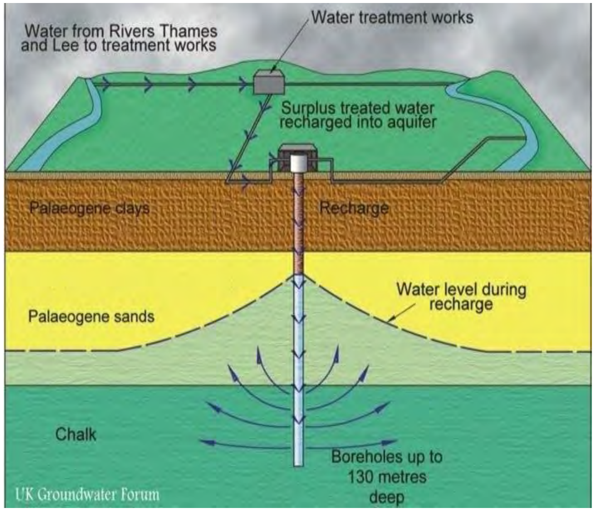
Step 3

$$\text{Dose, mg/L} = \frac{\text{lb}}{(\text{MG})\ (8.34)}$$

Step 4

Effluent Discharge

- The quality of discharge
- Permit requirements
- Water body discharge
- Groundwater injection
- Land application



Solids Treatment Processes

- Solid material is removed
- Sludge stabilization (sludge – biosolids)
- Thickening
- Dewatering
- Digestion
- Chemical stabilization
- Composting
- Reduce organic material, odors, pathogens, biodegradable toxins
- Bind heavy metals to inert solids

Types of Residuals

- Primary sludge – unprocessed (raw) organic/inorganic solids
  2-6% solids
- Secondary sludge – microorganisms
  < 1% solids
- Chemical sludge – dependent on treatment chemicals (alum)
- Tertiary treatment – phosphorous removal

Regulatory Requirements for Biosolids

- Disposal depends on treatment
- Combustibles – incinerated or landfill
- Grit – landfill
- Biosolids- land application
- CFR 503 – requirement for pathogen reduction
- Soil amendment / fertilizer
- CLASS A – pathogen reduction below detectable limits
- CLASS B – land applied for private land

Thickening

- Process used to remove water
- Thickened sludge typically contains 1.5 – 8% solids
- Less volume. Hauling costs reduced

1. Pre-thickening – DAFTS, centrifuges, gravity belts, rotary drum
2. Post-thickening – after stabilization (digestion) before beneficial use
3. Recuperative thickening – thickening biosolids

Digestion

- Digestion may be done aerobically or anaerobically
- Primary sludge is digested anaerobically
- Digesters contain primary and secondary sludge
- Endogenous respiration – reduce the volatile solids and pathogen content
- After digestion sludge can meet the 503 regulations
- Aerobic digestion – microbes break down organic matter into carbon dioxide, water and ammonia – 40 days / 40% reduction in volatile solids

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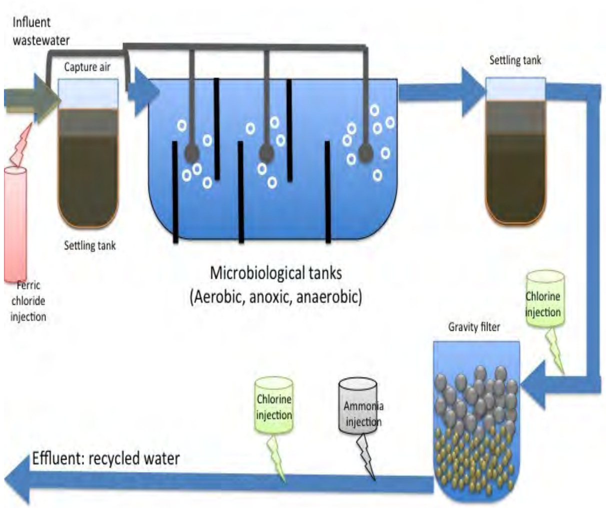
Chemical Stabilization

- Raising the sludge pH – 12.0 for 2 hours and maintain at 11.5 for 22 hours
- Reduces pathogens and odors
- 40 CFR 503



Fundamentals of Biological Treatment Chapter 5

Introduction

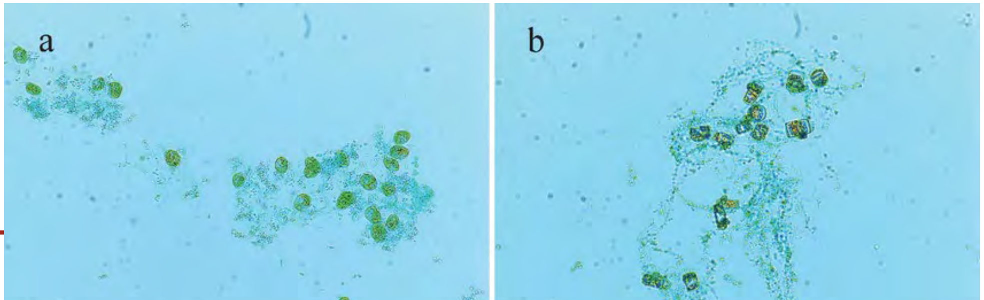
- Biological treatment depends on a healthy community of bacteria
- Very little biological oxygen demand (BOD) and total suspended solids (TSS)
- Removal of nitrogen and phosphorus
- Microorganism types
- Environmental conditions
- Physical effects of microbial activity

Biological Treatment

- Biological treatment was developed in the early part on the 20th century – early 1900's
- Biological treatment depends on naturally occurring microorganisms to break down organic matter into simple substances such as carbon dioxide and water.
- Microorganisms use organic material in the wastewater as food to grow and reproduce
- The higher the concentrations the faster the biological process
- Once treatment is complete, biomass is separated, treated wastewater can be discharged safely to a receiving water.

Physical and Chemical Requirements for Biological Treatment

- Specialized bacteria convert ammonia to nitrite and nitrate or uptake phosphorus
- Microorganisms form biofilms or flocs, bug communities
- Biofilms form on surface particles
- Flocs grow suspended in the wastewater
- Microorganisms incorporate biodegradable matter and convert it to biomass
- Exopolymer – sticky substance that helps bacteria stick together
- Biofilms and floc are denser than water, gravity will separate them.



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Organic Wastewater fractions

page 176 figure 5.1

various wastewater constituents found in the influent of WRRFs receiving significant industrial contributions. The example shown in Figure 5.1 was created from average data collected from many different facilities (Pasztor et al., 2009). Because of differences between service areas

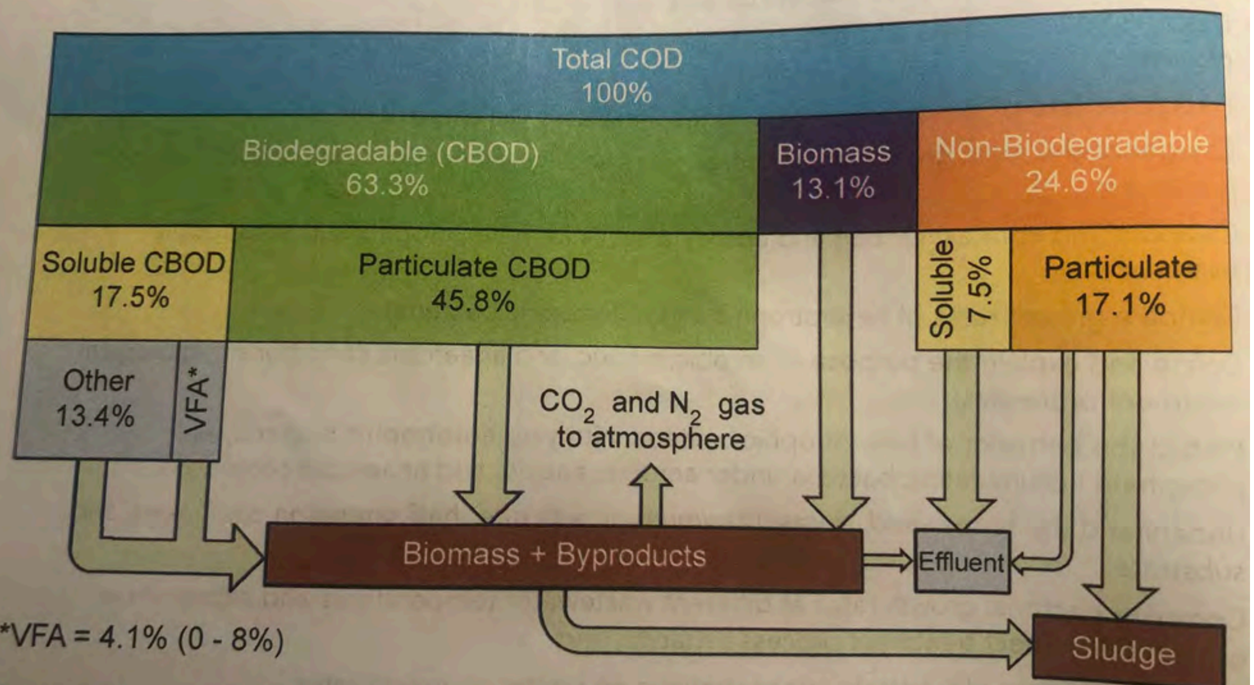
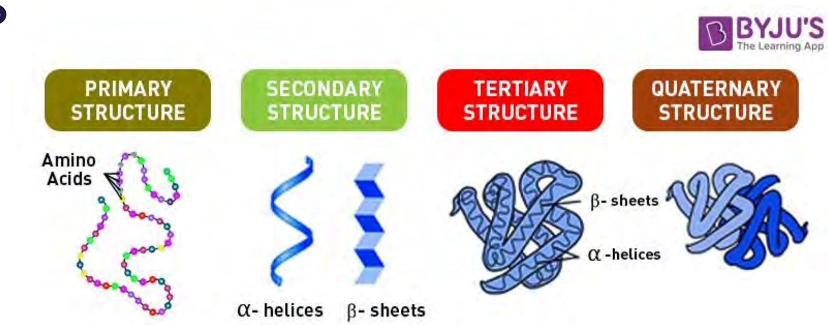


Figure 5.1 Organic Wastewater Fractions (COD = chemical oxygen demand, CBOD = carbonace biochemical oxygen demand, and VFA = volatile fatty acids) (adapted from Pasztor et al., 2009)

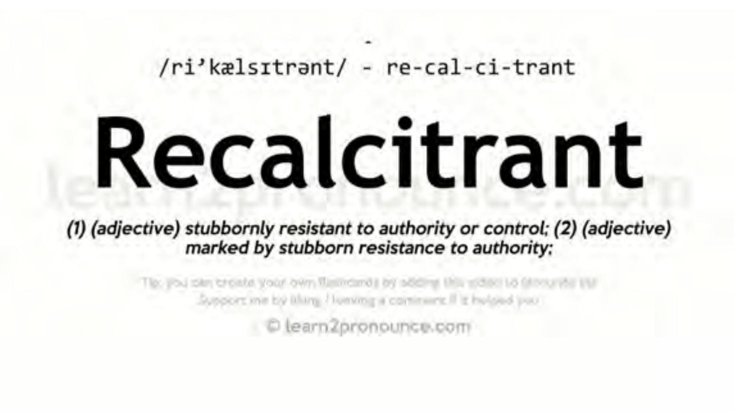
Biodegradable Waste

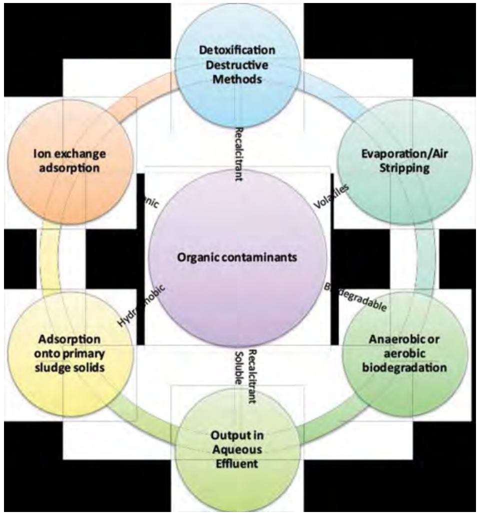
- Bacteria are responsible for most of the biodegradation
- Domestic wastewater consists of
  - Carbohydrates
  - Proteins
  - Fats



Non-Biodegradable Waste

- Recalcitrant – non-biodegradable organic chemicals
- Non-biodegradable inorganics (inert) – salt, sand, grit
- Some biodegradable microorganisms may not be removed by the WRRF treatment process or measured through a BOD test
- Physical methods must be used (settling or filtration)





Particulate Organic Matter

- 60% of the organic matter in wastewater is in particulate form
- Less than half is large enough to settle out of suspension
- Particles between 1-100 μm (1-100 microns) remain in colloidal suspension
- Colloidal particles become adsorbed <u>*onto*</u> (into) biomass
- Soluble Organic Matter (SOM) is a food source
- SOM can be measured two ways

1. Soluble CBOD
2. Readily biodegradable COD

If SOM exists in the effluent, it is assumed that to non-biodegradable

What are the Efficiencies

<u>Influent</u>

COD – 500 mg/L

CBOD – 250 mg/L

<u>Effluent</u>

COD – 25 mg/L

CBOD – 10 mg/L

COD 500-25/500 = .95 x 100 = 95%

CBOD 250-10/250 = .96 x 100 = 96%

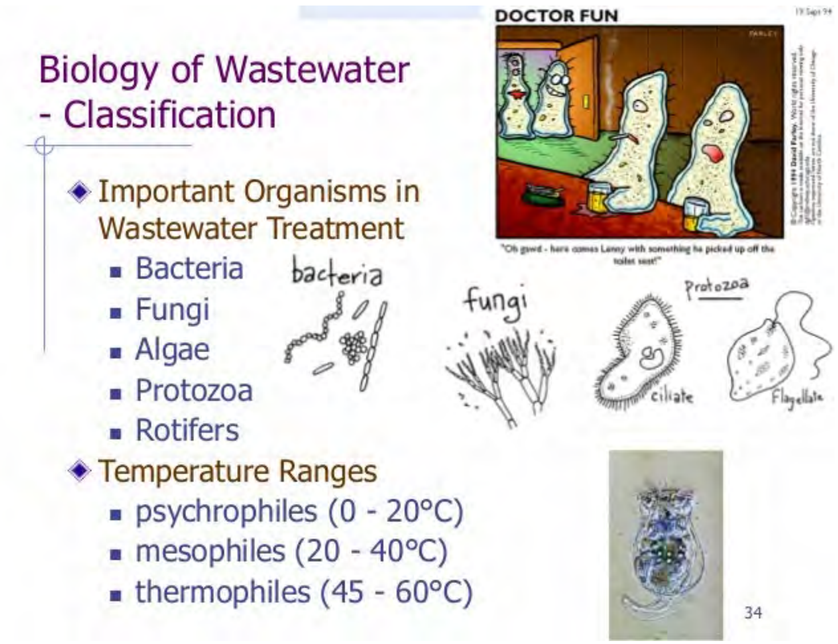
Microbiology

- Pages 180-202

Microbiology

- Biomass in biological treatment processes may contain as many as 300 different microorganisms
- 4 different classifications

1. Bacteria
2. Protozoa
3. Metazoa
4. Viruses



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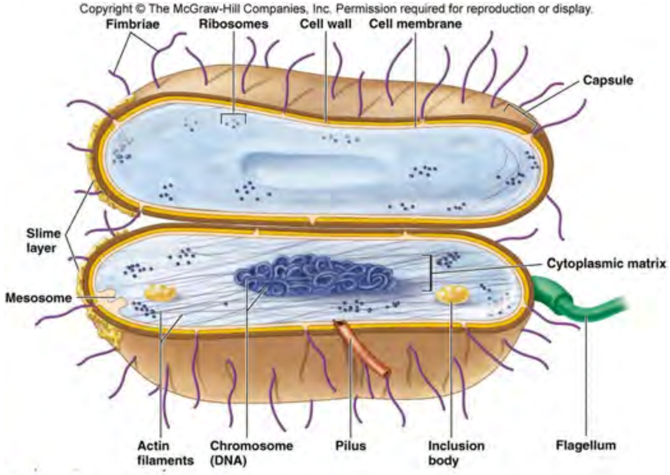
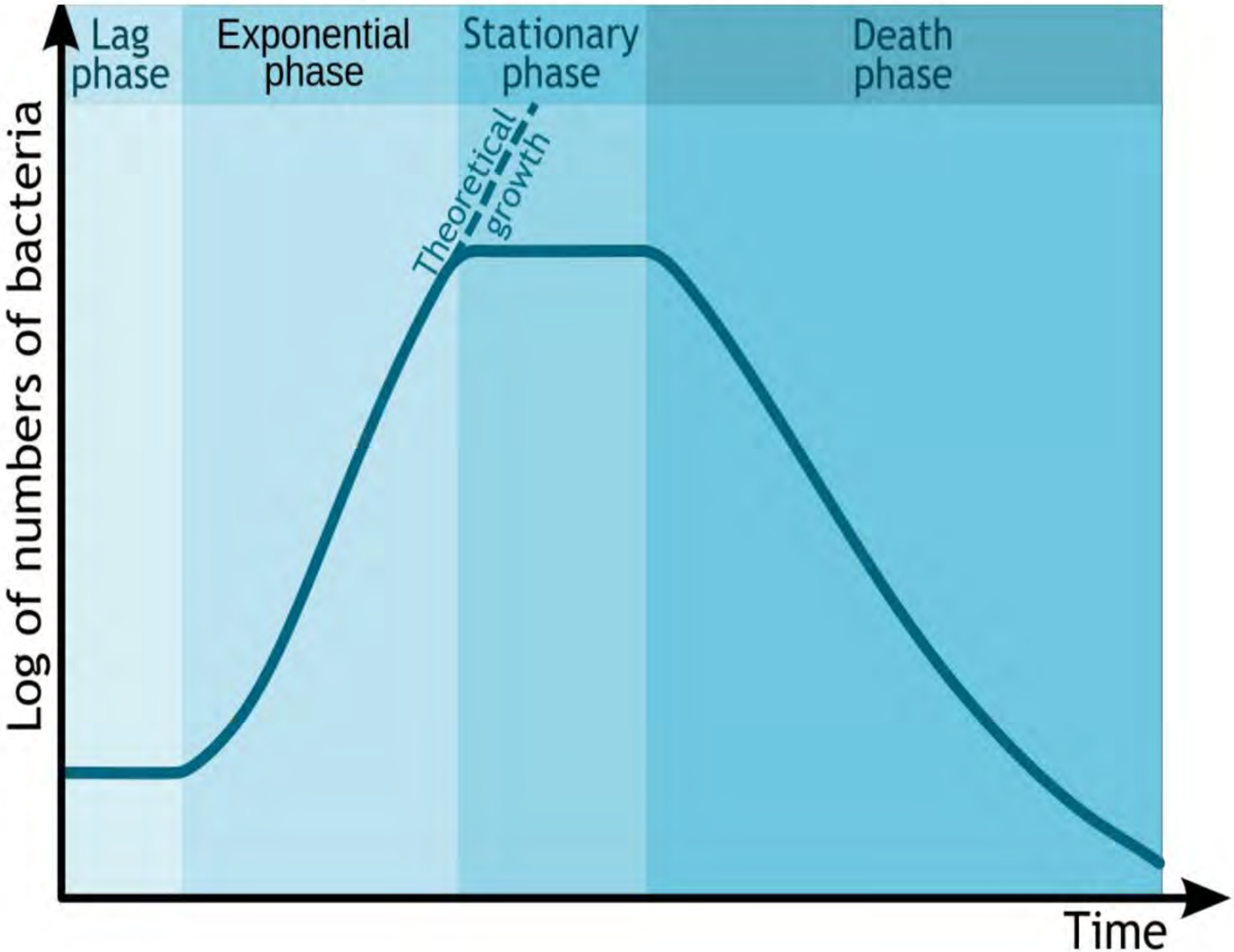
Bacteria 180-181



5 Cells secrete their enzymes in unison to digest food particles.

- Bacteria are Prokaryotes
- Pro-cari-yotes
- Diverse group of organisms
- Small single celled in very large groups
- 0.2 – 2 microns in size
- Filamentous bacteria are long chains
- Cell membrane controls the intake of food
- Cell wall provides structural support
- See Table 5.1

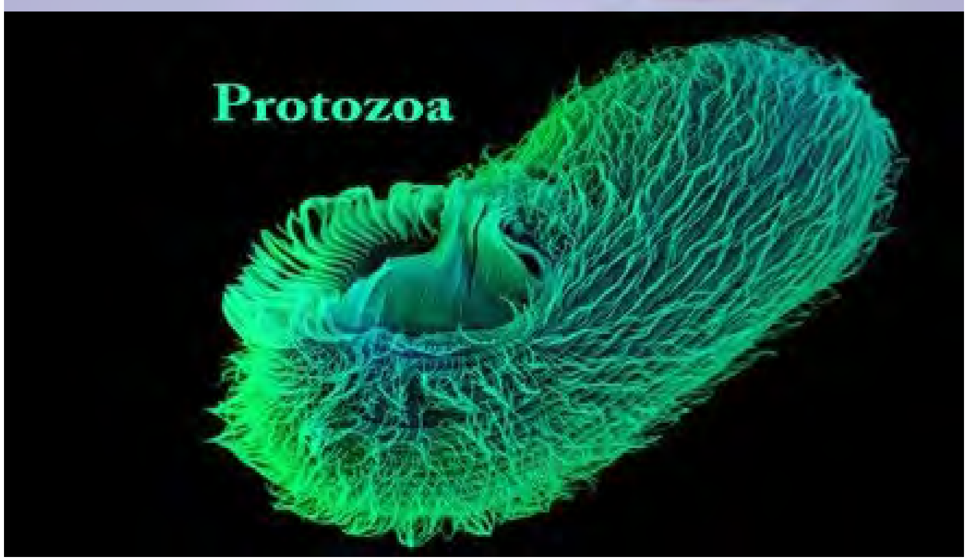
Bacterial Growth Curve

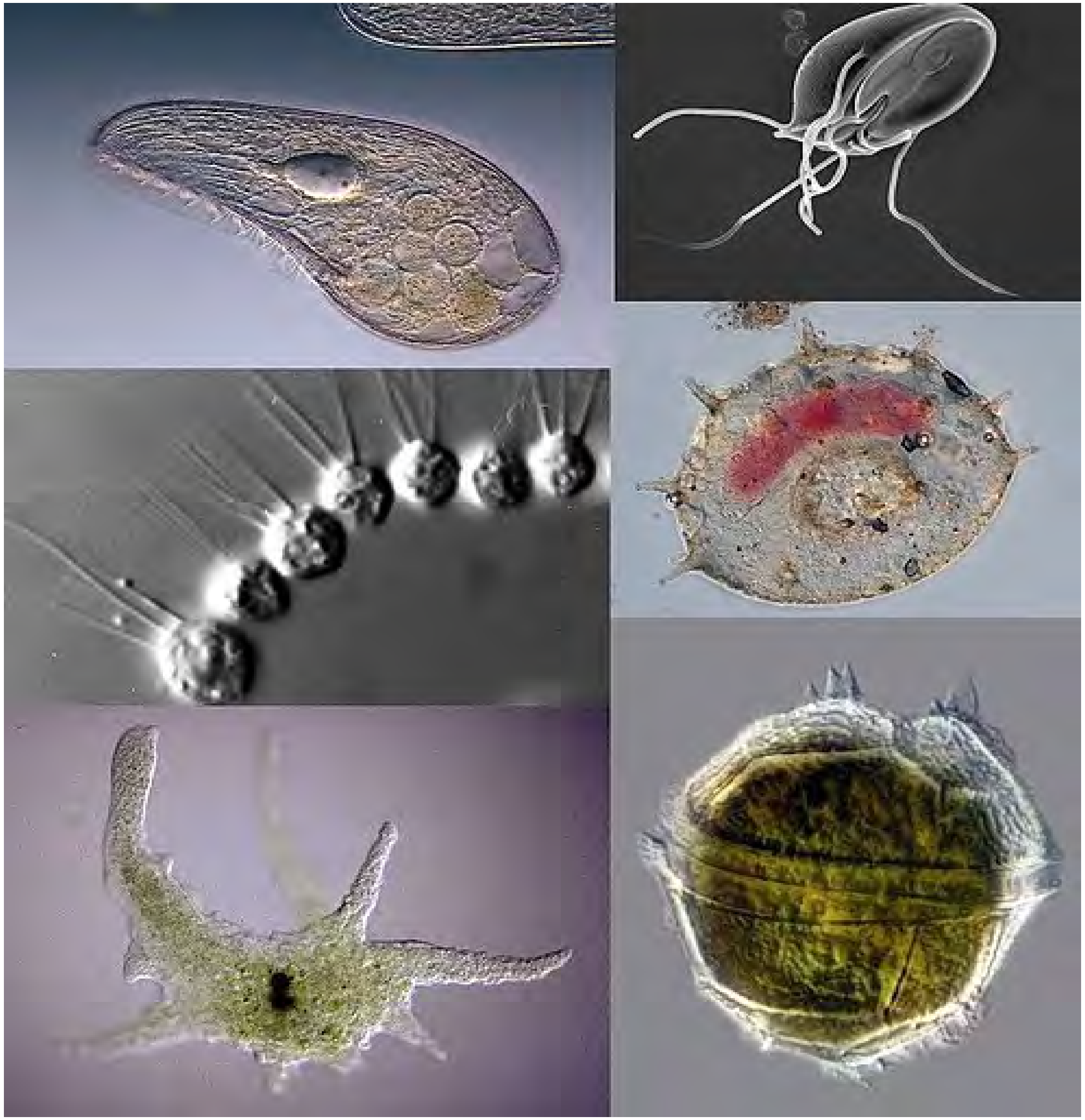


Protozoa

- Indicator organisms
- Unicellular
- Protozoa account for 90% of the non-bacterial biomass
- Found in large numbers
- Predators to bacteria and algae – consume hundreds per hour
- Absorption of colloidal particles improves settleability of suspended particles
- When protozoa are absent bacteria remain in effluent
- Giardia and Cryptosporidium are responsible for outbreak illnesses


About Protozoa


Protozoa



Clockwise from top left: *Blepharisma japonicum*, a ciliate; *Giardia muris*, a parasitic flagellate; *Centropyxis aculeata*, a testate (shelled) amoeba; *Peridinium willei*, a dinoflagellate; *Chaos carolinense*, a naked amoebozoan; *Desmerella moniliformis*, a choanoflagellate

Metazoa

- Metazoa – technical term for all animals composed of more than one cell
- Larger and more complex than a protozoa
- Rotifers – common in wastewater (rotating heads)
- Nematodes
- Water bears
- Bristle worms
- Water fleas
- Seed shrimp

Bacteria in Secondary Treatment Processes

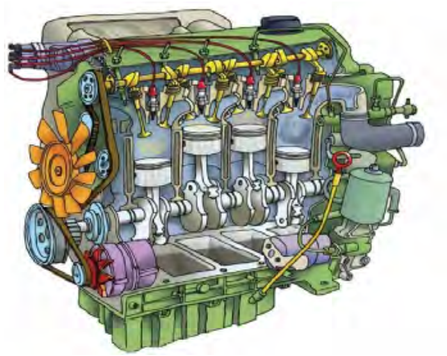
Bacteria Groups

- Bacteria in secondary treatment can be divided up into a few significant groups:

1. Heterotroph
2. Autotroph
3. Aerobic
4. Facultative
5. Anaerobic

FUEL

OXYGE
N



CARBON
DIOXIDE

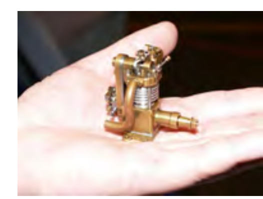
WATER

Bacteria Factory

- Reproduce
- Engine is their heart
- Spare parts
  - Carbon
  - Oxygen
  - Nitrogen
  - Phosphorus

CO_2
WATER

FUEL
OXYGEN
NUTRIENTS



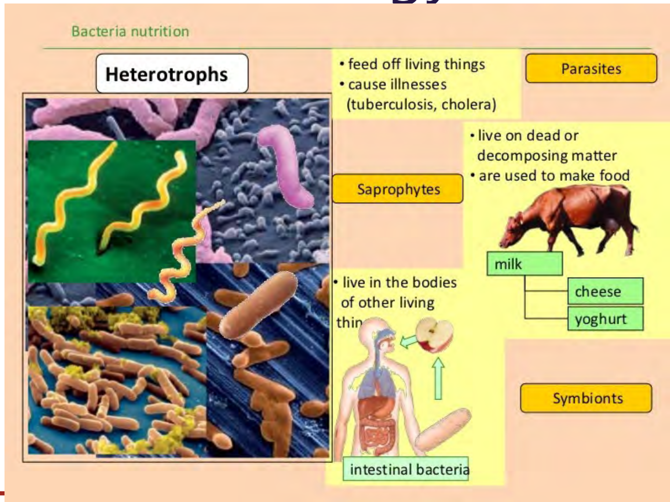
Energy and Carbon Sources

- Autotrophs - Organisms that use carbon dioxide as their carbon source for growth

Phototrophs

Heterotrophic Bacteria

- Feed mainly on organic matter
- Nourishment from others
- Do not consume each other
- Consume byproducts of bacteria
- Dominant bacteria in wastewater
- Require DO/nitrate/nitrite/sulfate to obtain energy



Autotrophic Bacteria

- Obtain their carbon source from inorganic chemicals
  - Carbon dioxide
  - Carbonates
  - Bicarbonates
- Auto – means self
- Troph – nourishing
- Build and synthesize all their own molecules (synthetic)

Most important Autotrophic Bacteria

1. Nitrifying Bacteria
2. Sulfur-reducing Bacteria

Oxygen Requirements

- 3 different oxygen requirements that can be present in wastewater

Aerobic *obligate*
Contain DO and may or may not contain nitrite or nitrate

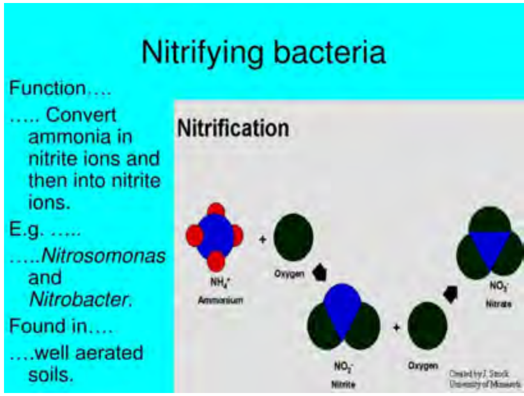
Anoxic
Contain nitrite and nitrate but do not contain DO

Anaerobic
Do not contain DO, nitrite or nitrate
Fermentation – respiration byproducts are organic acids and alcohols

Respiration – extraction of energy from organic and inorganic compounds

Nitrifying Bacteria

- Nitrifying bacteria use ammonia or nitrite as their fuel
- DO as their oxygen source
- Outputs from nitrifying bacteria – nitrite, nitrate, carbon dioxide, and water
- They are formed when carbon dioxide is dissolved in water
- For every 1 mg/L of ammonia that is converted to nitrite, 7.14 mg/L of alkalinity will be consumed



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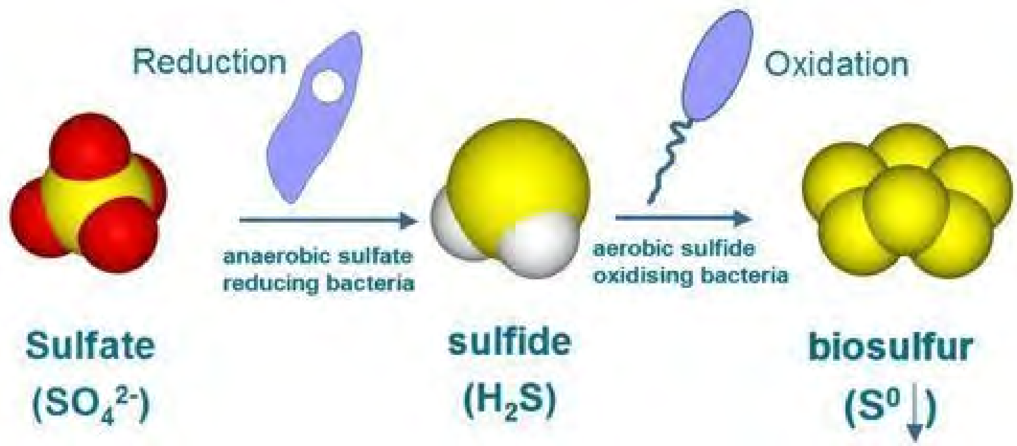
Sulfate Reducing Bacteria

- 220 known species
- Tolerate extreme pH conditions (2-10)
- Produce carbon dioxide and hydrogen sulfide (rotten egg smell)
- H_2S is extremely toxic



Microbial Growth Rate

- Each organism has a max. growth rate
- Lack of carbon, oxygen or nutrients can limit growth
- Growth increase when resources increase
- If more than one resource limits growth – compounding effects
- If excess resources – maximum growth rate is limited by MGR
- Environmental conditions limit growth rate
- Bacteria can only grow when food is available

Monod Equation

Application and importance

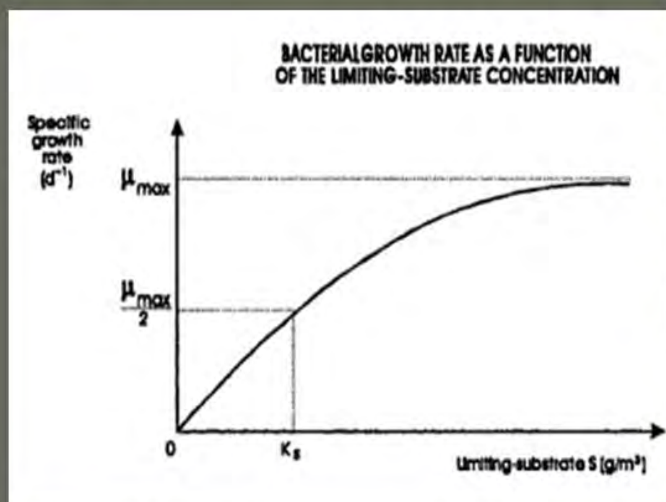


Figure 1 is a graphic representation of Monod's equation (Von Sperling and De Lemos Chernicharo 2005).

If the concentration of S is reduced, the population growth rate will decrease. If concentration of S increases to a specific limit where growth rate is maximum, then S is no longer regarded as a limiting factor.

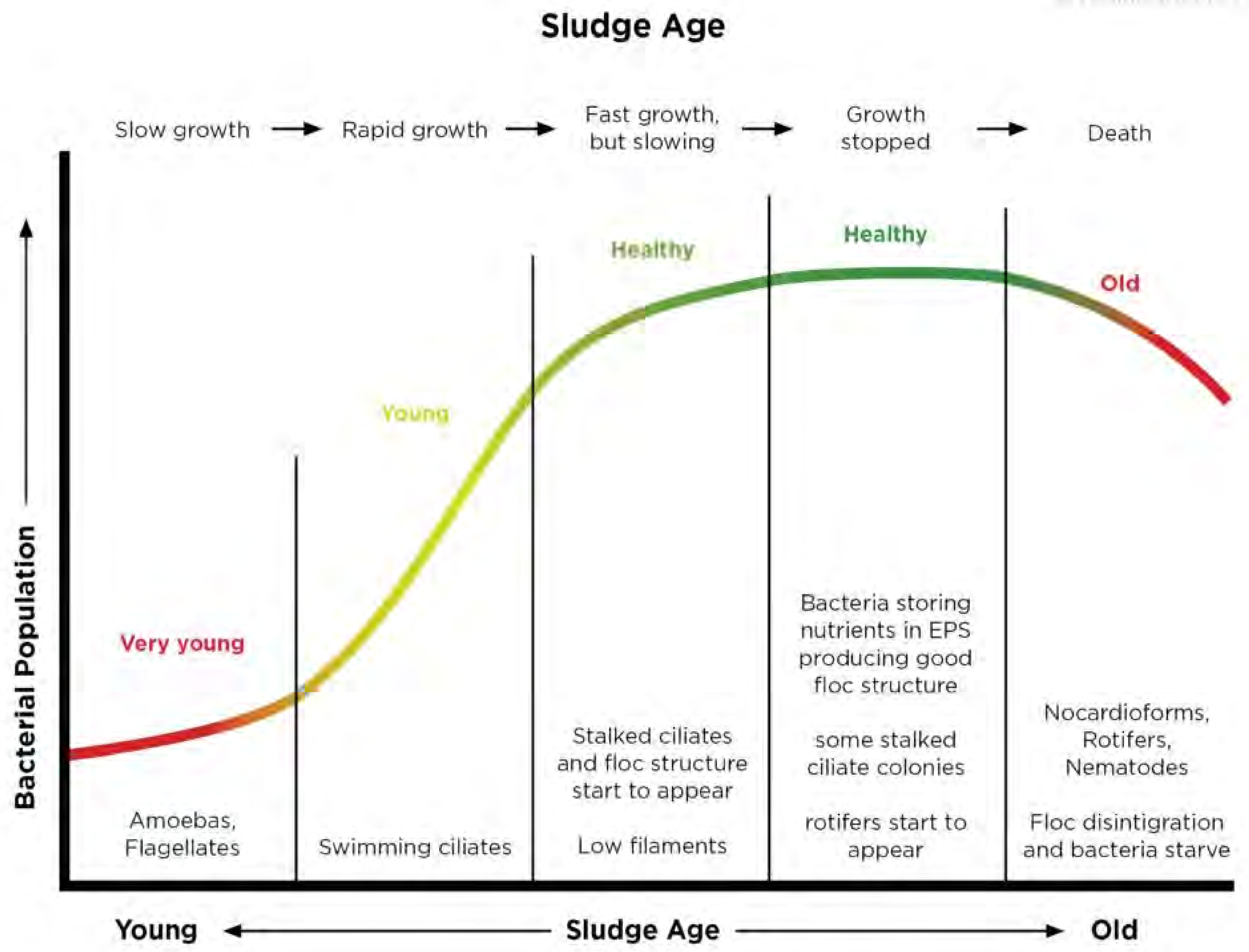
When Ks = S the term S/(Ks + S) becomes half (1/2) and the growth rate becomes equal to ½ maximum rate.

(Von Sperling and De Lemos Chernicharo 2005).

- Saturation coefficient – concentration of a resource that a microorganism needs to grow
- Half-Saturation coefficient – concentration of a resource to grow exactly half of its maximum growth rate
- Biomass yield – number of new microorganisms per the amount of substrate
- Biomass decay rate – decay accounts for losses caused by microorganisms consuming internal storage products and being eaten by other organisms

How many WRRF in the US?

14,748

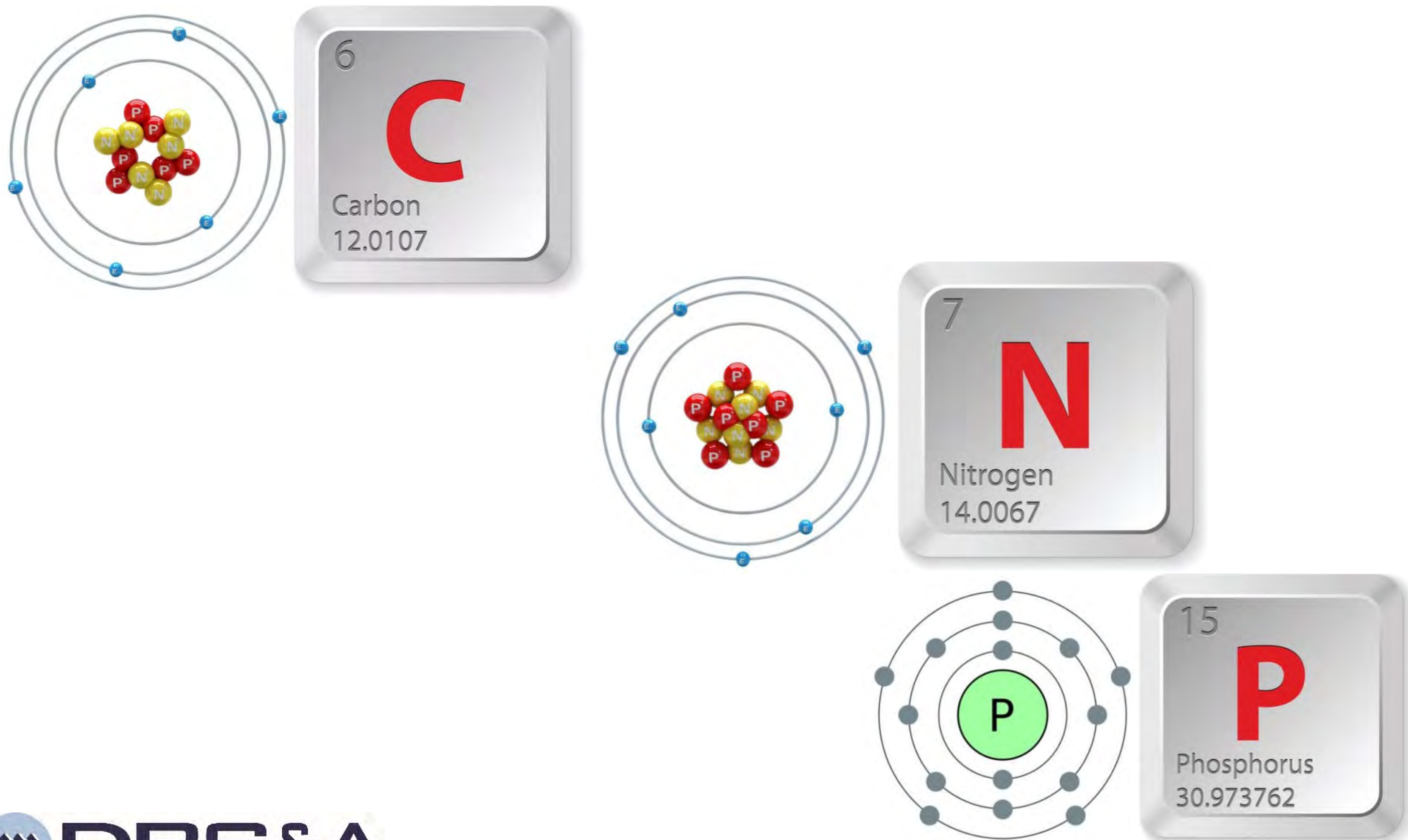

Sludge Age
Slow growth
Rapid growth
Fast growth, but slowing
Growth stopped
Death
Healthy
Healthy
Old
Young
Very young
Bacterial Population
Bacteria storing nutrients in EPS producing good floc structure
Nocardioforms, Rotifers, Nematodes
Stalked ciliates and floc structure start to appear
some stalked ciliate colonies
Amoebas, Flagellates
Swimming ciliates
Low filaments
rotifers start to appear
Floc disintigration and bacteria starve
Young
Sludge Age
Old

NUTRIENT REMOVAL

Nutrients

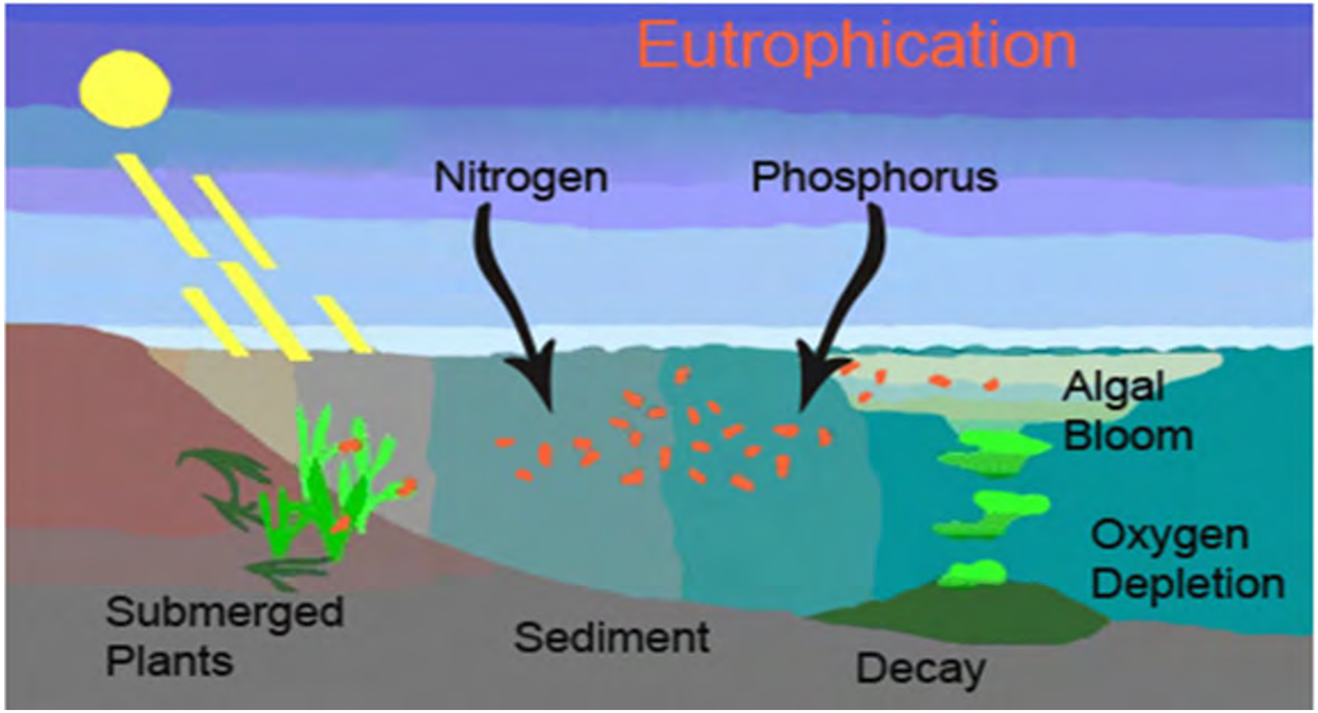
What are they and how do we remove them?

What are Nutrients?



Why Remove Nutrients?

The nutrients in wastewater contribute to eutrophication: "excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land, which causes a dense growth of plant life and death of animal life from lack of oxygen."



"Typical" wastewater

- Influent nitrogen – 23 to 69 mg/L total N, 60 to 70% of which is ammonia-nitrogen ; remaining 30 to 40% is organic
- Ammonium typical 5 mg/L, no NO_3- or NO_2-
- Influent phosphorus – 6 to 8 mg/L as P for domestic WW
- Sources are human waste, food and certain soaps and detergents.

Forms of Nitrogen in Wastewater

1) Ammonia (NH_3-N)
2) Nitrite (NO_2-N)
3) Nitrate (NO_3-N)
4) Nitrogen Gas (N_2)

Forms of Nitrogen

Total Kjeldahl Nitrogen (TKN) =

Organic N + NH_3-N

Total Inorganic Nitrogen (TIN) =

NH_3-N+ NO_2-N+ NO_3-N

Influent Nitrogen

- 99% is in the form of TKN
  - 40% organic nitrogen
  - 59% ammonia/ammonium
  - This ratio is dependent on pH, temperature and detention time in the collection system
- Less than 1% nitrate and nitrite

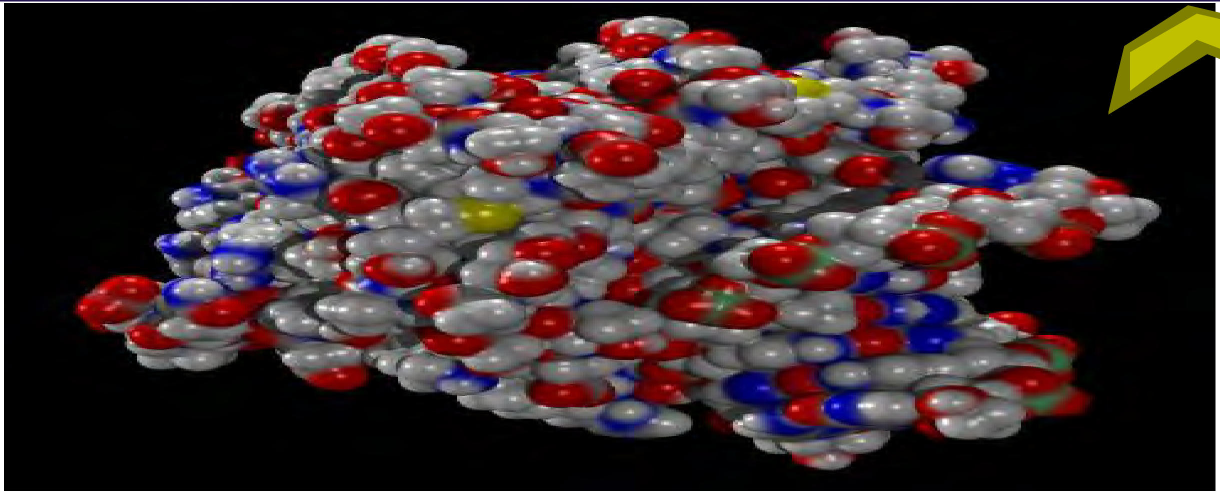
Forms of Influent Phophorus

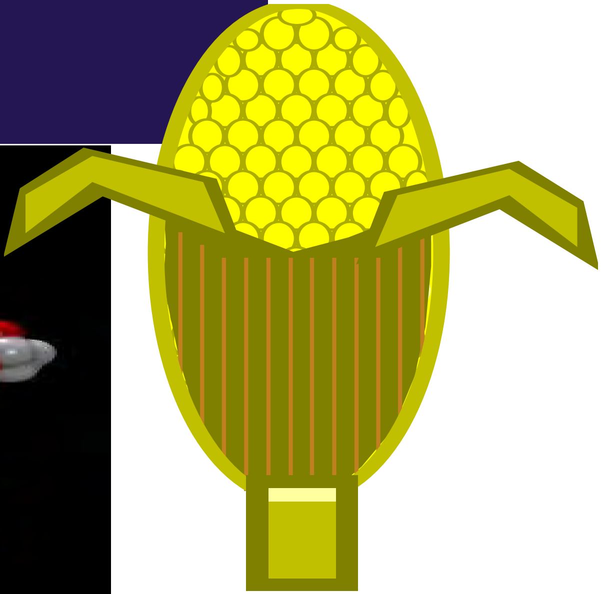
- Phosphate (aka orthophosphate) H_2PO_4- or HPO_4-^{2}
- Polyphosphate
- Organic phosphorus

Forms and Source of P

Organic Phosphorus

- complex organic compounds
- soluble or particulate
- decomposes to Ortho-P

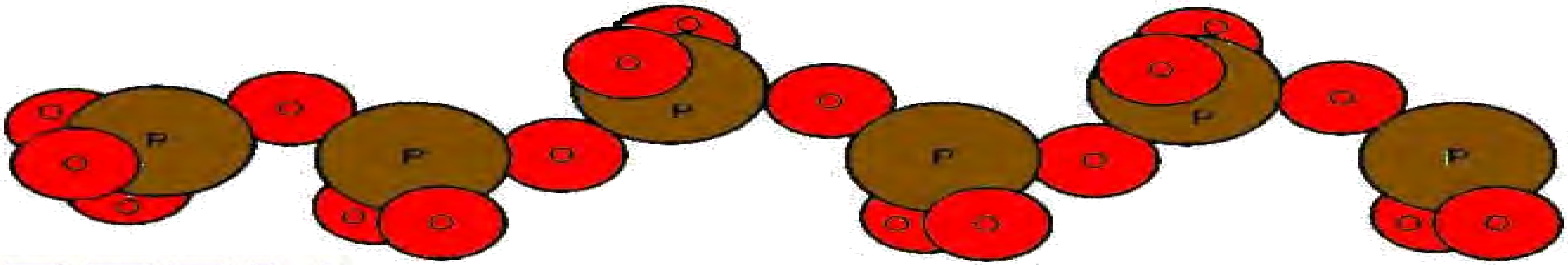




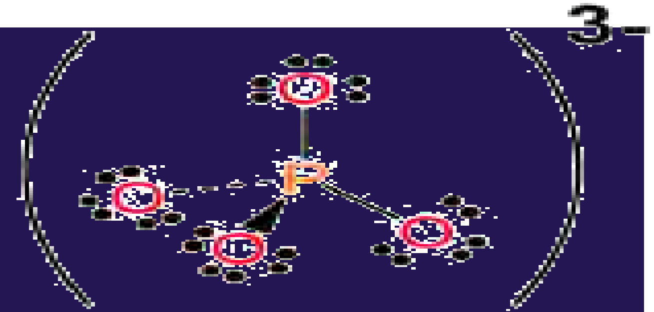
Forms and Sources of P

Polyphosphate (condensed phosphate)

- chained molecules
- soluble
- home, industrial detergents
- potable water treatment
- decomposes to Ortho-P

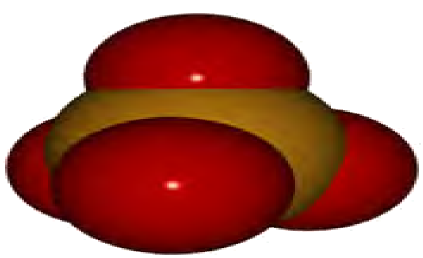


Forms and Sources of P



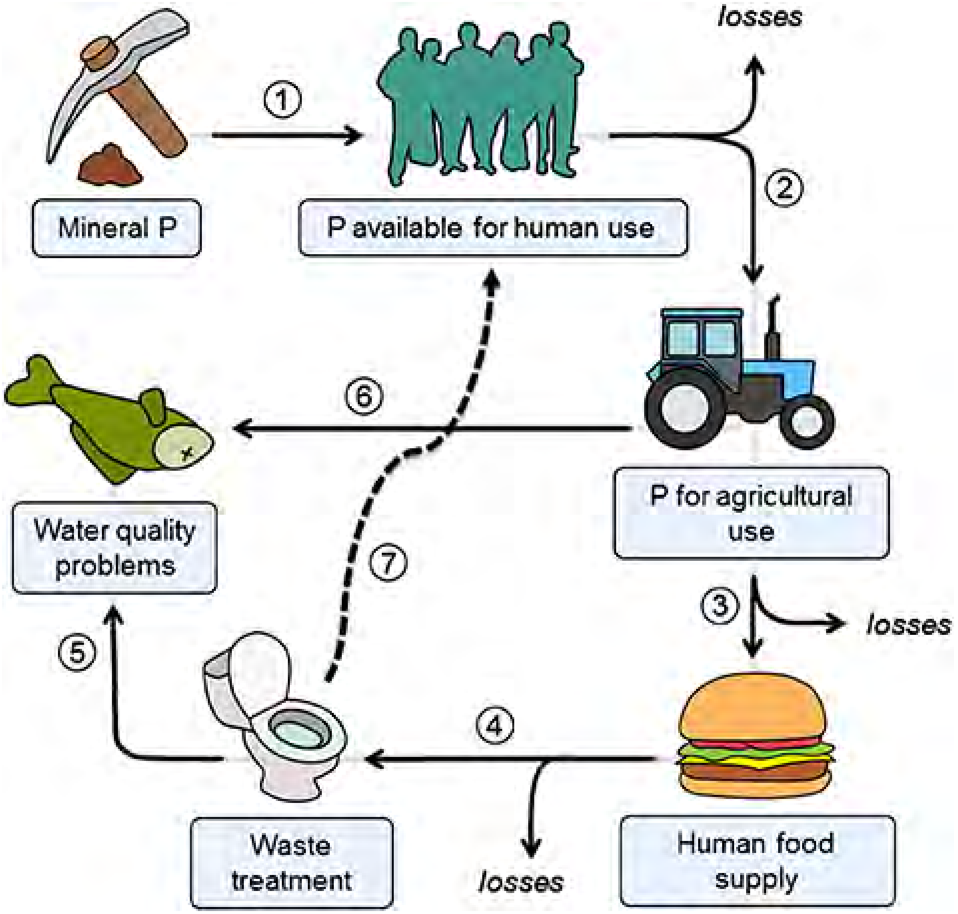
Orthophosphate

- Simple Phosphate, PO_4
- soluble
- household cleaning agents
- industrial cleaners;
- phosphoric acid
- conversion of organic and poly phosphate



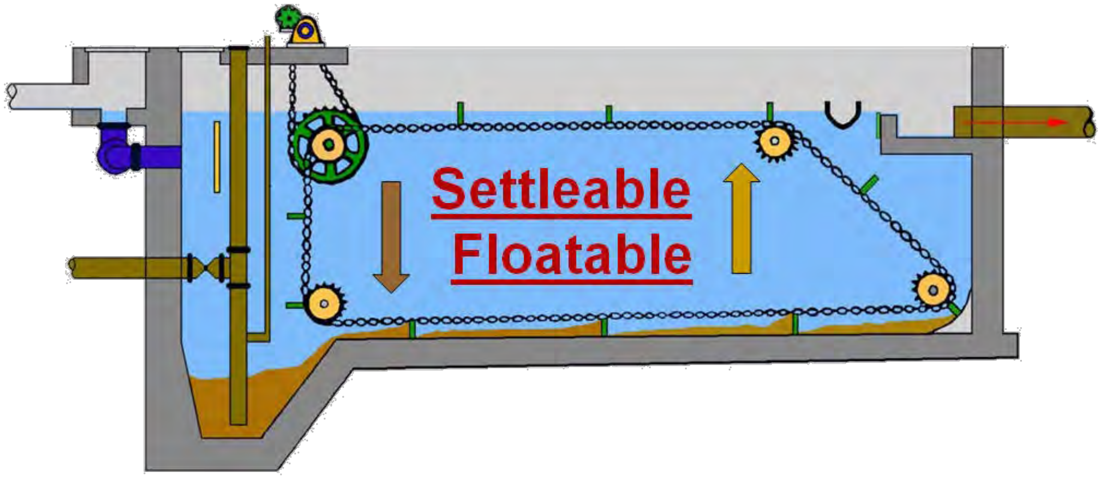
Influent Total Phosphorus

- 6 to 8 mg/L as P for domestic waste
- could be higher from industrial sources



Mechanisms for Nitrogen and Phosphorus Removal

- Bacteria cells contain N and P, which are incorporated to the biomass that is removed either through settling (ponds), sloughing (fixed film) or wasting (activated sludge).



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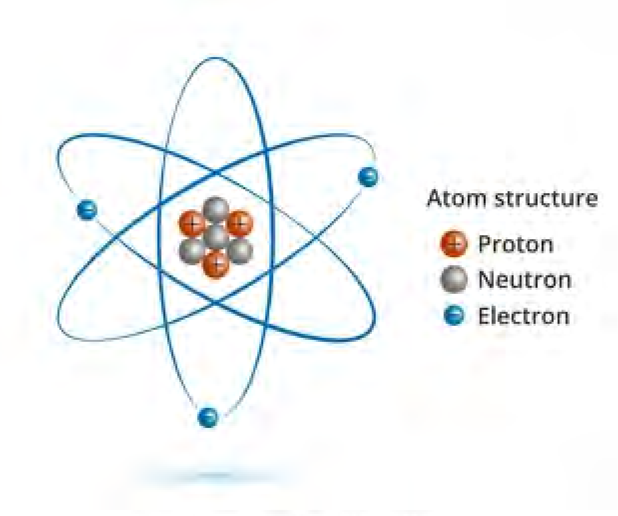
Quiz

1. Why do N and P need to be removed from wastewater?
2. What is a typical concentration of P in influent wastewater?
3. What is a typical concentration of nitrate in influent wastewater?

Chemistry Review

- Atoms: building blocks of nature
- Element: particular type of atom
- Atomic #: # of protons in the atom (specific to the type of element)



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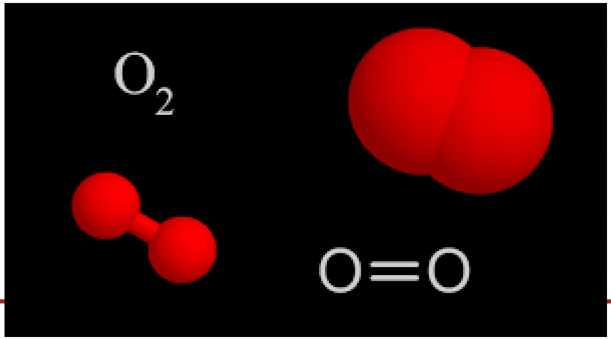
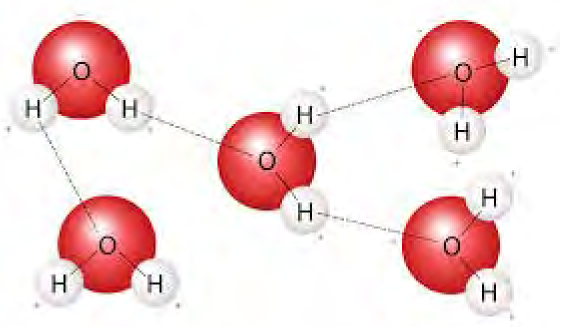
Chemistry Review

- Molecules and compounds: combination of 2 or more atoms that are chemically bound together
- Molecules made from 2 or more elements are compounds
- All compounds are molecules but not all molecules are compounds





Periodic Table

Periodic table of the elements

- Alkali metals
- Alkaline-earth metals
- Transition metals
- Other metals
- Other nonmetals
- Halogens
- Noble gases
- Rare-earth elements (21, 39, 57–71) and lanthanoid elements (57–71 only)
- Actinoid elements

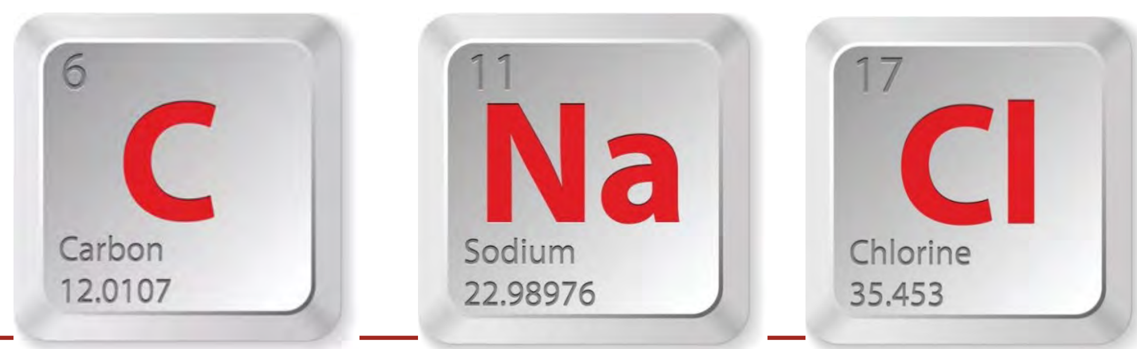
period \ group	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

lanthanoid series 6	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
actinoid series 7	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC).

Chemistry Review

- Moles: one mole = 6.022×10^{23} atoms
- Atomic weight: given in grams/mole
- (e.g., 602 200 000 000 000 000 000 000 atoms of carbon weighs 12.011 g)
- Molecular weight - how much 1 mole of a molecule weighs (Ex. table salt, NaCl, weighs 58.5 g)



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More Chemistry Vocabulary

- Ions: atoms or molecules that have a charge (cation +; anion -)
- Chemical Reactions: when molecules interact to form something new
- Stochiometry: the ratio of moles of reactants to moles of products needed to complete a reaction
- Equilibrium = balanced; reaction can go either way

Balancing Chemical Reactions

(ferric chloride + hydrogen sulfide goes to ferric sulfide + hydrochloric acid)

Reactants **Products**

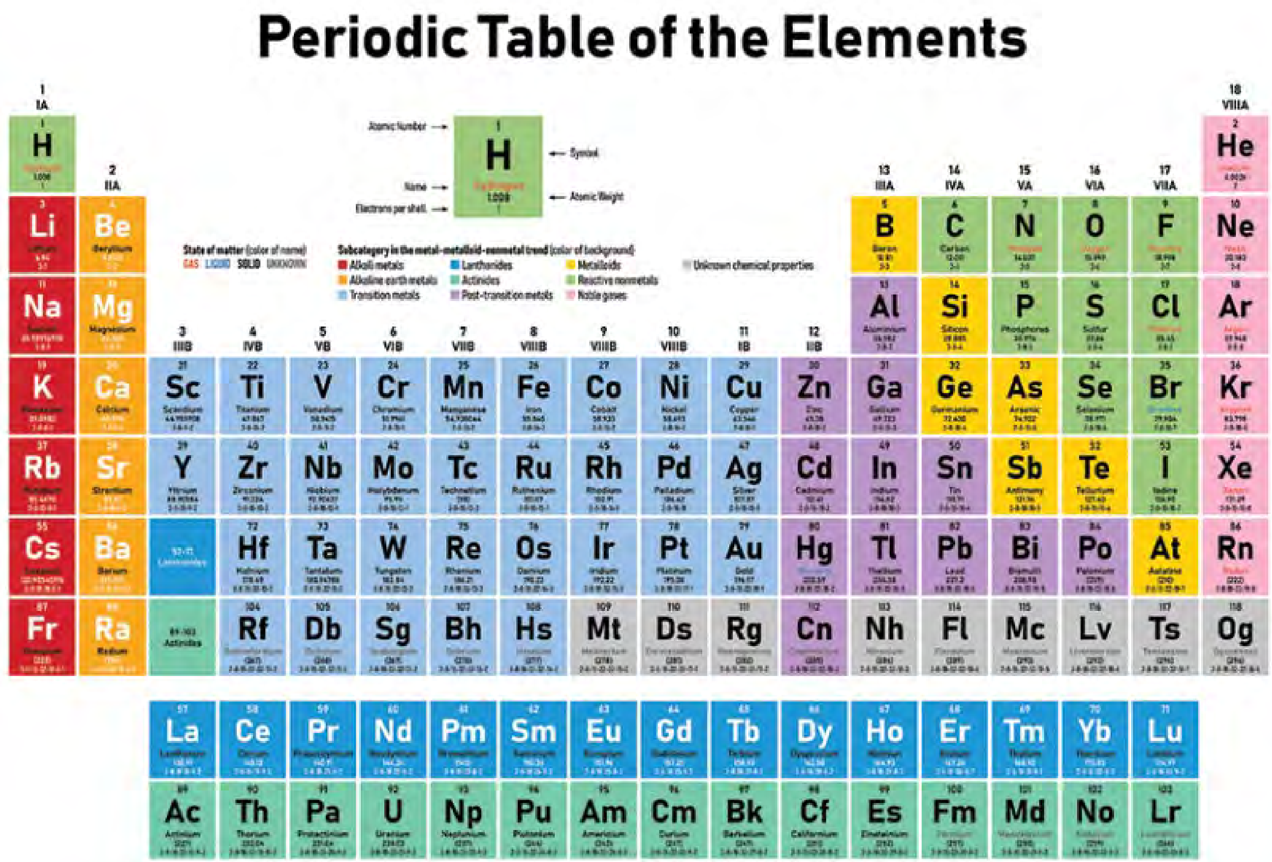
$$2FeCl_3 + 3\ H_2S_{(aq)} \ \text{<-->}\ Fe_2S_{3(s)} + 6\ HCL$$

Number of moles reacting

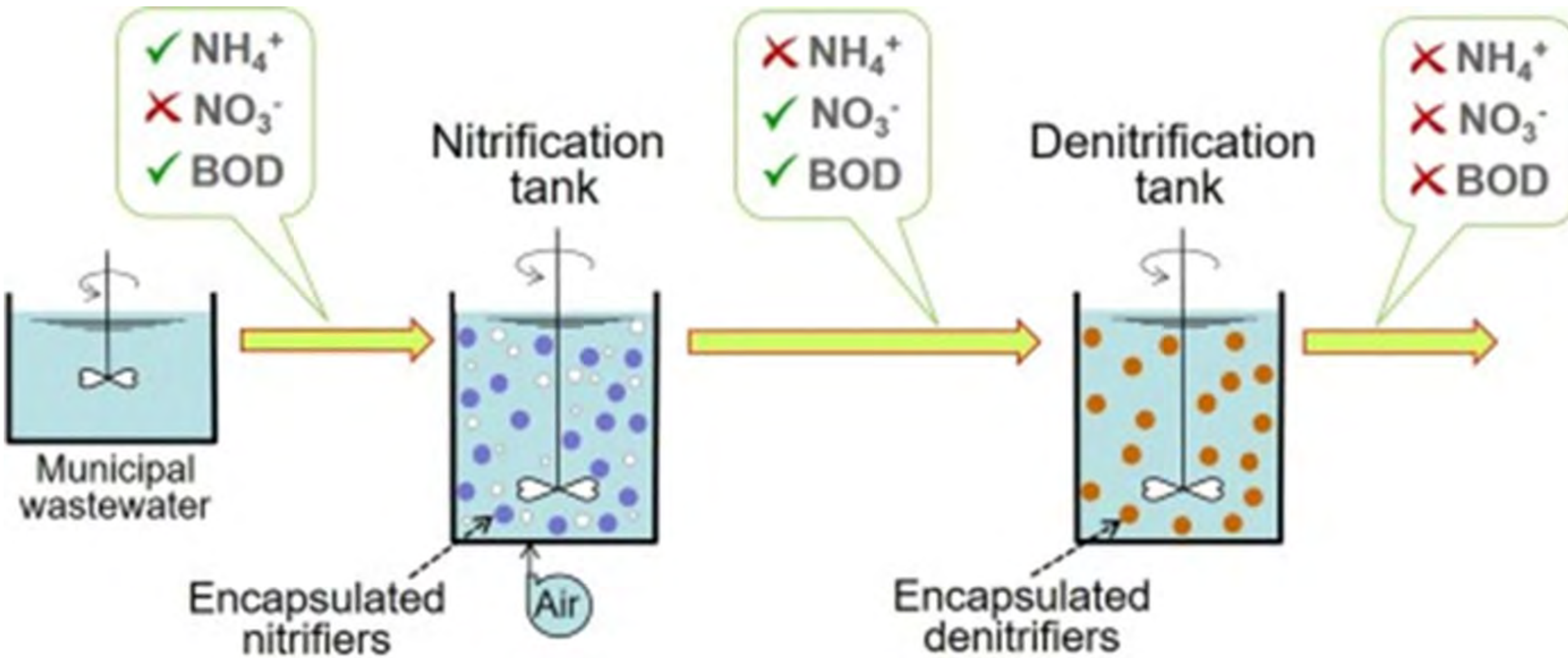
Solid precipitate formed

dissolved in water

Problem – Find the formula weight for calcium carbonate ($CaCO_3$)



Biological Nitrification

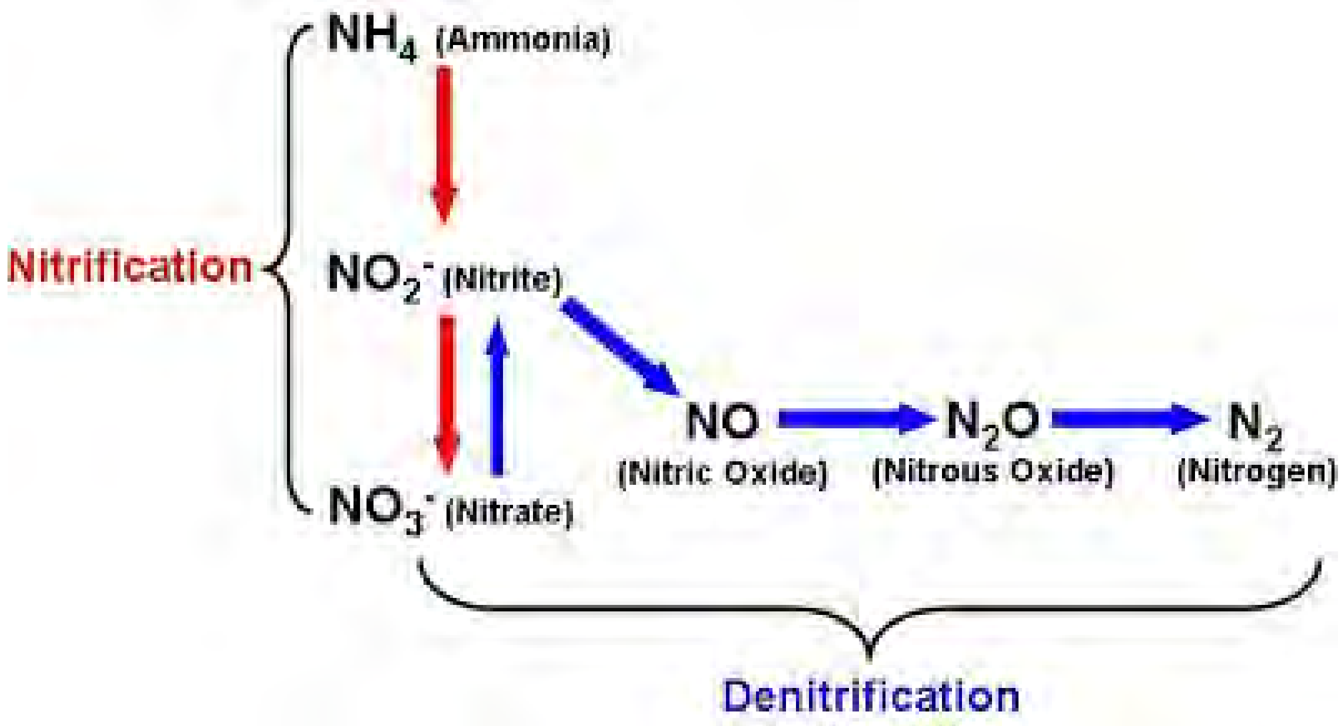


Bacteria

- Ammonia Oxidizing Bacteria (AOB) - convert ammonia (NH_3-N) to nitrite (NO_2-N)
- Nitrite Oxidizing Bacteria (NOB) - convert nitrite (NO_2-N) to nitrate (NO_3)j
- The NOB grow faster than the AOB when the water temperature is below 25°C (77°F)

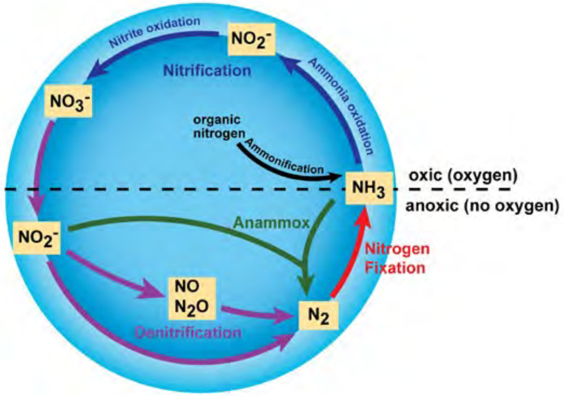
Biological Nitrification

Nitrification/Denitrification

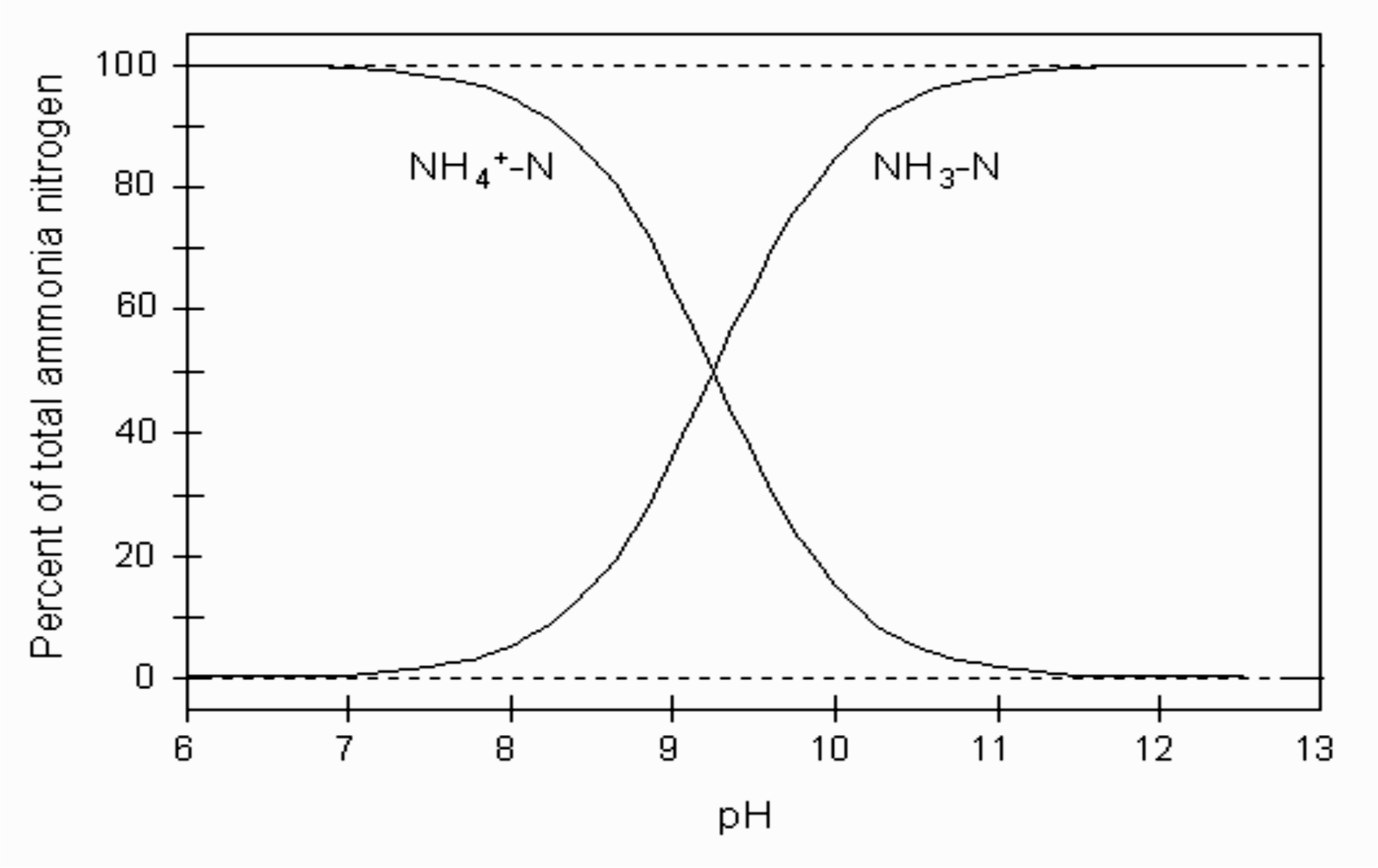


Chemical Reactions of Nitrification/Denitrification

Process	Reaction
Fixation	$N_2\ (g) + 8H^+ + 8e^- \rightarrow 2NH_3\ (g) + H_2\ (g)$
Ammonification	$NH_2\text{-}CO\text{-}NH_2 + H_2O\ (l) \rightarrow 2NH_3(g) + CO_2\ (g)$
Nitrification (Two Steps)	(1) $NH_4^+ + 1.5O_2\ (g) \rightarrow NO_2^- + 2H^+ + H_2O\ (l)$ (2) $NO_2^- + 0.5O_2\ (g) \rightarrow NO_3^-$
Denitrification	$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$



Ammonium ion vs. unionized ammonia - pH and temp sensitive



Quiz

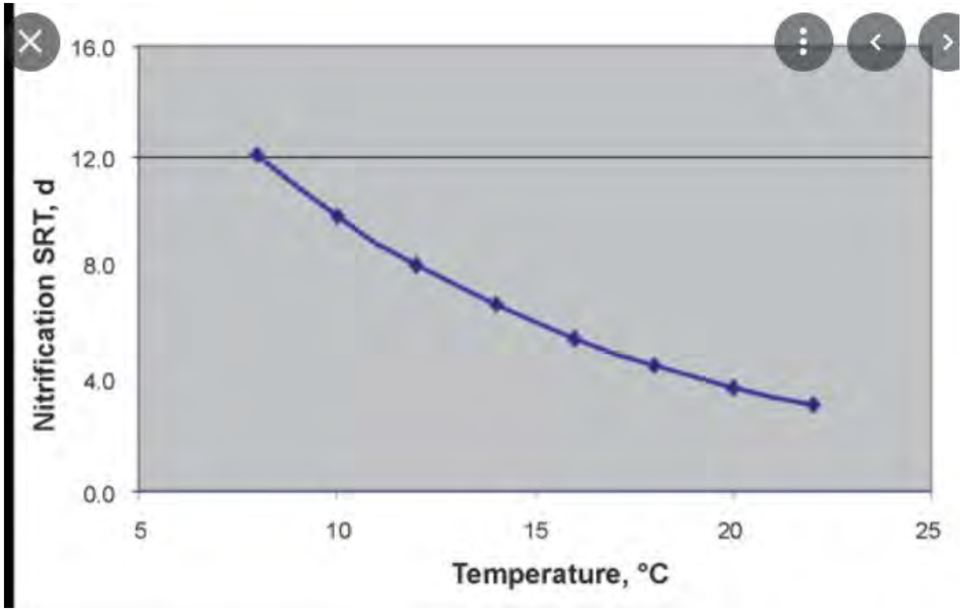
1. Nitrification is a 3 step process involving 2 groups of bacteria. T or F?
2. The NOB obtain their energy from nitrite and their carbon from alkalinity. T or F?
3. The AOB grow faster than the NOB when the water temperature is below 25°C (77°F) T or F?

Process Variables for Nitrification

- Temperature
- Aerobic solids retention time (SRT)
- organic loading rate (OLR)
- Dissolved Oxygen (DO)
- pH
- Alkalinity
- Nitrogen Loading Patterns
- Presence of Inhibitory compounds

Process Variables for Nitrification

- Temperature: typical between 39 and 113°F; optimum is about 86°F
- Aerobic SRT: most important variable for removing ammonia in activated sludge processes



Process Variables for Nitrification

- Organic Loading Rate (OLR) - high OLRs favor growth of heterotrophic bacteria over nitrifying bacteria. NOB won't become a significant portion of the biofilm until soluble BOD5 is <20 mg/L or the 5 day CBOD is less than 20 mg/L
- For biofilm process, removal and nitrification are generally sequential, so this will be more of a factor.

Process Variables for Nitrification

- Dissolved Oxygen (DO) concentration - Nitrification not limited if DO>2.0 mg/L

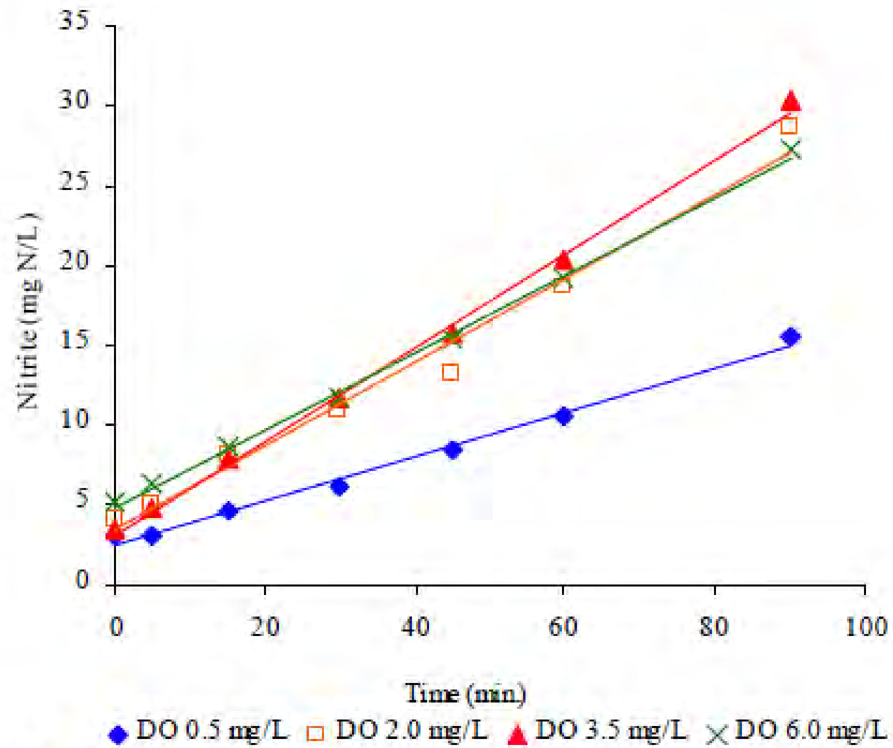


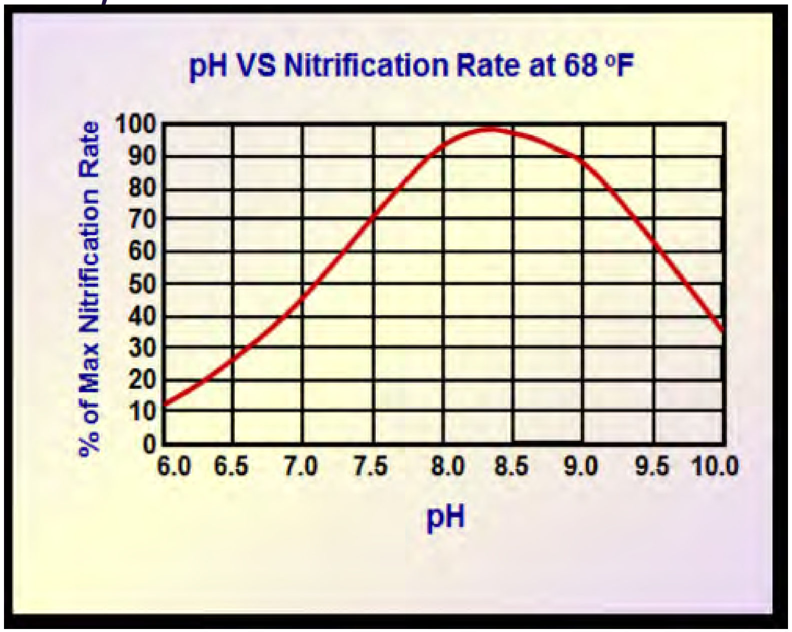
Fig. 3: Nitrite accumulation at different DO concentrations

Solids Retention Time

- SRT = **mass of MLSS in the aeration tank (lb) divided by the mass of solids wasted each day** (lb/d)
- Must be long enough for nitrifying bacteria to reproduce
- Nitrification "all of nothing" = either they have enough time to reproduce and build up a stable population – or NOT
- Theoretical minimum is 2 days at 20°C (68°F) and about 5 days at 10°C(55°F)
- Safety factors between 2 and 3.5 are usually used.

Process Variables for Nitrification

- pH and Alkalinity - nitrification rates decrease rapidly if $pH < 6.8$
- However, nitrification produces acid which consumes alkalinity.
- If enough alkalinity is consumed, the pH will decrease.
- A min effluent alkalinity of at least 50 mg/L and preferably 100 mg/L as CaCO3 should be maintained



Nitrogen Loading Pattern

- If environmental factors are not limiting, the quantity or mass of AOB and NOB will be a function of the ammonia loading
- Nitrifiers can't react quickly to peak loading...number reflect average loading

Other Factors

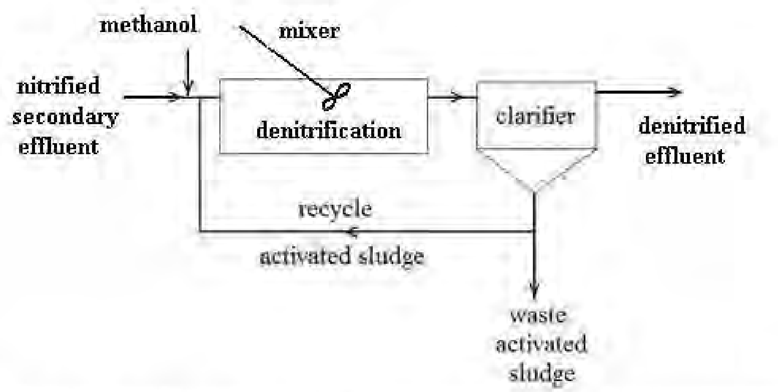
- Hydraulic detection time: not a big factor in activated sludge processes but can be in step-feed processes
- Inhibitory substances: more than 180 organic compounds and heavy metals (include nickel, chromium, cadmium)

Quiz

1. Nitrification can be inhibited when DO falls below ____ mg/L
2. Excess alkalinity of ___ to ___ mg/L is needed to prevent pH drop
3. What form of hydrogen is left after nitrification?

Denitrification

The conversion of nitrate to nitrogen gas



Denitrification Process Flow Diagram

3 Conditions for Denitrification

1. Carbon source (measured as BOD_5 or COD).
2. Low DO
3. Sufficient HDT

Stoichiometry of Denitrification 3 Different Carbon Sources

$C_{10}H_{19}O_3N$: often used to represent the biodegradable organic matter in wastewater

Wastewater:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + NH_3 + 10OH^-$$

Methanol:

$$5CH_3OH + 6NO_3^- \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

Acetate:

$$5CH_3COOH + 8NO_3^- \rightarrow 4N_2 + 10CO_2 + 6H_2O + 8OH^-$$

Stoichiometry for 3 different carbon sources

- 1 mole of hydroxide ion is produced for every 1 mole of nitrate ion converted to hydrogen gas.
- Hydroxide is a base and another component of alkalinity.
- Recovering lost alkalinity through denitrification can often reduce or eliminate the need for alkalinity addition

Process Variables for Denitrification

- Availability of organic carbon
- Scarcity of DO
- Process configuration

Process Variables for Denitrification

- BOD or COD Demand - 4 mg/L of influent or primary effluent BOD_5 (~8mg/L COD) is needed for every 1 mg/L of nitrate-nitrogen
- Facilities with primary clarifier may not have enough BOD to achieve low effluent nitrate values
- Supplemental carbon sources: methanol, molasses, food wastes

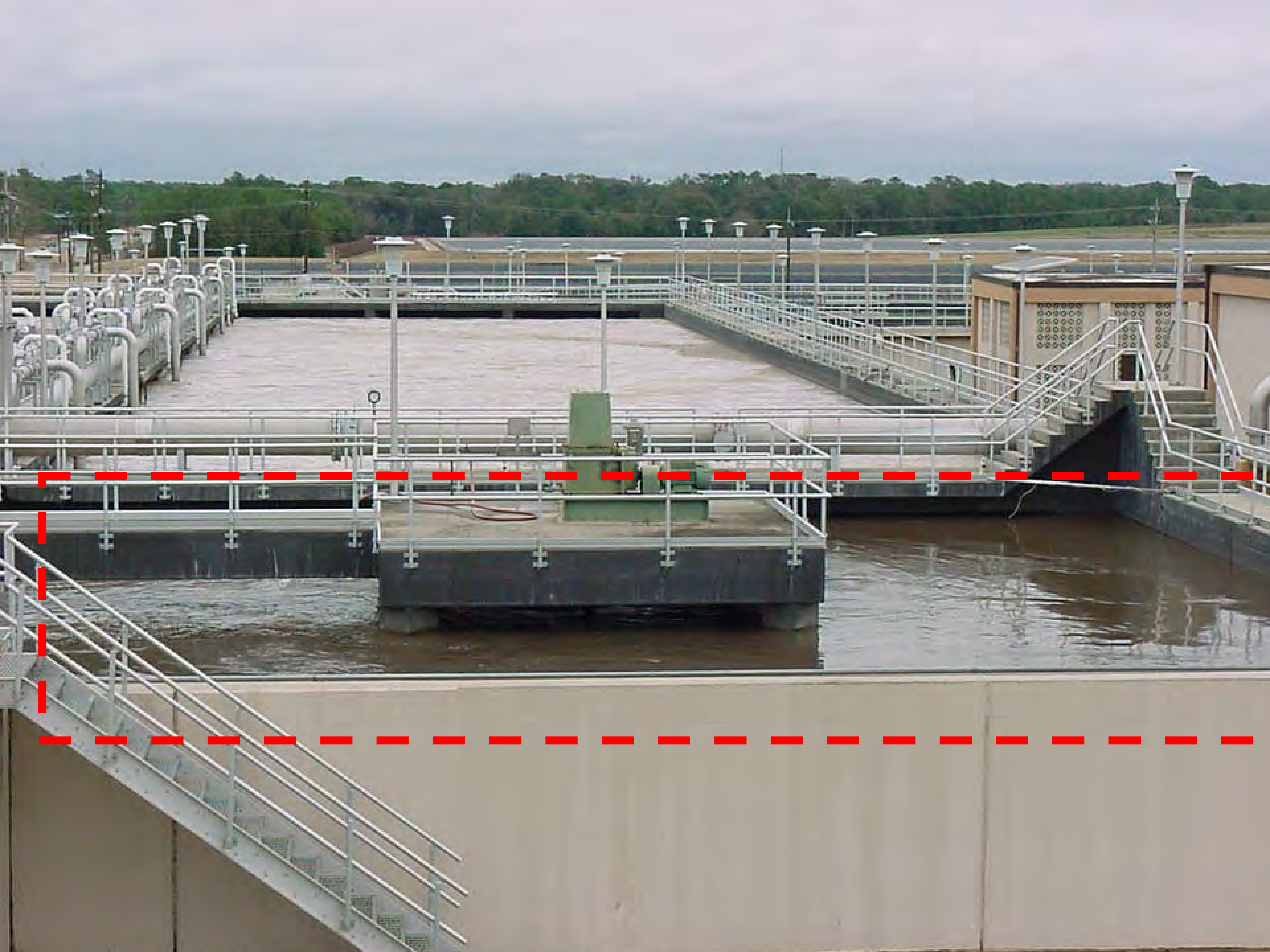

Carbon Source

Carbon or Food Sources

- Raw Wastewater
- Endogenous carbon
- Methanol
- Acetic acid
- Dog food

Anoxic Environment

- No free dissolved oxygen present
- NO_3 -N present
- Facultative bacteria utilize oxygen in the following order
  - O_2
  - NO_3
  - SO_4
  - CO_2



Anoxic Environment

- Anoxic processes contain nitrate but no oxygen
- separate unaerated tanks
- zones in long narrow basins
- cycling air on and off while continuing to mix (SBRs)


Anoxic
Zone


Di sol ed Oxyg n

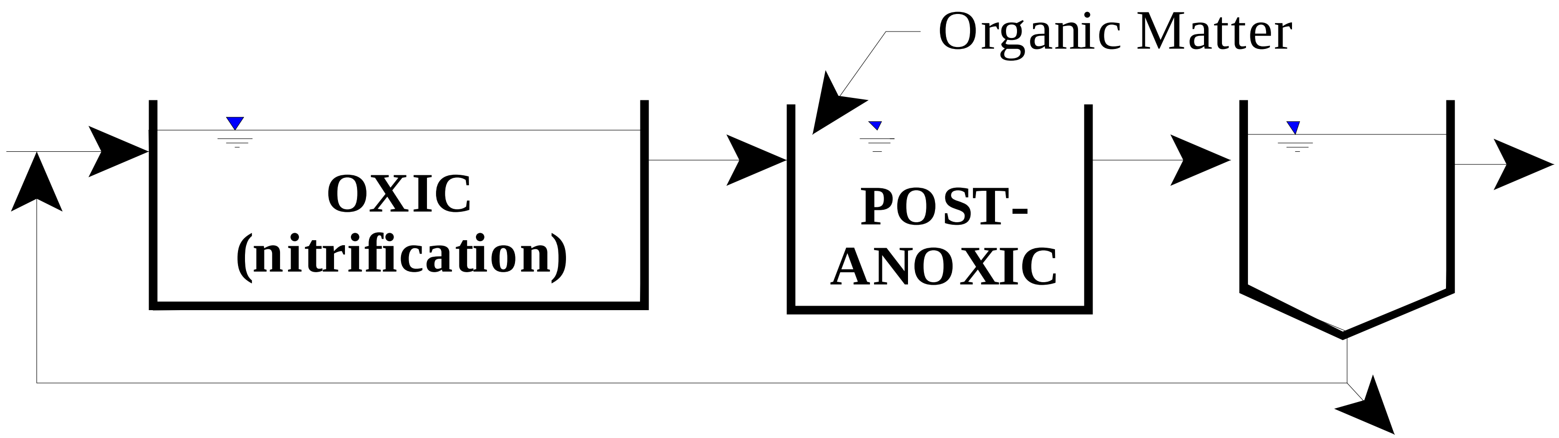

Mixing

Mixing

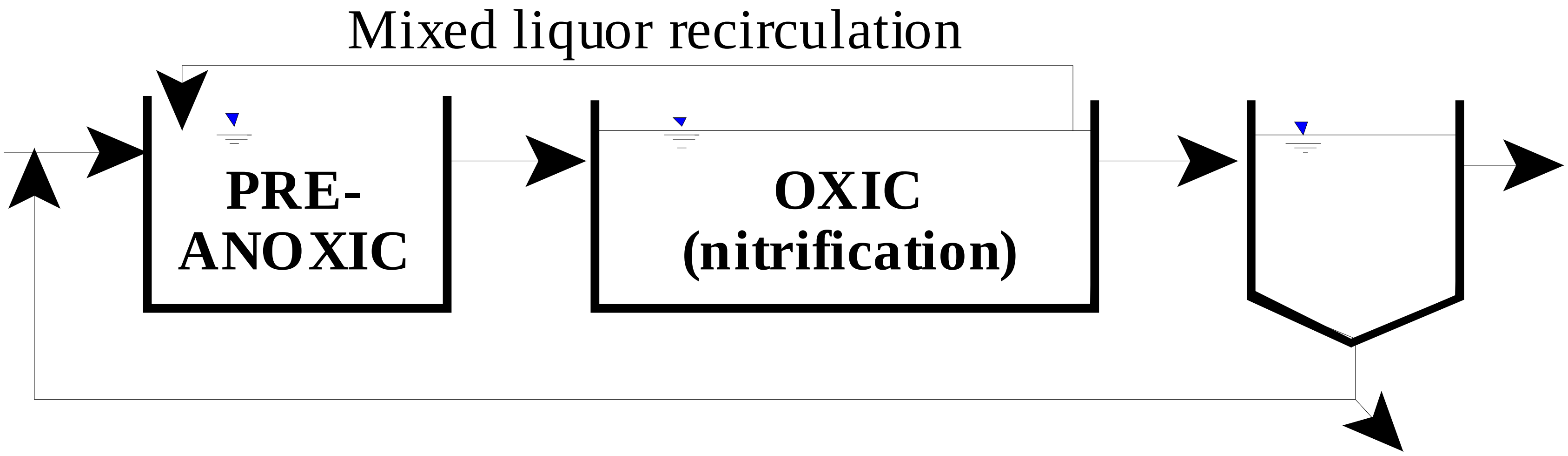
- Put the food and microorganisms in intimate contact
- Allow for adsorption and absorption

INTERNAL MIXED LIQUOR RECYCLE RATIO

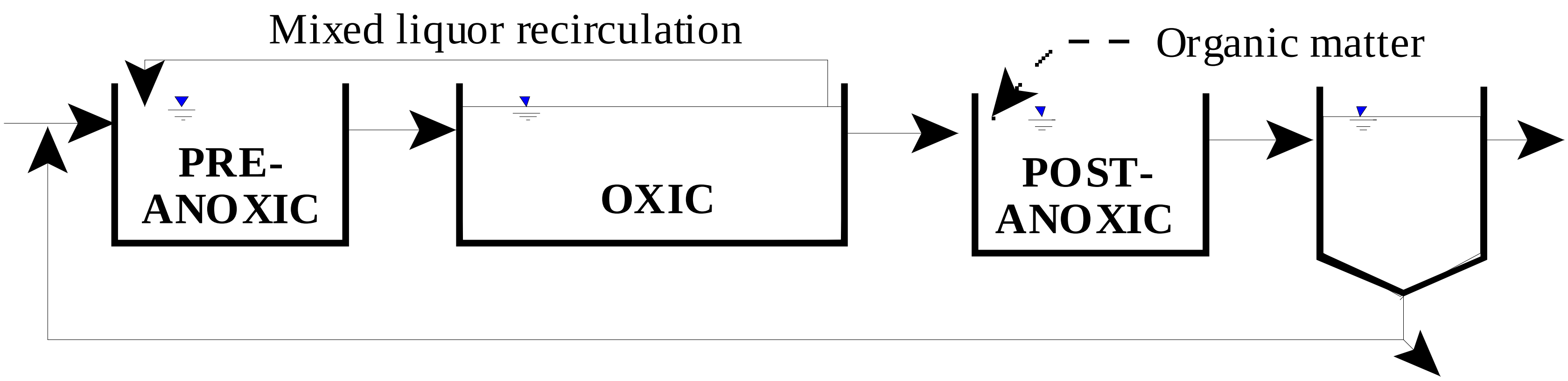
Wuhrman Process



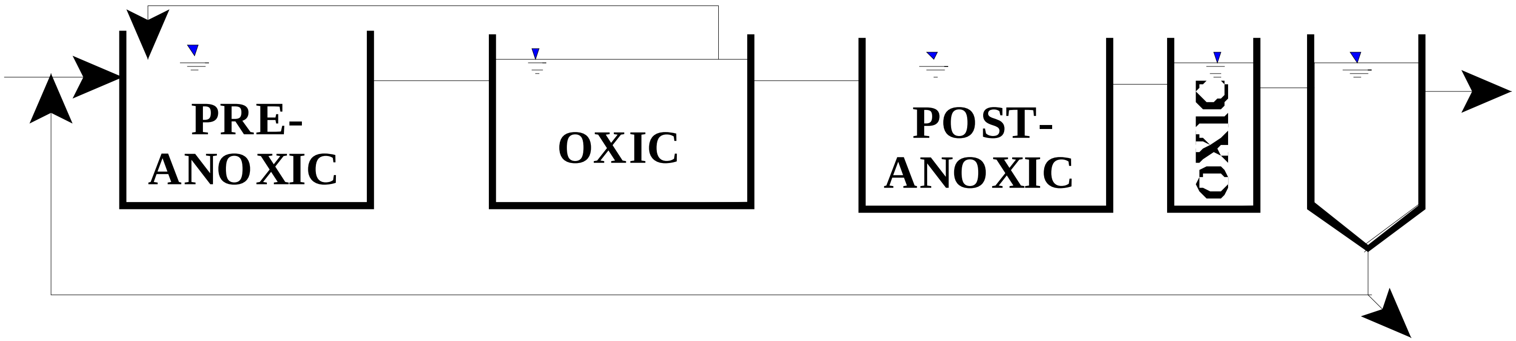
Ludzak Ettinger Process



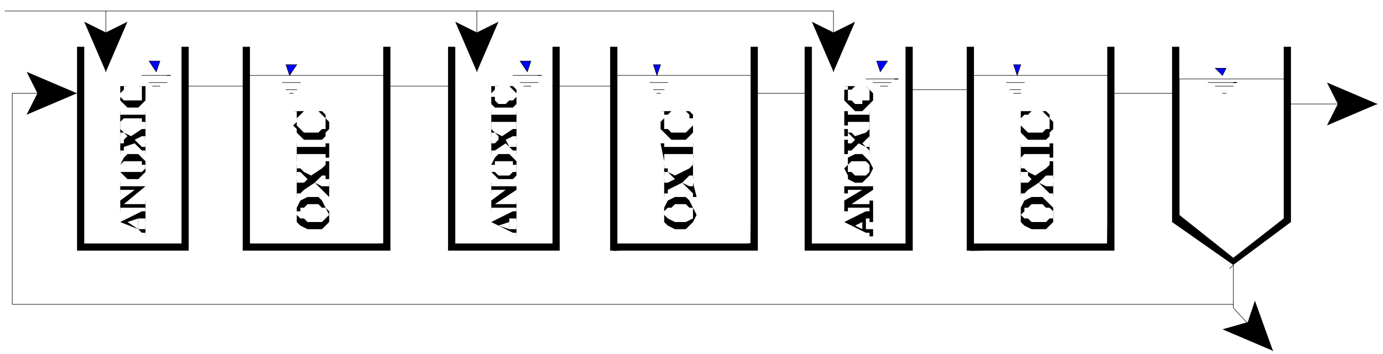
Dual Anoxic Zones



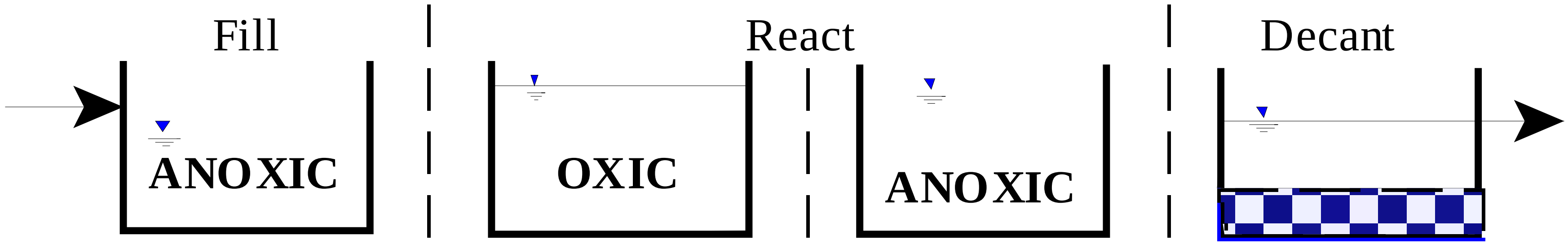
Four-Stage Bardenpho Process



Anoxic-Oxic Step Feed Process



Sequencing Batch Reactor



Nitrite Lock

- Nitrifying bacteria use ammonia or nitrite for energy and carbonate and bicarbonate for carbon source (instead of BOD)
- CO_3^{-2} and HCO_3^- are 2 components of alkalinity that dominate when pH > 6.5
- NOB grow fast than AOB when water temp <25°C (77°F)
- However, because the AOB produce nitrite that NOB need, they must be present before NOB can appear
- Nitrite-N rarely exceeds 1 mg/L in a well functioning plant
- An abnormal increase in nitrite concentrations is commonly referred to as "nitrite lock"
- Nitrite lock occurs when the AOB outperform the NOB

Quiz

The operator of an activated sludge process knows from past experience that the water temperature in the aeration basin will drop from 22°C (72°F) to 15°C (59°F) between August and December. What process change should be made?

a. Decrease the concentration wtih water temperature.
b. Increase the SRT gradually based on water temp.
c. Increase the SRT and MLSS concentration to build biomass before November.
d. Wait until mid-October and then double the SRT

Quiz

- The minimum SRT needed for nitification at 10°C is 5 days. If a safety factor of 2.5 is used, what is the target SRT?

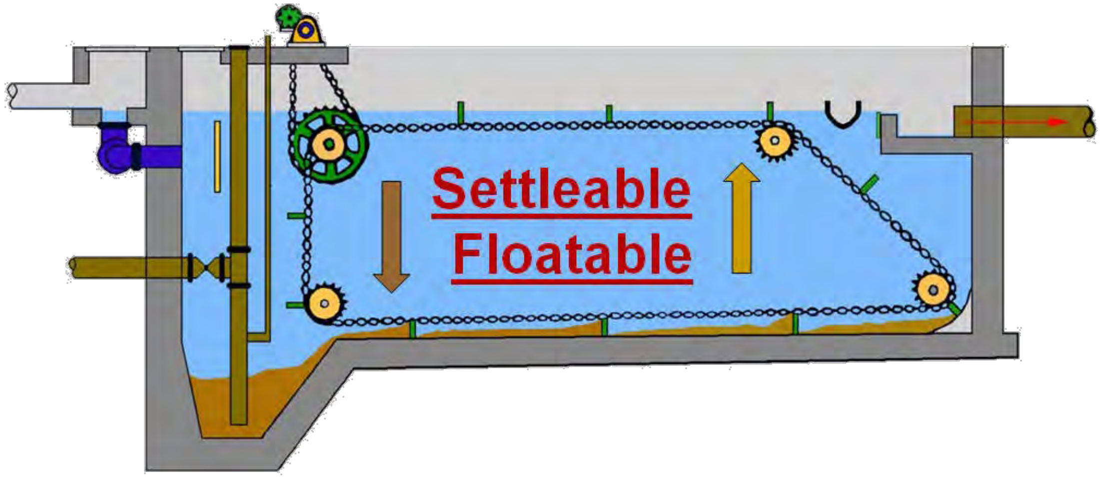
- a. 2.5 days
- b. 5 days
- c. 12.5 days
- d. 25 days

PHOSPHORUS REMOVAL

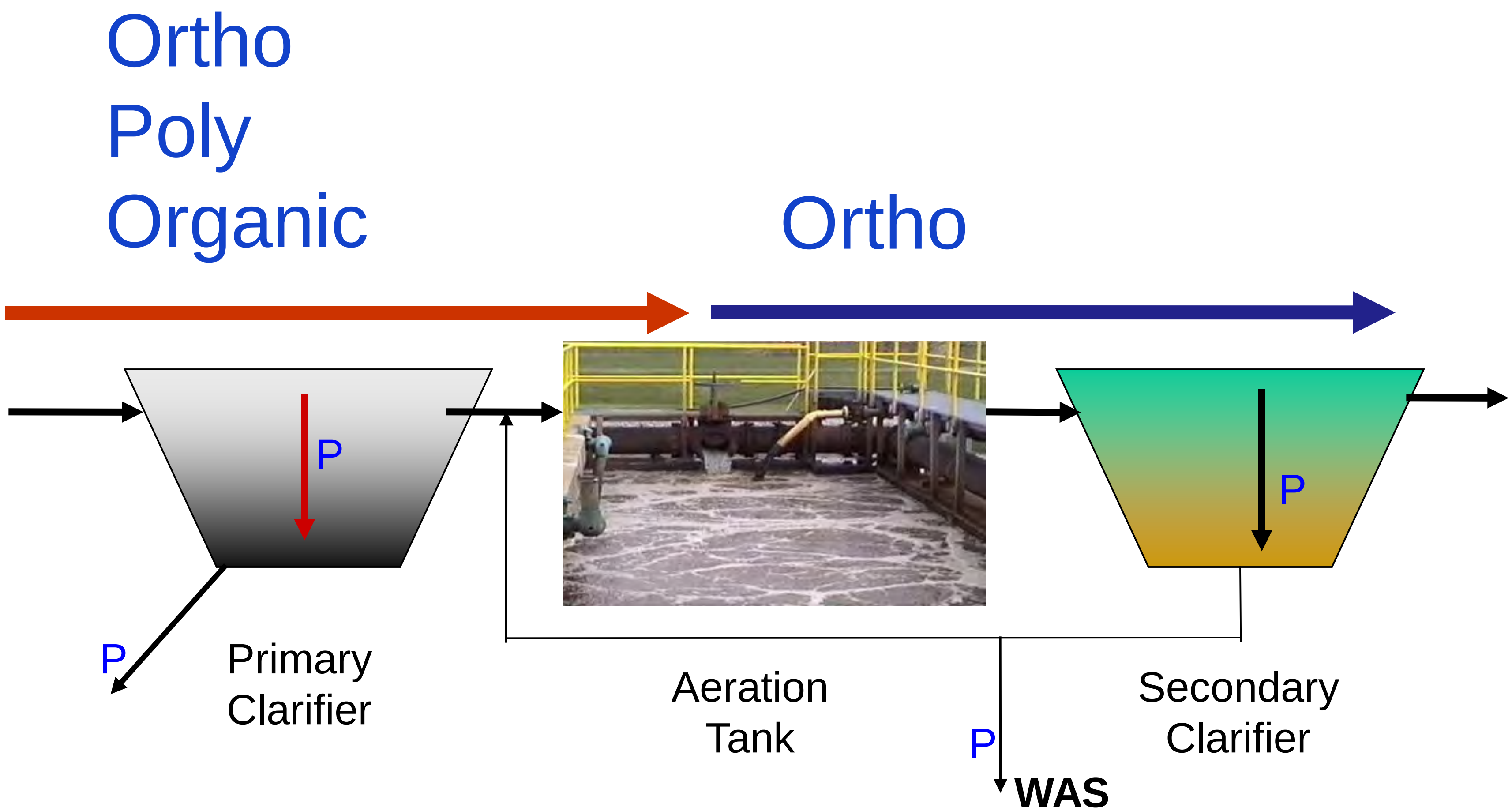
Settling

- Removal of Settleable Solids can provide some phosphorus removal

Primary Sedimentation 5 - 15 %



Conversion to Ortho-P



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Phosphorus Removal

- Biological Wastewater Treatment Systems Will Remove Phosphorus

  100:5:1 (C:N:P)

  Primary and TF 20 - 30 %

  Primary and AS 30 - 50 %

- Total Influent P Ranges from 2.5 to 6 mg/L
- NPDES Permits Limit Effluent P 1 mg/L and Lower

Most Facilities Will Require Additional Process for Phosphorous Removal

Phosphorus Removal

Removal of Ortho-P may Occur Through:

1. Chemical Precipitation

2. Enhanced Biological Uptake

Chemical Phosphorus Removal

Ortho Phosphate

(Soluble)

plus

Metal Salts

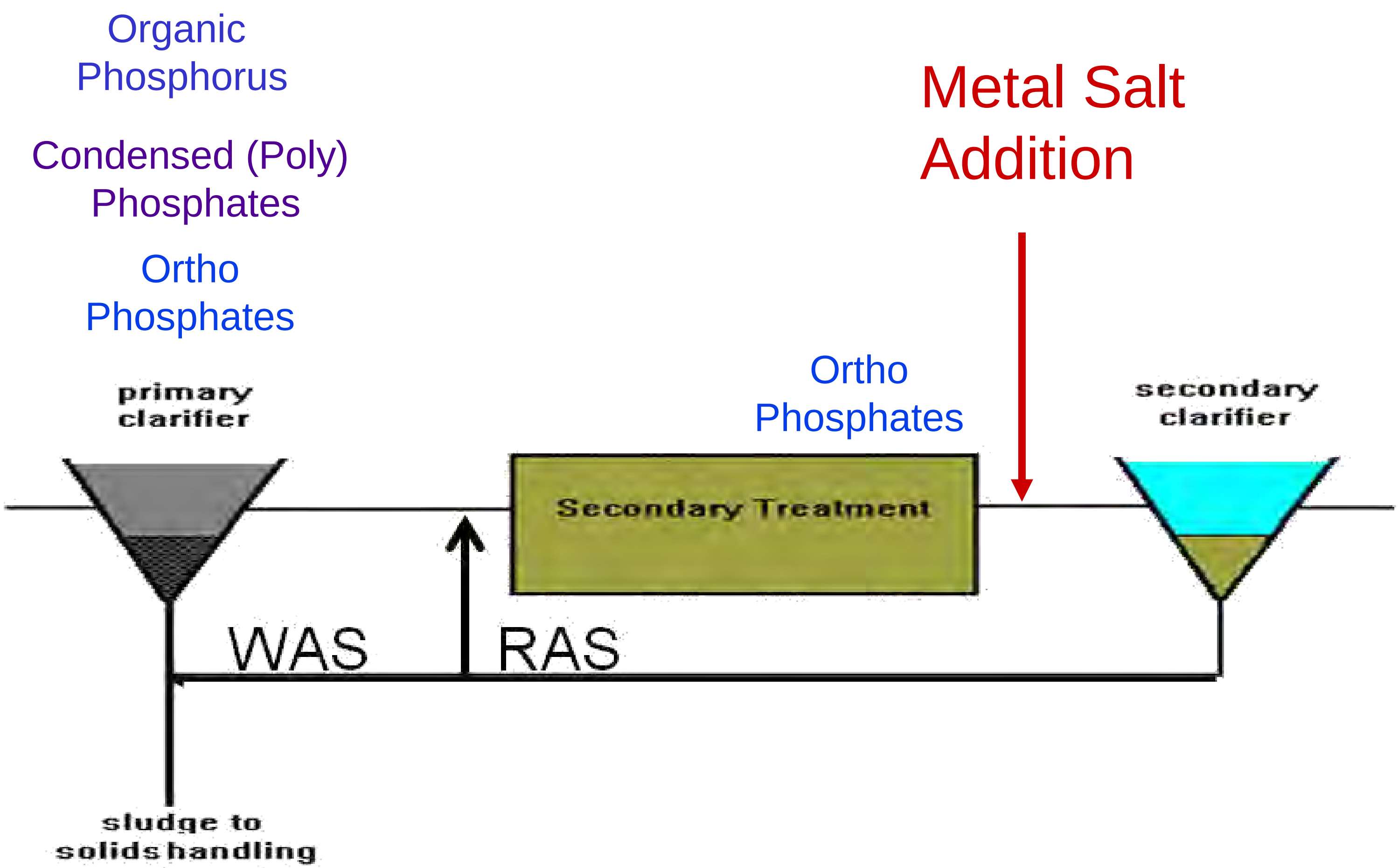
(Soluble)

form

Insoluble Phosphorus Compounds

Chemical Phosphorus Removal

Total Phosphorus



Chemical Phosphorus Removal

$$M^{+3} + PO_4^{-3} \rightarrow MPO_4 \downarrow$$

(M^{+3} = Metal in Solution)

PRECIPITATION

Metals used are: Aluminum, Al

Iron, Fe

Chemicals Used for Phosphorous Precipitation

Ferric Chloride
Ferrous Chloride
Alum

FERRIC IRON - Fe^{+3}

$M^{+3} + PO_4^{-3} \rightarrow MPO_4 \downarrow$

$Fe^{+3} + PO_4^{-3} \rightarrow FePO_4 \downarrow$

Weight Ratio

Fe^{+3} to P

1.8 : 1

$FeCl_3$: P

5.2 : 1

Starting Dosage 20-25 mg/L

ALUMINUM COMPOUNDS

Aluminum Sulfate (Alum)

$Al_2(SO_4)_3 \cdot 14H_2O$

Sodium Aluminate

$Na_2Al_2O_4$

Aluminum Chloride

$AlCl_3$

Alum Dosage Rates

$$Al_2(SO_4)_3 + 2PO_4^{-3} \longrightarrow 2AlPO_4 \downarrow$$

Weight Ratio

Al^{+3} : P

0.87 : 1

Alum to Phosphorus

9.6 : 1

Starting Dosage 40-50 mg/L

Chemical Phosphorus Removal

Total Phosphorus

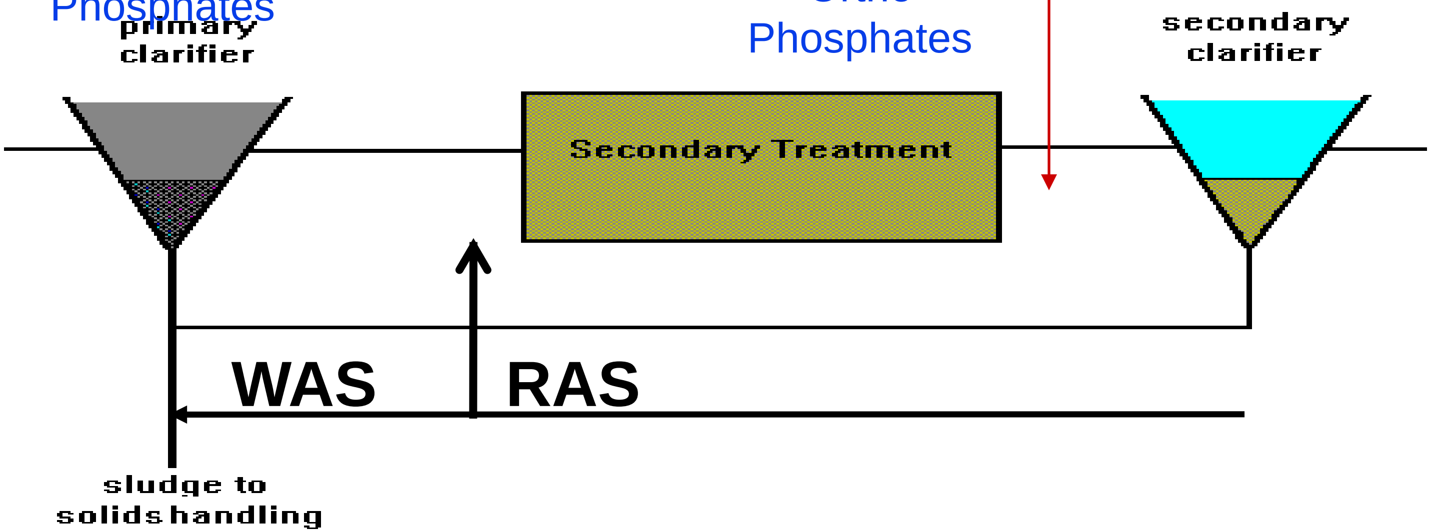
Organic Phosphorus

Condensed (Poly) Phosphates

Ortho Phosphates

Metal Salt Addition

Ortho Phosphates



Phosphorus Removal

Removal of Ortho-P may Occur Through:

1. Chemical Precipitation

2. Enhanced Biological Uptake

(EBPR)

Often Just Called
BIOLOGICAL P REMOVAL

Biological P Removal

Anaerobic Conditions

Heterotrophic Bacteria Break Down Organics
Fermentation
    Volatile Fatty Acids (VFAs)
    Acetate (Acetic Acid)

Also
Selection of PAO - Phosphate Accumulating Organisms
(Able to Out-Compete Other Aerobic Heterotrophic Bacteria for Food When Anaerobic)

Process Control for EBPR

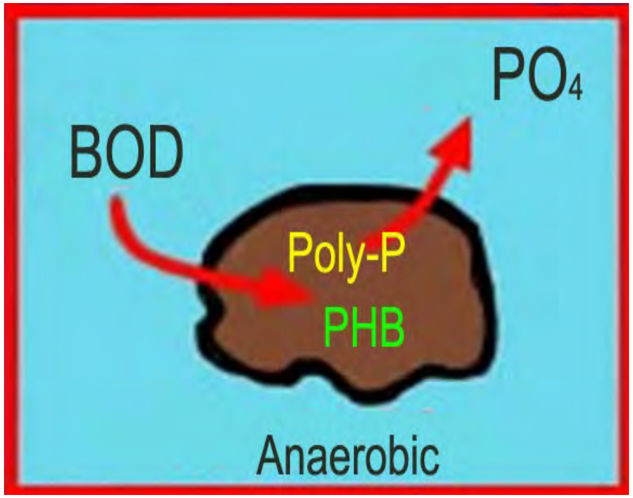
- Ensuring adequate supply of VFAs
- Protecting the anaerobic zone
- Maintaining a strongly negative ORP in the anaerobic zone
- Maximizing solids capture
- Minimizing recycle loads
- Avoiding secodary release of phosphorus,and
- minimizing competition from GAOs

Biological P Removal

Anaerobic Conditions

PAO Able to store soluble organics as Polyhydroxybutyrate (PHB)

PAO Break Energy-Rich Poly-P Bonds To Produce Energy Needed for the Production of PHB



Ortho-P is Released Into Solution

Biological P Removal

The MLSS Cycles From Anaerobic to Aerobic

This Promotes
Phosphate Accumulating Organisms (PAO)

Anaerobic
- Fermentation
- Acetate Production
- P Released to Produce Energy

Aerobic
- Stored Food Consumed
- Excess P Taken Up
- Sludge Wasted

Biological P Removal

Aerobic Conditions

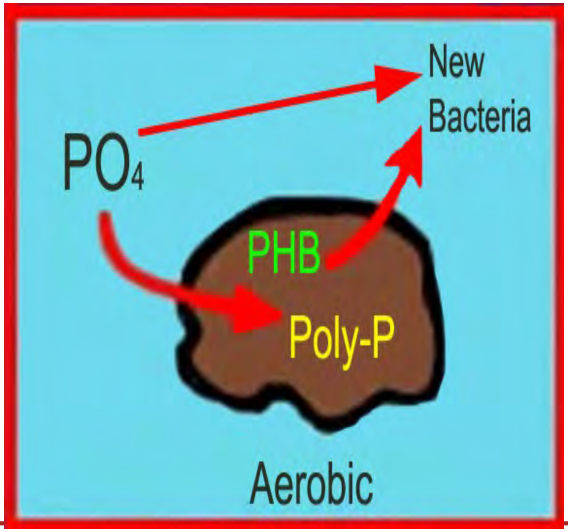
Rapid Aerobic Metabolism of Stored Food (PHB)

Producing New Cells

PO_4 Used in Cell Production

Excess Stored as Polyphosphate

("Luxury Uptake")



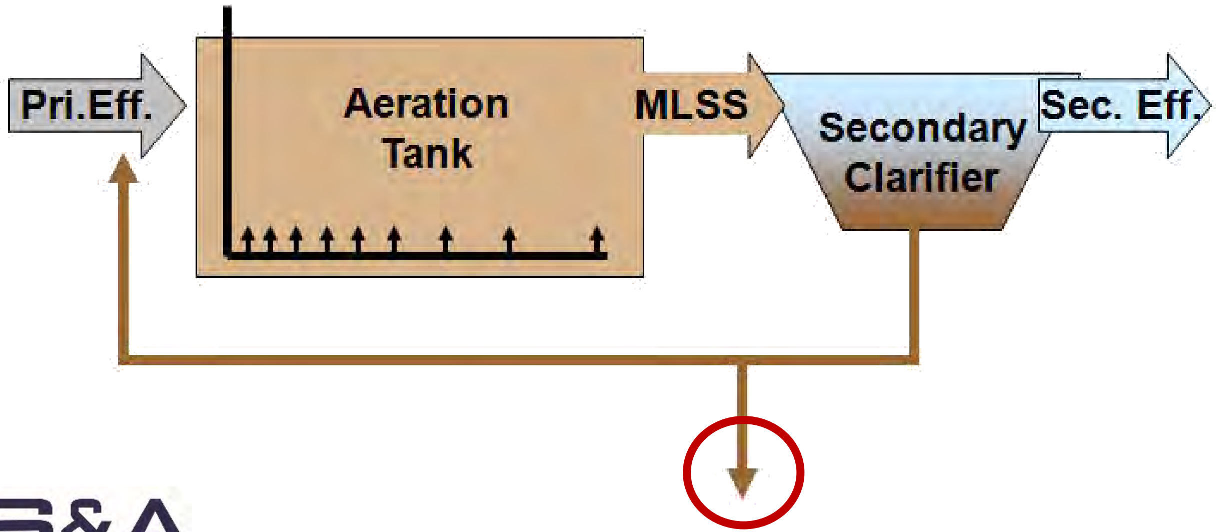
Biological P Removal

Aerobic Conditions

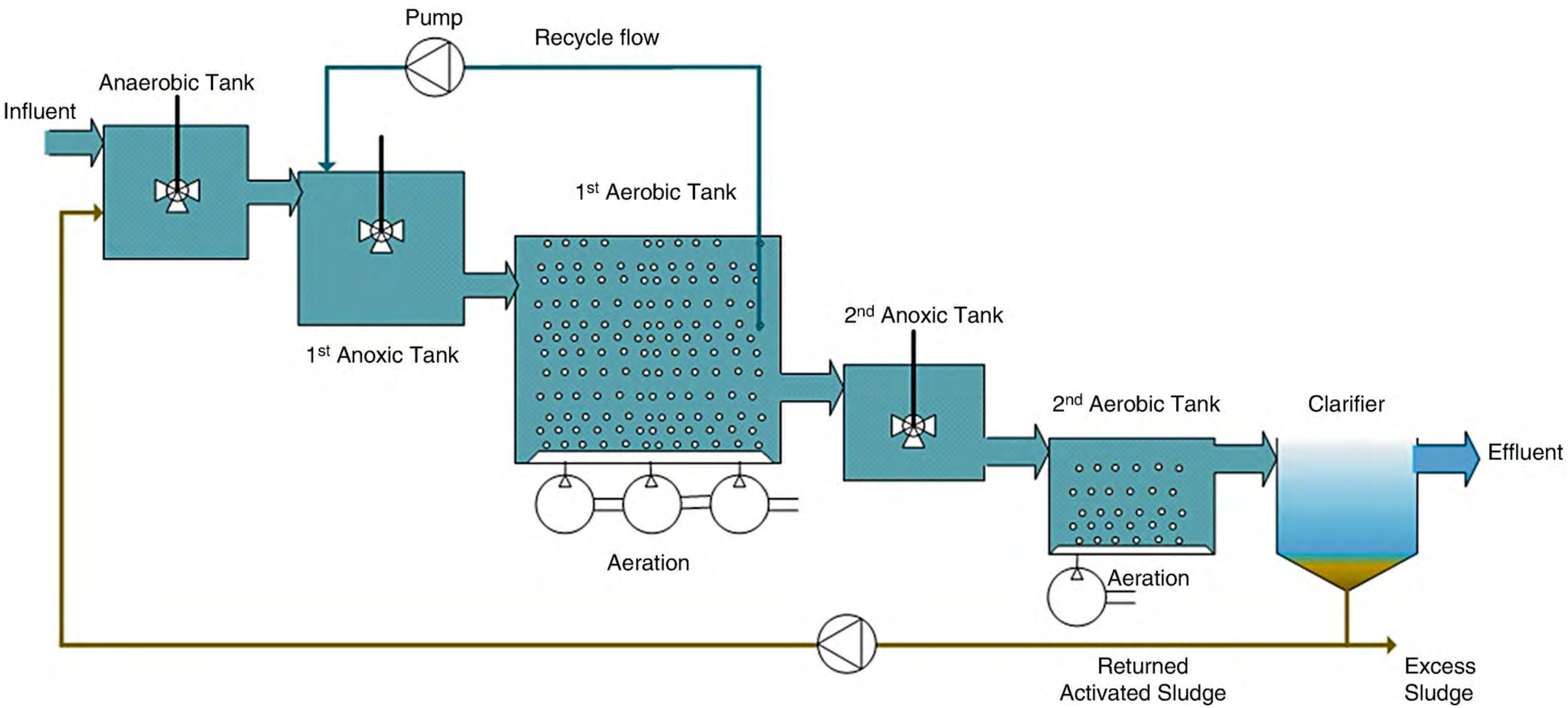
PO_4 Used in Cell Production
Excess Stored as Polyphosphate

Biomass Approximately 5 to 7% P by Weight
(Normal 1.5 to 2 %)

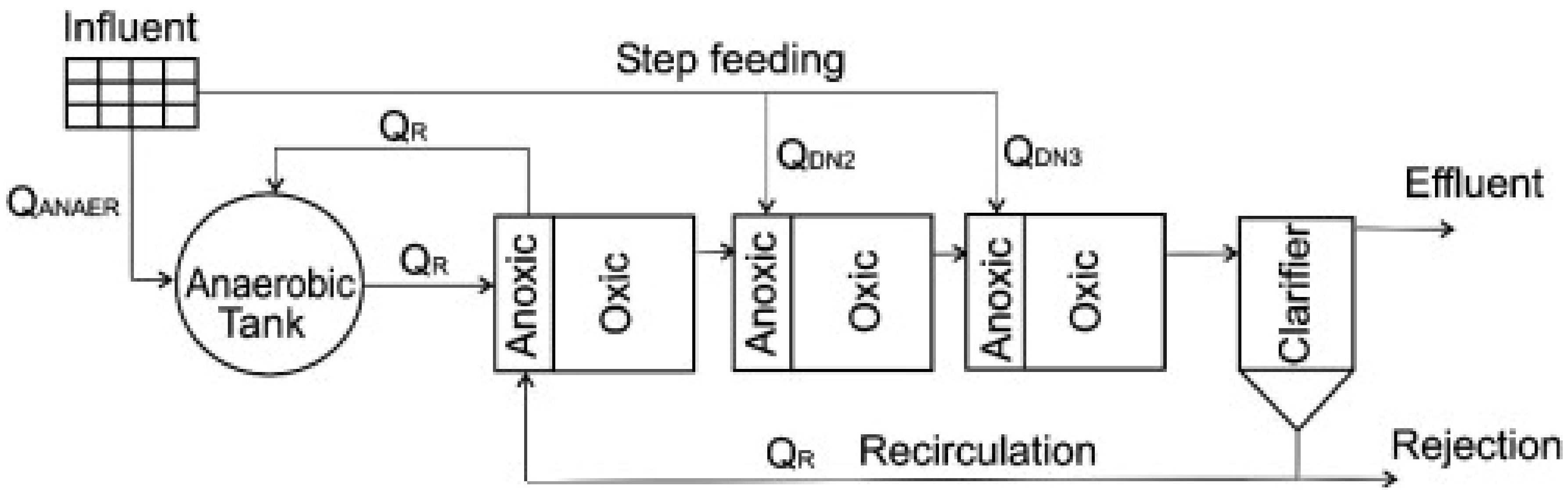
Sludge is Wasted When Loaded With P



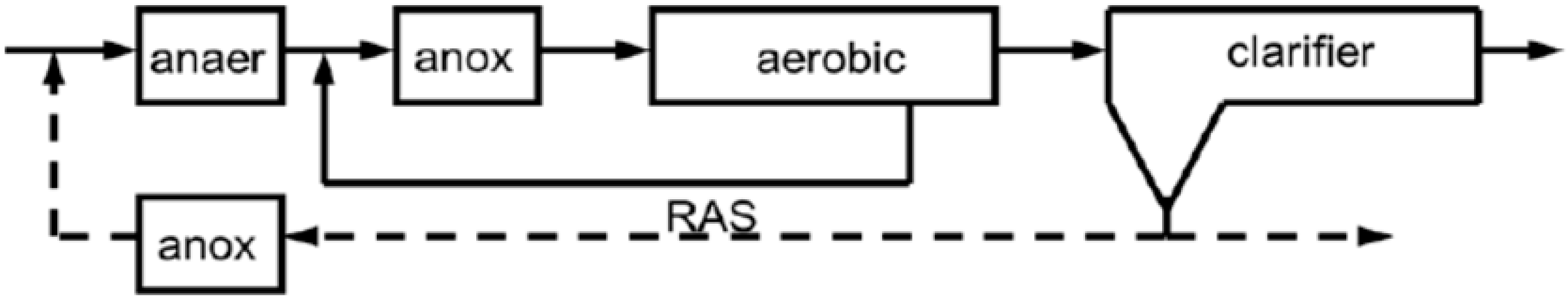
Modified Bardenpho Process



Modified UCT Process



Johanneseburg Process




Submersible
Mixers

Biological P Removal

Important Considerations

Adequate Influent BOD

(Enough O_2 demand to achieve anaerobic conditions)

BOD:P
20:1

Adequate Anaerobic Detention Time 1-3 hrs

(Not so long as to reduce sulfate to sulfide-septicity)

Adequate Aerobic Detention Time 4-5 hrs.

(Enough time for BOD removal & Nitrification)

Biological P Removal

Important Considerations

Low Effluent Suspended Solids
Below 20 mg/L (SS result in P in effluent)

Nitrification –Nitrate

(Adds O_2 in Anaerobic Zone)

Sludge Handling

(Supernatant P can overload P removal system)

Biological P Removal

Benefits

No Chemical Feed (Usually, Sometimes)

Lower Cost

Safety

No Tramp Metals

No Chemical Sludge Produced

Inhibits Growth of Filamentous Organisms

(Cycling between Anaerobic & Aerobic)

Biological P Removal

Disadvantages

Probably Need Chemical System Too

DO requirements Opposes Nitrification

Sludge Handling More Critical

Effluent Solids More Critical

Close Control Required

P in Anaerobic and Aerobic
D.O. in Anaerobic and Aerobic

May be Patented Process

Post Test

1. What does TMDL stand for?
2. What is the recommended range for sludge age in an extended aeration plant?
3. What happens in the activated sludge treatment process when Dissolved Oxygen (DO) is too low?
4. What does AOB stand for?
5. What is the difference between an anoxic zone and an aerobic zone?
6. What is the limit for nitrogen in WWTP effluent?
7. How does low temperature affect nutrient removal?

Answers

1. Total Maximum Daily Load
2. between about 15 and 30 days.
3. Treatment slows – nitrification can't occur
4. Ammonia Oxidizing Bacteria
5. Both have no air. Anaerobic has no nitrogen species. Anoxic has nitrogen species.
6. Depends on your permit

Prep for Day 2 of Training

- Virtual or in person?
- # attending 2nd day?
- Location
- Objectives
- Case studies

Case Study

- Flagstaff, AZ

SYSTEM OPTIMIZATION DESCRIPTION

A combined ammonia/nitrate probe (ISE type) was installed in the effluent end of the anoxic zone. Nitrate concentration is monitored and internal mixed liquor recycle is adjusted as needed to maintain a nitrate level of 0.5–1.0 mg/L nitrate-N at that point in the process to avoid overloading anoxic zones and further decreasing nitrogen removal by unnecessarily decreasing anoxic detention time.

Control of nitrogen sources (mainly sludge processing recycle) to decrease loading spikes was essential. The new nitrate probe indicated that the nitrate concentration at the anoxic zone effluent was often greater than 1 mg/L, indicating that more nitrate was being recycled than the anoxic zone could effectively remove. Excessive nitrate leaving the anoxic zone indicates either insufficiently anoxic conditions or insufficient oxygen demand (due to insufficient readily degradable carbon) at the anoxic zone.

Monitoring indicated that the BOD-to-nitrogen ratio in the primary effluent was low at times. Therefore, the primary clarifier operation was modified to encourage greater hydrolysis and/or fermentation of influent BOD. Pumping of settled sludge from the primary clarifiers was modified to provide longer detention time for solids in the primaries to allow additional conversion of particulate BOD to soluble BOD available for denitrification.

Oxidation-reduction potential profiling in the anoxic zone indicated that much of the zone was too aerobic (oxidizing) to expect denitrification, likely due to excessive oxygen loading from the internal mixed liquor recycle. Consequently, internal recycle rate control was modified.

Other operational changes included decreasing the rate of return from biosolids dewatering processes as needed to manage nitrogen loading spikes.

COSTS AND OTHER IMPACTS

Capital costs: Approximately $10,000 for ammonia/nitrate probe and installation.

Operational costs: Sensor cartridge replacement approximately $1,000 every 6 months. Probe cleaning and calibration weekly.

Technical assistance received or needed: A consultant was hired to recommend modifications to improve nutrient removal.

Flagstaff - Results

PERFORMANCE

Pre- and post-upgrade total nitrogen statistics are summarized below.

Parameter	April 2013	April 2014
Flow	3.3 mgd	3.9 mgd
Temp	18.3° C	18.4° C
Influent BOD	595 mg/L	498 mg/L
Primary Effluent BOD	203 mg/L	269 mg/L
Primary Effluent NH_3-N	22.1	32.6
Final Effluent NO_3	12.5	7.0
Final Effluent TN	14.0	8.5

Case Study

- Layton,FL

LAYTON, FLORIDA

SEQUENCING BATCH REACTOR—PROCESS CONTROL MODIFICATIONS

SYSTEM SUMMARY

Official Name: City of Layton Wastewater Treatment Plant (WWTP)

Location: 67711 Overseas Highway, Long Key, FL 33001. Monroe County. Florida Keys (latitude: 24° 49' 16.5593" N; longitude: 80° 49' 14.4679" W)

Permitted design flow: 0.066 MGD, monthly average

Service area: Approximately 350 EDUs[1], including Long Key State Park

System type: Sequencing batch reactor (SBR)

Initial year of operation: 2007

Upgrade type: Process control modifications

Upgrade year of operation: 2009

Permitted effluent nitrogen limit:
12.5 mg/l TN, monthly average; 10 mg/l TN, annual average

Pre- and post-upgrade effluent nitrogen performance: Pre- and post-upgrade TN statistics are summarized below

	Influent Total Nitrogen	Effluent Total Nitrogen		
	Average Concentration	Average Concentration	Standard Deviation	Units
Pre-upgrade	89.3	7.88	4.26	mg/l
Post-upgrade	64.1	3.33	1.87	mg/l

Permitted effluent phosphorus limit: 1.25 mg/l TP, monthly average; 1.0 mg/l TP, annual average

Pre- and post-upgrade phosphorus performance: 0.58 mg/l TP, average 2007–2013 (no TP removal improvements were made)

[1] EDU = Equivalent Dwelling Unit, which is the approximate number of residences served by the facility.

Layton , FL - System Optimization

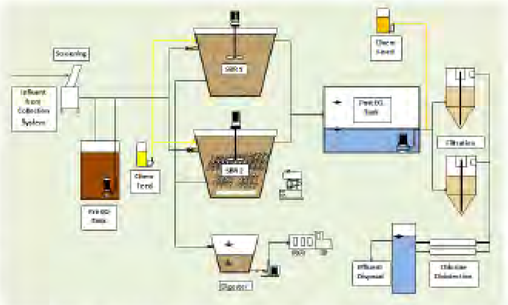
RATIONALE AND DECISION PROCESS

The plant was not consistently meeting permitted effluent TN limits. Therefore, Layton's approach focused on improving the control of their SBR system to achieve much more consistent effluent TN concentrations. Based on Florida Keys Aqueduct Authority (FKAA) experience with other similar SBR systems, operations staff were aware that programming adjustments to the control system could allow for better control of conditions during the batch cycle by mixing only for the fill cycle and then cycling blowers on and off as needed to ensure consistent nitrification-denitrification. Improved controls are supplemented by real-time dissolved oxygen (DO) and oxidation-reduction potential (ORP) monitors.

SYSTEM OPTIMIZATION DESCRIPTION

As indicated above, the focus of FKAA was to improve the control of the SBR cycle to maximize nitrification-denitrification. Biological nitrogen removal is a sequential process, first requiring aerobic conditions for converting ammonia and organic nitrogen to nitrate (nitrification) and then anoxic conditions to convert nitrate to harmless dinitrogen gas (denitrification). The aerobic conditions needed for nitrification can be maintained by actively aerating the mixed liquor (the contents of the reactor), while anoxic conditions are induced by suspending the mixed liquor using submerged mixers, with no aeration.

The original SBR wastewater facility was put into operation in 2007 and cost approximately $5.7 million. Upgrades to the City of Layton WWTP consisted mainly of reprogramming of the SBR control scheme. The original manufacturer of the SBR did not provide sufficient operational control over the "fill" and "react" cycles in each batch process to facilitate optimal nitrification and denitrification.



Each batch starts at bottom water level (BWL). At BWL, the tank is at a predefined depth that is established by the elevation of the fixed-hood decanter; this elevation cannot be adjusted. Next, the fill valve is opened and raw influent is pumped into one of the reactors. Raw influent pumping is controlled by floats in the collection system lift stations. This is important, because it can control the batch time, which had been targeted to be 4 hours, but could be longer if flows were insufficient or shorter if there was a hydraulic surge (e.g., from a storm event). Each batch includes a fill cycle, react cycle, settle cycle, decant/waste activated sludge (WAS) cycle, and idle cycle.

Questions and Wrap Up Discussion