The Basics of
<u>Phosphorus Removal</u>

Prepared by
Michigan Department of Environmental Quality
Operator Training and Certification Unit

WHY THE CONCERN OVER

P

Phosphorus

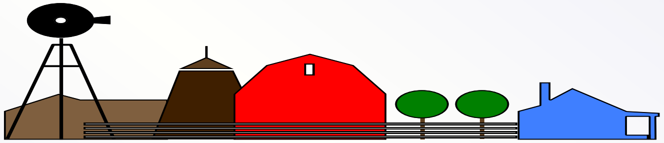
WHY IT'S REGULATED:

PHOSPHORUS IS A NUTRIENT

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

INCREASES PLANT GROWTH

Good for Food Crops



Phosphorus

WHY IT'S REGULATED:

PHOSPHORUS IS A NUTRIENT

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

INCREASES PLANT GROWTH

Good for Food Crops

Not Good for Aquatic Systems

Phosphorus

WHY IT'S REGULATED:

PHOSPHORUS IS A NUTRIENT

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

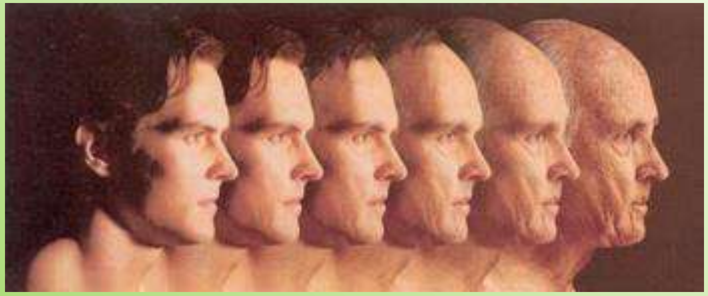
INCREASES EUTROPHICATION

Eutrophication

From the Greek word "Eutrophos", meaning "well nourished"

Describes the biological reactions of aquatic systems to nutrient enrichment

Natural aging process



"I can assure you, this is the finest anti-aging formula money can buy. And I should know because I've been selling it for over 150 years."

Eutrophication

Classification of Lakes

Oligotrophic

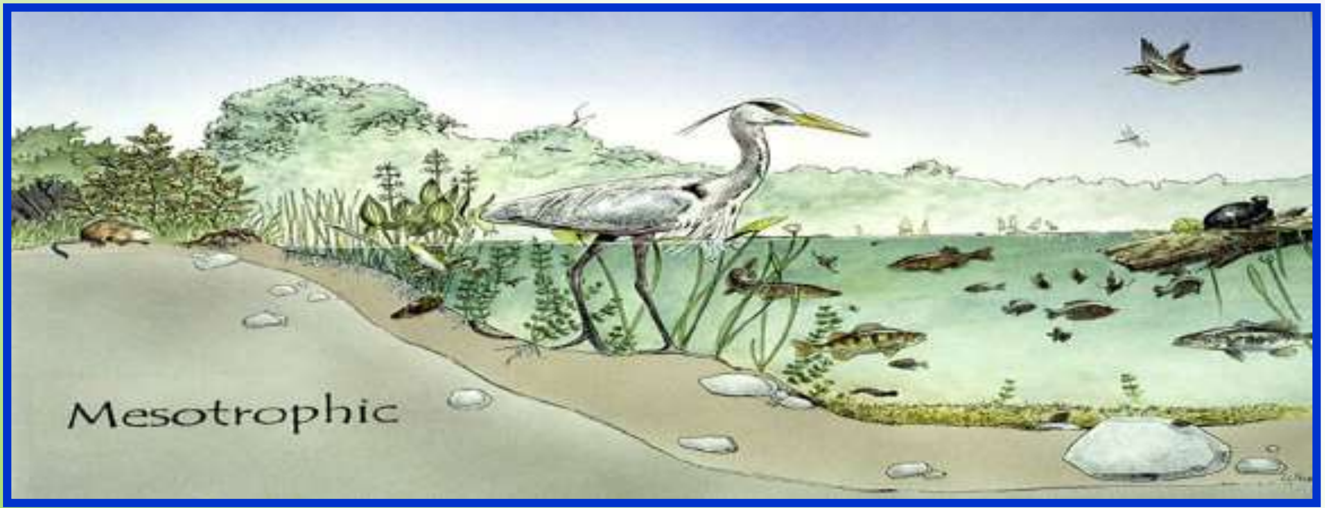
Cold, Deep, Low Nutrients

Eutrophication

Classification of Lakes

Mesotrophic

Increasing in Nutrient Load



Eutrophication

Classification of Lakes

Eutrophic

Shallow, Warm, High Nutrient Load

Eutrophication

Classification of Lakes

Oligotrophic

Cold, Deep, Low Nutrients

Mesotrophic

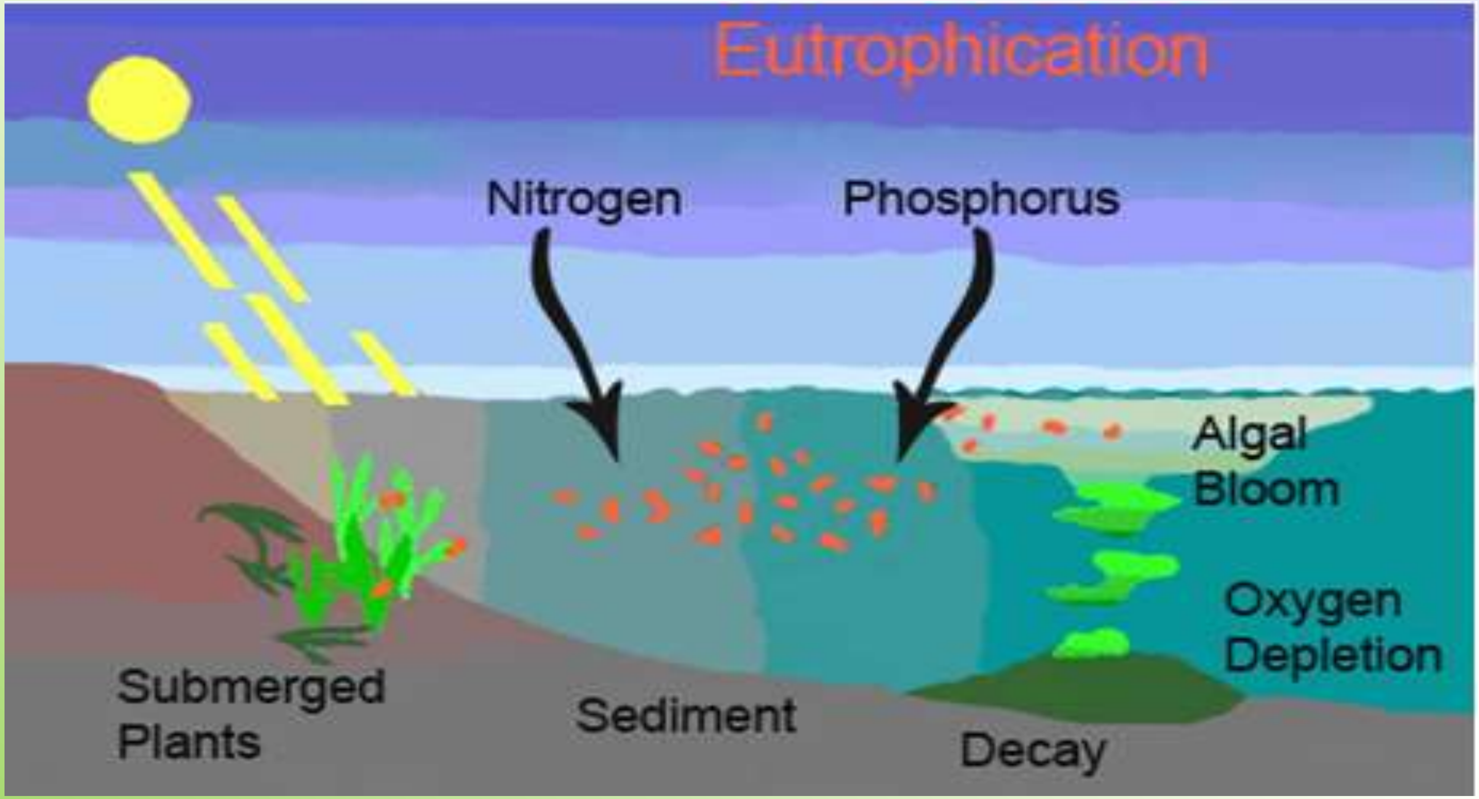
Increasing in Nutrient Load

Eutrophic

Shallow, Warm, High Nutrient Load

Control of Eutrophication

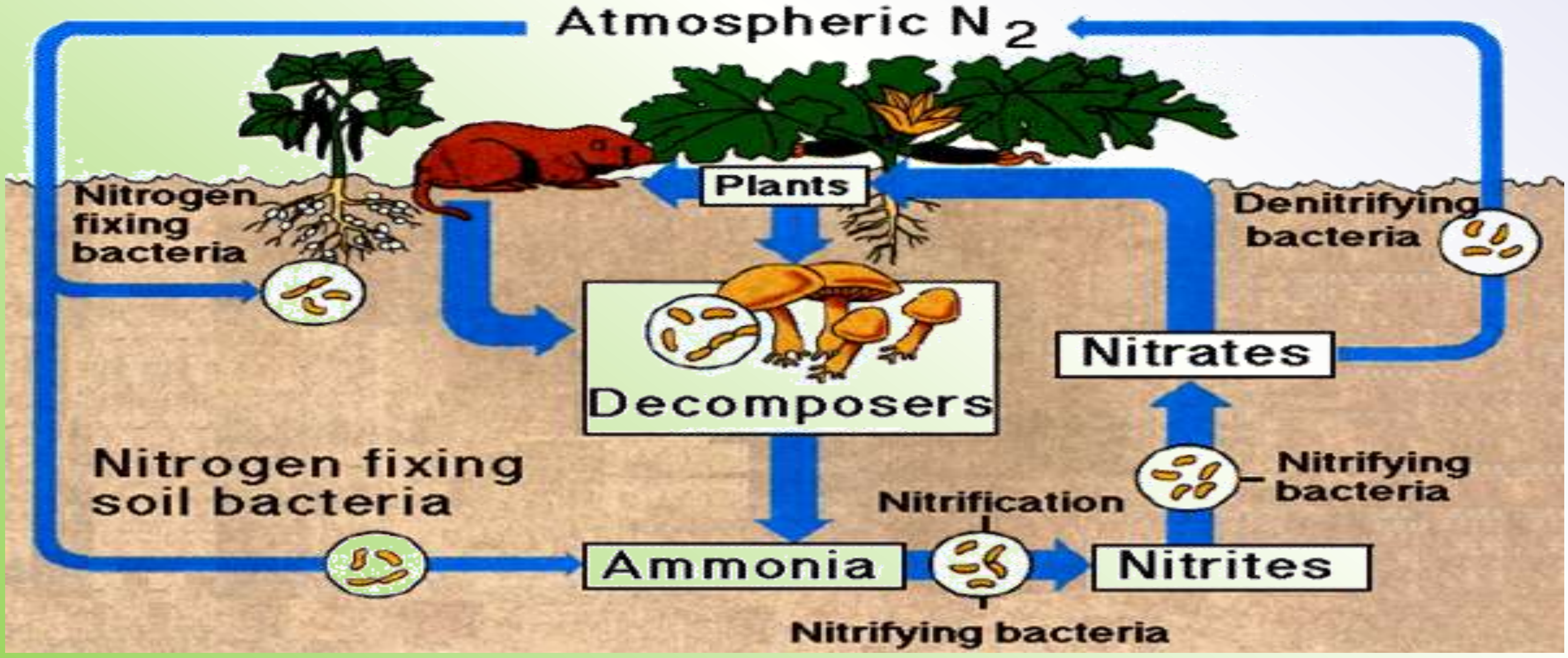
Control Nutrient Load



Control of Eutrophication

Nitrogen

Essential Nutrient
Very available in nature
Not practical to control

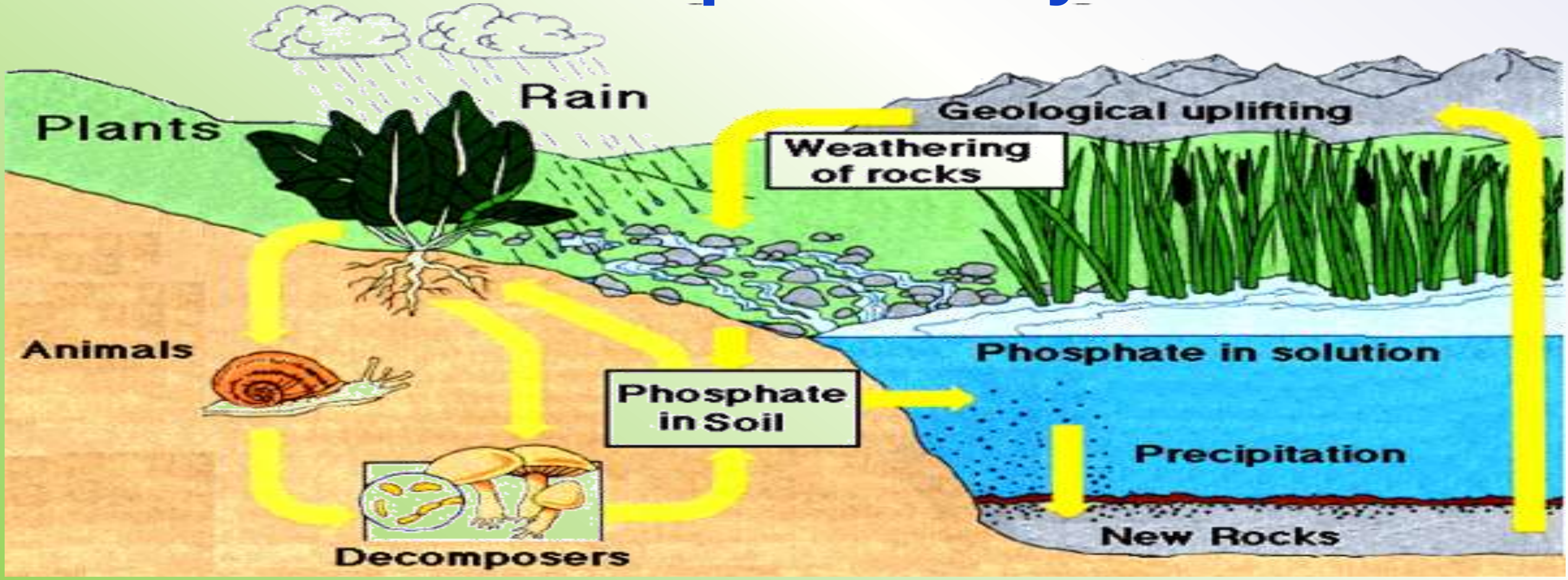


Control of Eutrophication

Phosphorus

Essential Nutrient
Not easily replaced in nature
P removal is practical

The Phosphorus Cycle

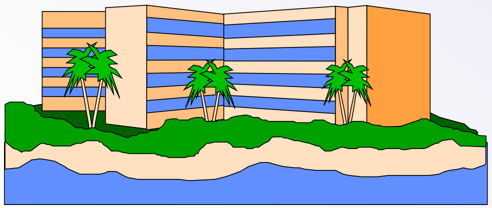


Eutrophication

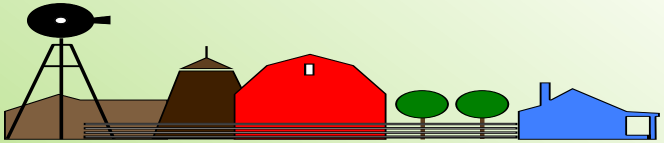
Rate of Eutrophication is increased by human activities

(Cultural Eutrophication)

Development



Stormwater Run-Off



Agriculture

Wastewater Discharges
- **WWTP**
- **On-Site Systems**
- **Combined Sewer Overflow**

Phosphorus

Wastewater Discharges

USUALLY LIMITED IN MICHIGAN TO 1 mg/L OR LESS IN DISCHARGES TO SURFACE WATER

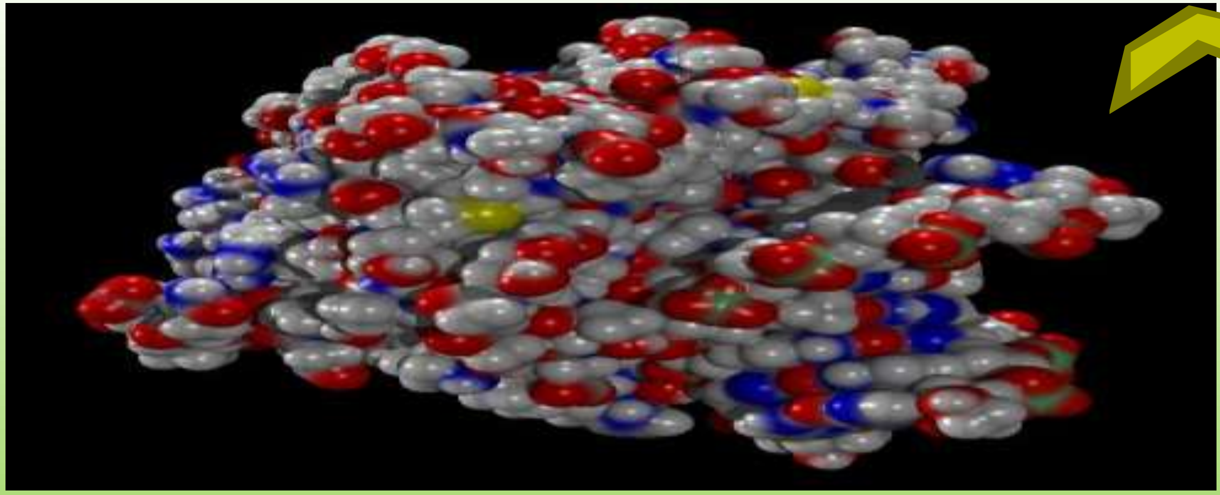
(Many Have Pounds Limit)

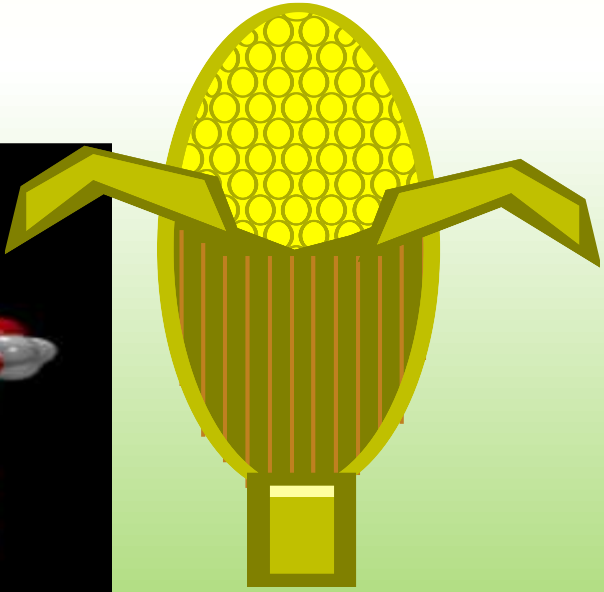
Limits Getting More Restrictive

Forms and Sources of Phosphorus

Organic Phosphorus

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

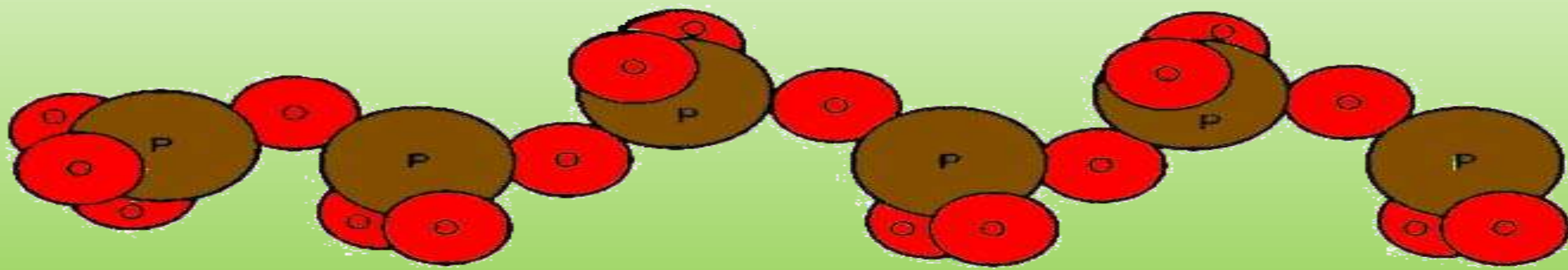




Forms and Sources of Phosphorus

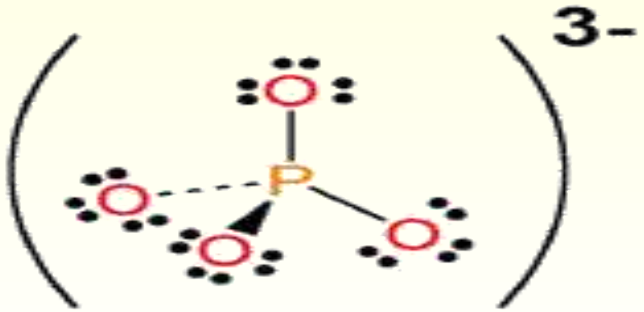
Polyphosphate (condensed phosphate)

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

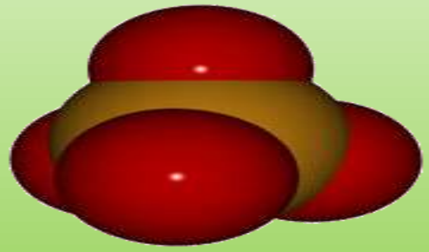


Forms and Sources of Phosphorus

Orthophosphate



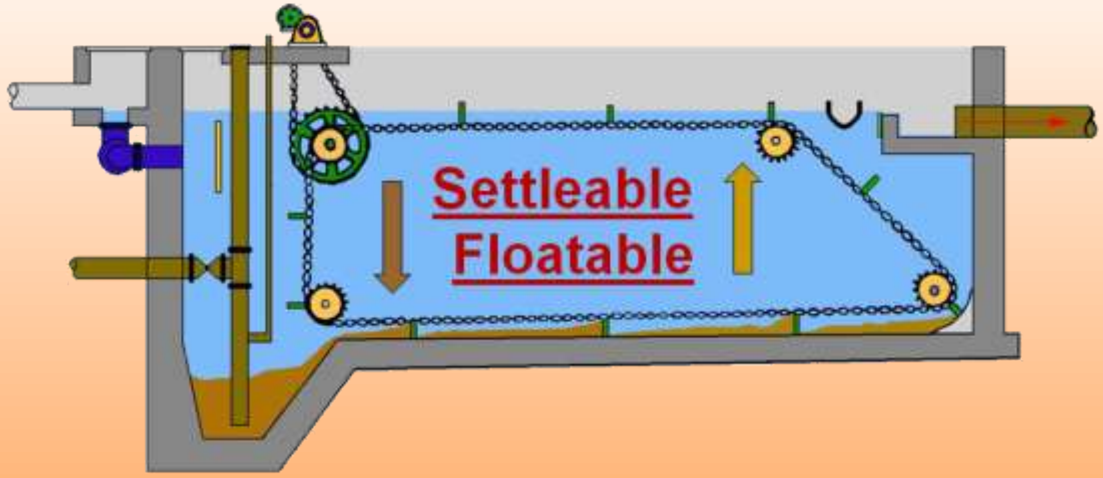
- Simple Phosphate, PO_4
- soluble
- household cleaning agents
- industrial cleaners;
- phosphoric acid
- conversion of organic and poly phosphate



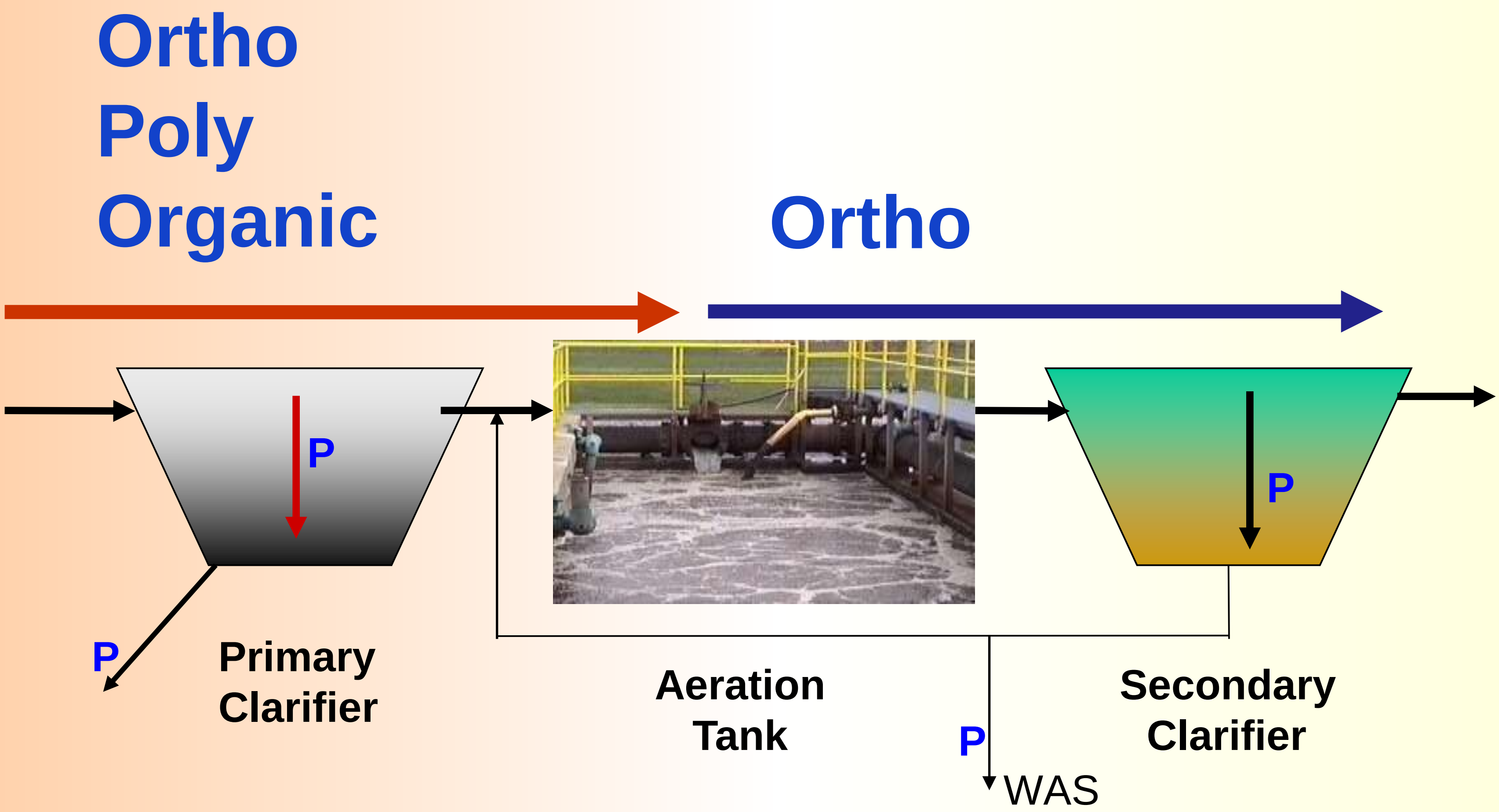
Phosphorus Removal

- Removal of Settleable Solids Provides Some Phosphorus Removal

Primary Sedimentation 5 - 15 %



Conversion to Ortho-P



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

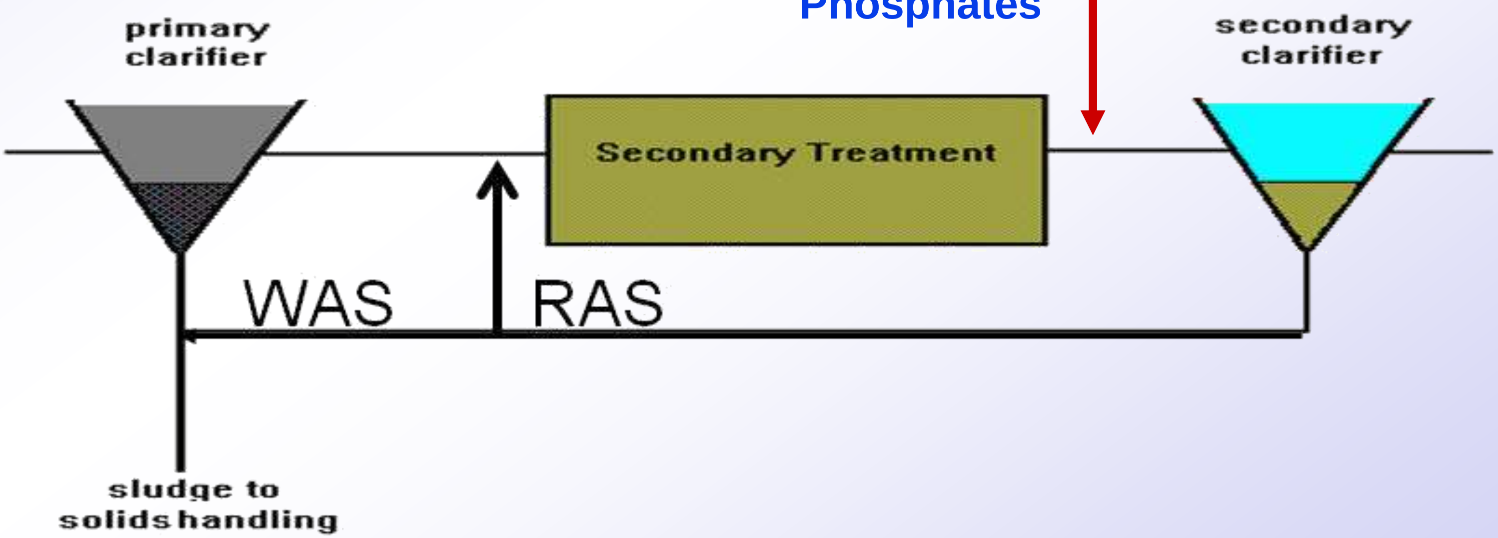
Organic Phosphorus

Condensed (Poly) Phosphates

Ortho Phosphates

Ortho Phosphates

Metal Salt Addition



Chemical Removal

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

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

PRECIPITATION

Metals used are:

Aluminum, Al

Iron, Fe

Chemicals Used
for
Phosphorous Precipitation

Most Common in Michigan:

Ferric Chloride
Ferrous Chloride
Alum

FERRIC IRON - Fe^{+3}

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

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

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

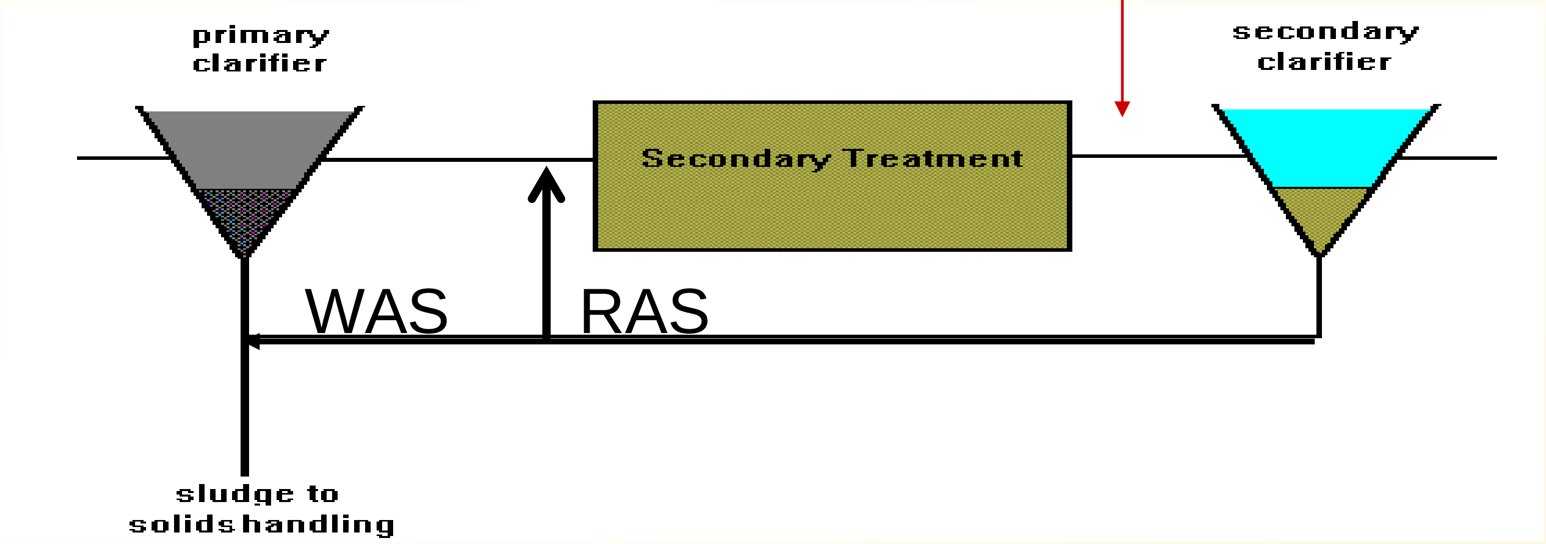
Organic Phosphorus

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)

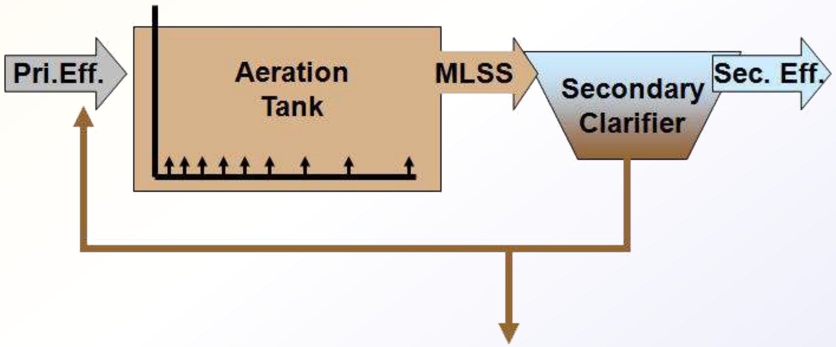
Often Just Called
BIOLOGICAL P REMOVAL

Biological P Removal

All Biological Systems Take Up P

100:5:1

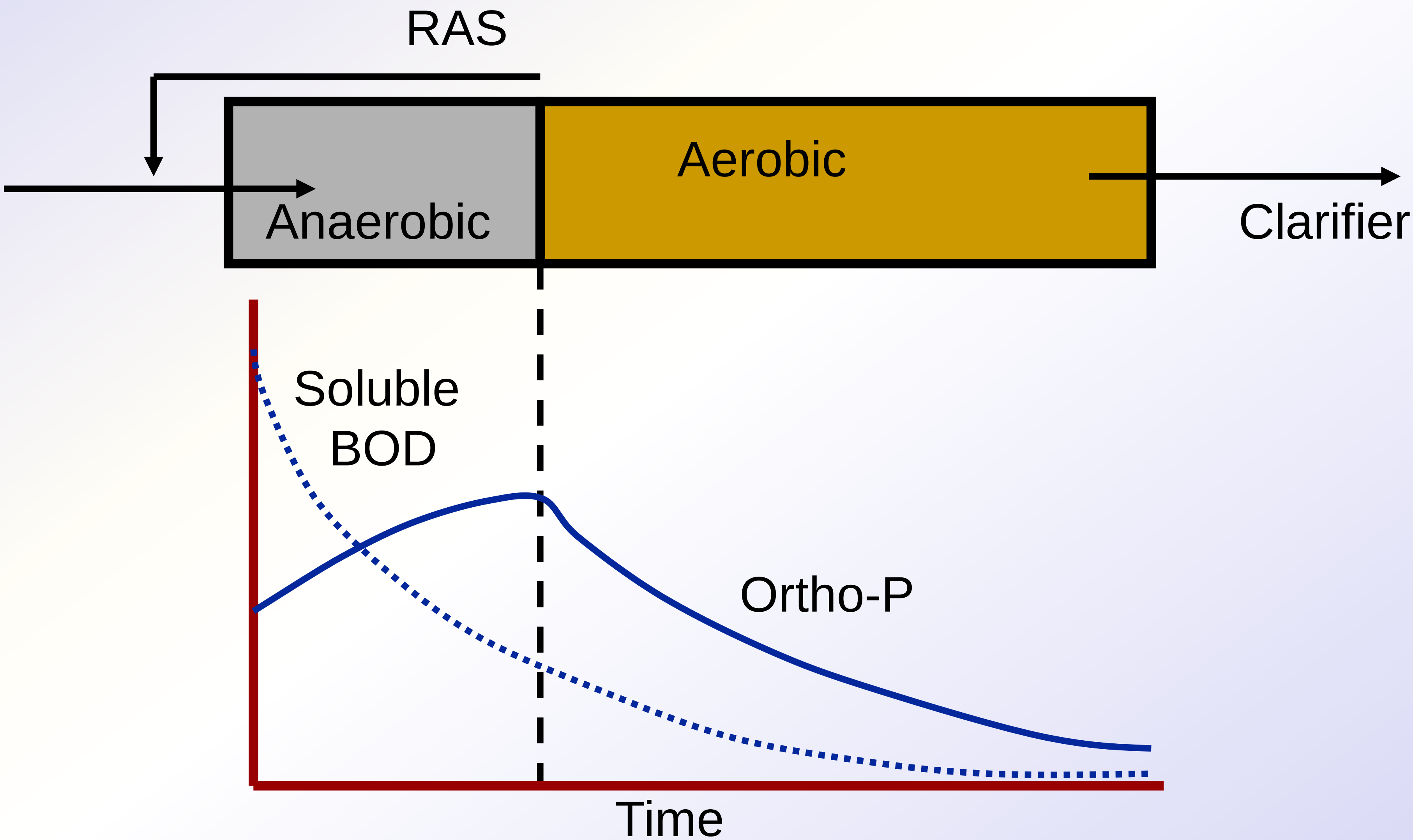
C:N:P



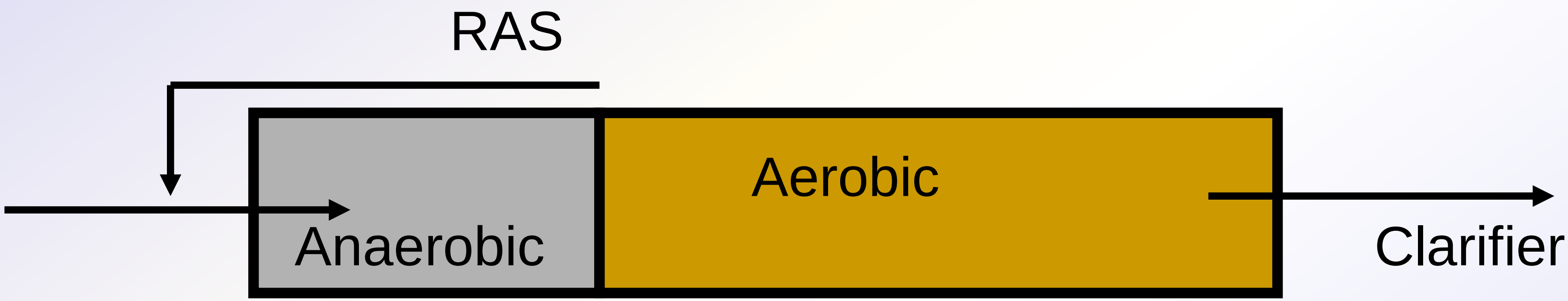
Some Facilities Removed More P Than 1P:100BOD

?

The MLSS in Those Facilities Cycled From <u>Anaerobic</u> to <u>Aerobic</u>



The MLSS in Those Facilities Cycled From <u>Anaerobic</u> to <u>Aerobic</u>



This Promoted the Accumulation of Bacteria that Uses P as an <u>Energy Storage Mechanism</u>

Acinetobacter (Assin Eato Back Ter)

& Other

Phosphate Accumulating Organisms (PAO)

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)

Biological P Removal

Anaerobic Conditions

PAO Take Up VFAs and Covert them to Polyhydroxybutyrate (PHB)

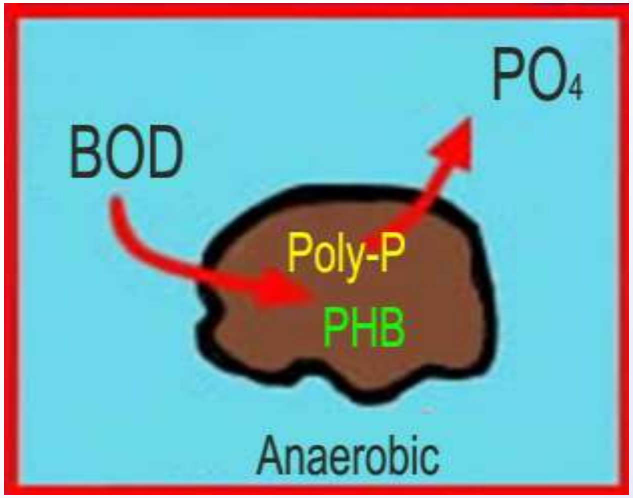
PAO Able to store soluble organics as Polyhydroxybutyrate (PHB)

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

Aerobic Conditions

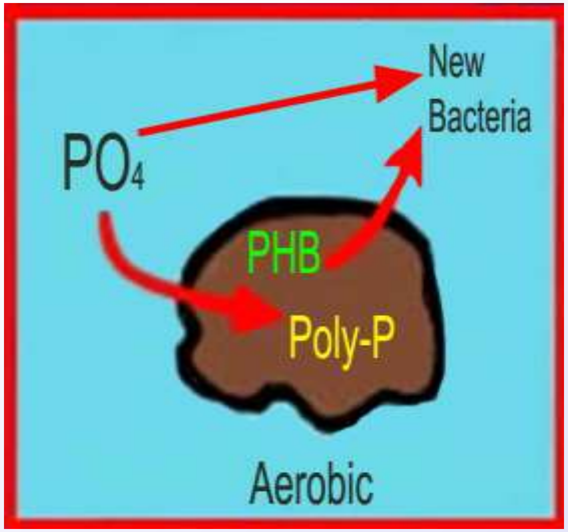
Rapid Aerobic Metabolism of Stored Food (PHB)

Producing New Cells

PO_4 Used in Cell Production

Excess Stored as Polyphosphate

("Luxury Uptake")



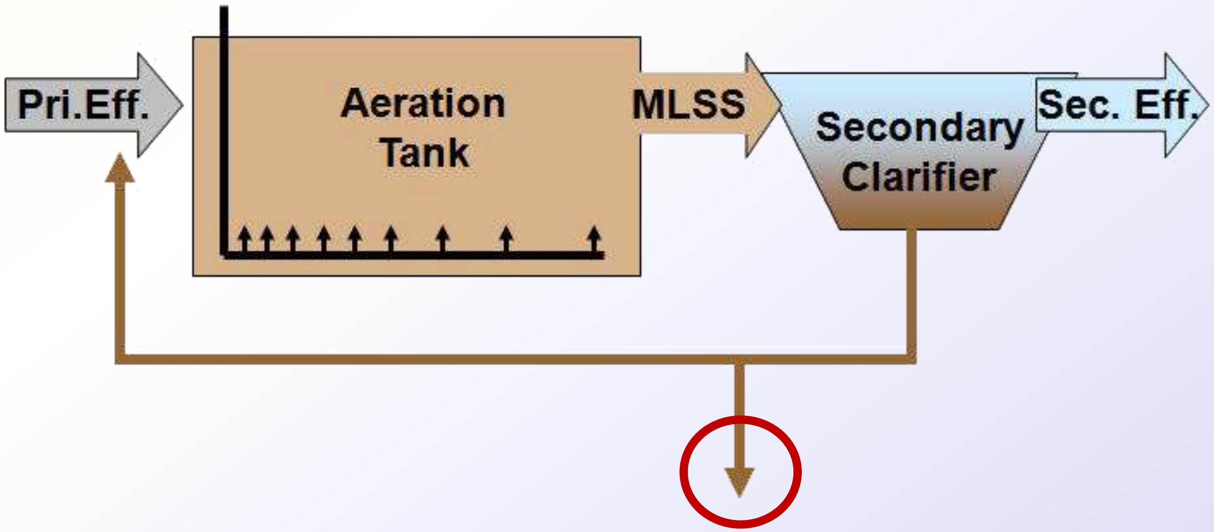
Biological P Removal

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



Biological P Removal

EBPR
BSCOD
BOD
VFAs
PAO
PHB
Ortho-P
Poly-P
Luxury Uptake
Acinetobacter

Biological P Removal

Phosphorus Accumulating Bacteria (**PAO)**

Anaerobic

Fermentation

Acetate Production

Selection of Acinetobacter/PAO

P Released to Produce Energy

Biological P Removal

Phosphorus Accumulating Bacteria (**PAO)**

Anaerobic

Fermentation

Acetate Production

Selection of Acinetobacter/PAO

P Released to Produce Energy

Aerobic

Stored Food Consumed

Excess P Taken Up

Sludge Wasted

Biological P Removal

Most often Used Processes

A/O
Phostrip
A2/O
Concentric Ring Oxidation Ditch
Sequencing Batch Reactor

Definitions

Aerobic – Dissolved (Free) Oxygen Present – O_2

Oxic – Dissolved (Free) Oxygen Present – O_2

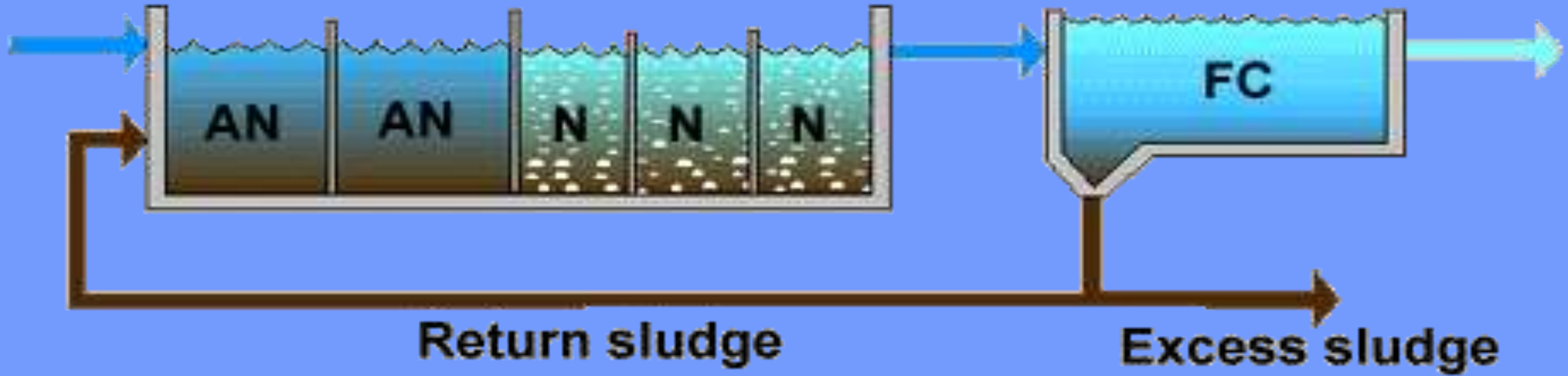
Anoxic – No Free Oxygen

(Combined Oxygen –Nitrates NO_2 and Nitrites NO_3)

Anaerobic – Oxygen Absent

A/O Process

(Anaerobic/Oxic)



Head End of Aeration Tank Baffled and Mechanically Mixed

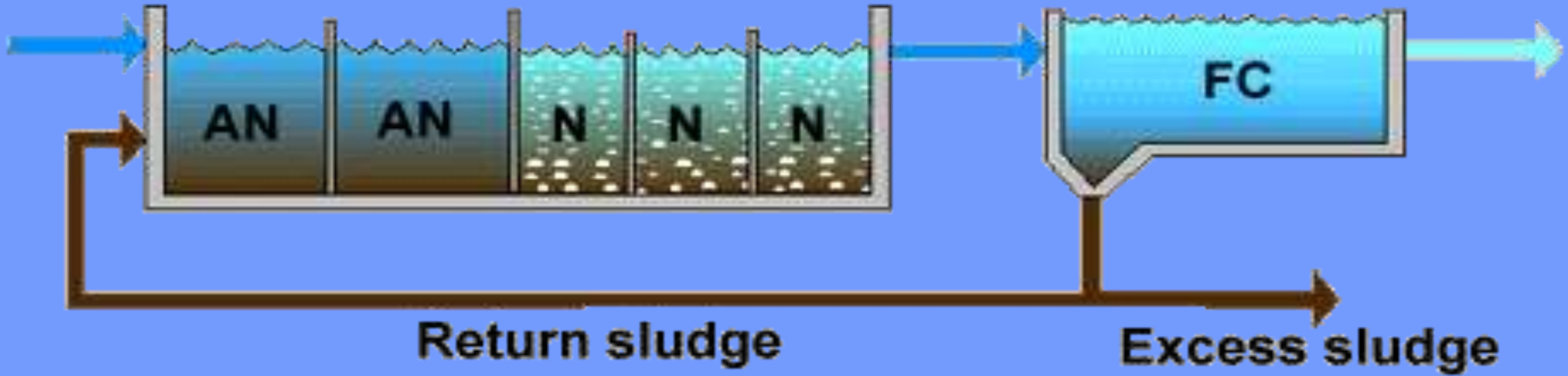
Primary Effluent and RAS Produce Anaerobic Conditions

Phosphorus Released

“Luxury Uptake” of Phosphorus in Aerated End

A/O Process

(Anaerobic/Oxic)



Studies in Florida and Pontiac, MI

At Pontiac (Cold Weather Testing)

Side by Side with Conventional

Cold Weather P removal achieved

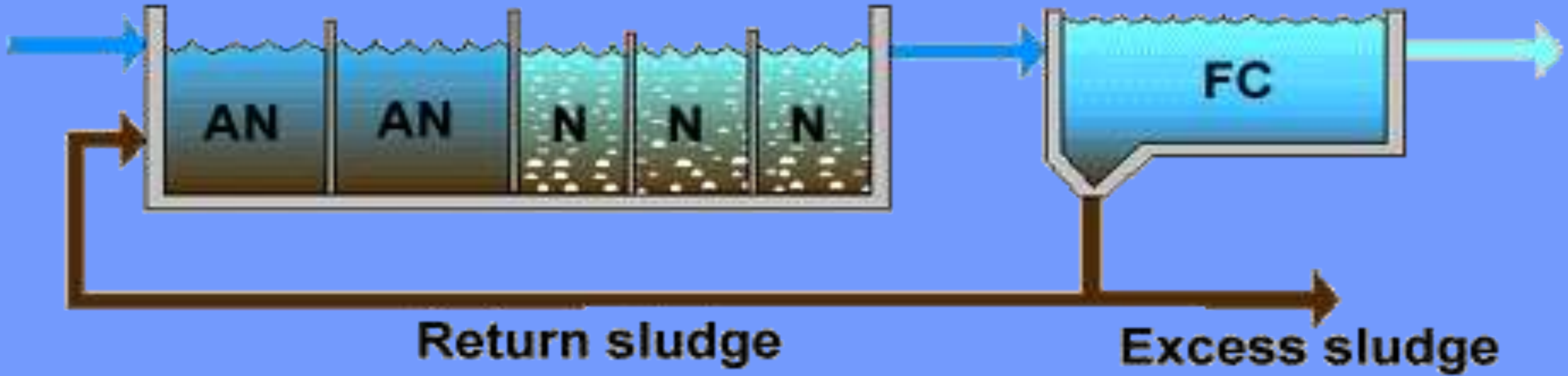
Nitrification process continued

Anaerobic Digester recycle not detrimental

A/O Process

A/O Process

(Anaerobic/Oxic)



Control Issues

Patented Process

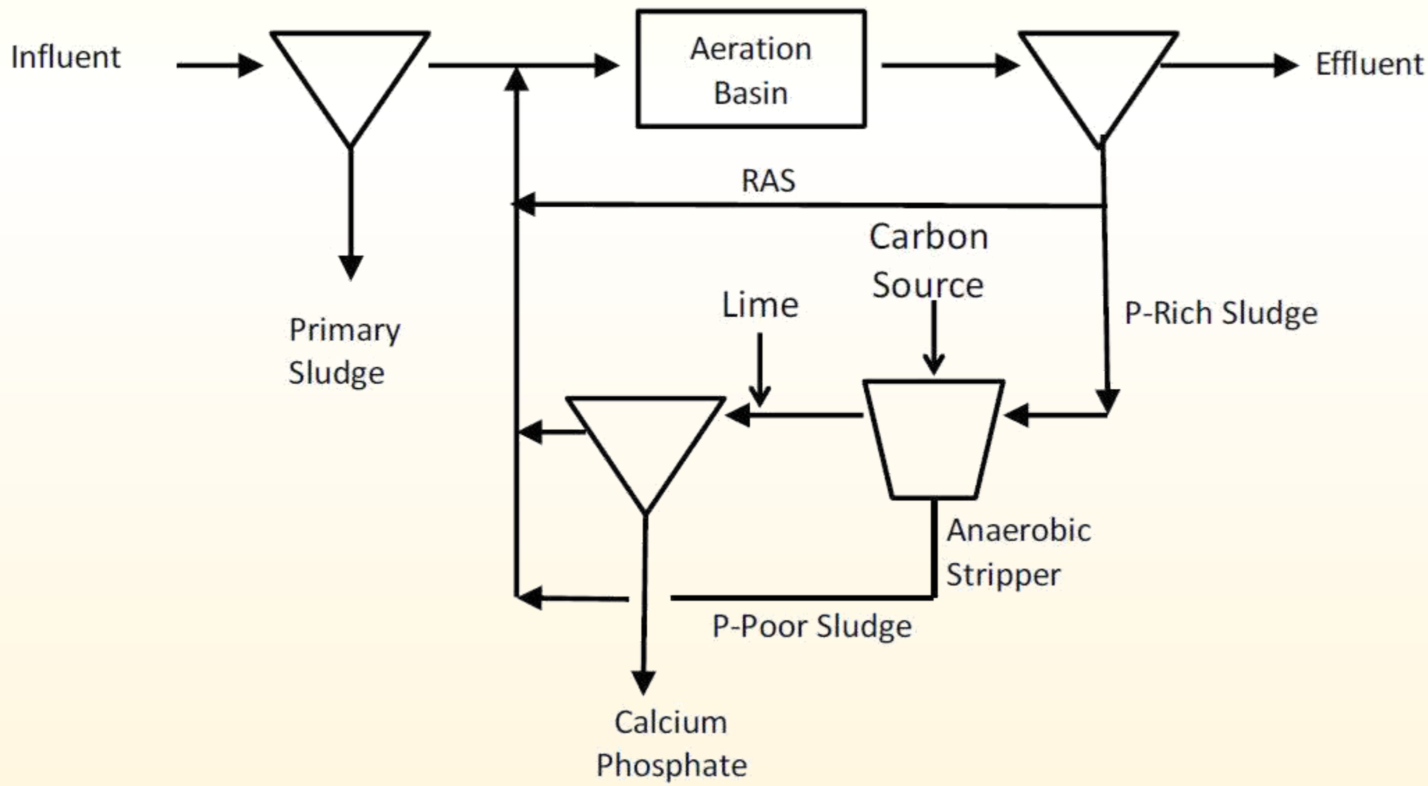
Phostrip

Some Return Sludge Diverted to Anaerobic Stripper

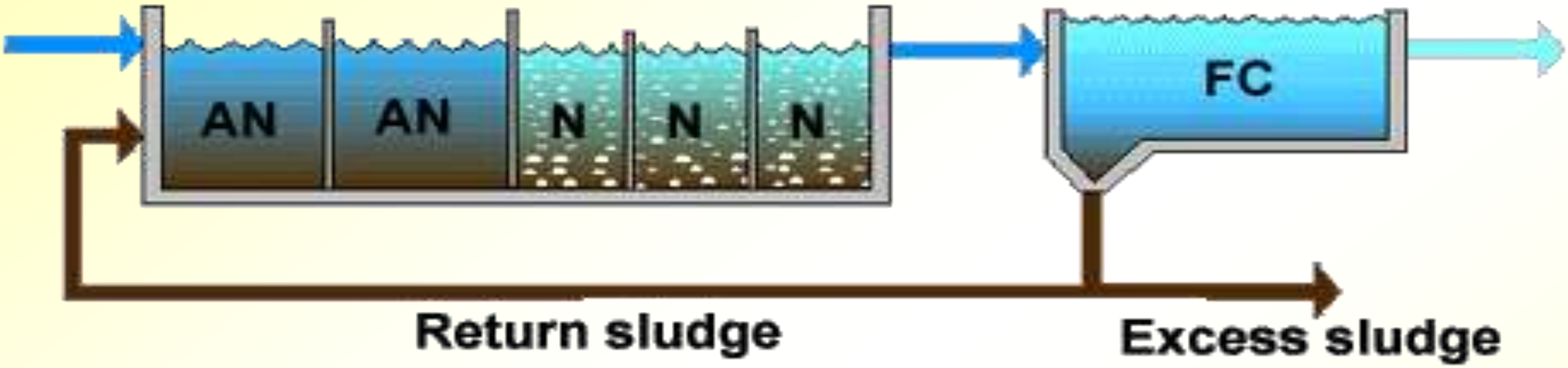
Phosphorus Released

Elutriated (Washed) to a Precipitation Tank

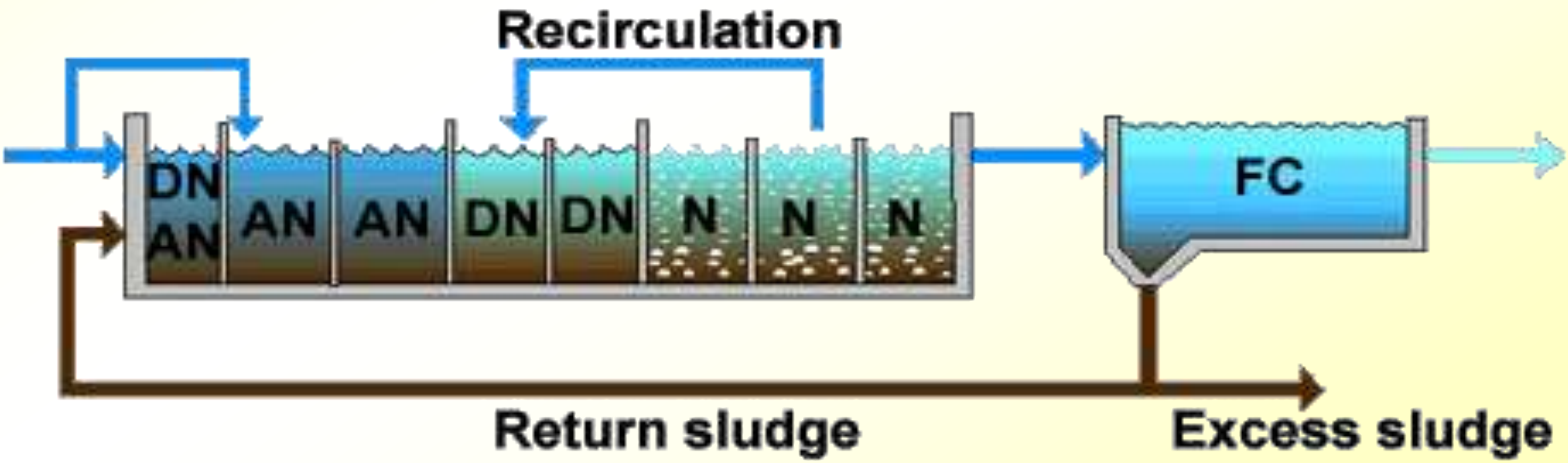
Precipitated With Lime – Sludge Removed



A/O Process (Anaerobic/Oxic)

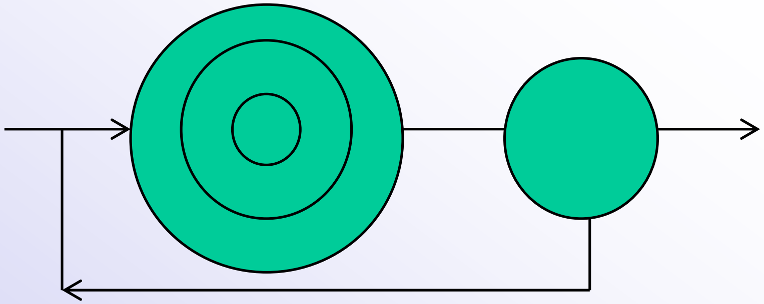


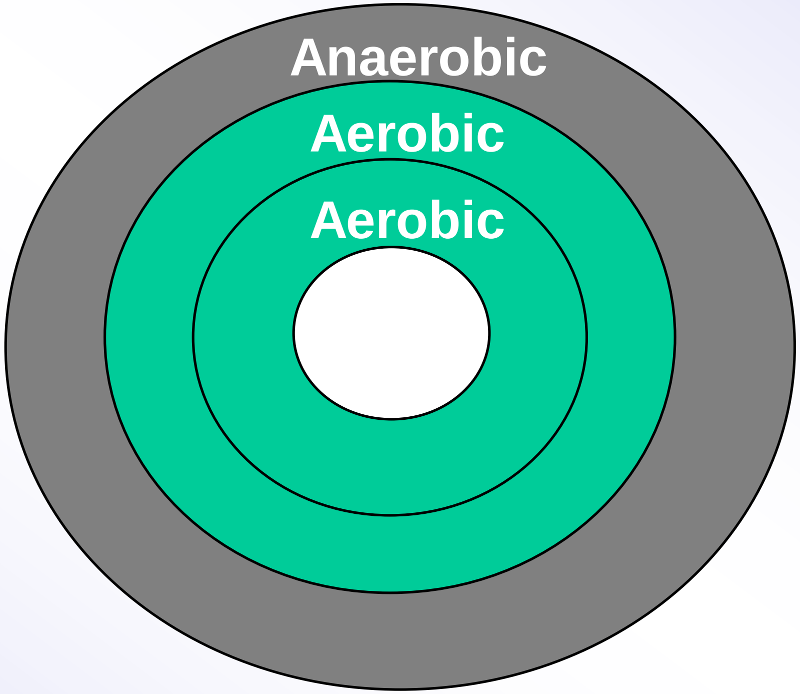
A2/O (Anaerobic/Anoxic/Oxic)



Concentric Ring Oxidation Ditch

Three Aeration Tanks in Concentric Rings





Concentric Ring Oxidation Ditch

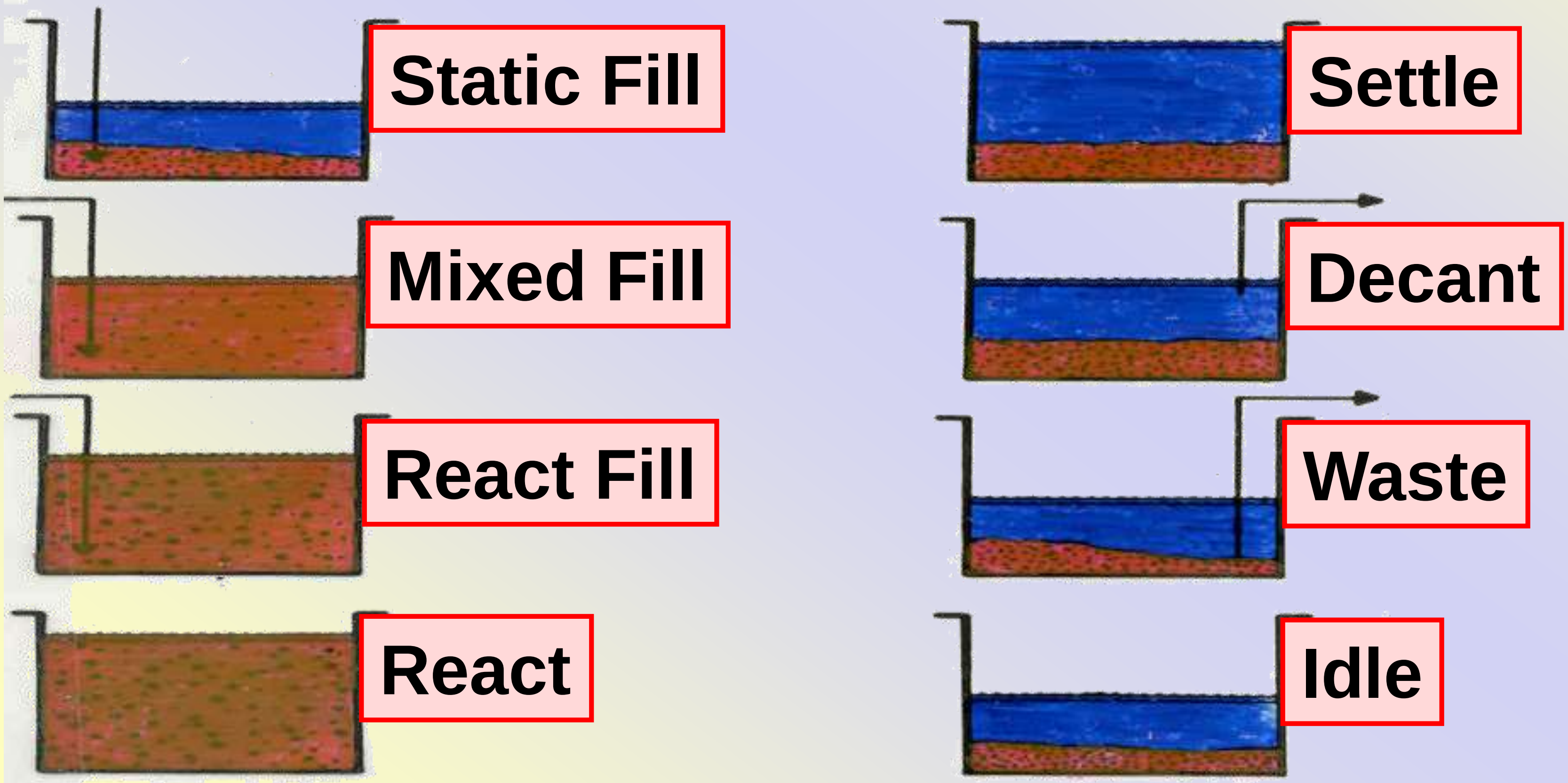
Three Aeration Tanks in Concentric Rings

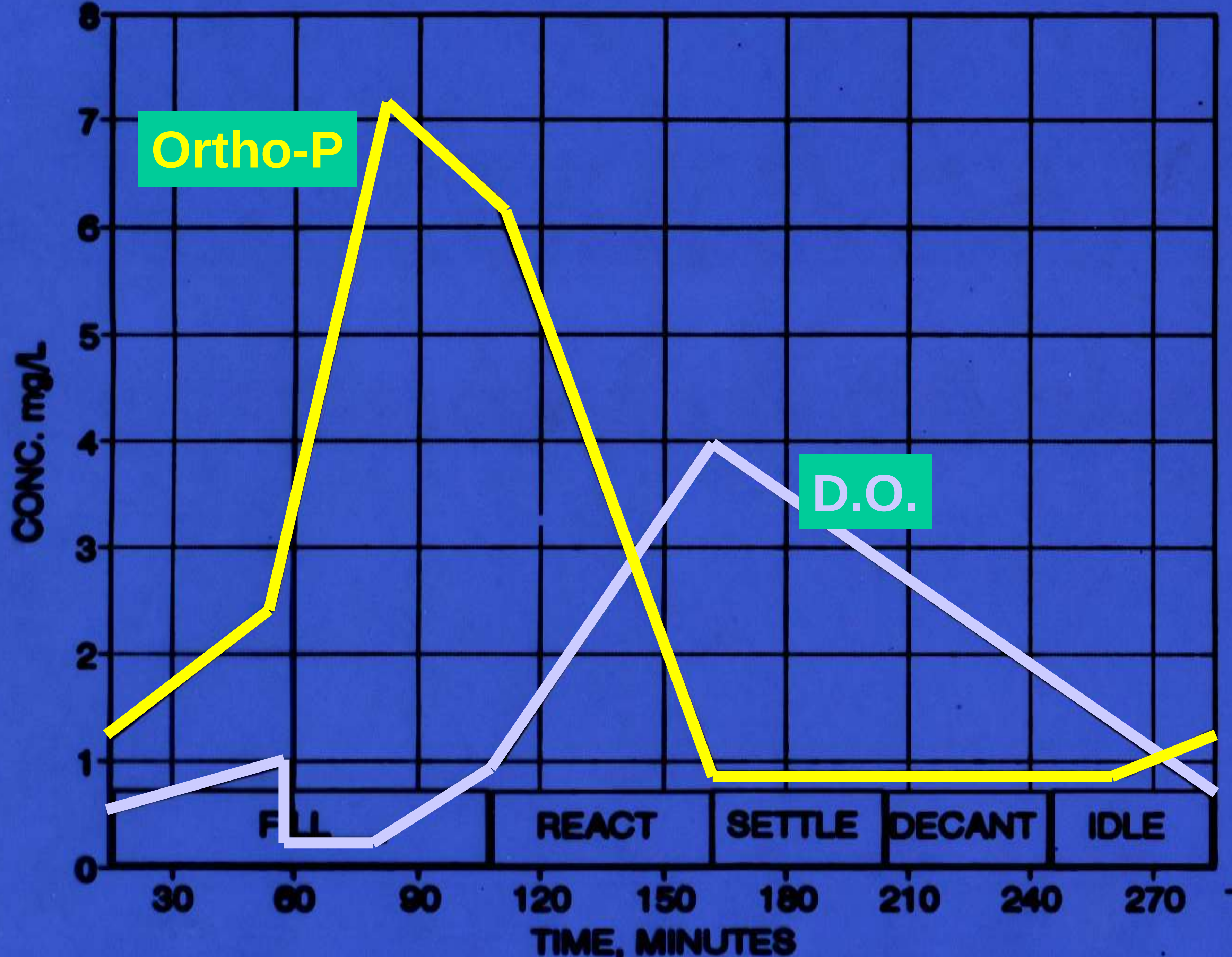
Wasting Aerobic the Bio-solids Removes Phosphorus

Sequencing Batch Reactor

Sequencing Batch Reactor

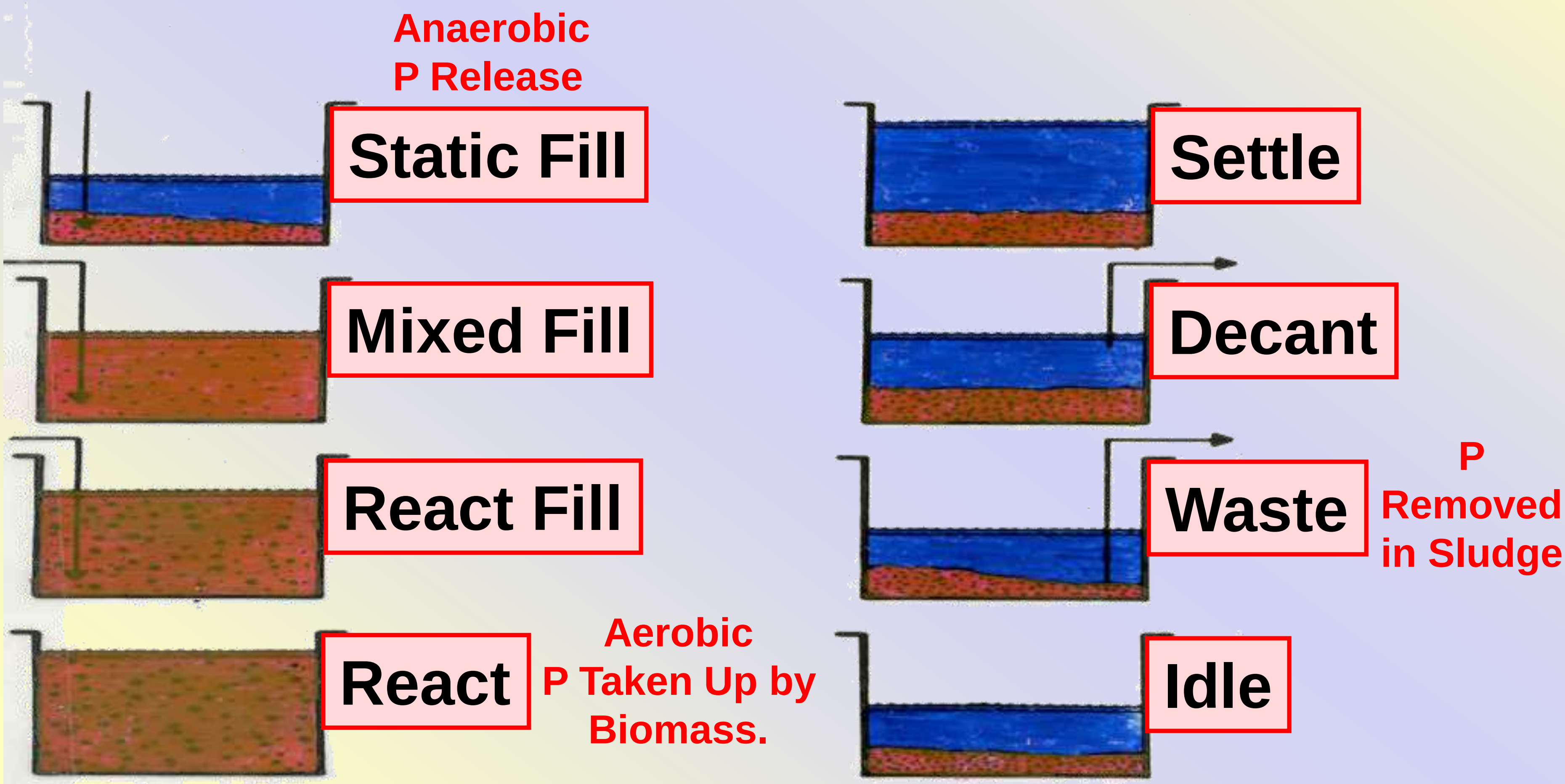
Batch Treatment in Sequence of Steps



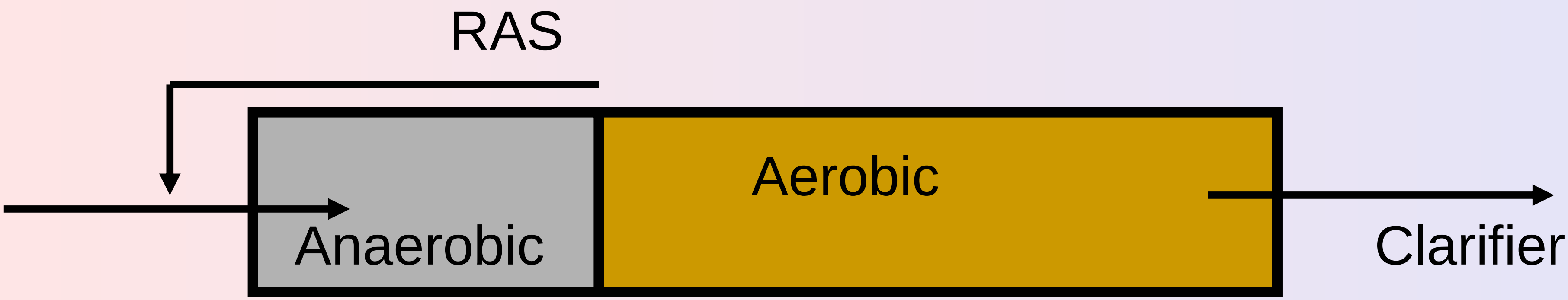

Ortho-P
D.O.
CONC. mg/L
0
1
2
3
4
5
6
7
8
FILL
REACT
SETTLE
DECANT
IDLE
30
60
90
120
150
180
210
240
270
TIME, MINUTES

Sequencing Batch Reactor

Batch Treatment in Sequence of Steps



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

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

Unbenefits

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

The Basics of Phosphorus Removal

Prepared by
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Operator Training and Certification Unit