

# SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

## SWIM-H2020 SM Regional Activities 14

Presented by:

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**SWIM and Horizon 2020 SM REG-14: Refugee Emergency: Fast track project Design of wastewater**

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## Chemical Addition & Biological & Chemical Phosphorus Removal



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## ALKALINITY CORRECTION

- **Nitrification consumes alkalinity. Typically 7.14 mg of alkalinity (as  $\text{CaCO}_3$ ) is required for each mg of  $\text{NO}_3\text{-N}$  removed.**
- **High influent TKN load imposes a high alkalinity demand.**
- **This may be replaced by dosing alkaline chemical (e.g. lime or Sodium Hydroxide).**
- **Denitrification yields partial alkalinity recovery. Typically 3.57 mg of alkalinity is released for each mg of  $\text{NO}_3\text{-N}$  denitrified.**
- **High recycle rate in an oxidation ditch enables a high rate of denitrification, therefore good alkalinity recovery.**
- **If the alkalinity is not available in the incoming sewage, there could be a lowering of the PH to cause a reduction in the nitrification rate.**

# ALKALINITY MASS BALANCE

Item	Unit	Value	mg/L	kg/day
Q	m <sup>3</sup> /day	56700		
Influent Alkalinity (as CaCO <sub>3</sub> )			750	42,525
TKN to be nitrified			107	6,040
Rate of alkalinity consumption for nitrification	kg/kg N	7.10		
Alkalinity consumed by nitrification			756	42,884
NO <sub>3</sub> -N to be denitrified			88	5,008
Rate of alkalinity recovery by denitrification	kg/kg N	3.57		
Alkalinity recovered by denitrification			315	17,879
100% FeCl <sub>3</sub> dose	kg/d	2675		
Rate of alkalinity consumption for FeCl <sub>3</sub>	kg/kg			3
Molecular weight FeCl <sub>3</sub>	gm/mole	162.21		
Molecular weight CaCO <sub>3</sub>	gm/mole	100		
Alkalinity consumed by ferric			87	4,947
Alkalinity in effluent			222	12,573

Alkalinity  
Mass Balance

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## CHEMICALS USED TO CONTROL pH

Item	Chemical	Formula	Molecular Weight	Equivalent Weight	Form			
					Powder	Granules	Liquid	Others
Chemicals Used to Raise pH	Calcium carbonate	CaCO <sub>3</sub>	100	50	✓	✓		
	Calcium Hydroxide (Hydrated Lime)	Ca(OH) <sub>2</sub>	74.1	37.1	✓	✓		
	Calcium Oxide (Quick Lime)	CaO	56.1	28				✓
	Magnesium hydroxide	Mg(OH) <sub>2</sub>	58.3	29.2	✓			
	Sodium Bicarbonate	NaHCO <sub>3</sub>	84	84	✓	✓		
	Sodium Carbonate (Soda Ash)	Na <sub>2</sub> CO <sub>3</sub>	106	53	✓			
	Sodium Hydroxide (Caustic Soda)	NaOH	40	40			✓	✓
Chemicals Used to Lower pH	Carbonic Acid	H <sub>2</sub> CO <sub>3</sub>	62	31				Gas CO <sub>2</sub>
	Hydrochloric Acid	HCL	36.5	36.5			✓	
	Sulfuric Acid	H <sub>2</sub> SO <sub>4</sub>	98.1	49			✓	

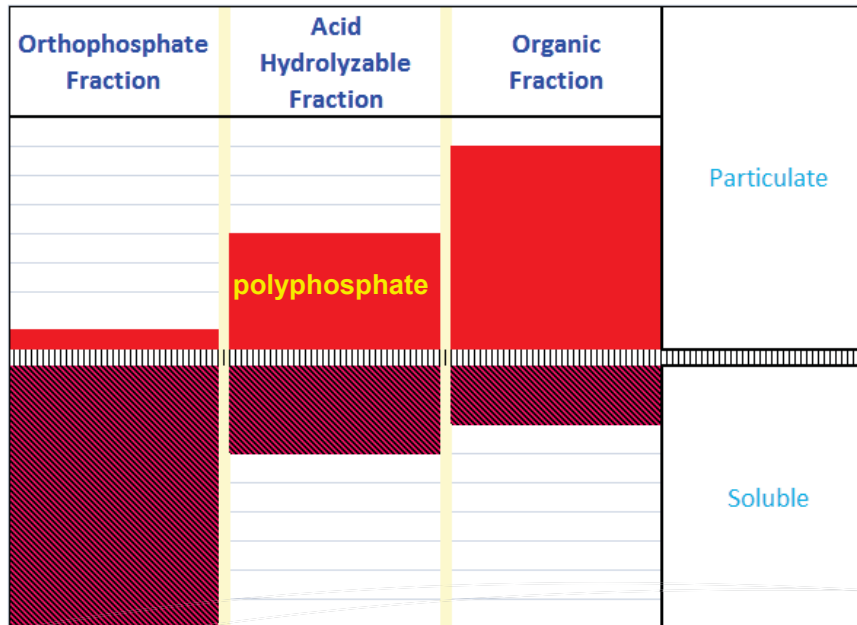


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# TOTAL PHOSPHORUS(TP) FORMS

Phosphorus in wastewater is one of three forms

- a) Phosphate(Orthophosphate)- $\text{PO}_4^{3-}$
- b) Polyphosphate
- c) Organic phosphorus



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## PHOSPHORUS REMOVAL APPROACH

- Convert orthophosphate to a solid, then remove the solid.
- Type of solids
  - Biological (microorganisms)
  - Chemical (Precipitation)
- Type of removal
  - Gravitational settling
  - Floatation
  - Filtration
  - Membrane

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# PHOSPHURUS REMOVAL METHODS

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- Biological Treatment in Anaerobic Reactor.
  - Requires excellent sludge handling otherwise release of phosphate from microbial cells is possible.
- Chemical Addition to enhance TP settlement with solids.
  - Aluminum Sulfate(Alum) and Ferric Chloride are used as coagulant, it will capture TP and settle it out for removal with sludge.

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## JORDANIAN STANDARDS FOR P REMOVAL

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Jordanian Standard for Phosphorus in mg/l

Parameter		PO4	PO4-P
Irrigation	Cooked vegetables A	30	9.8
	Fruit trees B		
	Field Crops C		
	Flowers		
Discharge	Groundwater recharge	15	4.9
	Streams, Wadis & Reservoirs		

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# PHOSPHURUS MASS BALANCE

- Some phosphorus will be removed in the primary sedimentation tanks. It can be estimated based on influent composition.
- Some phosphorus will be removed in the secondary treatment process to satisfy biological growth requirements.



## Rule of thumb

Approximately 1 mg/l-P is needed for growth for every 100 mg/l of BOD<sub>5</sub> that is removed

Phosphorus fraction of primary sludge= 1%

Phosphorus fraction of VSS= 1.5%

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# PHOSPHURUS MASS BALANCE

Item	Concentration (mg/l)			
	With PST		Without PST	
	Irrigation	Disposal	Irrigation	Disposal
TP in Influent	22.5	22.5	22.5	22.5
PO <sub>4</sub> /TP	0.5	0.5	0.5	0.5
PO <sub>4</sub> -P in Influent	11.25	11.25	11.25	11.25
Influent TSS	996	996	996	996
Design TSS removal rate	56%	56%	0%	0%
Influent VSS/TSS	78%	78%	78%	78%
Phosphorus fraction in Primary sludge	1%	1%	1%	1%
TP removed in Primary Tank	4.4	4.4	0	0
TP to Secondary Process	18.1	18.1	22.5	22.5
BOD <sub>5</sub> to secondary process	777	777	1130	1130
Observed Yield	0.74	0.74	0.74	0.74
MLSS VSS/TSS	72%	72%	72%	72%
Phosphorus fraction of waste sludge	1.5%	1.5%	1.5%	1.5%
TP Assimilated	6.2	6.2	9.0	9.0
Standard TP Required	9.8	4.9	9.8	4.9
Calculated TP in Effluent	11.9	11.9	13.5	13.5
TP to be Removed	2.1	7.0	3.7	8.6

Phosphorus  
Mass Balance

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# CHEMICAL PHOSPHORUS REMOVAL

- Common Chemicals used for phosphorus removal:
  - Aluminum Sulfate(Alum)  $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$
  - Ferric Chloride  $\text{FeCl}_3$
  - Other materials(Lime  $\text{CaO}$ ,  $\text{Ca}(\text{OH})_2$ )
- Removable Phosphorus
  - Chemical precipitation will remove only the phosphate (i.e, orthophosphate) fraction of total phosphorus in wastewater. Influent phosphate is typically 50 to 80% of TP.

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## CHEMICAL DOSE FOR FERRIC CHLORIDE

$$y = \frac{a}{(1 + b \times e^{-cx})}$$

Where:

y = mole iron required per mole soluble phosphate removed

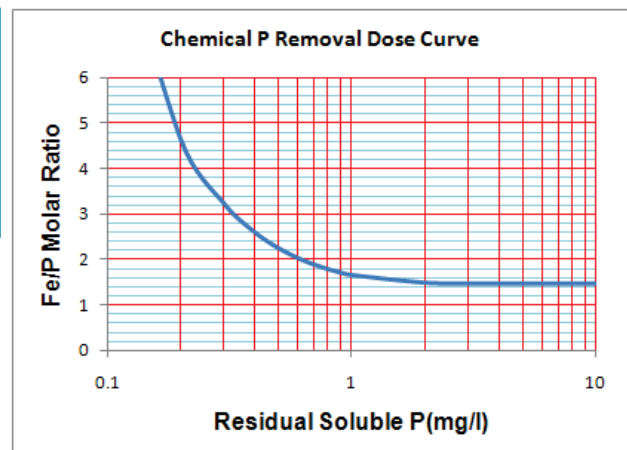
x = residual soluble phosphate(mg/l P)

a = 1.48

b = -1.07

c = 2.25

The molar dose for phosphorus precipitation is based on the desired final effluent soluble phosphorus concentration rather than the starting phosphorus concentration



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## PROCESS CALCULATIONS FOR CHEMICAL DOSE FOR FERRIC CHLORIDE

### PHOSPHORUS REMOVAL By Ferric Chloride

Q	m <sup>3</sup> /day	12,445
TP to be removed	mg/l	2.25
TP load to be removed	Kg /day	28
Residual P	mg/l	2.5
Fe Dose	mol Fe <sup>3+</sup> / mol P	1.49
Dose used		4.00
Molecular weight for P	gm/mole	31.0
Molecular weight for Fe	gm/mole	55.9
Fe/p Atomic weight ratio		1.8
Molecular weight FeCl <sub>3</sub>	gm/mole	162.4
Atomic number Fe		26.0
Ferric iron dose(as a metal)	Kg /day	202
	Kg mole Fe/day	8
	mg/l Fe	16.23
100% FeCl <sub>3</sub>	Kg/day	587.2
	mg/l	47.2
Ferric Chloride Solution %		36%
Density of ferric solution	kg/l	1.4
36% Ferric Solution Dose	Kg/day	1631
	mg/l	131
Amount of FeCl <sub>3</sub> required	l/day	1141
	m <sup>3</sup> /day	1.141
Ferric Phosphate Sludge Production	Kg SS/Kg dosed iron	2.5
Solids Production	Kg SS/day	505

Ferric Chloride  
Dose for P Removal

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## CHEMICAL DOSE FOR ALUMINUM SULFATE

$$y = \frac{a}{(1 + b \times e^{-cx})}$$

Where:

y = mole iron required per mole soluble phosphate removed

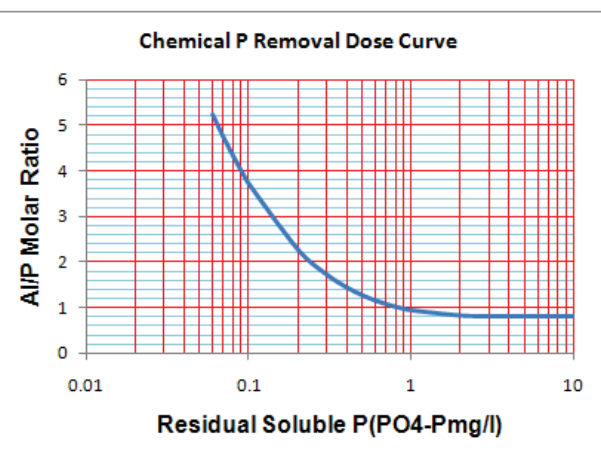
x = residual soluble phosphate(mg/l P)

a = 0.8

b = -0.95

c = 1.9

The molar dose for phosphorus precipitation is based on the desired final effluent soluble phosphorus concentration rather than the starting phosphorus concentration



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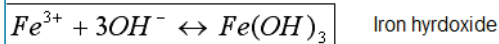
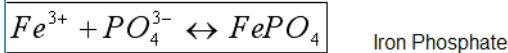
# INCREASE IN SLUDGE PRODUCTION FROM CHEMICAL ADDITION FOR P REMOVAL

Reactions required to determine sludge produced.

## Alum



## Iron

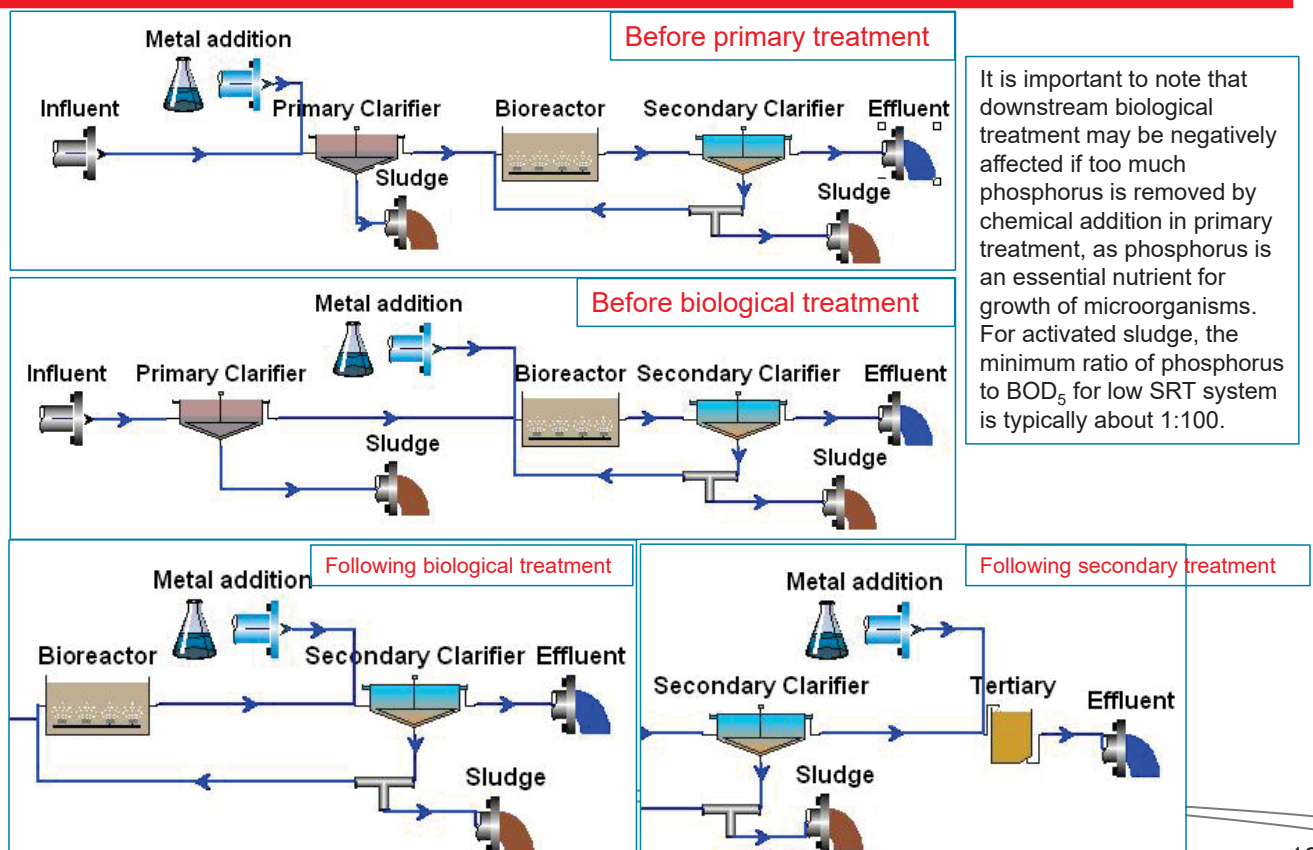


## Rule of thumb

- ❑ 10 kg of chemical sludge is produced per 1 kg of P removed<sup>1</sup>.
- ❑ 2.5 kg of chemical sludge is produced per 1 kg of dosed iron.

<sup>1</sup>. Nutrient control design manual(EPA, August 2010, page 9-23.)

## POINTS OF APPLICATION OF CHEMICALS FOR P REMOVAL



## ADVANTAGES & DISADVANTAGES OF CHEMICAL FEED AT PRIMARY CLARIFIERS

Application Point	Advantages	Disadvantages
Primary Clarifier only (pre-precipitation)	<ul style="list-style-type: none"> <li>Removes additional BOD and solids</li> <li>Uses lower stoichiometric dose</li> <li>Iron addition can reduce sulfide odors</li> <li>Reduces oxygen transfer requirements in the biological process, and reduces the amount of excess biomass sludge produced.</li> </ul>	<ul style="list-style-type: none"> <li>Control issue of leaving enough P for biotreatment but low enough for effluent</li> <li>Does not remove polyphosphates which will be converted to orthophosphate in the bioprocess</li> <li>Competing reactions for hydroxides can decrease dose efficiency</li> <li>Removes alkalinity before nitrification process, which can result in low pH levels that inhibit nitrification</li> <li>Removes BOD that can be used downstream for denitrification. Can result in larger anoxic tanks or an increased need for an exogenous carbon source for nitrogen removal.</li> </ul>

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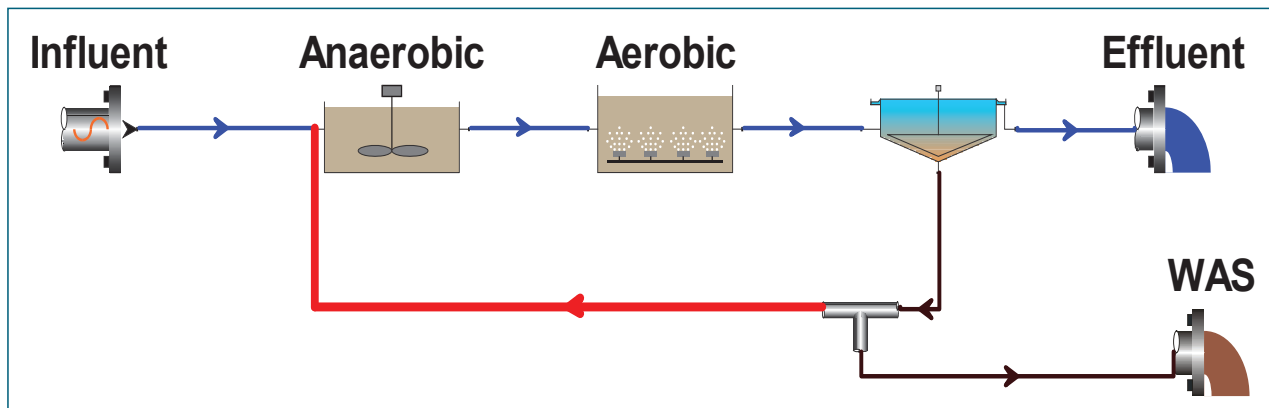
## ADVANTAGES & DISADVANTAGES OF CHEMICAL FEED BEFORE SECONDARY & TERTIARY TREATMENT

Application Point	Advantages	Disadvantages
Secondary Treatment only , e.g., aeration basin or before secondary clarifier (co-precipitation)	<ul style="list-style-type: none"> <li>For effluent P less than 1.0 mg/L good final control point for chemical dosing</li> <li>Polyphosphates converted so most of P is available</li> <li>May help improve TSS removal in clarifiers</li> <li>Help prevent fouling in MBR systems</li> </ul>	<ul style="list-style-type: none"> <li>Removes alkalinity within the biological nitrification process which can lower pH and inhibit nitrification</li> <li>MLSS increases with production of chemical sludge, which increases the solids loading to the final clarifiers. May need larger activated sludge tanks or larger clarifiers.</li> </ul>
Tertiary Treatment only (post-precipitation)	<ul style="list-style-type: none"> <li>For effluent P less than 0.5 mg/L good final control point for chemical dosing</li> <li>Polyphosphates already converted so most of P is available</li> <li>Will help improve TSS removal</li> <li>Can recycle precipitant to headworks for added P removal</li> </ul>	<ul style="list-style-type: none"> <li>Filtration increases capital and operating costs</li> <li>Filtration increases operational complexity and maintenance</li> <li>Filter solids breakthrough can lead to spikes in effluent P</li> <li>P removal to low levels can inhibit or prevent nitrogen removal by denitrification filters</li> <li>Requires separate sludge handling</li> </ul>

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## ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL(EBPR)

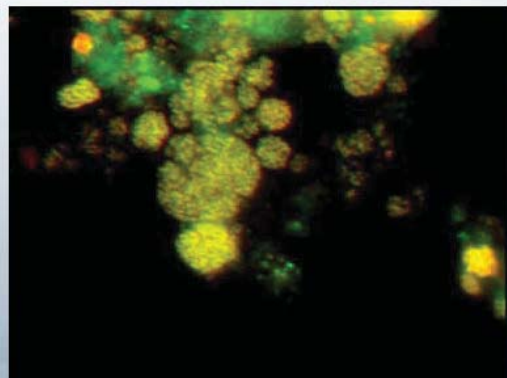
- Environment is created to cause the activated sludge organisms to take up more phosphorus than required for normal metabolism.
- Typical activated sludge consists of 1.5% to 2 % phosphorus.
- When Phosphorus accumulating organisms(PAOs) are present in the activated sludge, the ratio will increase to 5% to 15%.
- Phosphorus removal is achieved by wasting PAOs from the system.



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## POLY-B HETEROTROPHIC BACTERIA

- Heterotrophic bacteria capable of storing phosphorus intracellularly.
- Metabolic environment must cycle between anaerobic (with no nitrate present) and aerobic.
- Volatile fatty acids must be present in anaerobic bioreactor.
- MLSS enriched with PAO wasted for enhanced biological phosphorus removal.



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# BIOLOGICAL PHOSPHORUS REMOVAL

- Biological phosphorus removal(BPR) in wastewater treatment is accomplished by encouraging the growth of phosphate accumulating organisms(PAOs).
- Anaerobic reactors for P-removal are sized based on the dissolved P to be removed and the available rbCOD in the influent.
- The available rbCOD(VFA) will be given a priority for consumption by the DO or nitrate available in the return sludge before it is taken up by PAOs.

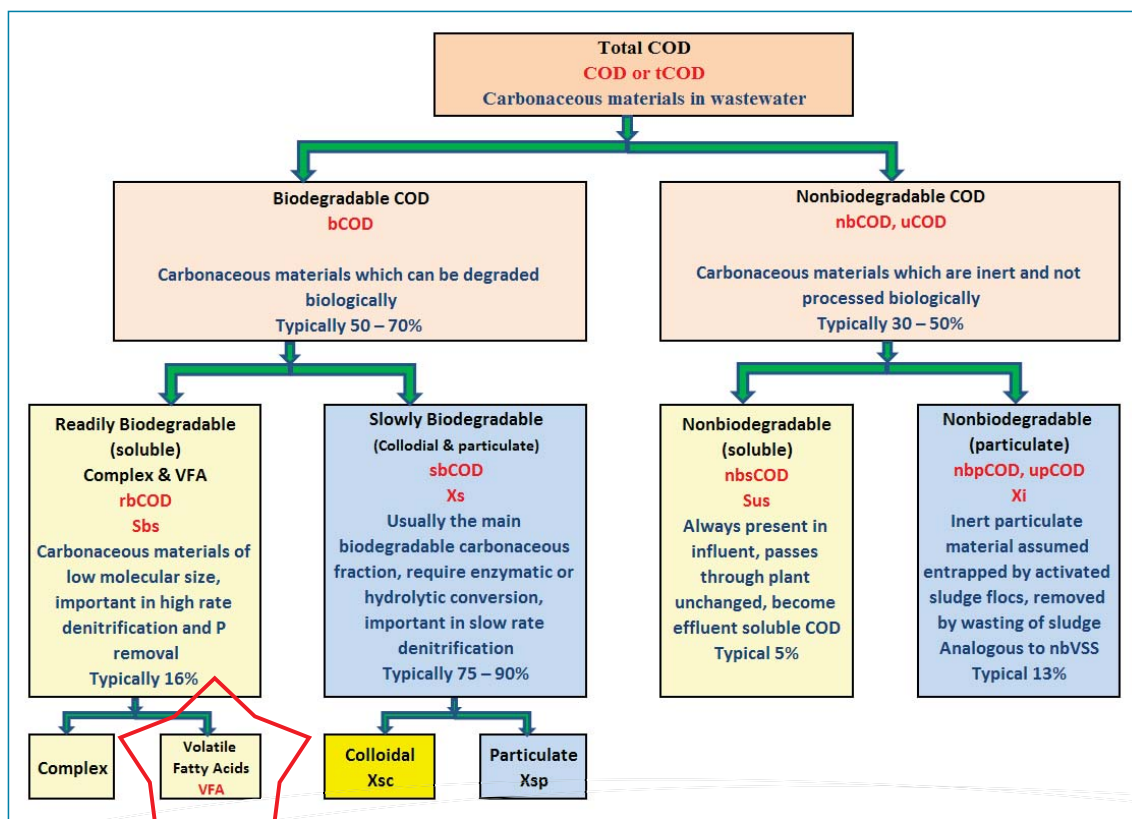


## Rule of thumb

7-10 gm of rbCOD(VFAs) will be required to remove 1 gm of P biologically.

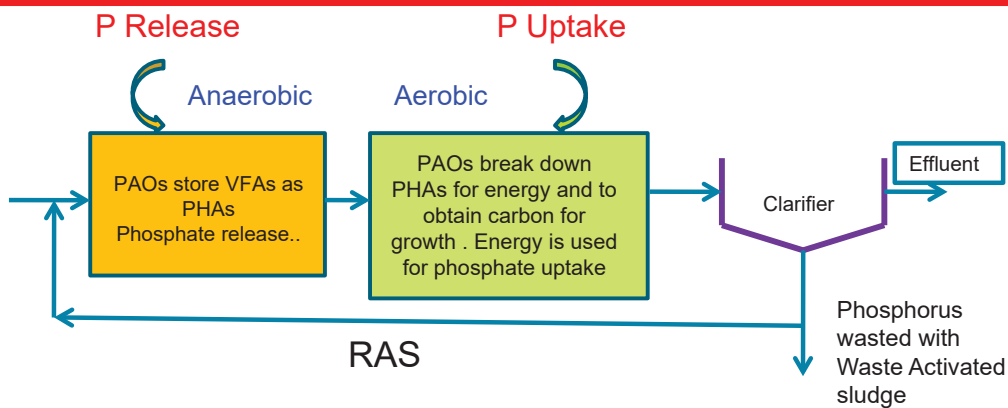
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## CHARACTERIZATION OF THE rbCOD CONTENT OF THE INFLUENT



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# BIOCHEMISTRY OF BIOLOGICAL PHOSPHORUS REMOVAL(BPR)



## Anaerobic Zone

- Acetate is produced by fermentation of bsCOD.
- PAOs uptake & assimilate acetate and produce PHB(Polyhydroxybutyrate)
- Orthophosphate( $O-PO_4$ ) is released.

## Aerobic Zone

- $O-PO_4$  is removed from solution and incorporated into polyphosphates within the bacterial cell.

## Waste sludge

- As a portion of the biomass is wasted stored phosphorus is removed with the waste sludge.

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# ANAEROBIC CONTACT TIME

- Sufficient detention time(0.25-1 hours) is needed for the fermentation of non-VFA rbCOD to VFAs and for the storage of PHAs.
- One day SRT is recommended for the anaerobic contact zone design.
- Too long anaerobic contact time may cause secondary release of phosphorus, which is phosphorus release not associated with rbCOD(acetate uptake).
- When secondary release occurs, bacteria haven't accumulated PHB for subsequent oxidation in the aerobic zone.
- Secondary phosphorus release occurred for anaerobic contact times in excess of 3 hours.

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## BIOLOGICAL PHOSPHORUS REMOVAL CAPACITY

$$BioP\_Removal\_Capacity = \frac{rbCOD\_available\_BioP}{\left[ \frac{rbCOD\_consumed}{P\_removed} \right]}$$

rbCOD available for BioP=

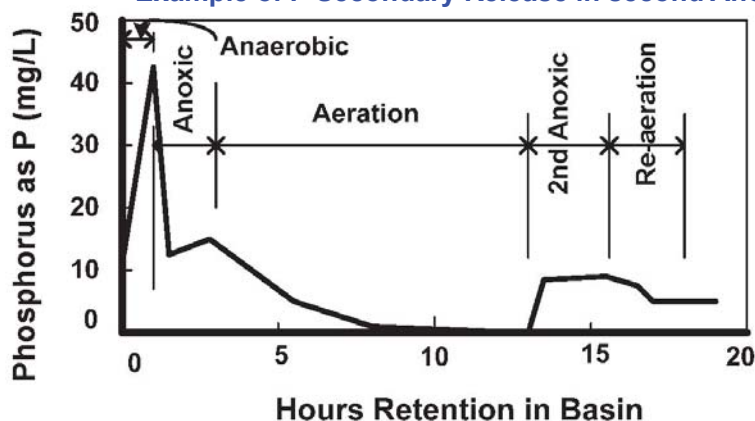
Total rbCOD-  
rbCOD consumed by NO<sub>3</sub>-  
rbCOD consumed by DO.

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## SECONDARY RELEASE OF PHOSPHURUS

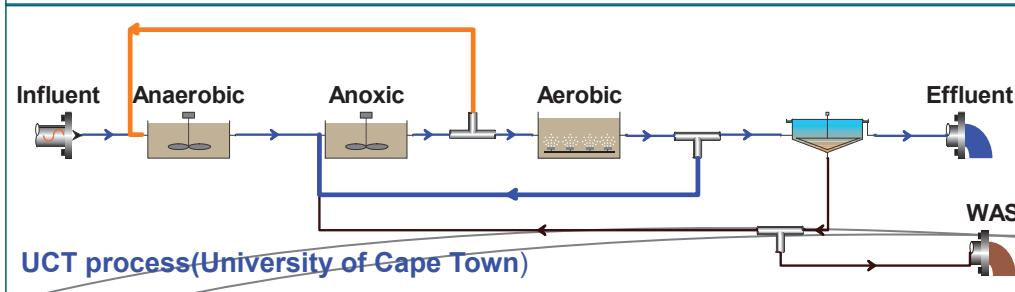
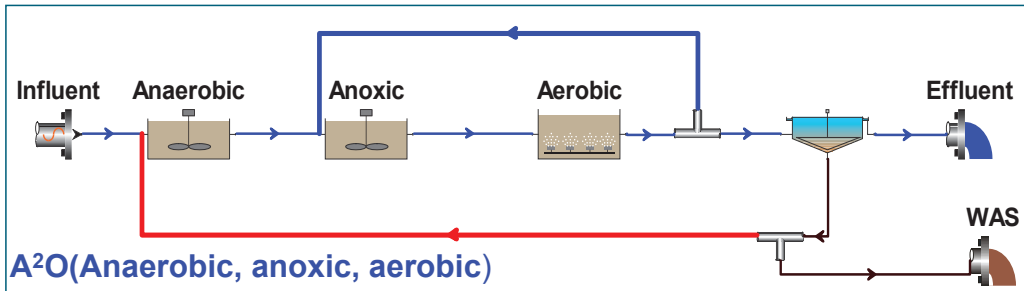
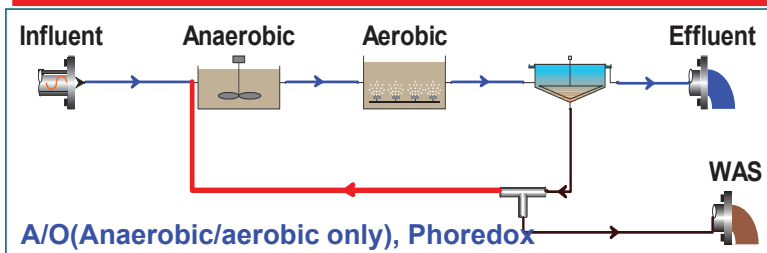
- Phosphorus will be released from PAOs in anaerobic sludge treatment processes.
- Long retention time in gravity thickeners can lead to phosphorus release. Therefore mechanical dewatering instead of gravity dewatering are preferred.
- Dissolved air flotation(DAF) is usually recommended to thicken sludge to reduce the amount of P release.

Example of P Secondary Release in second Anoxic Zone.



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## BIOLOGICAL PHOSPHORUS REMOVAL(BPR) PROCESSESS



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## EFFECT OF DO & NITRATE IN RECYCLE SLUDGE ON BPR

The rbCOD in the influent wastewater added to the anaerobic zone will be removed by bacteria using oxygen and nitrate before it is available for biological phosphorus removal.

2.3 g rbCOD used/g DO added

6.6 g rbCOD used/g NO<sub>3</sub>-N added

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## WHY SIMULATION MODELS SHOULD BE USED FOR DESIGN OF ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL(EBPR)

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There are numerous reasons why design of an EBPR must be based on use of a simulation model. This is particularly true if the plant is a full biological nutrient removal(BNR) plant, requiring TN removal as well as TP removal:

- Because phosphorus removal depends on wasting solids from the system, EBPR plants perform better at lower SRT. Optimization of the EBPR process conflicts with optimization of TN removal processes, requiring longer SRT. Only by modeling can the optimum SRT for balancing EBPR and TN removal be found.
- Placing anaerobic zones ahead of anoxic zones ( $A^2O$  process) decreases the denitrification efficiency in the anoxic zone as a result of the removal of soluble carbon in the anaerobic zone. This effect is impossible to simulate using empirical methods.

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## WHY SIMULATION MODELS SHOULD BE USED FOR DESIGN OF ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL(EBPR)

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- Downstream processing of biosolids with high phosphorus content is a very important issue, particularly plants with anaerobic digestion. Only by modeling can the release of TP in digestion/dewatering side streams and resulting load of TP on the liquid train be simulated.
- RAS flows to anaerobic reactor will diminish EBPR, as portion of the influent VFAs will be used for denitrification in the anaerobic basins. Modeling is critical to quantifying this effect and can be used to size RAS denitrification zones for enhancement of EBPR.

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# SWIM-H2020 SM

## For further information

### Website

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## SWIM and Horizon 2020 Support Mechanism

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**Thank you for your attention.**

This Project is funded by the European Union

