Biological Nutrient Removal

TIMOTHY D. BRETT, P.E.
NORTHEAST TERRITORY MANAGER – XYLEM/SANITAIRE

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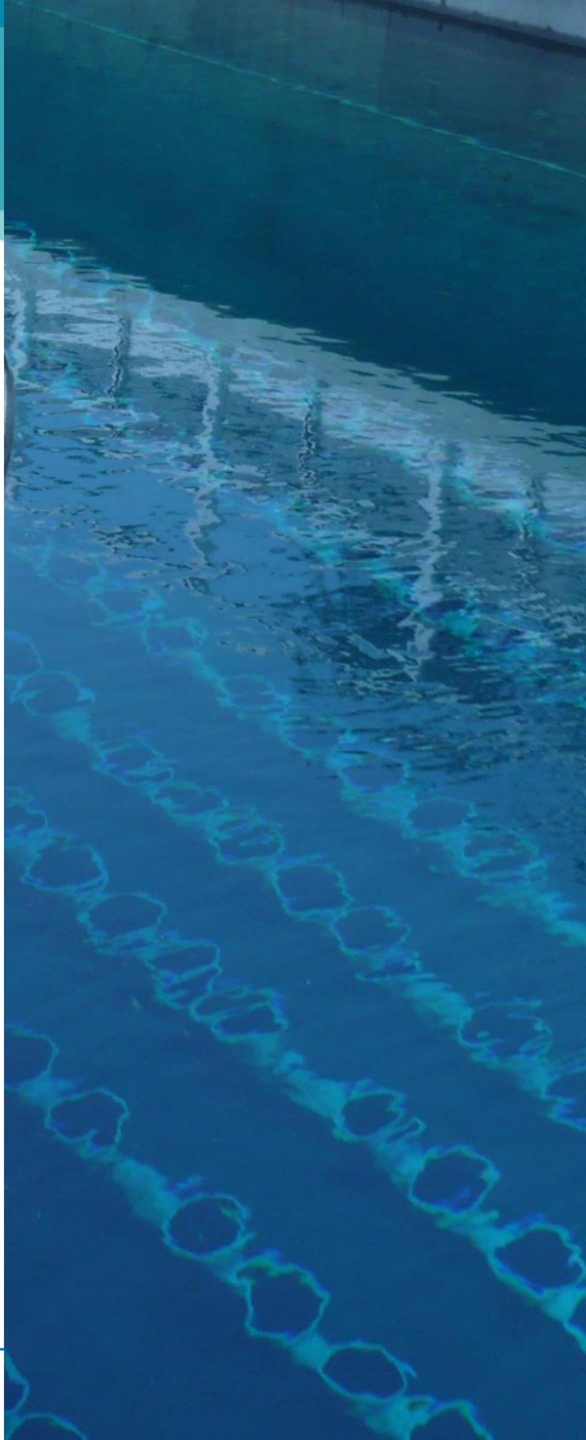
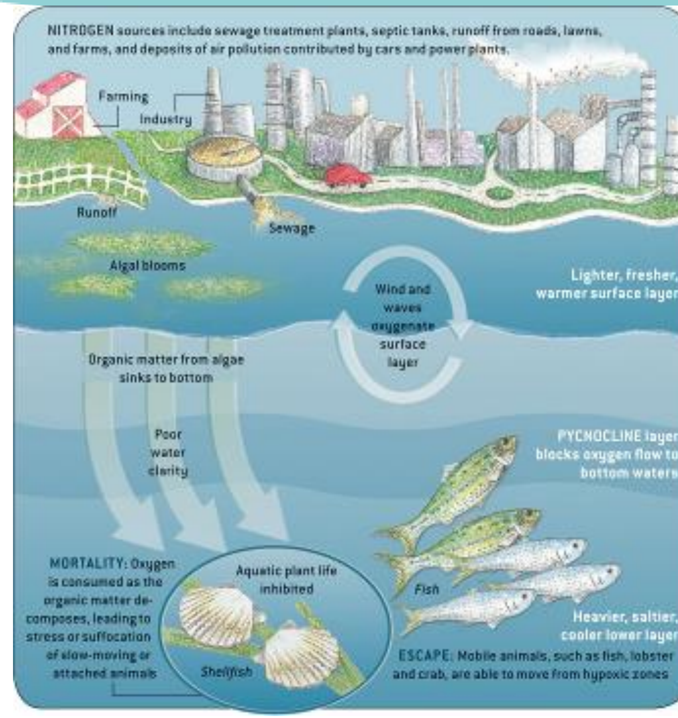
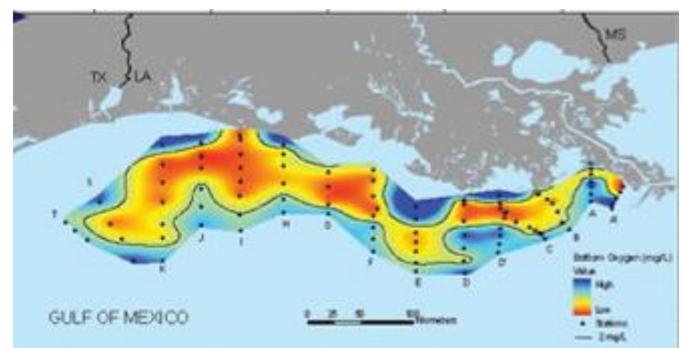


1. Introduction

Wastewater—what is the concern?

- Nutrients
  - » Nitrogen
  - » Phosphorus
  - » Promote aquatic plant growth
- Hypoxia
  - » Low dissolved oxygen caused by decaying aquatic plant life
- Point and non-point sources
  - » Point (WWTP)
  - » Non-point (run-off)





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2. Activated Sludge 101

Flow Characterization

Flow Variations characterized by:

- Size and type of community
- Water saving appliances
- Type of sewerage system (combined, age)
- Industrial contribution and type
- Geographical, socioeconomic

Size of catchments - Population equivalents

Definition of flows – Average and maximum flows

Sewer types - combined & separate

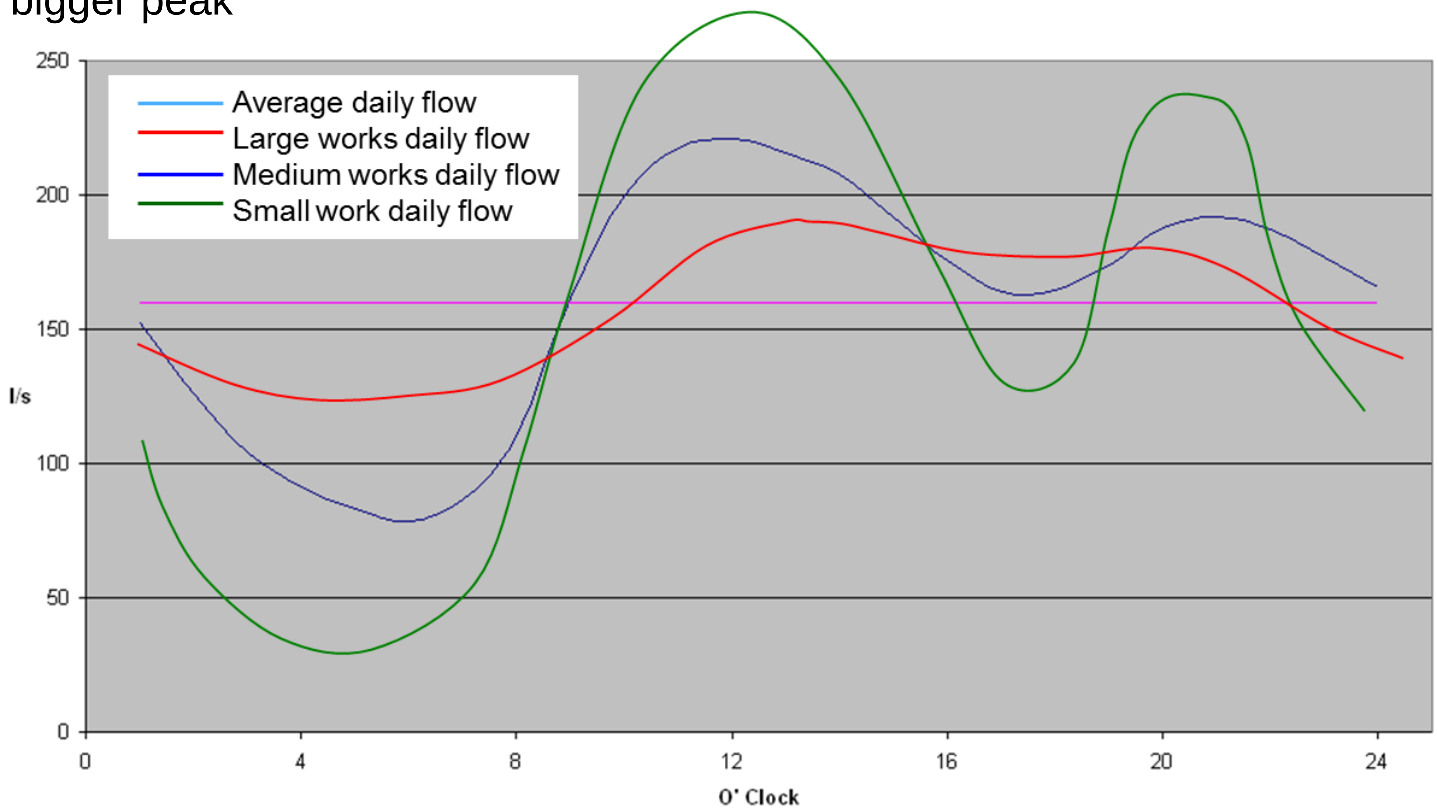
Water usage – highly dependent upon region

Determined by consultant in tender specification

Variation in daily flows

Flows vary through the day with peaks in the morning and evening

- In a large network, it takes time for flow to go through the sewers, so peak flows are attenuated.
- In small networks, the sewers are short, so peak flows arrive at the same time giving a bigger peak



Operational Parameters
Biological Oxygen Demand (BOD)

The amount of oxygen needed to “clean” wastewater biologically

Five day bioassay test; primary measure of oxygen demand in wastewater by organic matter present

Organic matter commonly measured as:

- BOD_5: 5-Day Bio-chemical Oxygen Demand (No nitrification)
- BOD_U: Ultimate Bio-chemical Oxygen Demand (No nitrification)
- BOD_7: Easier test, start on Monday Finish Monday

BOD 50 -70 g/p.d usually 60 g/p.d

Operational Parameters
Solids

Total Suspended Solids (TSS)

- Volatile suspended solids (VSS)
- Non-volatile suspended solids (NVSS)

Total Solids (TS) represents all materials remaining after heating at 103^{0}C. TS includes:

- Suspended solids
- Dissolved solids

Typically incoming solids 75-80% volatile

Solids load 60-80 g/p.d but is highly variable

Operational Parameters

Nitrogen

Macronutrient for biomass (100C:10N)

Domestic sewage TKN

- 40 - 60 mg/L

Ammonia nitrogen (NH_3-N)

- 60% TKN
- 25 - 40 mg/L

Organic nitrogen (Org-N)

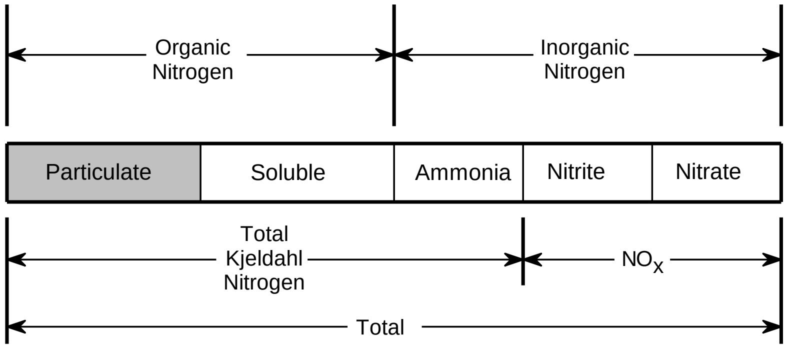
- 40% TKN

Biological removal process

Operational Parameters

Nitrogen

- Exists in following forms in Wastewater:
  - Ammonium Ion NH_4^+-N pH 4.3 - 9.3
  - Nitrate Ion NO_3-N
  - Nitrite Ion NO_2-N
  - Organic-N Proteins (Amino Acids)
- Total Nitrogen
  - Ammonium-N + Org-N + Nitrate-N + Nitrite-N
- Total Kjeldahl Nitrogen (TKN)
  - Ammonium-N + Org-N
  - For crude sewage = Total nitrogen



Operational Parameters

Phosphorus

Macronutrient for biomass (100C:2P)

Domestic sewage total-P

- 6 - 10 mg/L
- Typical municipal = 8 mg/L

Organic-P (organically bound-tissue)	2 - 5 mg/L
Inorganic-P (ortho- and poly-P)	4 - 8 mg/L
P content in sludge	2% - 7%

Biological, chemical, and physical removal processes

Operational Parameters

Alkalinity and pH

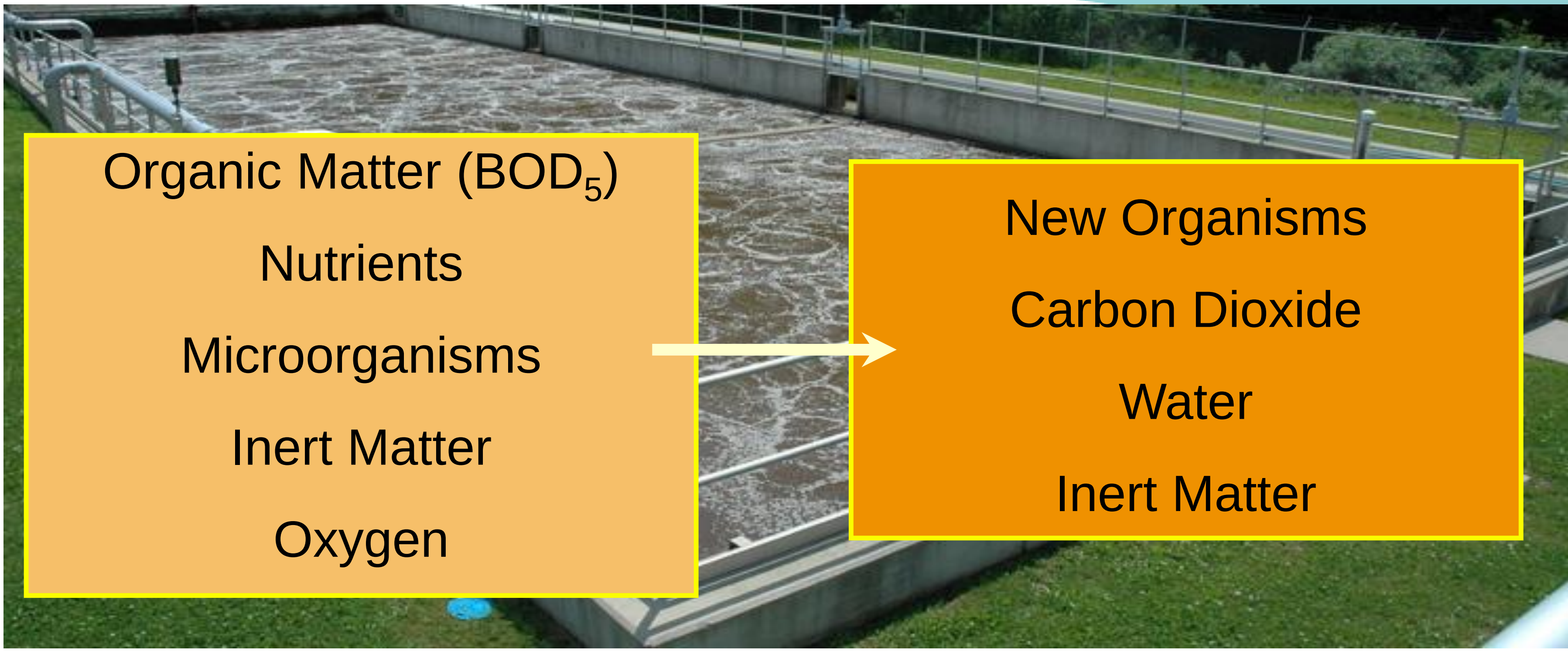
- pH range for optimal biological treatment = 6.8 – 7.5 s.u.
- Alkalinity is the buffering capacity; resistant to pH changes
- Alkalinity is very important in balancing acid generated by nitrification
- Alkalinity varies based upon raw water source and geographical area

Operational Parameters

Temperature

- Temperature affects chemical and biological reaction rates and may prevent some from occurring altogether
  - Optimal temp for biological treatment = 25-32^{o} C
  - Minimum for BOD removal = 2^{o} C
  - Maximum for biological activity = ~40^{o} C
  - Minimum for nitrification process = 5-8^{o} C

Principles of Biological Treatment



Heterotrophic microorganisms predominate, and use organic matter as food for energy and cell synthesis.

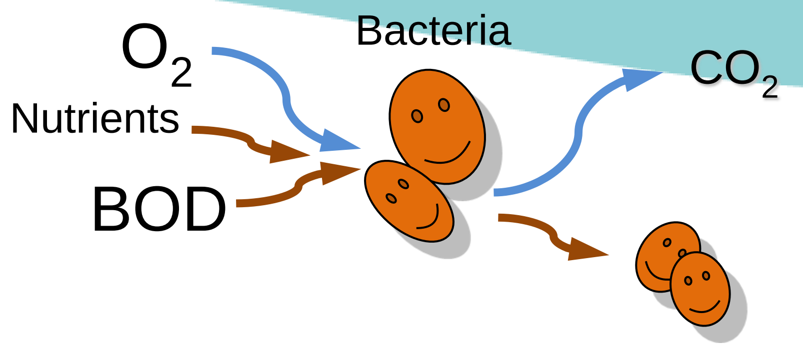
Dissolved oxygen > 0.5 mg/L

Principles of Biological Treatment

Carbon (BOD) removal

Removes the majority of pollutant load

Fast growing bacteria

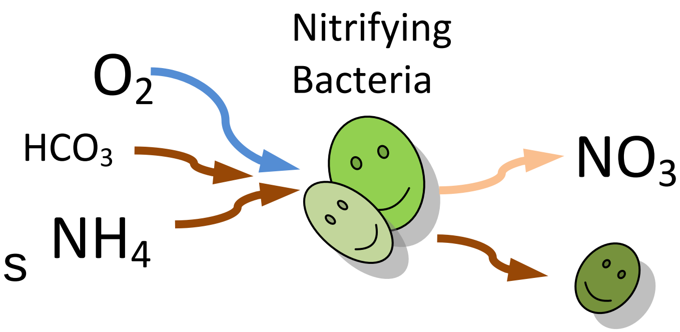


Nitrification

Converts ammonia (NH4) to nitrate (NO3)

Slow growing bacteria - 2 types

Can be flushed out of conventional systems

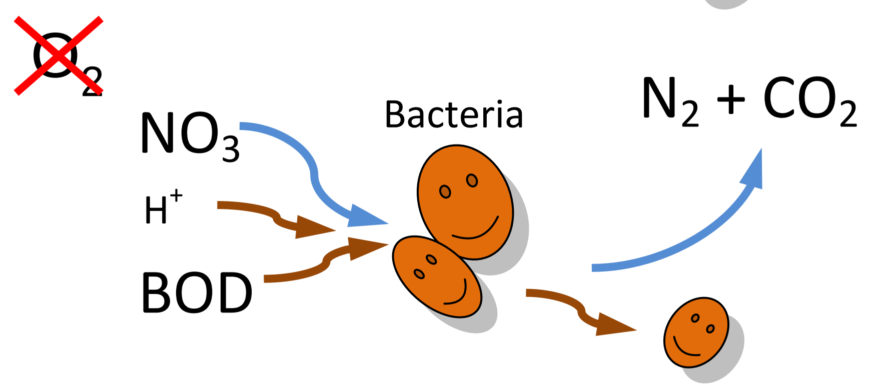


Denitrification

No Oxygen present

Bacteria use oxygen in Nitrate NO3

Nitrogen released as gas



Basic Terminology

MLSS: Mixed Liquor Suspended Solids, biomass or microorganism mass including other particulates.

F/M Ratio: "F" is the food or biodegradable organic matter (BOD_5). "M" are the microorganisms or MLSS.

SRT (or MCRT): solids retention time or mean cell residence time is the average duration of time an organism spends in the system. Often the first step in plant design, dictated by need to nitrify and wastewater temperature.

Need to have basic understanding of the determinants and process understanding to be able to talk about biological systems.

Nitrification

Temperature   4 - 45° C

- For every 10°C drop, nitrifier growth rate will drop by ≈ 50%

Alkalinity   50 mg/L as $CaCO_3$ min effluent

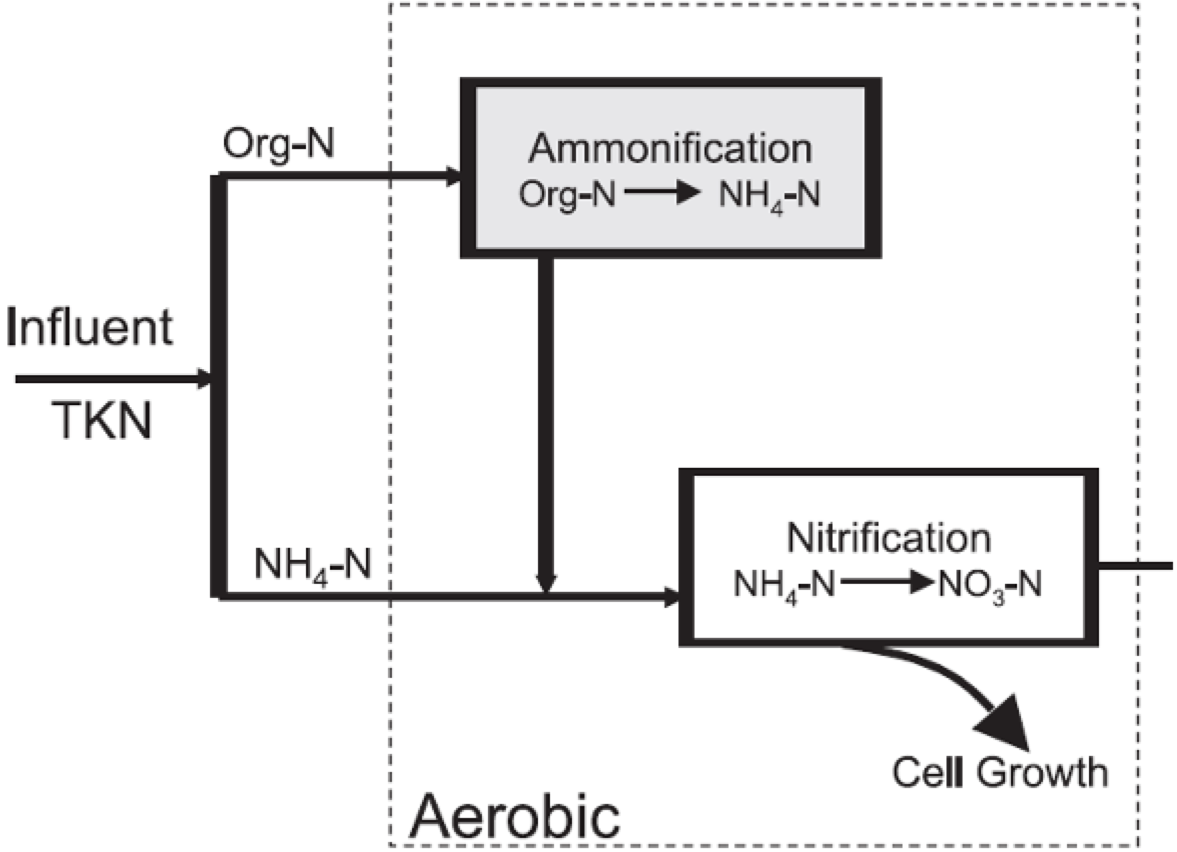
D.O.   0.5 - 2.5 mg/L (>2.0)

pH 6.5 - 8.8

SRT   10 - 25 days (temp dependent)

Nitrifiers (autotrophic) are more susceptible to toxicity than BOD removers (heterotrophic) and slowest growing.

Nitrification



Denitrification

Nitrate and organic carbon in presence of denitrifiers + anoxic conditions results in $O_2 \Uparrow + N_2 \Uparrow$

- 2.86 g O_2 recovered / g NO_3-N denitrified

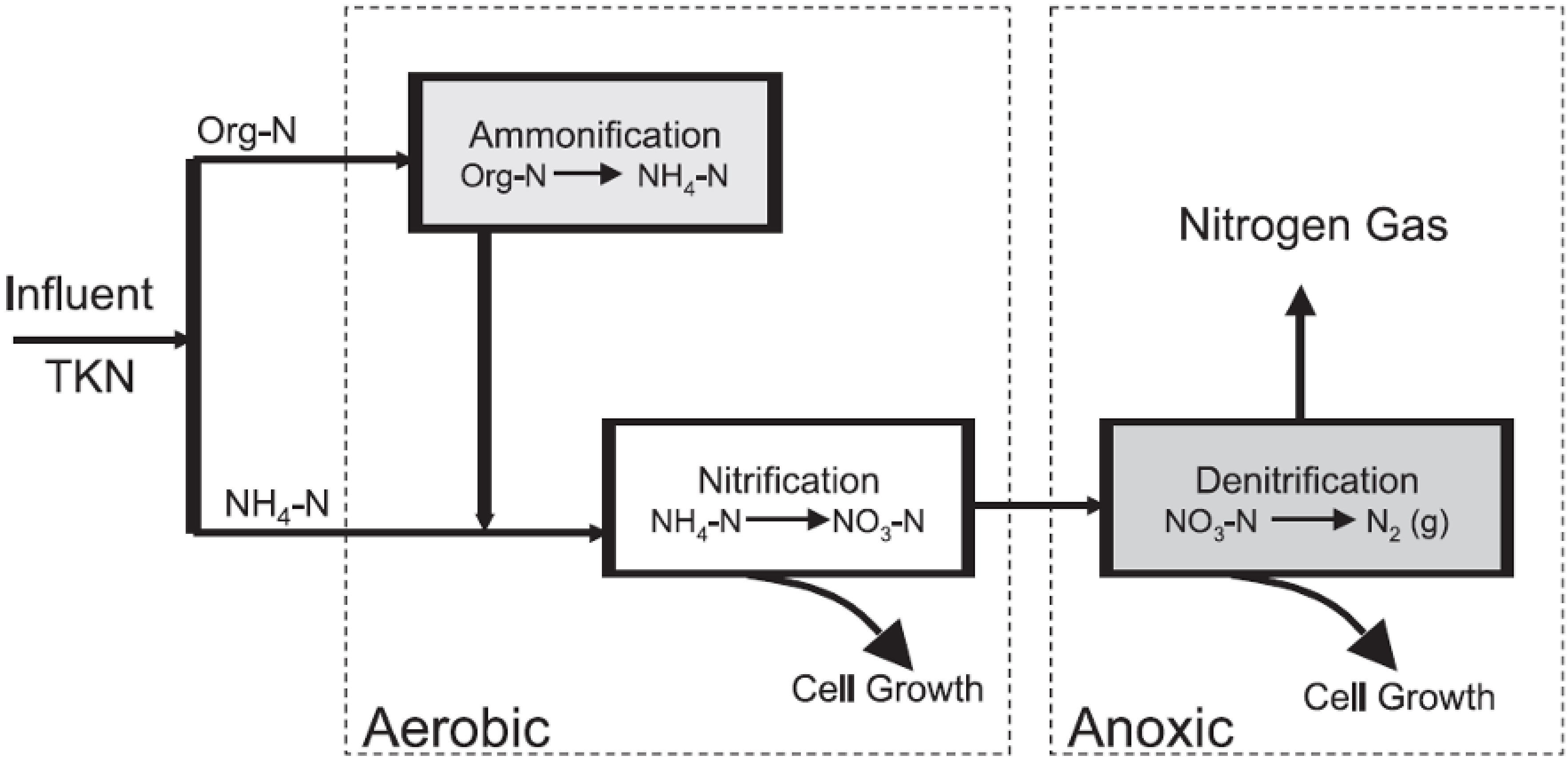
External carbon source (requirements based on influent)

Alkalinity recovered

- 3.54 g as $CaCO_3$ / g of NO_3-N denitrified

Oxidation reduction potential (ORP) -50 to +50 mV

Denitrification



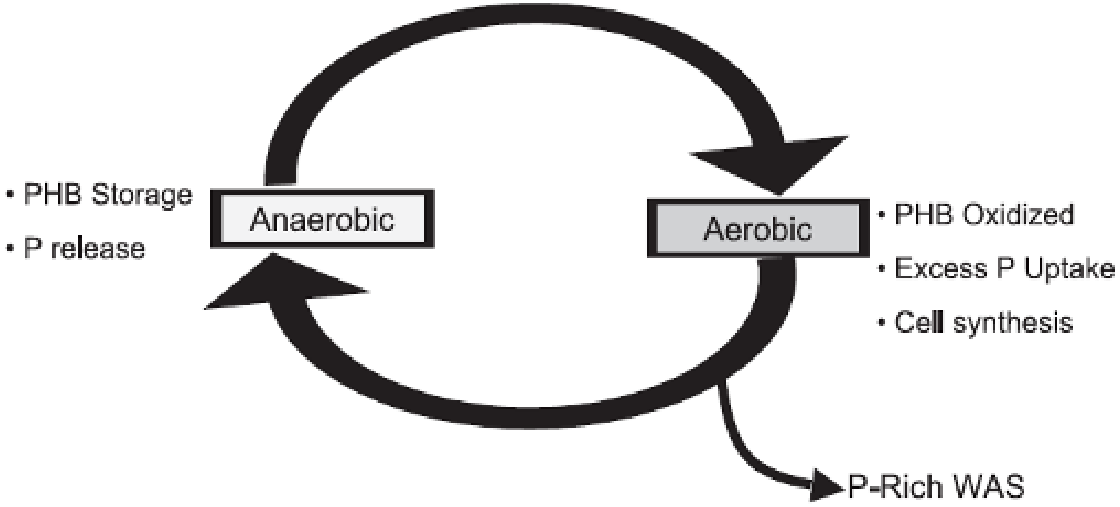
Biological Phosphorus Removal

Step 1: Anaerobic Phase

- Phosphorus release

Step 2: Aerobic Phase

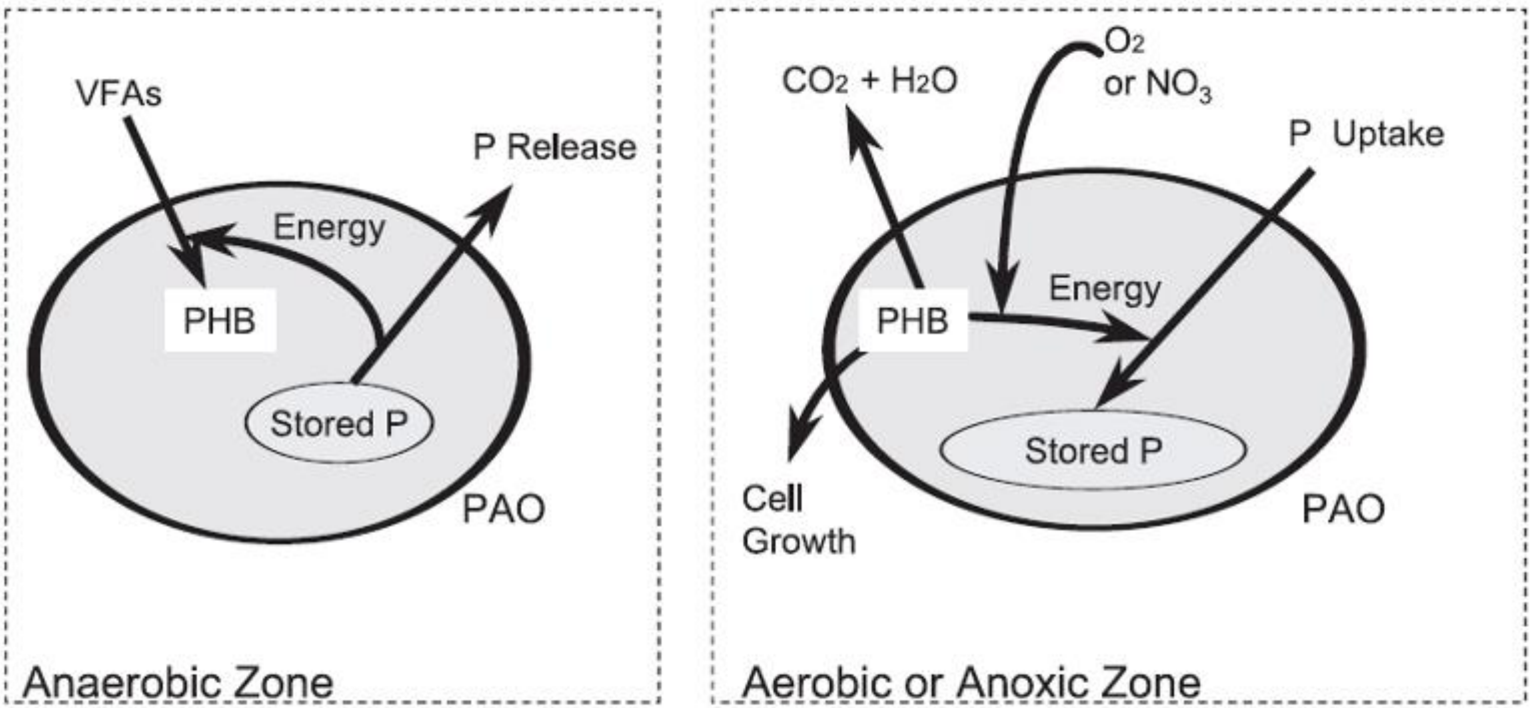
- Phosphorus uptake and creation of new PAOs
- Phosphorus removal by sludge wasting



Biological Phosphorus Removal

Successful bio-P removal depends on:

- Anaerobic conditions (zero dissolved oxygen and zero nitrate)
- Volatile fatty acids (VFA, rbCOD)
- Solids management (SRT, WAS, and side streams)



Chemical Phosphorus Removal

Precipitation or adsorption with chemical addition

- Ferric chloride (ferric)
- Aluminum sulfate (alum)
- Poly aluminum chlorides (PAC)

Chemical dosing

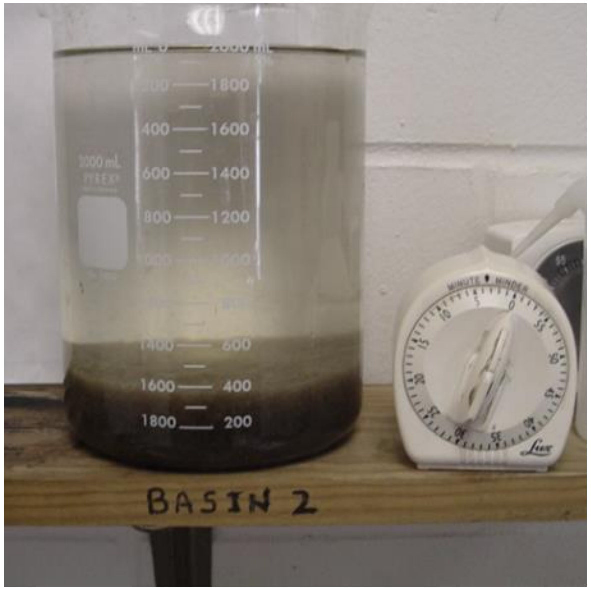
- Depends on chemical
- % phosphorus removal

Removal mechanism

- Gravity separation (0.8 mg/L to 1.0 mg/L)
- Physical removal—filter or membrane (0.05 mg/L to 0.5 mg/L)

Activated Sludge – Summary

- Dissolved Oxygen is needed by biology to remove COD, BOD and ammonia
- Nutrients needed for cell growth
- Temperature affects reaction speed
- Selecting Floc forming bacteria
- Settling has to be good
- pH & Alkalinity may affect performance



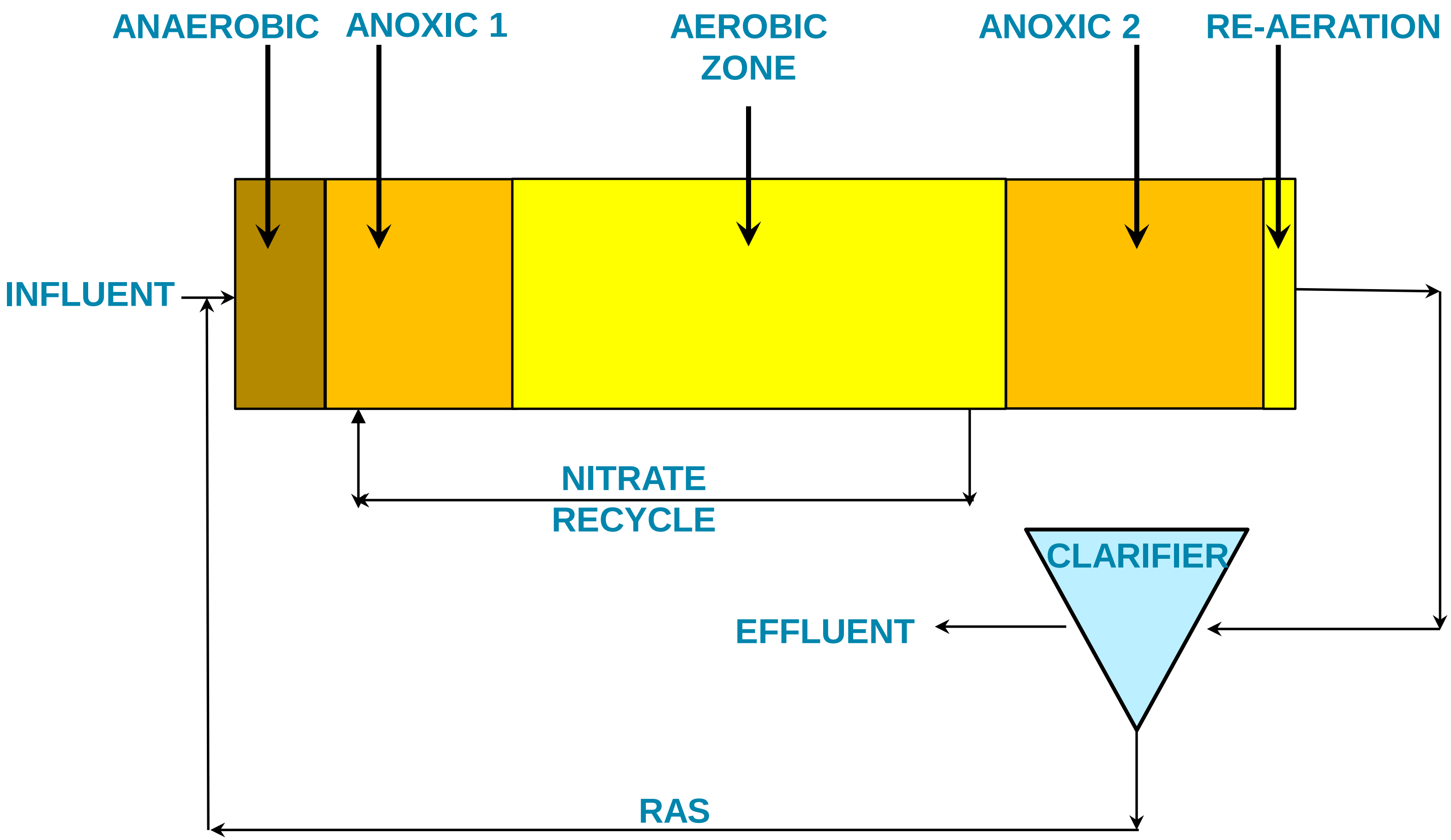
3. Process Design

CASPERON Process Tailored Process Design

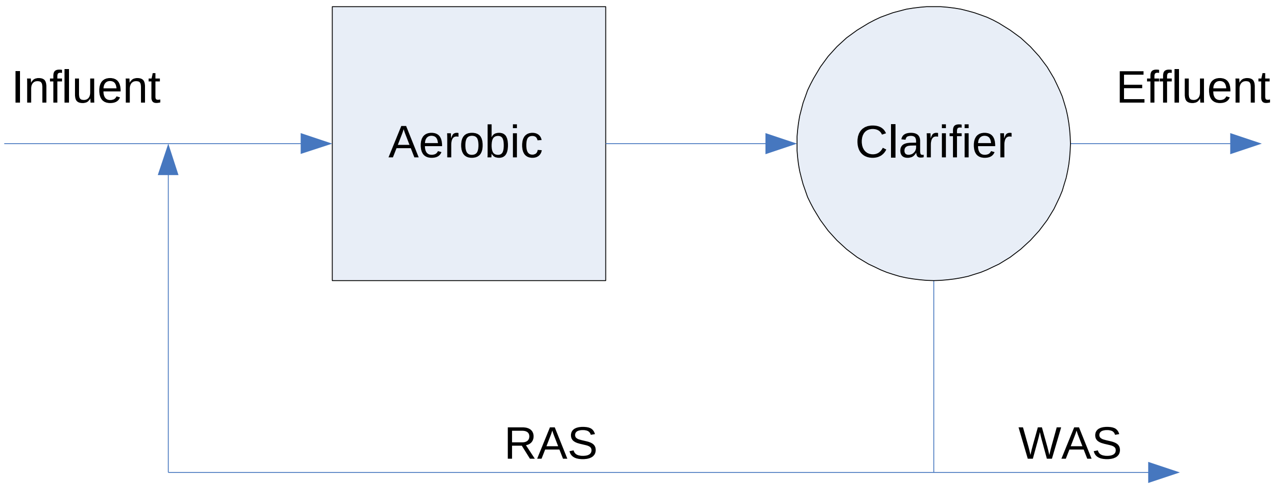
Sanitaire offers multiple process configurations:

- NIT: aerobic only
- MLE (Modified Ludzack-Ettinger): anoxic + aerobic
- A^2O: anaerobic + anoxic + aerobic
- Bardenpho 4-stage (MLE with post-anoxic)
- Bardenpho 5-stage (A^2O with post-anoxic)
- Simultaneous Nitrification and Denitrification (SNDN) (aerated reactors in series)

Process Configurations



Single Stage: Aerobic

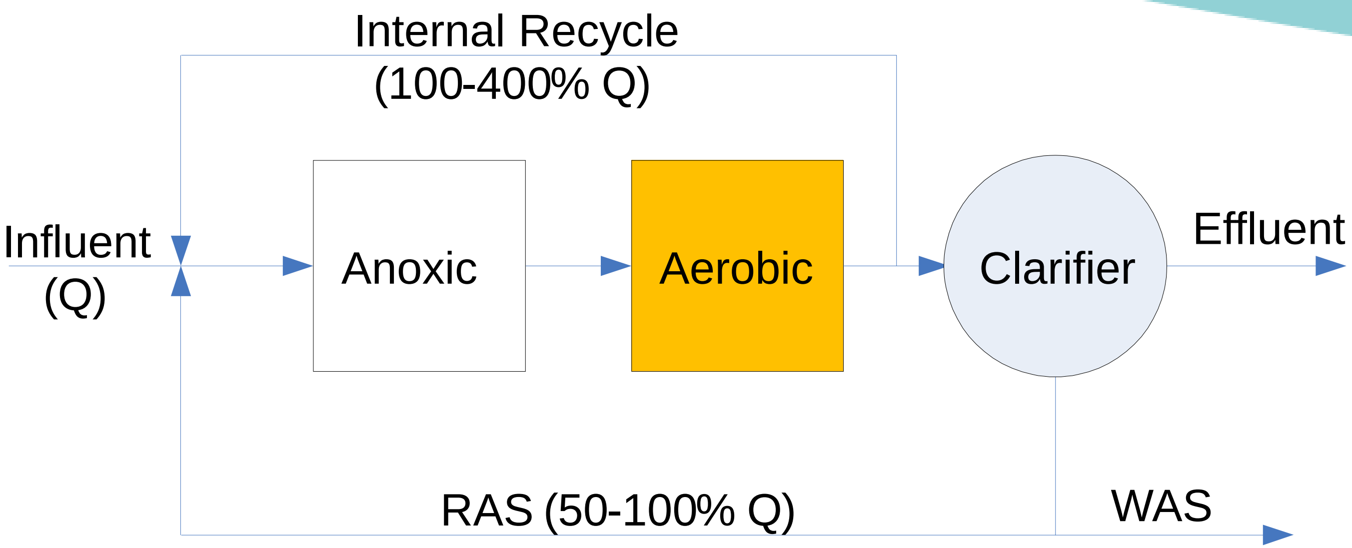


<u>Application</u>
Removal of BOD, TSS, and Ammonia only (no nitrate limit)

<u>Pros</u>
Low Capital Cost

<u>Cons</u>
Higher Energy Cost
Potential for Poor Settling
Supplemental Alkalinity may be needed

MLE Process



Application

Removal of BOD, TSS, and TN < 8 mg/l

Pros

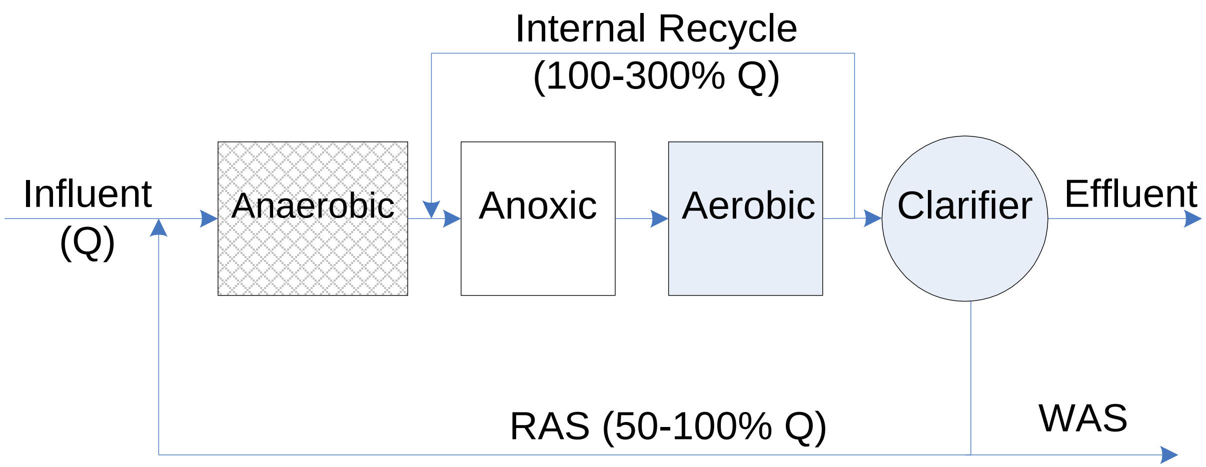
High F:M in Anoxic Zone selects out filamentous bacteria

Denitrification recovers alkalinity

Cons

Increased capital cost to add anoxic zone and mixers

A^2O: Anaerobic – Anoxic – Aerobic

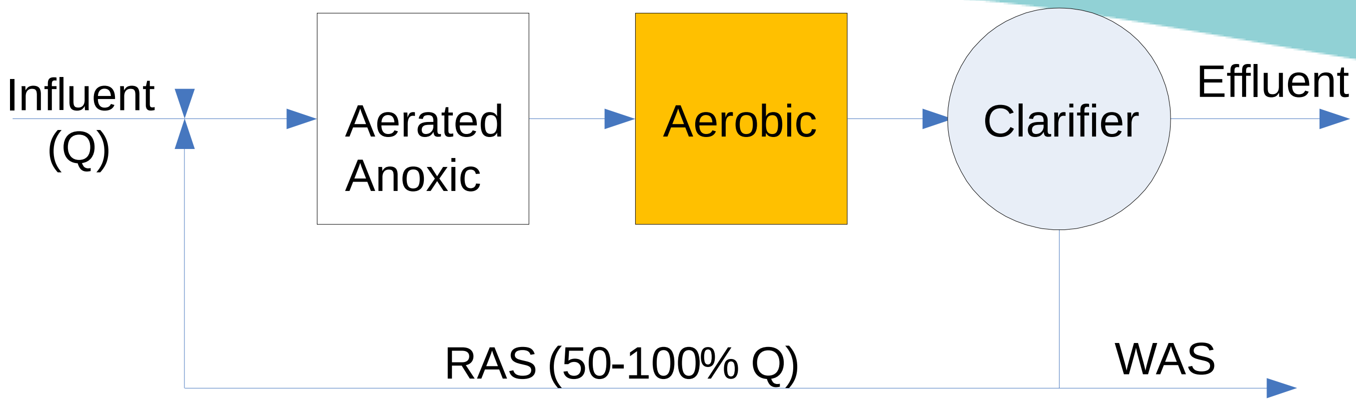


Application

Removal of BOD, TSS, TN < 8 mg/l, and enhanced biological phosphorus removal

Pros and Cons same as MLE, except added benefit of reduced chemical costs to meet P-removal requirements

SNDN



Application

Removal of BOD, TSS, TN < 5 mg/l (also can be designed for bio-P)

Pros

High F:M in Aerated Anoxic Zone selects out filamentous bacteria

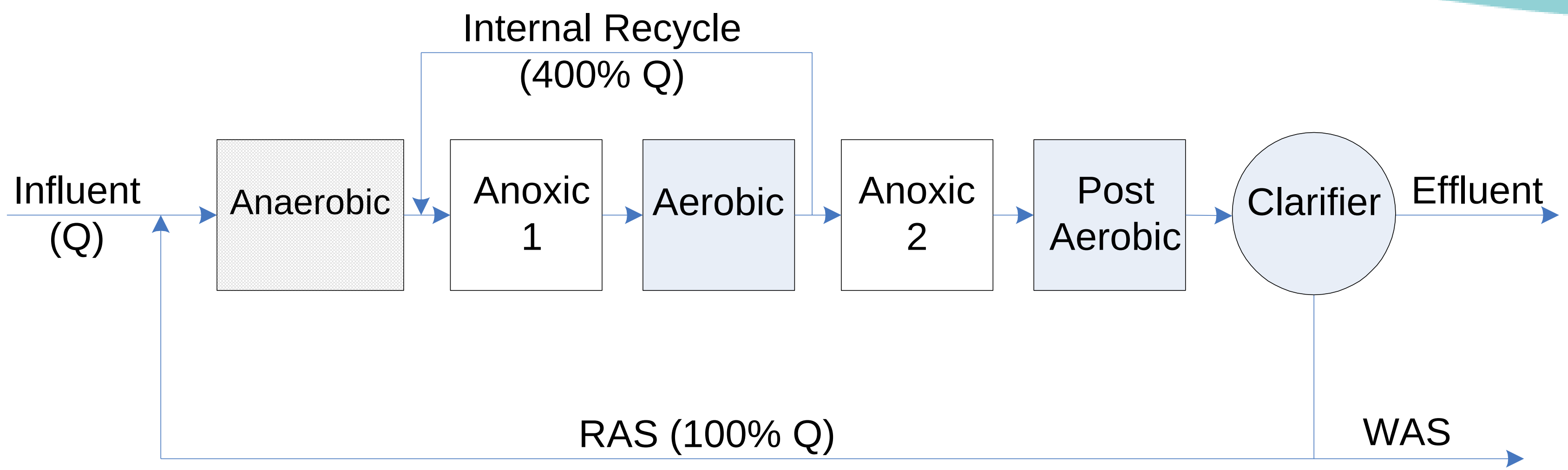
Lower construction cost without Anoxic reactor or nitrate recycle

Lower power consumption, with significant oxygen transfer in low DO zone

Cons

Requires two or more aerated reactors in series

Optional Post Anoxic and Post Aerobic Zones



<u>Application</u>

Add to back end of MLE, A^2O, or SNDN process to reduce TN < 3 mg/l

Process Comparison

	BOD & TSS	NH_3	TN	Bio-P	Pros	Cons
NIT	X	X			• Low Capital Cost	• Higher Energy Cost • Potential for Poor Settling • Supplemental Alkalinity may be needed
MLE	X	X	< 8 mg/L		• High F:M in Anoxic Zone selects out filamentous bacteria • Denitrification recovers alkalinity	• Increased capital cost to add anoxic zone and mixers
A_2O	X	X	< 8 mg/L	X	• Same as MLE • Reduced chemical costs to meet P-removal requirements	• Same as MLE, with extra capital cost of anaerobic zone
Bardenpho 4-stage	X	X	< 3 mg/l		• Same as MLE, except lower effluent TN is possible	• Same as MLE, with extra capital cost of post-anoxic & re-aeration zones
Bardenpho 5-stage	X	X	< 3 mg/l	X	• Same as A_2O, except lower effluent TN and TP is possible	• Same as A2O, with extra capital cost of post-anoxic & re-aeration zones
SNDN	X	X	< 5 mg/L	Bio-P if anaerobic zone included	• High F:M in Aerated Anoxic Zone selects out filamentous bacteria • Lower construction cost without anoxic reactor or nitrate recycle • Lower power consumption, with significant oxygen transfer in low DO zone	Requires two or more ditches in series

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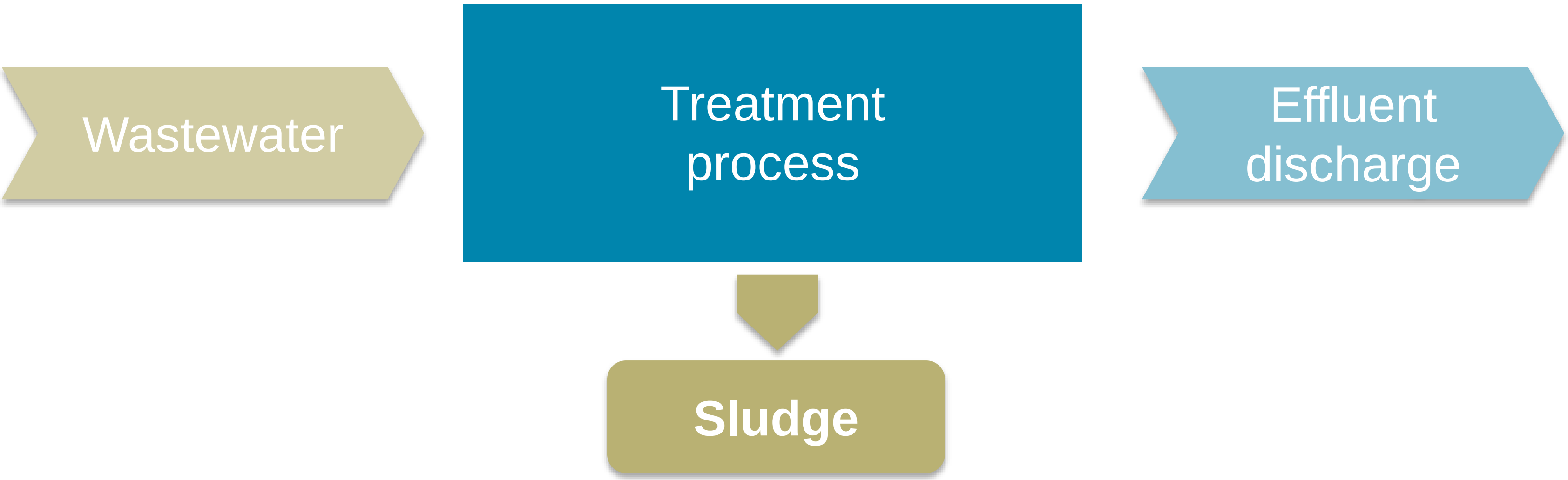
4. Aerobic Digestion

Aerobic digestion impact

Why care about Aerobic Digestion:

- 2nd largest consumer of energy at a plant
- Up to 50% of influent nutrient load generated by digestion recycles
- Poor digestion can lead to treatment instability and high chemical consumption

What is Sludge?



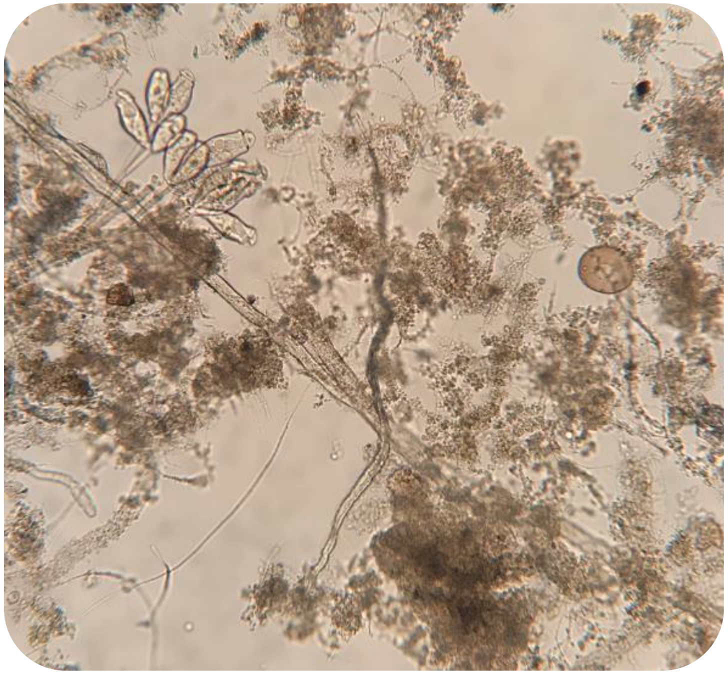
- Primary Sludge: Grit, food waste, human waste
- Waste Activated Sludge: Biomass from wastewater process

Aerobic Digestion

Stabilization makes biological activity in the sludge difficult by the reduction of the organic content

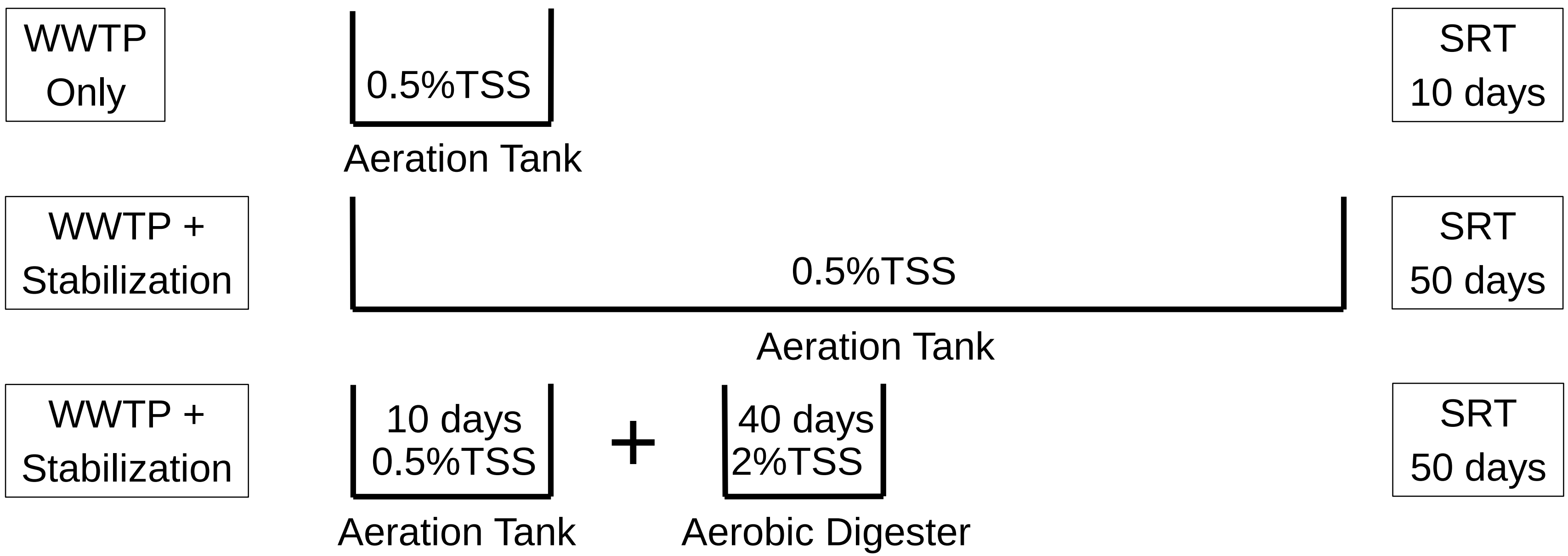
This has the effect of:

- Reducing pathogens
- Reducing odor
- Reducing mass of solids to be
- disposed



Aerobic Digestion

- Some stabilization occurs in main WWTP
- Aerobic digestion continues this process
- High degree of stabilization requires long sludge age and large tanks
- High sludge concentration reduces tank size



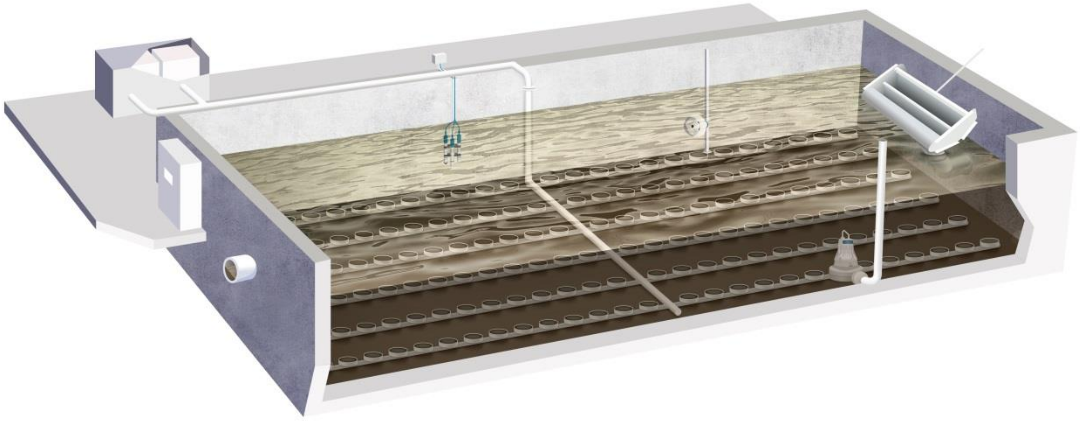
Biosolids Quality Gradation

- **Class A – Can be given or sold to public**
  - Not common; generally only large facilities > 5 MGD
- **Class B – Can be land applied under specific rules**
  - Most common, land application is frequently the lowest cost disposal option
- **Less than Class B – Usually landfilled**
  - Landfilling is also common but usually more expensive than land application

Digester Design Options:

- Provide **stable aerobic digestion** up to 2% TS
- **Decrease energy consumption** up to 90%
- **Reduce N and P return** up to 90%
- **Automatically adapt** to dynamic conditions using Xylem's proprietary control algorithms
- Provide **user-friendly human-machine interface** with intuitive graphics and remote accessibility
- Produce beneficial **reuse of biosolids** for agricultural purposes

Two process design options



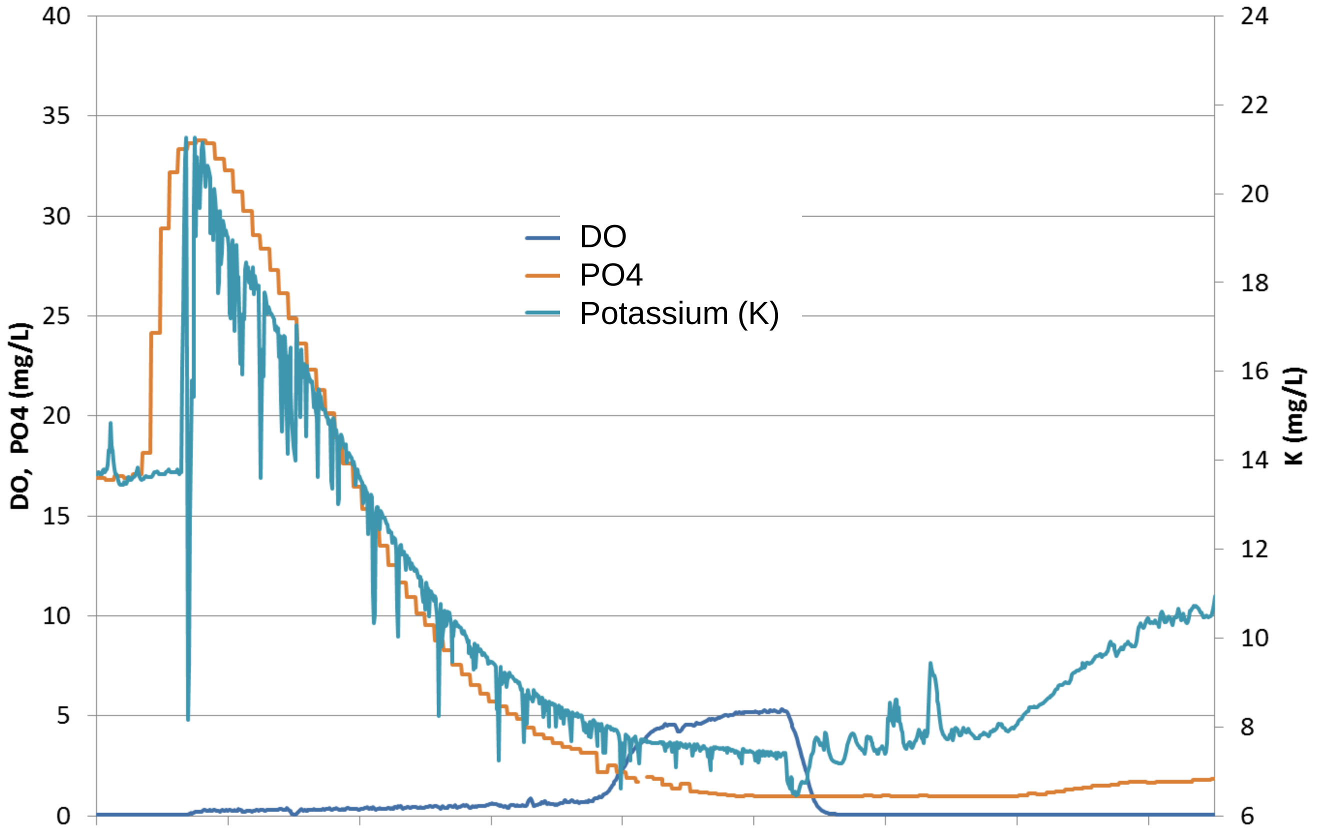
Design option: Vorelodos with DINO

- Blower and aeration designed for 30 scfm/kcf or process needs
- Possible to include DINO Digester Nutrient Optimizer control for improved nutrient reduction

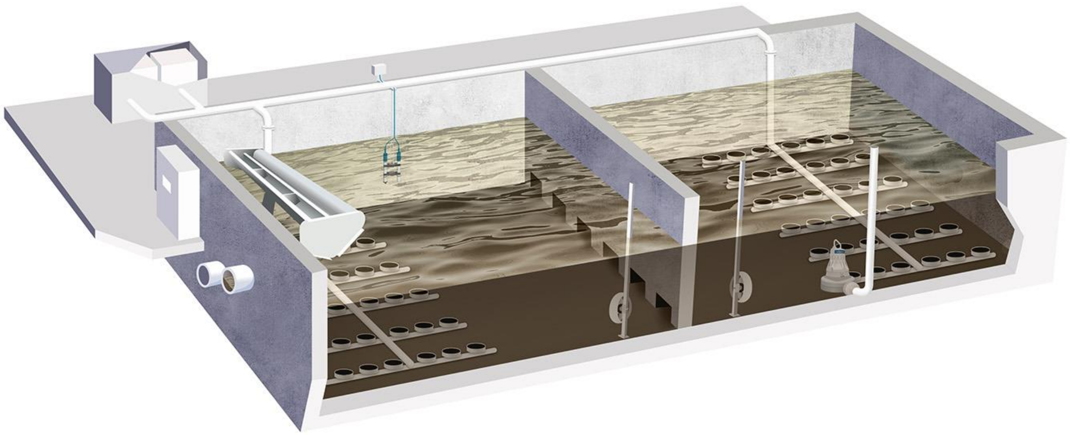
→ Up to 90% reduction in energy and soluble PO4, NH4 and TN in decant and dewatering return compared to conventional 30 scfm/kcf design

DINO Control

Based on strong correlation between potassium (K) and PO4



Two process design options



Design option: Vorelodos for energy savings only

- Flygt mixer included; physically offset from aeration
- Mixer operates continuously except during settle/decant
- Blower and aeration designed based on treatment need

→ Up to 90% reduction in energy compared to conventional 30 scfm/kcf design

5. Examples

Fond Du Lac, WI

Fond Du Lac, WI – CASPERON with VEMA Controller

SNDN Process

Project Overview

15 MGD Conventional Activated Sludge Plant

3 parallel trains, each with anaerobic zone and 3 aeration passes in series;
Up to 3 of 9 aeration grids will pulse at the any time

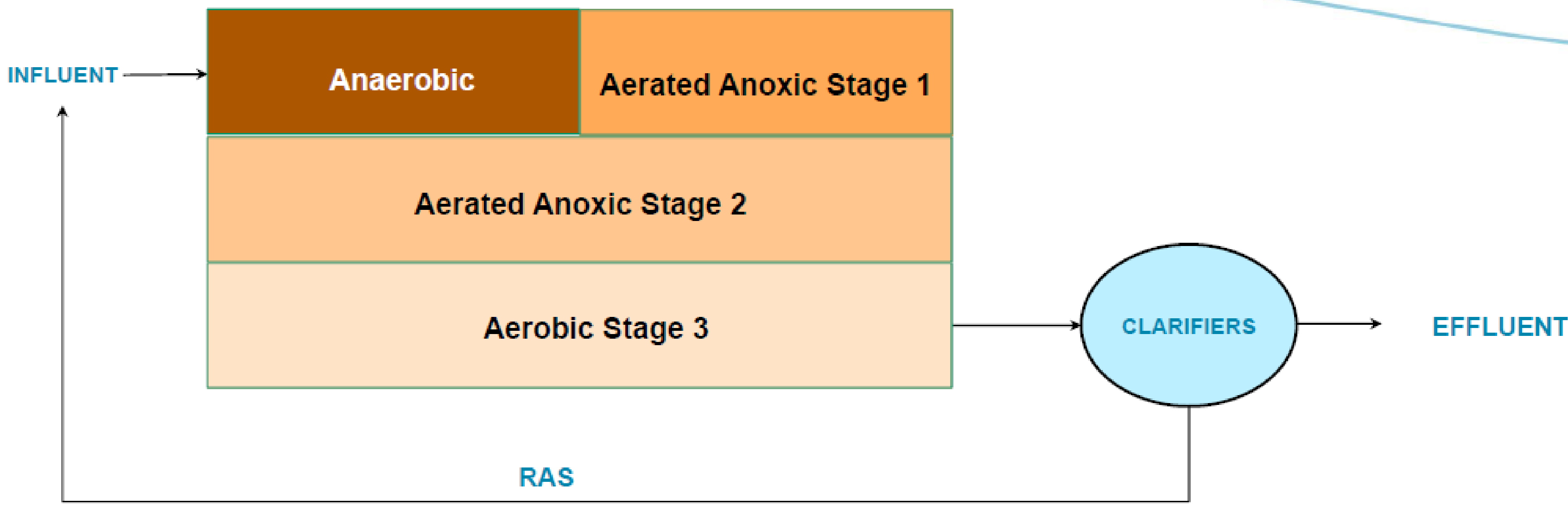
Goals

- Utilize Simultaneous Nitrification and Denitrification (SNDN) with VEMA Controller to reduce nitrate concentrations, allowing better enhanced biological Phosphorus removal

Timeline

- Startup in 2018

Fond Du Lac CASPERON SNDN Upgrade



Benefits

• Aerated Anoxic Stages designed for SNDN to reduce nitrate levels in RAS
• First reactor converted from Anoxic to Anaerobic by eliminating nitrate recirculation and reducing nitrates in RAS
• Last stage maintained in aerobic state; Ammonium probes provided to dynamically adjust DO
setpoints to save energy while maintaining compliance with effluent ammonia permit
• Energy consumption reduced with Most Open Valve (MOV) operation and VEMA controller

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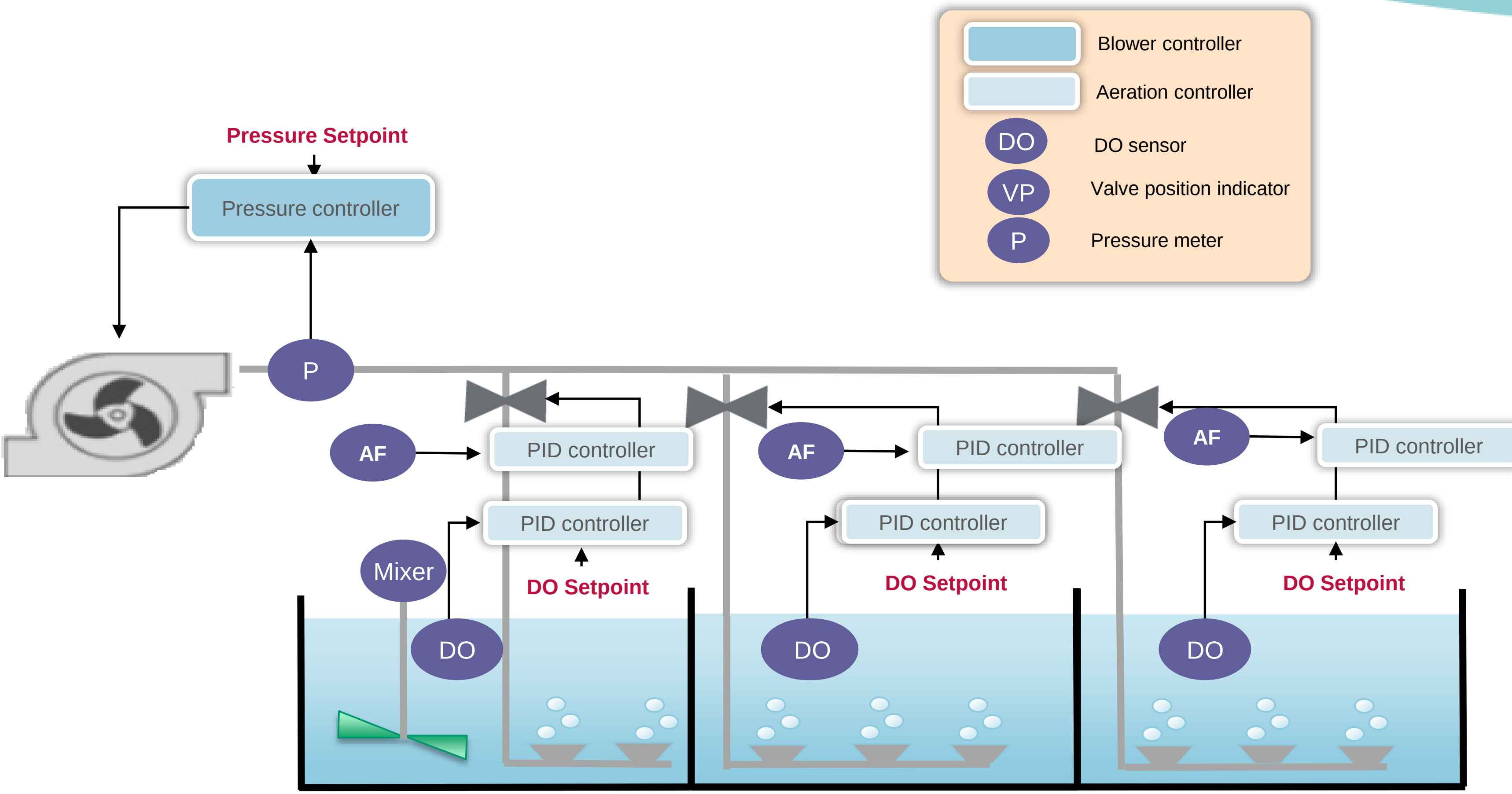
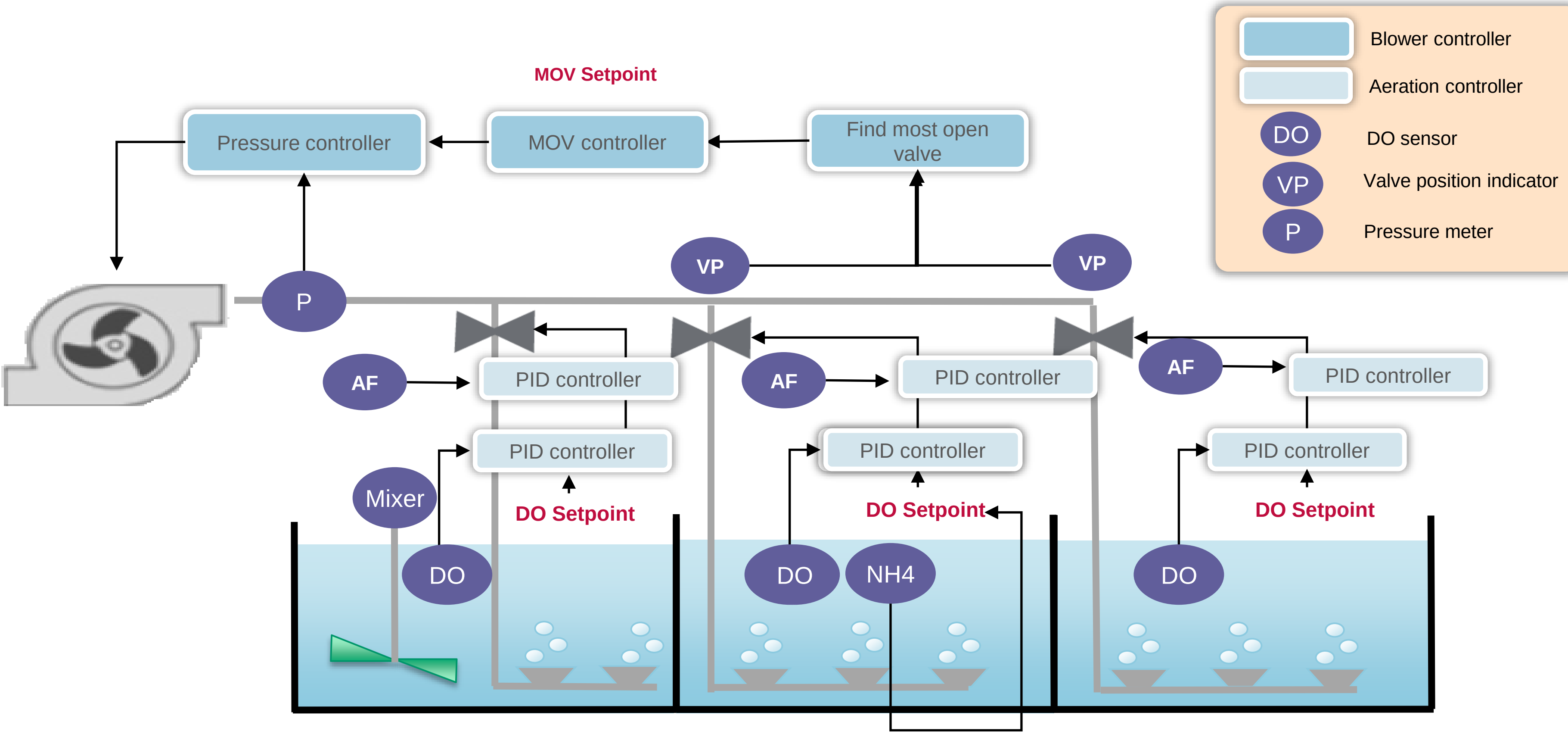
Original Aeration control - header pressure control



Problem

- System had to always operate at high pressure to treat peak industrial load

Upgrade Aeration control – MOV with Ammonia Control



Benefits

- Pressure matched to load with Stage 2 as Swing Zone with DO variable based on NH4 load

FDL Effluent Quality & Chemical Use before/after Upgrade

BOD, mg/l		TSS, mg/l		TP, mg/l		NH4-N, mg/l		Ferric, gal/yr	
2018	2022	2018	2022	2018	2022	2018	2022	2018	2022
8.8	9.3	6.3	6.1	0.39	0.25	1.28	0.76	55,522	31,975

FDL Power (June/August) – before vs after upgrade

Power, kWh		BOD, lb/d		kWh/lb BOD		
2018	2022	2018	2022	2018	2022	Drop
500,962	424,597	1,263,198	1,461,066	0.40	0.29	-26.7%

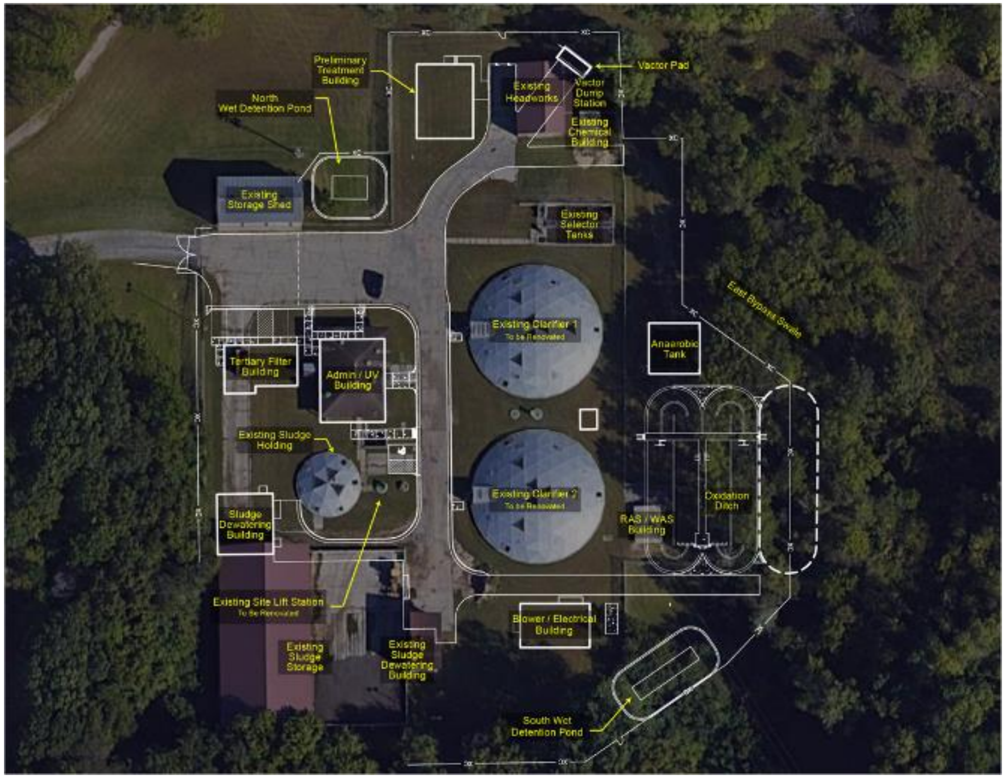
Holmen, WI

Reasons for Upgrade of Holmen WWTP

- Original Plant was Constructed in 1982, with major upgrades in 1999 and 2010
- Fine screen, 2 activated sludge package plants, aerobic digestion, sludge thickening and storage
- Upgrade needed due to :
  - Existing equipment past its useful life
  - Community rapidly expanding
  - Upcoming low phosphorus limits
    - 0.075 mg/L 6-mo ave / 0.225 mg/l mo. max
  - Regionalized WWTP w/LaCrosse too expensive

Solution – Bioloop SNDN w/Vorelodos aerobic digestion

- Ditches designed for Simultaneous Nitrification and Denitrification (SNDN) and Enhanced Biological Phosphorus Removal (EBPR)
- Tertiary Filters minimize particulate phosphorus levels
- Aerobic Digesters designed with Vorelodos cyclic Anaerobic / Aerobic sequence to retain Phosphorus in Biosolids



Effluent – before vs after upgrade

	BOD, mg/l		TSS, mg/l		TP, mg/l		NH4-N, mg/l	
Mo	2018-19	2021-22	2018-19	2021-22	2018-19	2021-22	2018-19	2021-22
Oct	3.4	0.2	2.0	1.5	0.43	0.075	1.3	0.02
Nov	5.4	0.3	3.2	1.1	0.39	0.067	1.3	0.12
Dec	10.7	1.0	3.0	1.5	0.24	0.051	4.6	0.14
Jan	10.5	3.5	3.1	3.2	0.12	0.120	3.5	0.24
Feb	8.4	3.4	2.9	3.3	0.13	0.136	1.3	0.13
Ave	7.7	1.7	2.8	2.1	0.26	0.090	2.4	0.13

Power Consumption – before vs after upgrade

	Power, kWh		BOD, lb/d		kWh/lb BOD		
Mo	2019	2022	2019	2022	2019	2022	Drop
Jan	92,033	89,557	1,422	1,706	64.7	52.5	18.9%
Feb	94,325	92,316	1,373	1,715	68.7	53.8	21.7%
Mar	96,647	98,777	1,418	1,731	68.2	57.1	16.3%
Ave	94,335	93,550	1,404	1,717	67.2	54.5	19.0%

Ferric use after upgrade (dose point upstream of filters)

Mo	Flow, MGD	BOD, lb/d	Ferric, mg/l
Oct 2021	0.61	1,706	58.5
Nov 2021	0.61	1,715	63.0
Dec 2021	0.63	1,731	51.3
Jan 2022	0.64	1,883	41.6
Feb 2022	0.64	2,109	54.1
Ave	0.62	1,829	53.7

- Vorelodos DINO process started up in November 2021 and ferric dosages declined shortly afterwards
- Longer SRT's in Jan/Feb resulted in less biological P removal, so ferric dose increased again
- Ferric dose expected to drop again in summer as wasting rates are increased

Green Lake, WI

Green Lake, WI Case Study

		US Units	Metric Units
Flow (Average)	gpd | lpd	5,380	20,360
WAS feed TSS	mg/L	8,000	8,000
Temp	F | C	41-77	5-25
Total Volume	Gals | m^3	185,000	700
SRT	days	34.4	34.4

	Fully Aerated	Using DINO controller
Blower Energy (Kwhr/wk)	3,000	160
Blower Energy (USD$/yr)	$11,800	$1,500
Blower Energy (% on peak)	36%	0%
PO4 returned to plant (lbs/wk)	7	0.5
PO4 returned to plant (% influent)	15-25%	1-2%
NO3 returned to plant (lbs/wk)	27	0
NO3 returned to plant (% influent)	15-25%	0%

Fully Aerated – Blower Runs 100% of time
DINO controller – Blower is turned on at 12 AM T, W, R and the aerated time is controlled based on online measurement of Potassium

Added DO, ORP and Varion sensors (NH4, K, NO3)

Implemented new DINO control

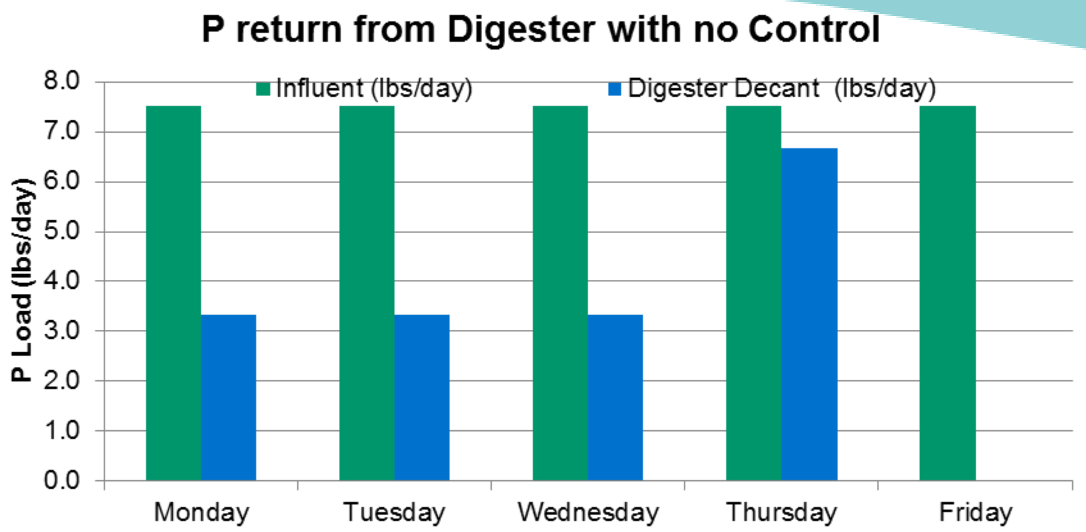
>90% Energy Savings

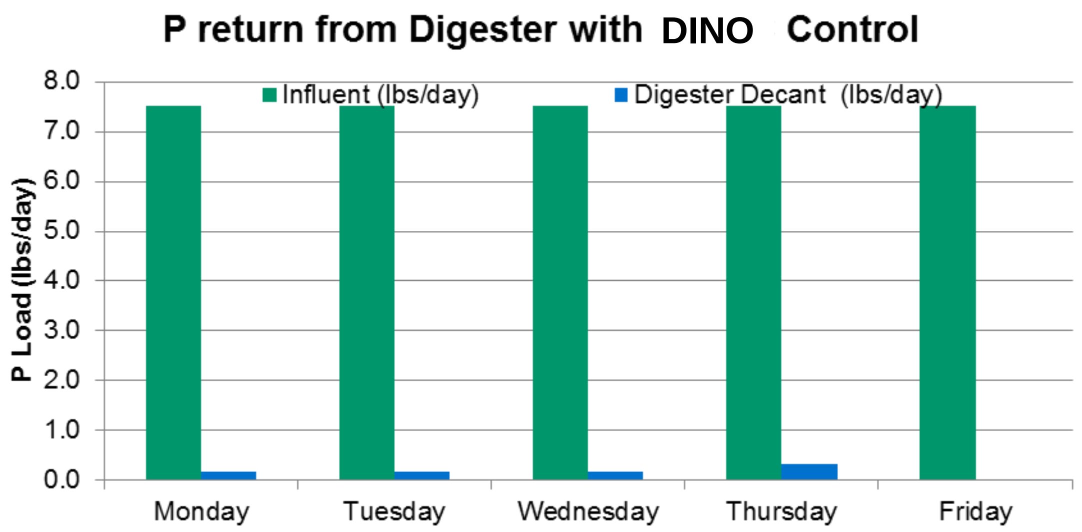
>90% reduction in phosphate returned to main plant

  >90% reduction in chemical consumption for phosphorus removal*

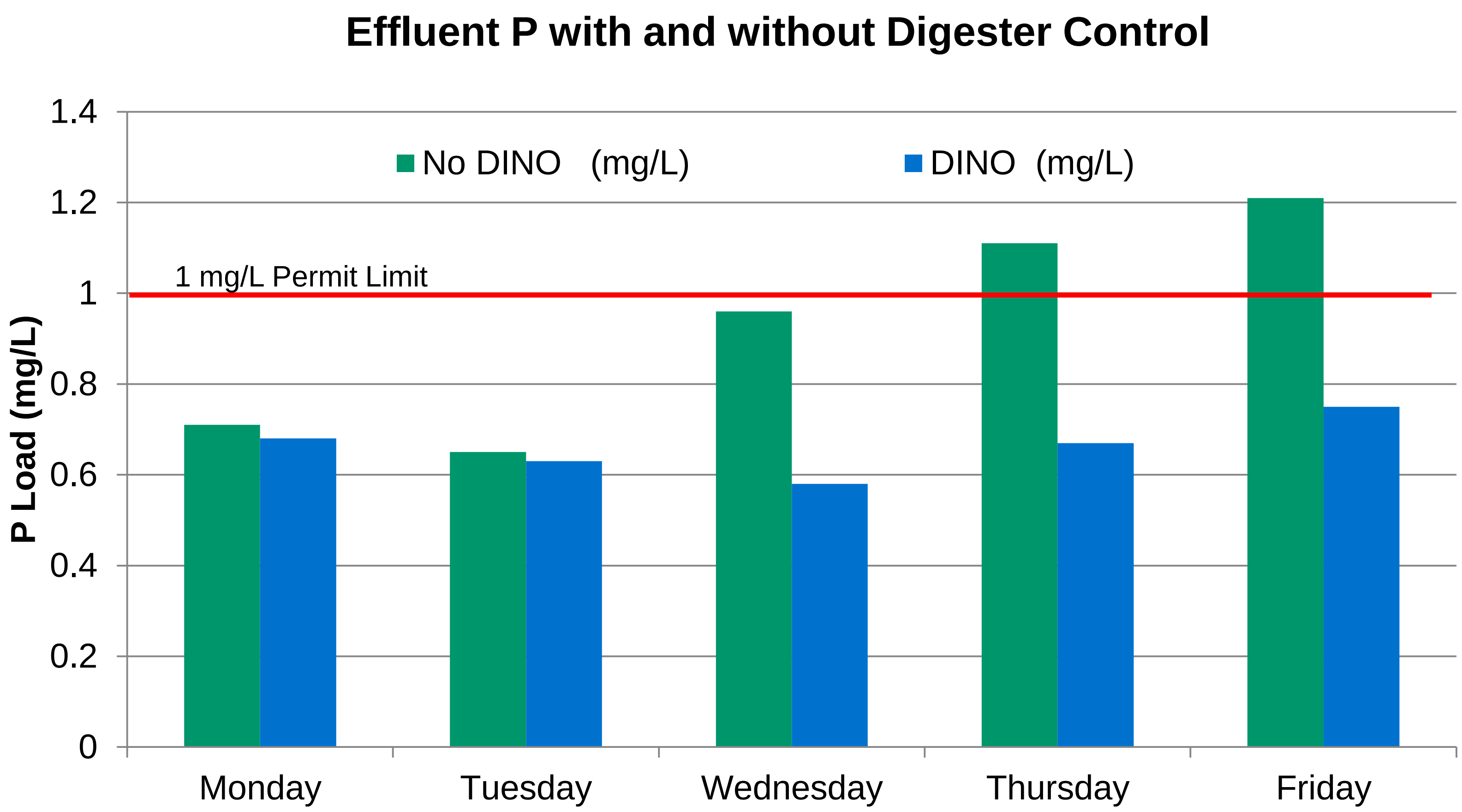
*Plant also implemented new NURO controller in mainstream ICEAS process to enhance Biological Phosphorus removal

DINO: 90% reduction in P returned to the main plant





DINO: Improved Effluent P



Muncie, IN – CASPERON with VEMA Controller

20 MGD Conventional Activated Sludge Plant

4 parallel trains, each with 3 passes in series; Up to 2 of 12 aeration grids will pulse at the any time

- After VEMA was implemented, overall energy savings average $5,000 per month less than before the upgrade (640,000 kW-hr/year)
- After 1 year of operation, a train was taken offline, and plant staff observed that there was no significant solids deposition

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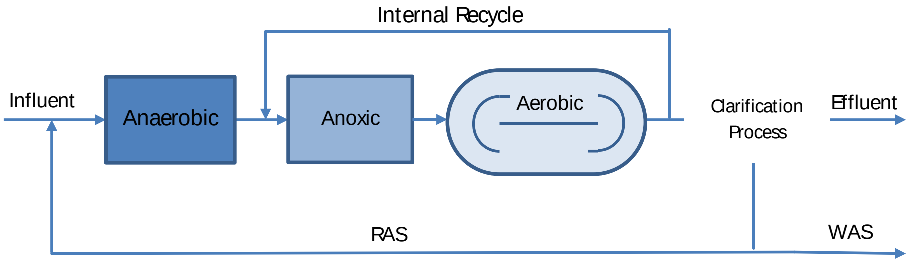
Owego, NY – CASPERON with VEMA Controller



1 MGD A2O Process

Current load is 1/3 of design load

4 parallel trains, currently 2 operating

- Before VEMA, airflow was 0.12 scfm/ft2 = 620 scfm
- With VEMA, ave. airflow = 0.5 scfm/diff = 330 scfm (47% reduction)
- Before VEMA, DO was 5 mg/l and effluent nitrates were 15 mg/l
- With VEMA, DO=2 mg/l and effluent nitrates were 2 mg/l

Zeeland, MI

CASPERON A2O Process

Project Overview

Sanitaire Designed a Complete Solution:

- Aeration (aerobic tanks and digester)
- Flygt mixers (six 4410 and two 4630)
- OSCAR™ with DO, NH4, NO3 & PO4 control
- Blowers
- Air control valves and air flow meters
- FRP Baffle walls

Goals

- Added Anaerobic and Anoxic zones, along with MOV control, for better enhanced biological Phosphorus removal

Timeline

- Operating since 2018

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Let’s solve water