Operation of Activated Sludge Denitrification and Total Nitrogen Removal Systems

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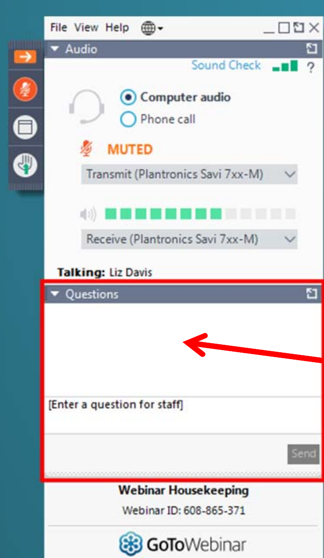
How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

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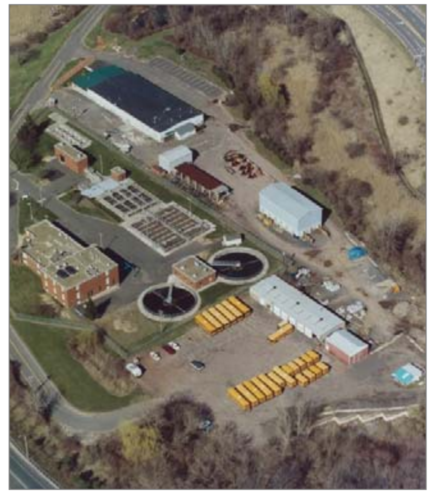
4

Webinar Agenda

- Introductions
- Activated Sludge and Nitrification Overview
- Simulator Description and Overview
- Denitrification Fundamentals
- Simulator Examples
- Hydromantis Case Study
- Questions



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Activated Sludge and Nitrification Overview

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Activated Sludge Operation

- The Activated Sludge Process is a **SYSTEM**
  - Aeration Tank
  - Secondary Clarifier
  - RAS & WAS Pumps
  - Aeration Equipment
- Secondary Treatment (BOD, TSS)
  - Aeration Tanks - Convert soluble, colloidal and remaining suspended BOD into biomass that can be removed by settling
  - Secondary Clarifiers – Flocculate, settle and compact solids to provide effluent low in TSS
  - **KEY – Create a biomass that flocculates well and settles rapidly**

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Key Activated Sludge Relationships

Mean Cell Residence Time (days)
(from WEF WW Treatment Fundamentals)

"Average time any particle remains in Biological System"

$$\textbf{MCRT} = \frac{\text{lbs MLSS in Reactor Tanks + in Sec. Clarifiers}}{\text{lbs/d WAS } (X_w) + \text{lbs/d Effluent TSS } (X_e)}$$

What parts of this can an operator control?

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Key Activated Sludge Relationships

Solids Retention Time (days)

"Average time any particle remains in Reactor Tanks"

SRT = $\frac{\text{lbs MLSS in Reactor Tanks}}{\text{lbs/d WAS } (X_w) + \text{lbs/d Effluent TSS } (X_e)}$

What parts of this can an operator control?

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Key Activated Sludge Relationships

Aerobic Solids Retention Time (days)

"Average time any particle remains in Aeration Tanks"

Aerobic SRT = $\frac{\text{lbs MLSS in Aeration Tank}}{\text{lbs/d WAS } (X_w) + \text{lbs/d Effluent TSS } (X_e)}$

What part of the SRT is excluded from the Aerobic SRT?

THE ANOXIC AND ANAEROBIC ZONE MLSS INVENTORY

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Secondary Clarifier Impacts on BNR

Two Key Concepts:

- Effluent TSS contains nutrients
- Secondary clarifiers define allowable reactor MLSS
  - High Aerobic SRT required for nitrification
  - As SRT increases for a given reactor volume, MLSS concentration must increase
  - As a result, allowable MLSS can limit SRT

HOW DOES REACTOR SRT AND MLSS CONC. IMPACT DENITE?

HIGHER SRT RESULTS IN A HIGHER RATE OF ENDOGENOUS RESPIRATION (O_2 and NO_x DEMAND)

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Nitrification Basics

NH_4^+-N + 2 O_2 → NO_3^--N + 2 H^+ + H_2O + Bacteria

Autotrophic Bacteria – Ammonia and Nitrite Oxidizing Bacteria (AOB and NOB)

- Energy from Oxidation of NH_4^+-N and NO_2-N
- Carbon from HCO_3^- (BiCarbonate)
- Aerobic Organisms – DO Sensitive (Require 4.6 lb/lb NH_4-N)
- Low Growth Rate – Temperature Sensitive
- Produces Acid – Consumes Alkalinity (7.2 lb/lb NH_4-N)
- pH Sensitive – Acclimation
- Sensitive to Toxics

NITRIFICATION DOES NOT RESULT IN A NET REMOVAL OF NITROGEN FROM WASTEWATER!

NITRIFICATION MUST PRECEDE DENITRIFICATION!

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Process Simulators

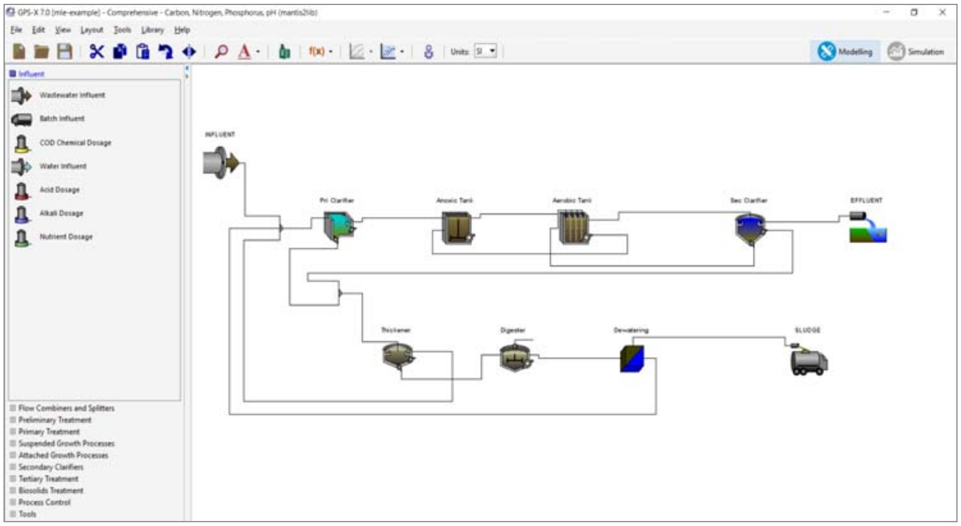
13

Simulator Overview

- Model = Series of equations that defines a process or plant
  - Model based on mass balances and biological conversions of organics (COD), nitrogen, phosphorus and solids
- Simulator = Program that uses a process model to experiment with a plant configuration
- OpTool SimuWorks Overlay = Plant-specific layout that provides graphical interface for plant operational testing and training

14

GPS-X Process Simulator



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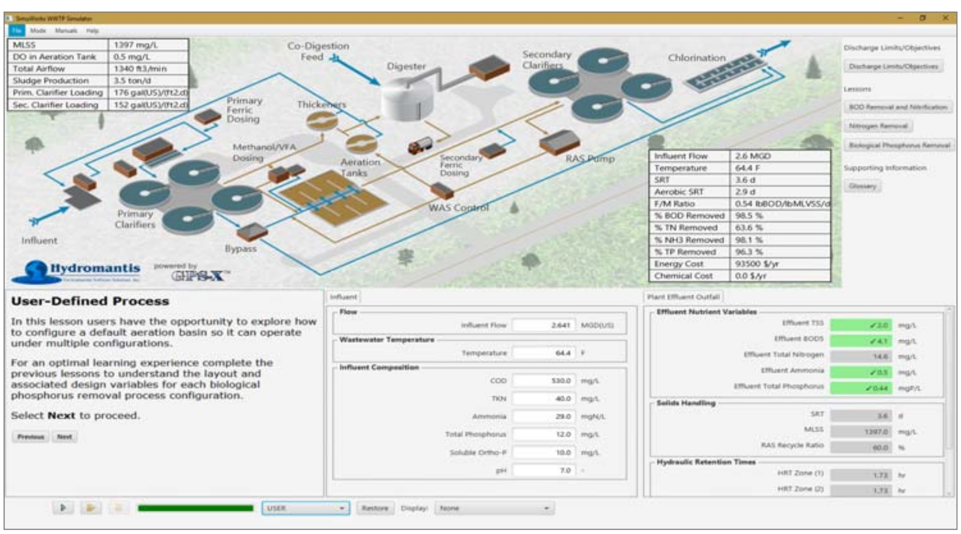
Process Simulator Layout



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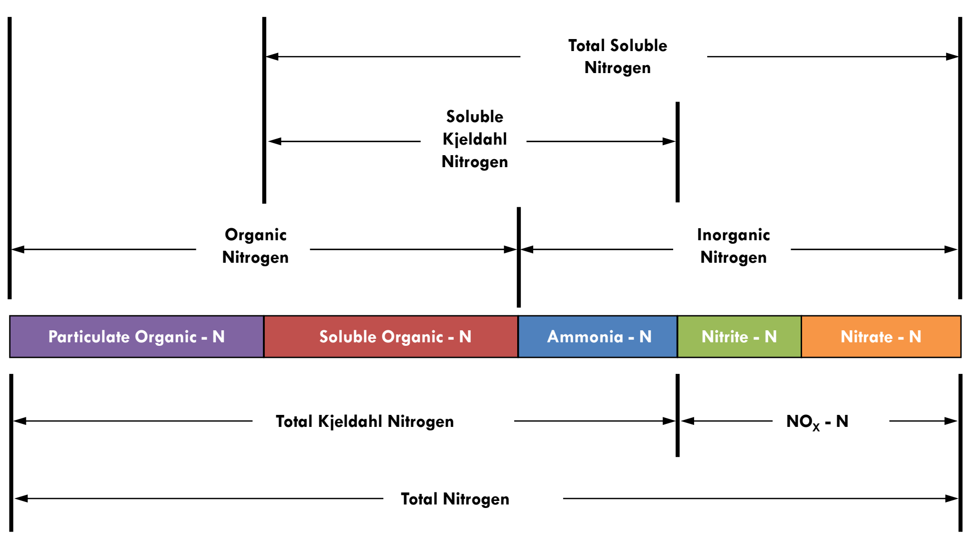
Nitrogen in the Environment

17

Forms of Nitrogen



18

Why Remove Nitrogen?

- Toxicity: Ammonia
- Oxygen Demand: Ammonia
- Groundwater Contamination: Nitrate
- Eutrophication: Total Nitrogen
  - Long Island Sound
  - Narragansett Bay
  - Chesapeake Bay
  - San Francisco Bay

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Environmental Conditions

- Aerobic ← **NITRIFICATION**
  - Free dissolved oxygen present
- Anoxic ← **DENITRIFICATION**
  - No free dissolved oxygen
  - Nitrite and/or nitrate present
- Anaerobic
  - No free dissolved oxygen
  - No nitrite or nitrate

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Biological Nitrogen Removal

- Assimilation
  - Incorporation of nitrogen into cell mass, typically 5% of BOD removed (7-10% of VSS formed)
- Ammonification
  - Conversion of organic nitrogen into ammonia
- Nitrification
  - Oxidation of ammonia to nitrite then nitrate
- Denitrification
  - Reduction of nitrate to nitrogen gas

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Denitrification

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Denitrification Basics

2 NO_3^- -N + 12 H^+ + 2.9 BOD → N_2 + 6 H_2O + Bacteria

Reduction of nitrate to nitrogen gas

Heterotrophic Bacteria – "BOD Removers"

- Energy from Oxidation of Organic Carbon
- Recovers Oxygen – (2.9 lbs O_2 / lb NO_3-N)
- Anoxic Conditions Req'd – No or Low DO
- Consumes Acid – Produces Alkalinity (3.6 lb $CaCO_3$ / lb NO_3-N)
- Mixing Req'd - Maintain Complete Solids Suspension without adding DO

DENITRIFICATION MUST FOLLOW NITRIFICATION!

DENITRIFICATION IS NECESSARY TO ACHIEVE TOTAL NITROGEN REMOVAL!

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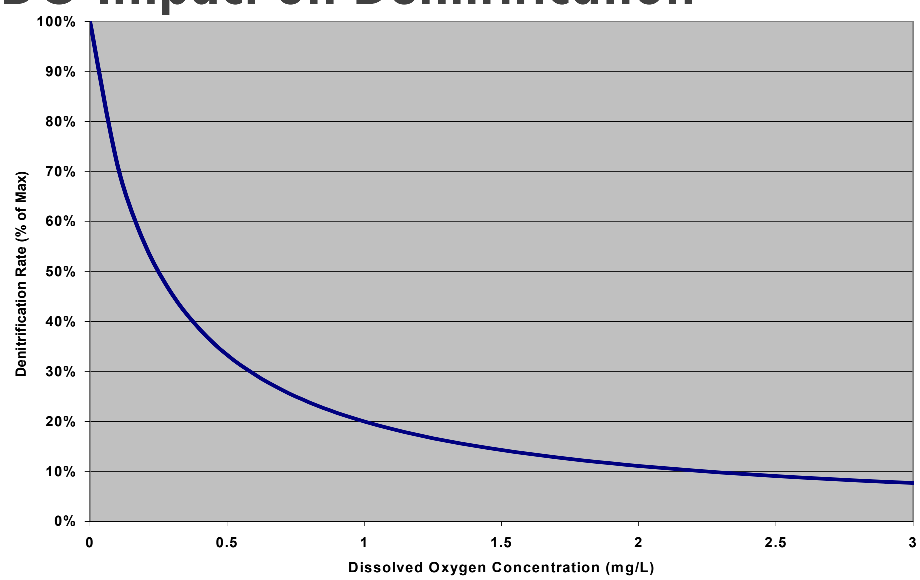
DO Impact on Denitrification



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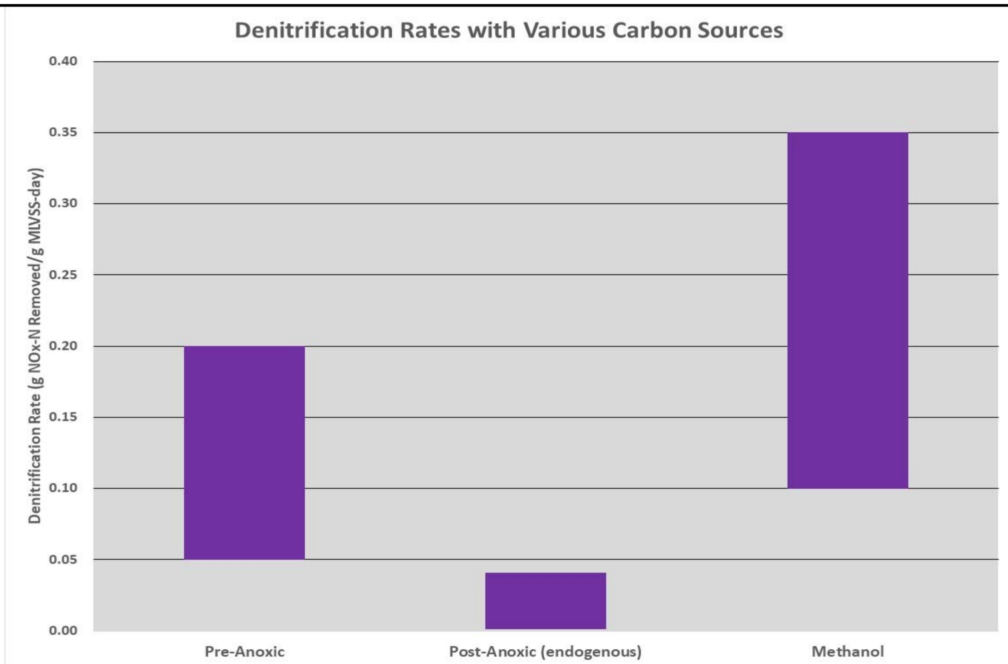

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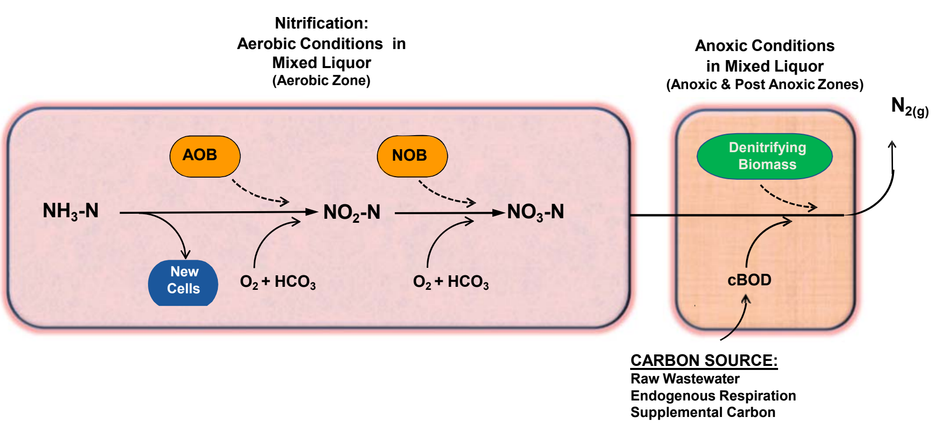
Factors Impacting Denitrification



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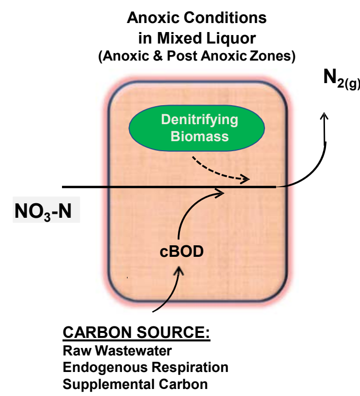
Factors Impacting Denitrification

Keys to Denitrification

1. Nitrate
2. Biomass
3. Carbon (BOD)
4. Anoxic Conditions



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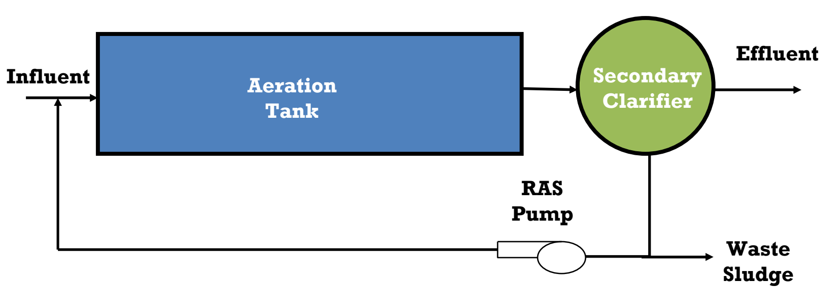
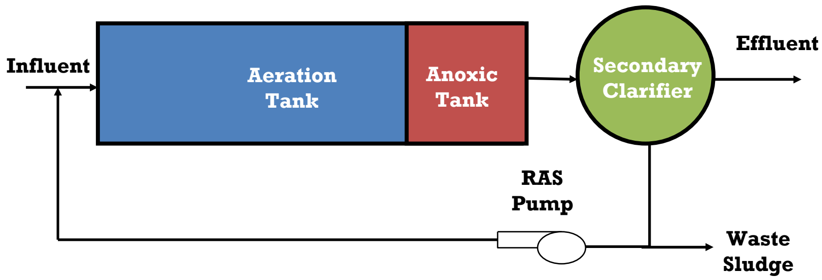
Single Sludge Nitrification



BOD Removal, Nitrification

28

Wuhrman Process



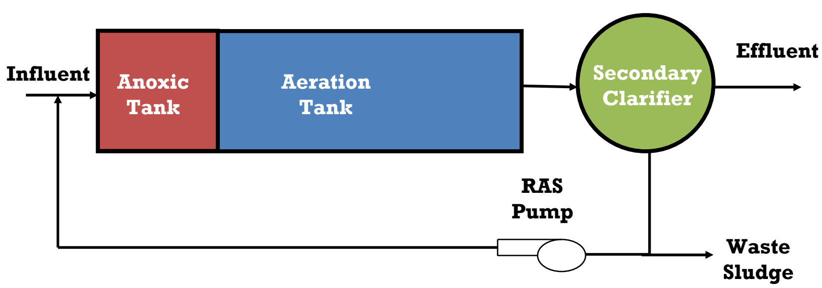
BOD Removal, Nitrification & Denitrification

Which of the 4 Factors will most likely limit denitrification?

ORGANIC CARBON

29

Ludzack-Ettinger Process



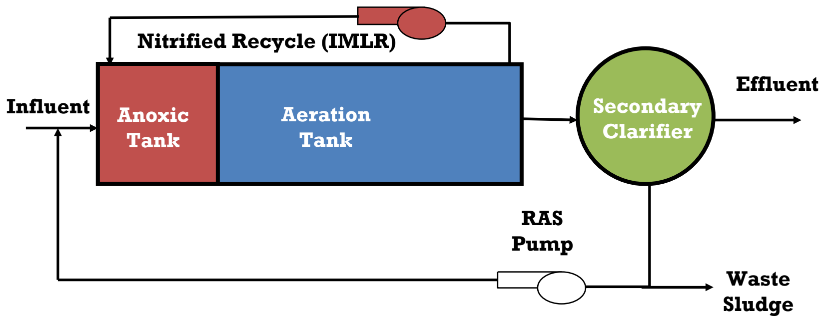
BOD Removal, Nitrification & Denitrification

Which of the 4 Factors will most likely limit denitrification?

NITRATE

30

Modified Ludzack-Ettinger (MLE) Process

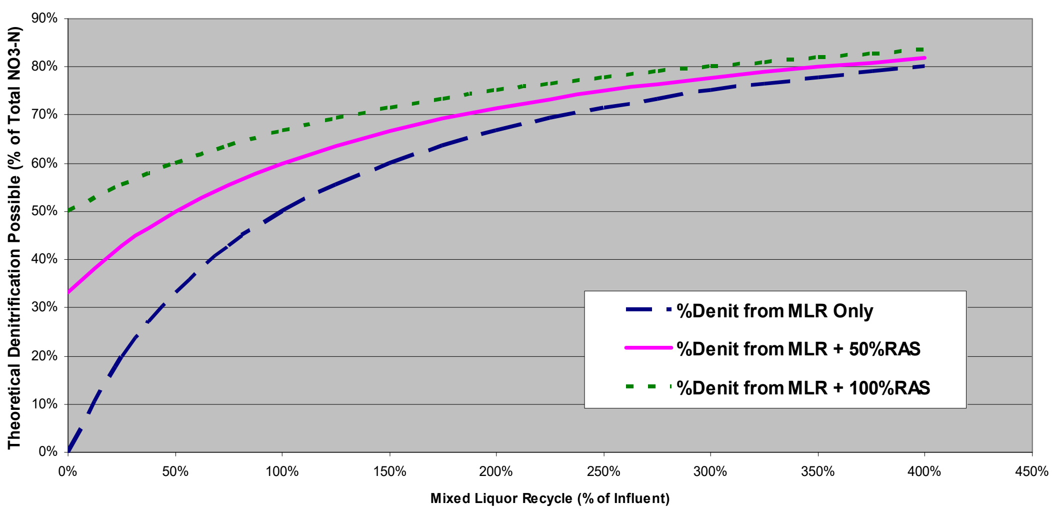


BOD Removal, Nitrification & Denitrification

Which of the 4 Factors will most likely limit denitrification?

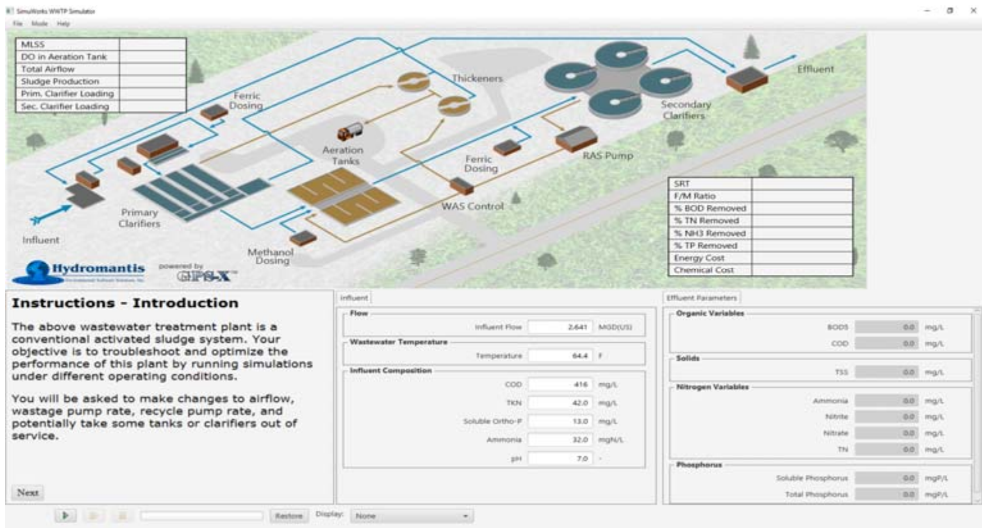
31

MLE Recycle Relationship (Internal ML Recycle)



32

Process Simulator – ML Recycle Example



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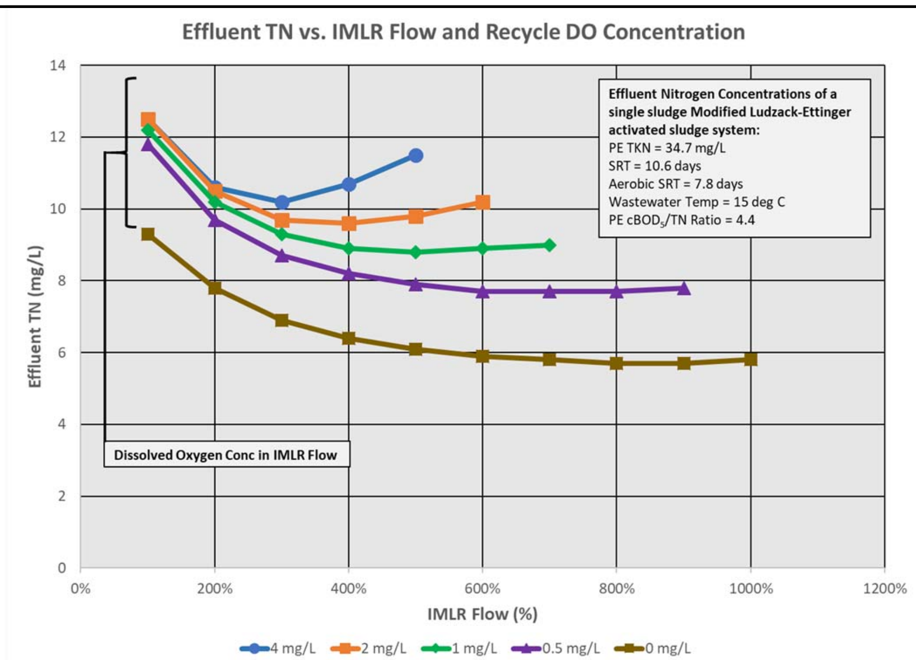
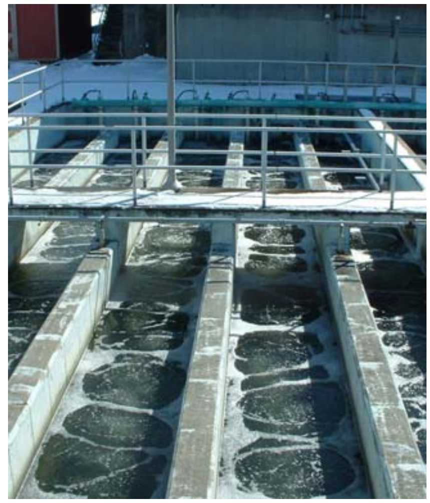


34

Influent Nitrogen Concentrations

- **Conventional Pollutants**
  - BOD_5 200 mg/L
  - TSS 200 mg/L
- **Unoxidized Nitrogen:**
  - Ammonia N (NH_3-N) 20 mg/L
  - Organic Nitrogen 20 mg/L
  - **Total Kjeldahl Nitrogen (TKN) 40 mg/L**
- **Oxidized Nitrogen:**
  - Nitrite (NO_2-N) 0 mg/L
  - Nitrate (NO_3-N) 0 mg/L
  - **Total Oxidized Nitrogen 0 mg/L**
- **Total Nitrogen 40 mg/L**



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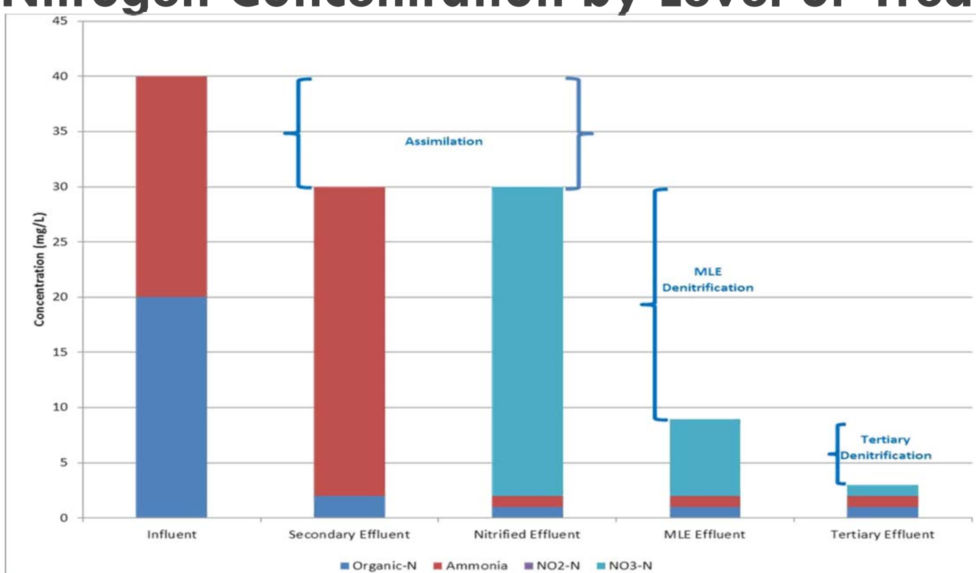
Nitrogen Concentration by Level of Treatment



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Evaluating and Improving Denitrification

UNDERSTAND THE LIMITING FACTORS

NITRATE

Increase Nitrate Mass to Anoxic Conditions

- Increase IMLR Flow

BIOMASS

Increase Biomass operating under Anoxic Conditions

- Increase Anoxic Volume
- Increase MLSS

CARBON

Increase/Improve Carbon Source

- Supplemental Source (methanol, Micro-C)
- Primary Clarifier Bypass
- Fermentation

ANOXIC CONDITIONS

Decrease Dissolved Oxygen Input

- Dissolved Oxygen Control
- D.O. Exhauster Zone

If that's not good enough → **Tertiary Processes**

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Post- Denitrification

- Often required to achieve very low TN Levels (<5 mg/L)
- Carbon source is often the key factor
  - Endogenous respiration
  - Supplemental carbon addition
- Activated Sludge Options
  - Single Sludge
  - Separate Sludge
- Fixed Film Options
  - Denitrification Filters
  - Moving Bed Biofilm Reactors (MBBR)

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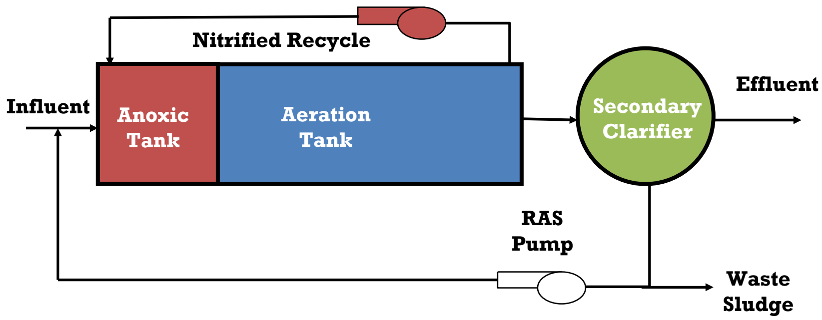
38

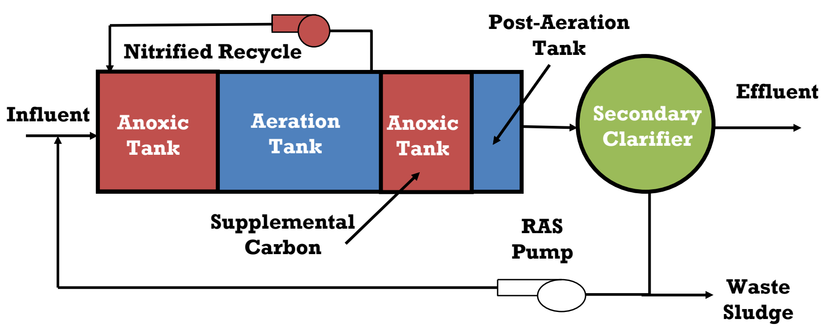
Modified Ludzack-Ettinger (MLE) Process



BOD Removal, Nitrification & Denitrification

39

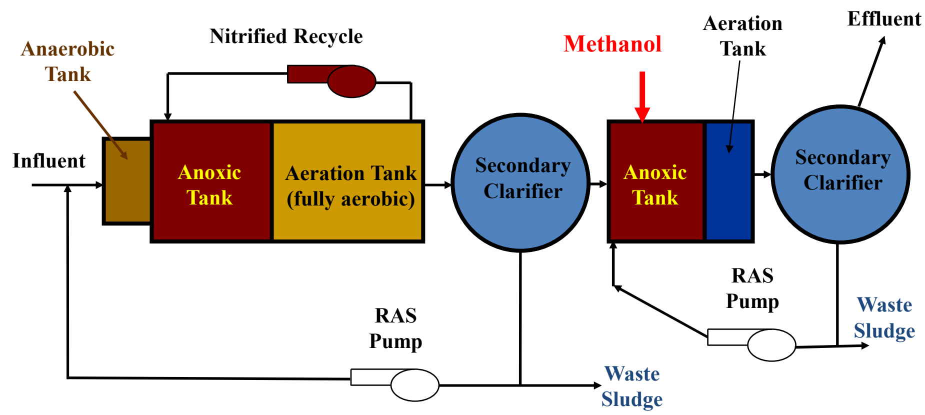
4-Stage Bardenpho Process



BOD Removal, Nitrification & Denitrification

40

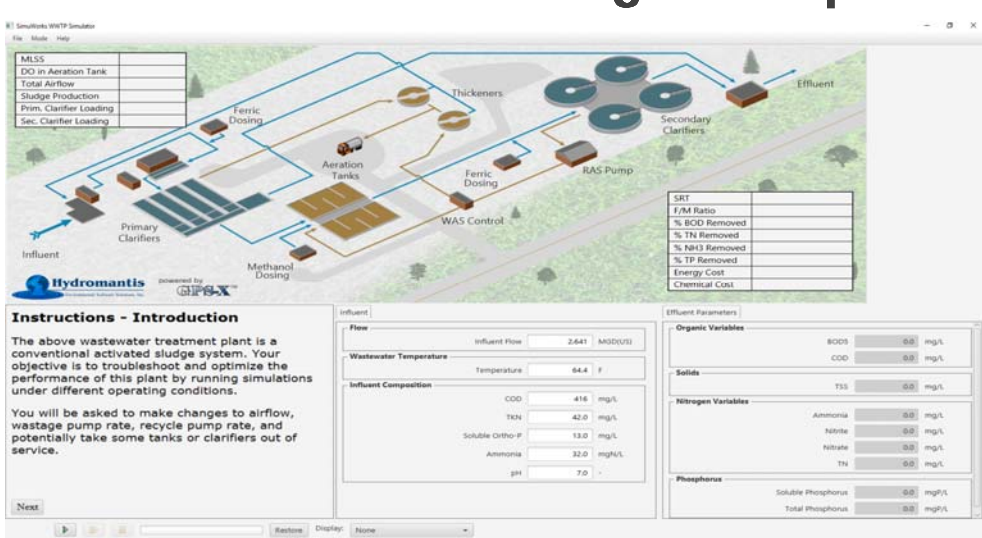
Separate Sludge 5-Stage Bardenpho Process



BOD Removal, Nitrification, Denitrification & Phosphorus

41

Process Simulator – 4-Stage Example



42

Summary of Nitrification vs. Denitrification

	Nitrification	Denitrification
FINAL PRODUCT	Nitrate	Nitrogen Gas
ENVIRONMENTAL CONDITIONS	Aerobic	Anoxic
BIOMASS INVOLVED	Autotrophs – Slow Growth	Heterotrophs – Fast Growth
OXYGEN	Consumes Oxygen (4.6 lb O_2/ lb NH_4-N)	Recovers Oxygen (2.9 lb O_2/ lb NH_4-N)
ALKALINITY	Consumes Alkalinity (7.2 lb $CaCO_3$/ lb NH_4-N)	Produces Alkalinity (3.6 lb $CaCO_3$/ lb NH_4-N)

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Hydromantis Denitrification Case Study

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44

Total Nitrogen (TN) Removal Case Study

- **Green Valley WRF**
  Pima County, AZ
- Biological Nitrogen Removal
  - Nitrification and Denitrification
- 4.1 MGD capacity:
  - 2.1 MGD Aerated Ponds
  - 2.0 MGD Oxidation Ditch

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TN Removal With ON/OFF Aeration

- Conventional denitrification uses an aerobic zone for nitrification and an anoxic zone for denitrification
- Both can be achieved in a single tank by alternating between aerobic and anoxic conditions
  - Aerobic conditions = nitrification
  - Anoxic conditions = denitrification

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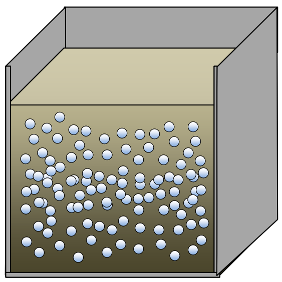
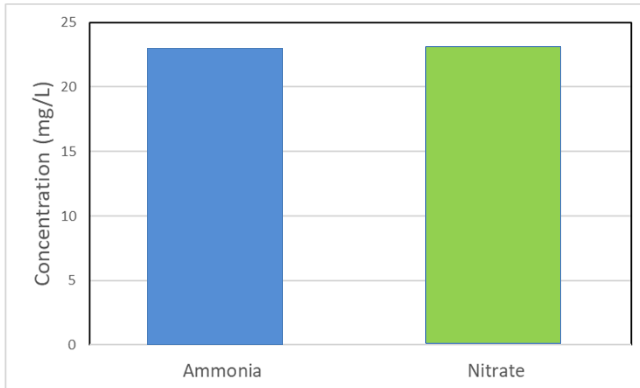
TN Removal With ON/OFF Aeration

- Aerobic conditions promote nitrification (Ammonia → Nitrate)
  Anoxic conditions promote denitrification (Nitrate → N_2 gas)





47

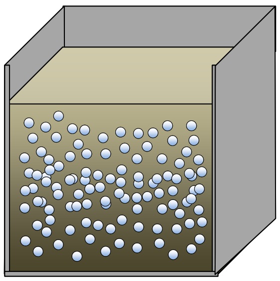
TN Removal With ON/OFF Aeration

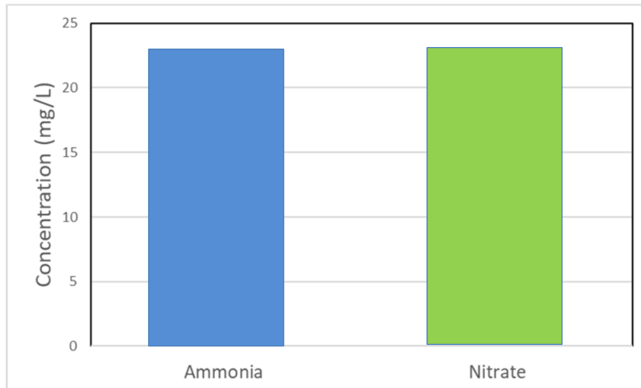
- Control systems can optimize the TN removal by adjusting the cycle times for varying loads/temperatures
- There is a sweet spot of low-DO "partial aeration" where nitrification and denitrification can occur simultaneously

48

TN Removal With Low-DO Aeration

- Low aeration allows for a combination of aerobic and anoxic conditions





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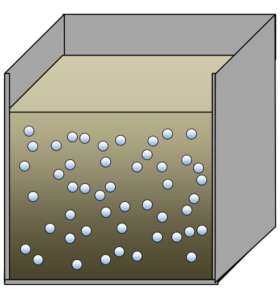
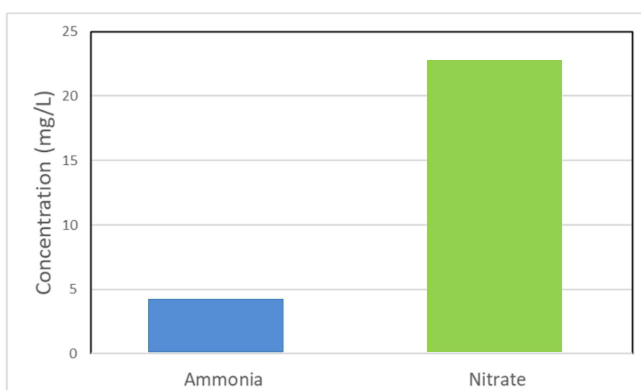
TN Removal With Low-DO Aeration

- Low aeration allows for a combination of aerobic and anoxic conditions





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TN Removal With Low-DO Aeration

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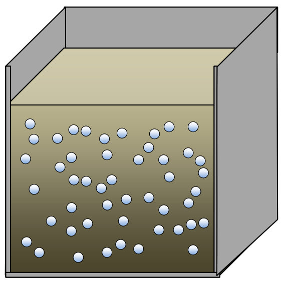

- Low DO conditions can, however cause other issues:
  - Potential to grow filamentous biomass
  - Settlement of solids

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Green Valley WRF (Pima County, AZ)

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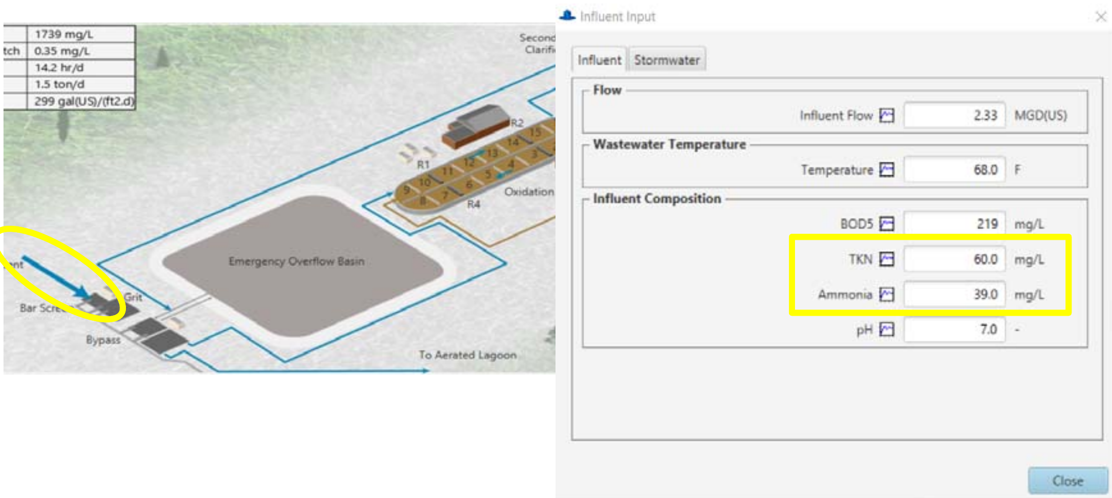
52

Green Valley WRF (Pima County, AZ)



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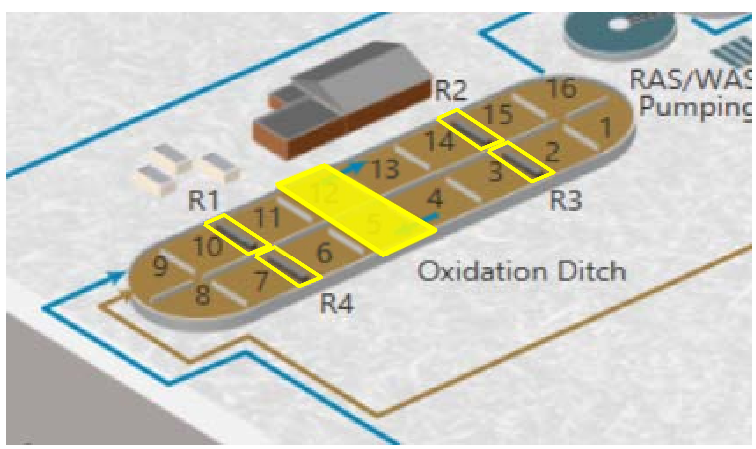
Green Valley WRF – Aeration / DO Control

- 4 Rotors:
  - Independent control
- DO Controller:
  - DO is average of tanks 5 and 12



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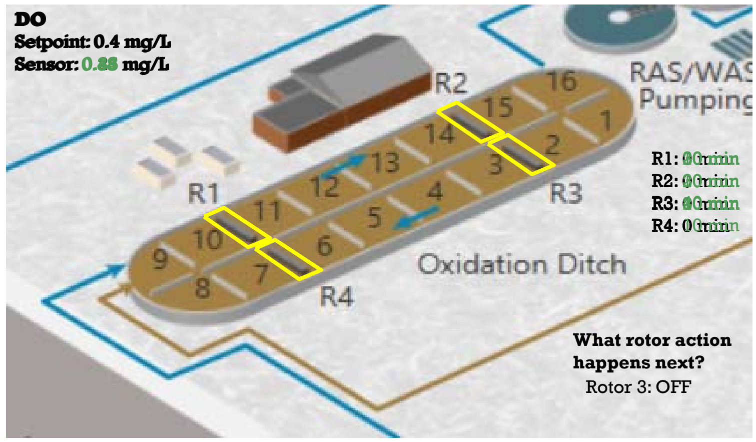
Green Valley WRF – Aeration / DO Control

- Sequencing rotors:
  - Switched ON/OFF to meet setpoint
  - If DO > Setpoint
    - Turn OFF the rotor that has been running the most
  - If DO < Setpoint
    - Turn ON the rotor that has been running the least



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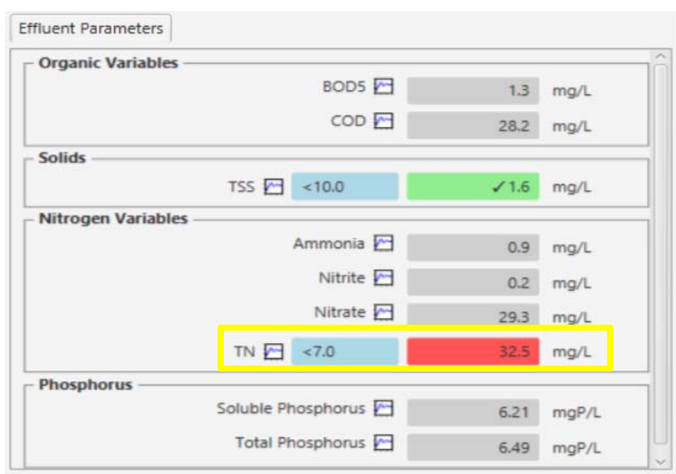
Green Valley WRF (Pima County, AZ)

- Denitrification Study:
  - Start from conditions resulting in high effluent Total Nitrogen (TN)
  - What changes are required to get effluent TN to < 7.0 mgN/L?

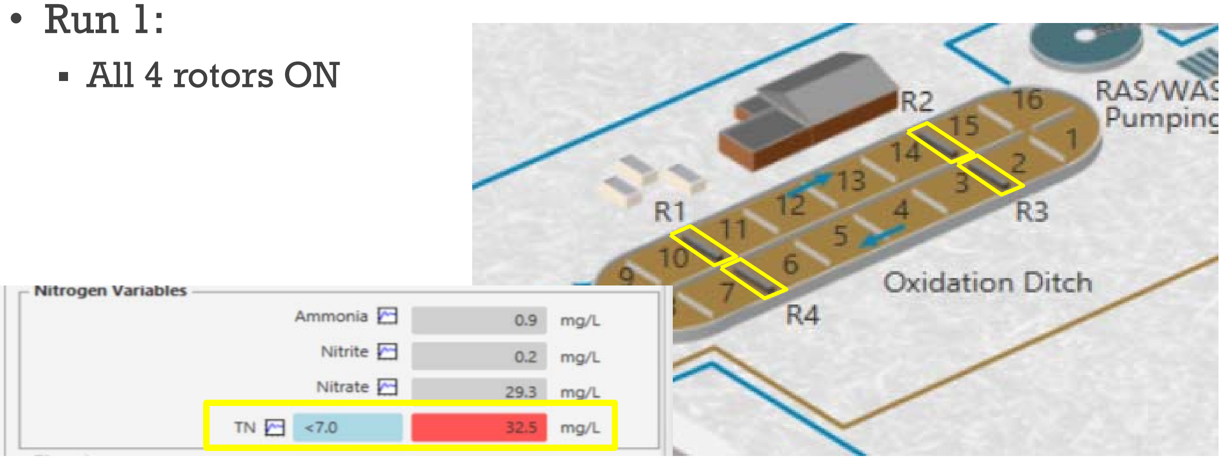

Effluent Parameters

Organic Variables			
BOD5		1.3	mg/L
COD		28.2	mg/L
Solids			
TSS	<10.0	✓1.6	mg/L
Nitrogen Variables			
Ammonia		0.9	mg/L
Nitrite		0.2	mg/L
Nitrate		29.3	mg/L
TN	<7.0	32.5	mg/L
Phosphorus			
Soluble Phosphorus		6.21	mgP/L
Total Phosphorus		6.49	mgP/L

56

Green Valley WRF (Pima County, AZ)

- Run 1:
  - All 4 rotors ON



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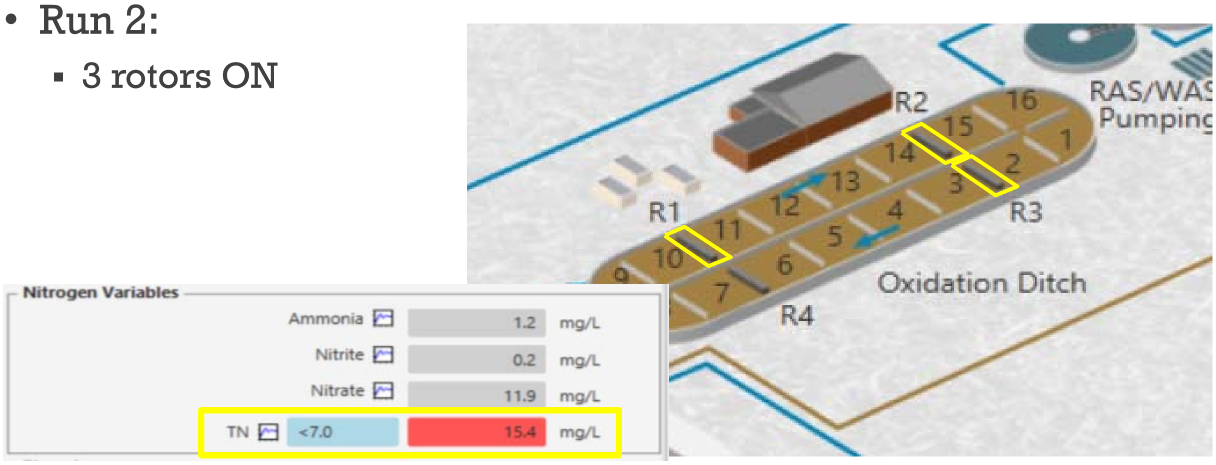
Green Valley WRF (Pima County, AZ)

- Run 2:
  - 3 rotors ON



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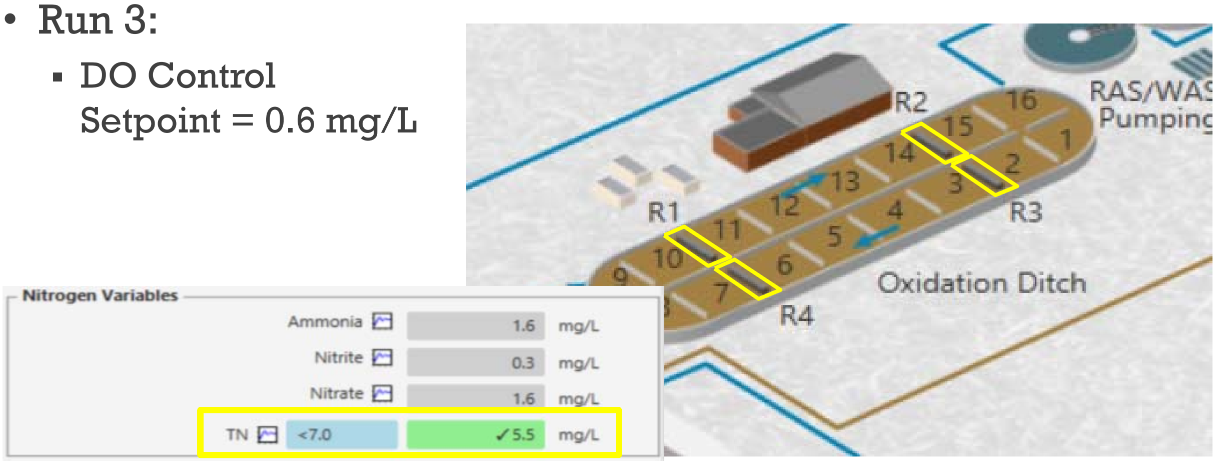
Green Valley WRF (Pima County, AZ)

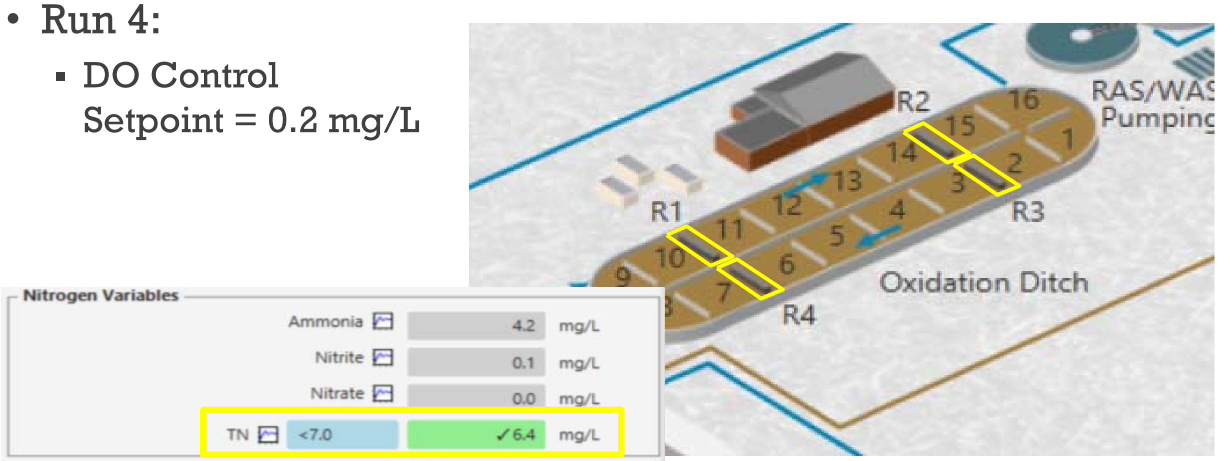
- Run 3:
  - DO Control
    Setpoint = 0.6 mg/L



59

Green Valley WRF (Pima County, AZ)

- Run 4:
  - DO Control
    Setpoint = 0.2 mg/L



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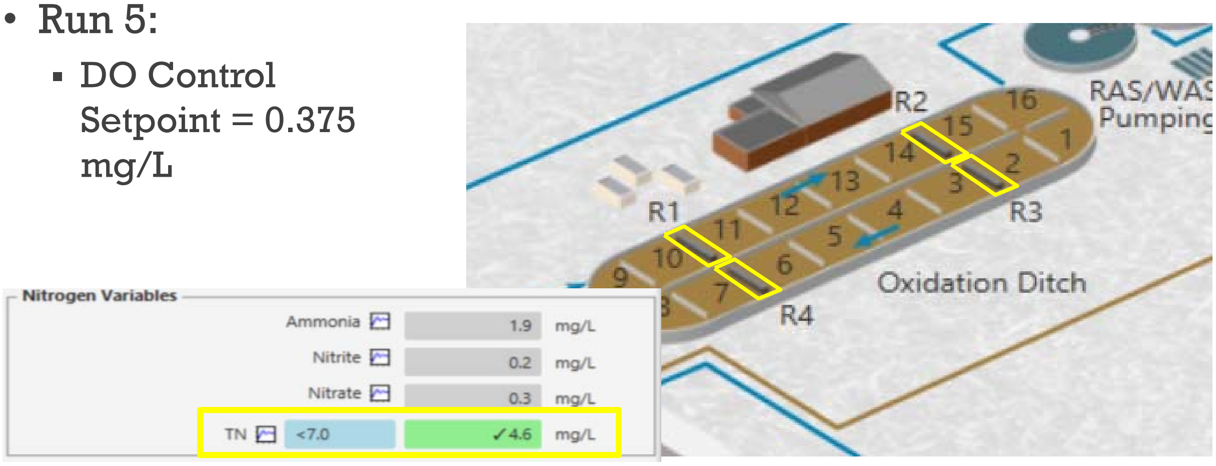
Green Valley WRF (Pima County, AZ)

- Run 5:
  - DO Control Setpoint = 0.375 mg/L



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DO Control – Finding the Sweet Spot

- Too much or too little aeration can move away from the optimal point:
  - Too high DO → higher nitrate
  - Too low DO → higher ammonia

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Comparison

- Summary of simulation results:

#	Description	Effluent TN (mg/L)	Avg DO (mg/L)	Avg Aerator On-Time (hr/d)	Energy Cost ($/yr)
1	All Rotors On	32.9	1.65	24	$145,600
2	3 Rotors On	15.7	0.53	18.1	$117,000
3	DO Control 0.6 mg/L	5.5	0.5 - 0.6	16.4	$108,800
4	DO Control 0.2 mg/L	6.4	0.17 - 0.2	11.5	$85,200
5	DO Control 0.375 mg/L	4.6	0.35 - 0.4	14.1	$97,600

Case Study Summary

- Simultaneous nitrification/denitrification is an effective way to optimize for TN removal while optimizing energy usage
- Green Valley WRF uses a sophisticated control system to manage treatment performance and energy use

Questions?

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65