



# Wastewater Treatment Process Modifications for Nutrient Reduction

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# Why Nutrient Reduction?

Undesirable algae growth  
(eutrophication)



Exert oxygen demand in receiving  
streams and depress DO

Public Health concern due to  
Nitrate-N (10 mg-N/L MCL) Blue  
Baby Syndrome



Aquatic Toxicity due to Ammonia-  
N (pH and temperature  
dependent)

# Nitrogen Compounds of Interest

Form of Nitrogen	Common Removal Mechanism	Technology Limit (mg/L)
Ammonia-N	Nitrification	< 0.5
Nitrate-N	Denitrification	1 – 2
Particulate Organic-N	Solids Separation	< 1.0
Soluble Organic-N	None	0.5 – 1.5

# Familiar Nitrogen Removal Processes

## Physical Treatment Methods

- Sedimentation
- Gas Stripping



## Chemical Treatment Methods

- Breakpoint Chlorination
- Ion Exchange



## Biological Treatment Methods

- Wetland Treatment Systems
- Overland Flow Systems



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## Obstacles to Implementation

*Difficult or Impossible to avoid*

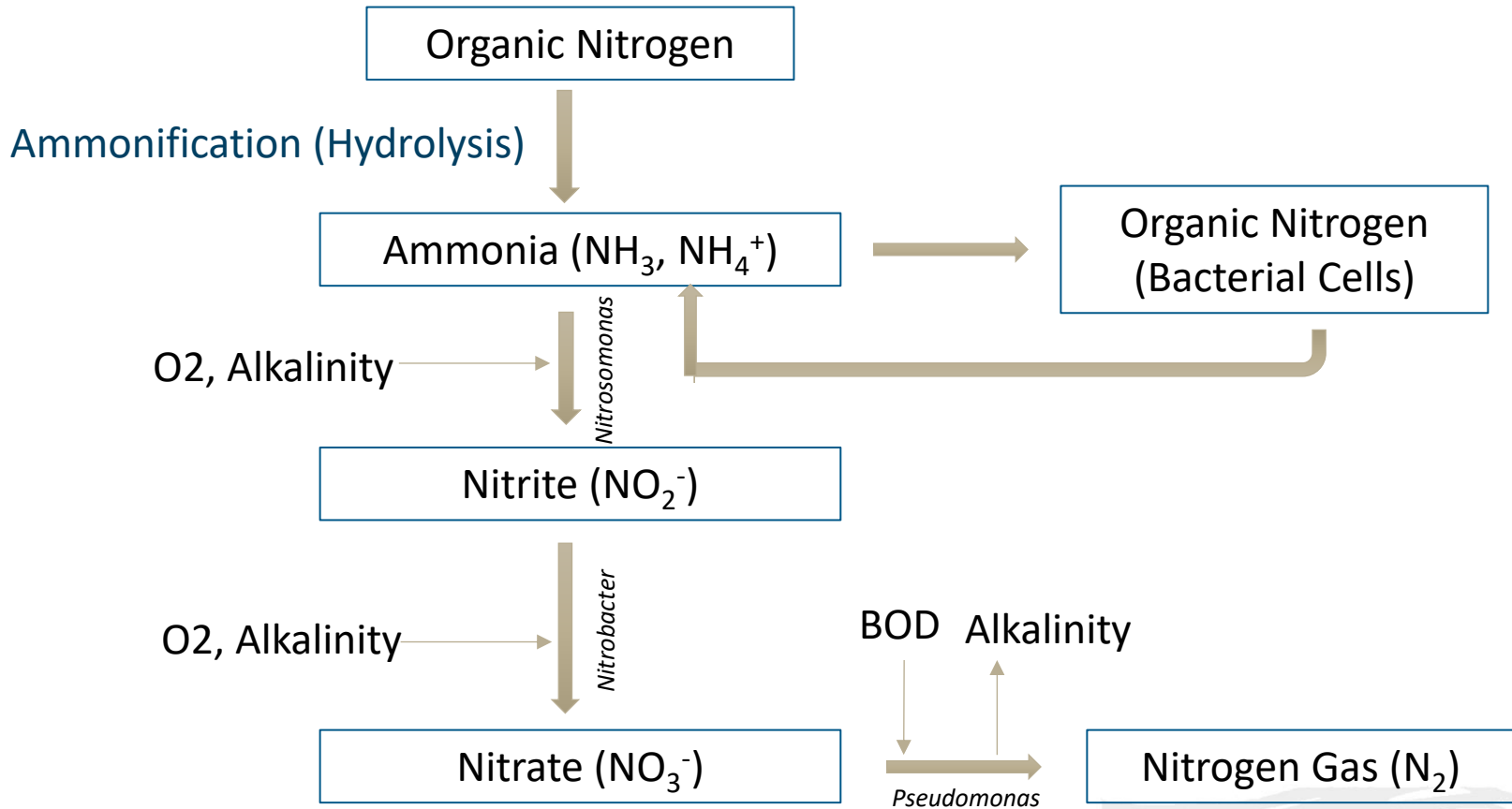
- Overwhelming Expense
- Complexity of Treatment
- Training and Experience Required
- Special Considerations
  - Available Land Space
  - Conformity to Current Practices
  - Chemical Storage Risk

# The “Black Box” Approach

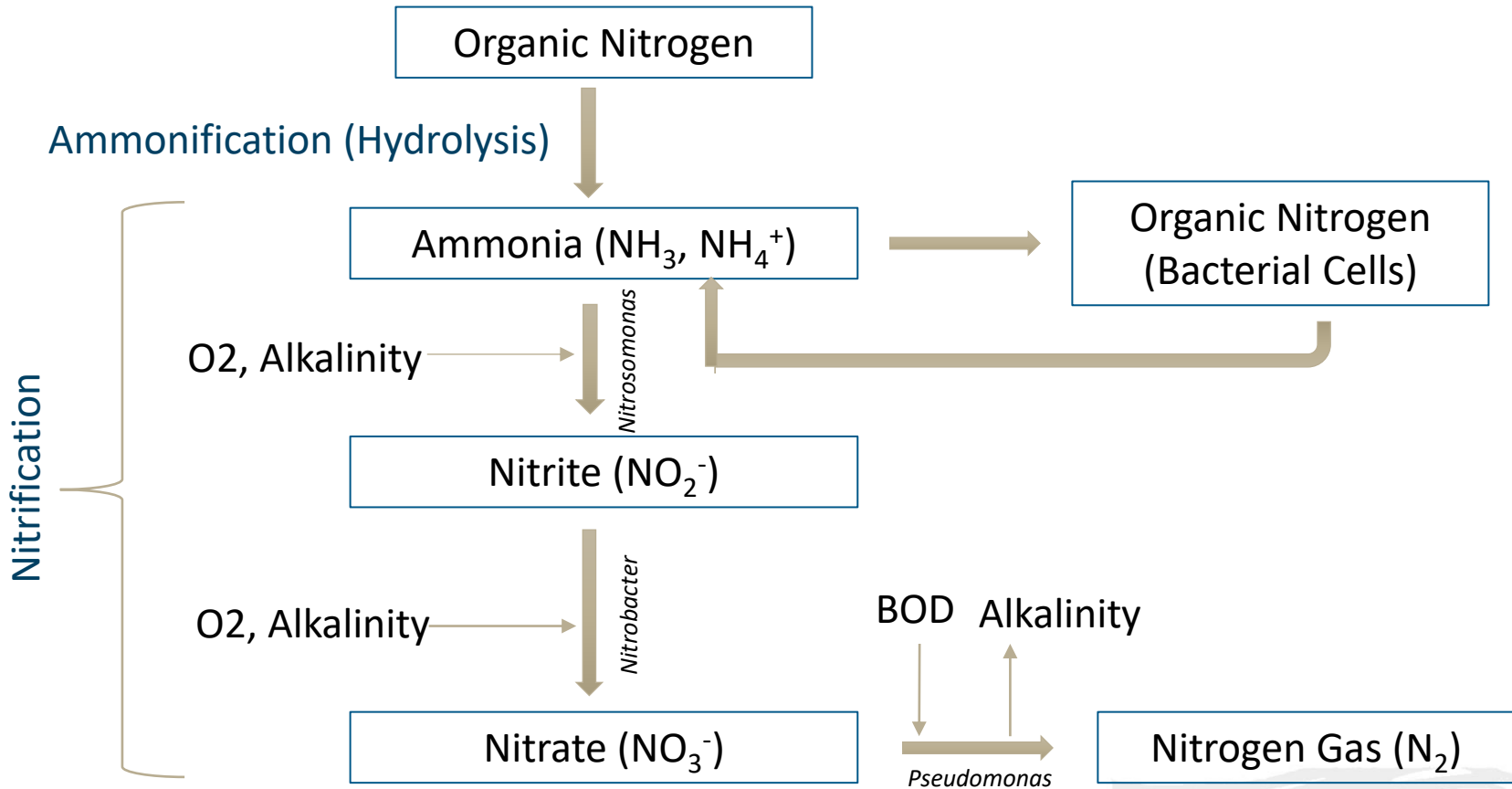


**Lacks understanding of the process!**

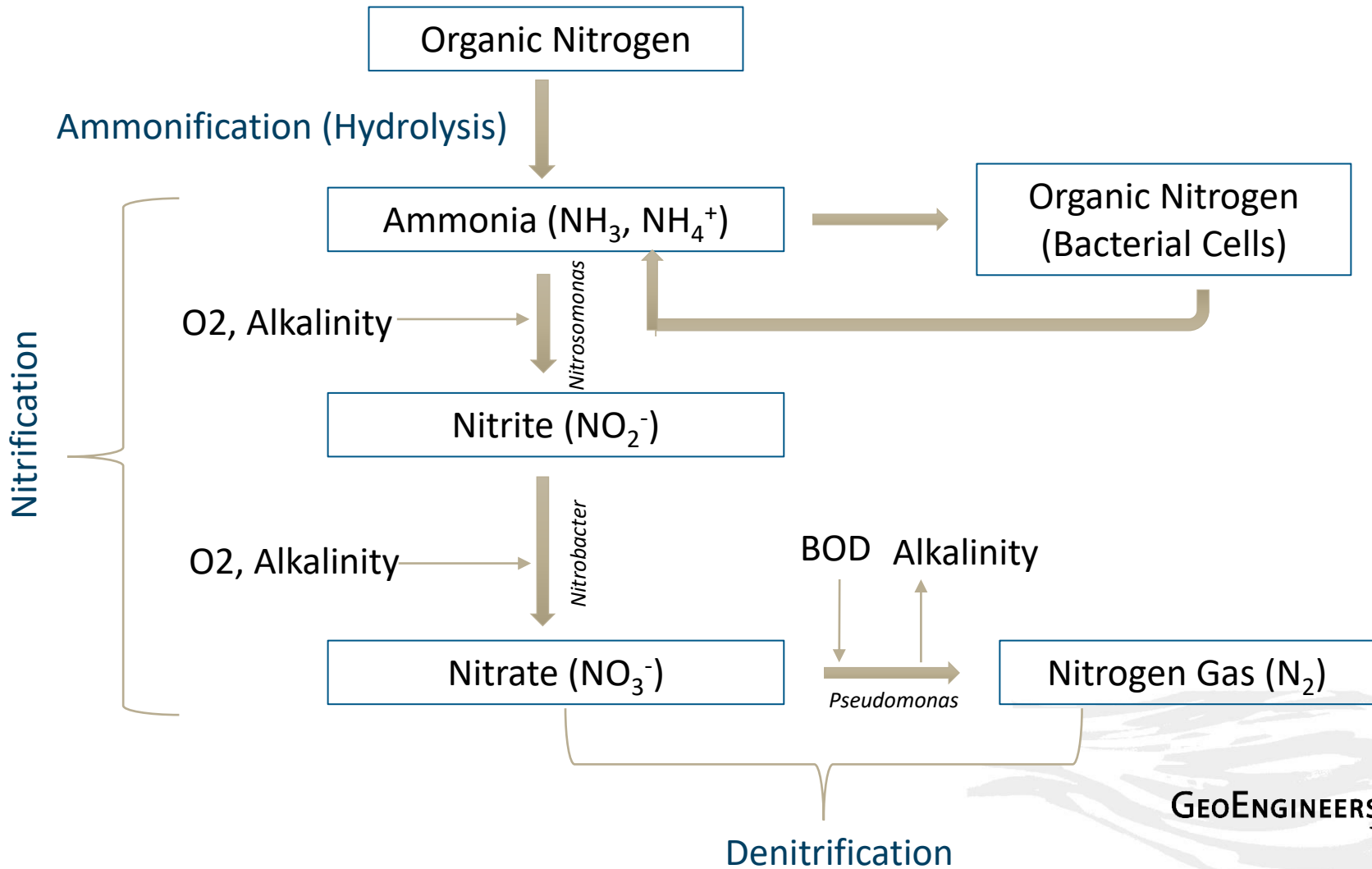
# Nitrogen Transformations



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# Nitrogen Transformations



# Factors Impacting Nitrification

- Sensitive to pH
  - Nitrification rates drop significantly at pH values below 6.8
  - Optimum pH is 7.5
- Sensitive to temperature
  - Optimum range is 25-35° C
- Rate of nitrification has been shown to be limited at Dissolved Oxygen (DO) concentrations below 2.0 mg/L
- Nitrification rates depend on organic loading and floc structure (Bulk liquid DO vs Floc DO)

# Factors Impacting Nitrification

- Inhibitory Effects: nitrification rates are depressed

*Examples:*

- Organic: some amines, cyanates, carbamates, ethers, benzene, organic solvents, phenol (100 ppm), etc.
- Metals: Nickel (0.25 ppm), chromium (0.25 ppm), copper (0.1-0.5 ppm), etc.
- Unionized ammonia ( $\text{NH}_3$ ) and unionized nitrous acid ( $\text{HNO}_2$ )-- also known as Free ammonia (FA) and Free Nitrous acid (FNA)
  - FA @ 10-150 mg/L inhibit *Nitrosomonas* and @ 0.1-1.0 mg/L inhibit *Nitrobacter*.
  - FNA @ 0.22 to 2.8 mg/L inhibit *Nitrobacter*

# Factors Impacting Denitrification

- Denitrification can occur by heterotrophic and autotrophic bacteria
- Denitrifying bacteria are facultative bacteria
- Denitrification is inhibited by high DO levels ( $>0.1-0.2$  mg/L)
- Activated sludge floc structure impact DO environment within the floc (bulk liquid DO could be higher and still have denitrification)

## Factors Impacting Denitrification

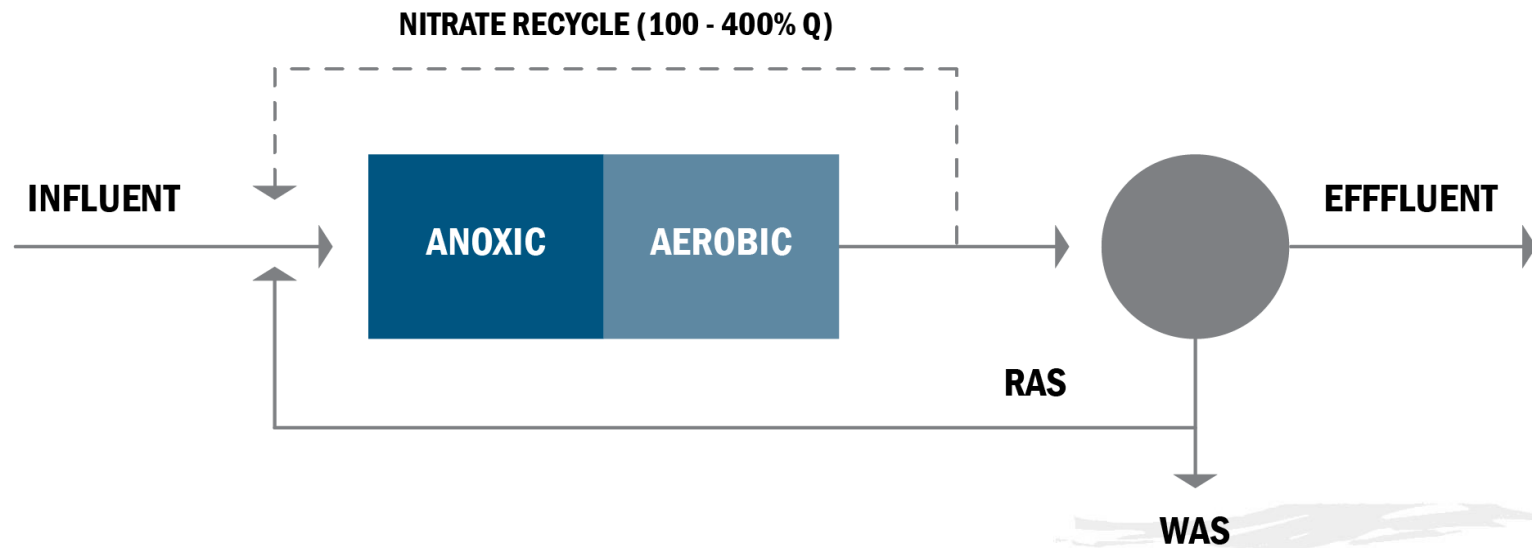
- Organic carbon has to be present/supplied for adequate denitrification
- Denitrification rates depend on carbon source supplied
- Alkalinity is produced and pH is elevated
- Optimum pH for denitrification is around 6.5-7.5.

# Current Trends

## Modified Activated Sludge Systems for Combined Biological Removal of Nitrogen and Phosphorus

# BNR Process Descriptions

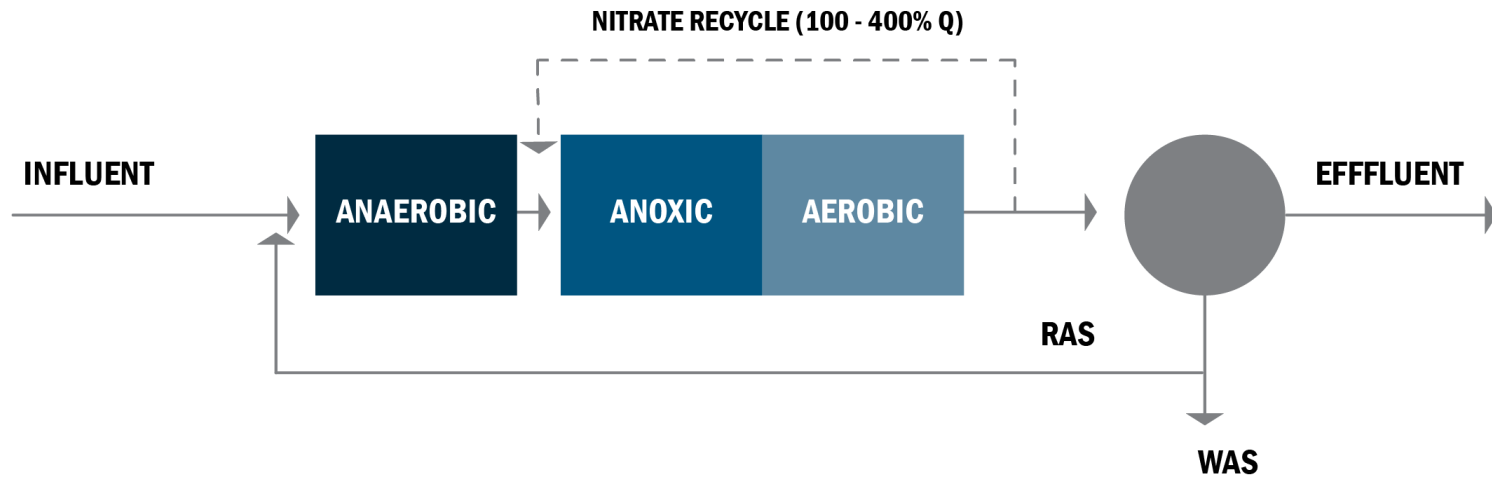
- Ludzack-Ettinger & Modified Ludzack-Ettinger Processes
  - Continuous flow, suspended growth
  - Anoxic followed by aerobic to reduce TN
  - Modified process includes nitrate recycle



# BNR Process Descriptions

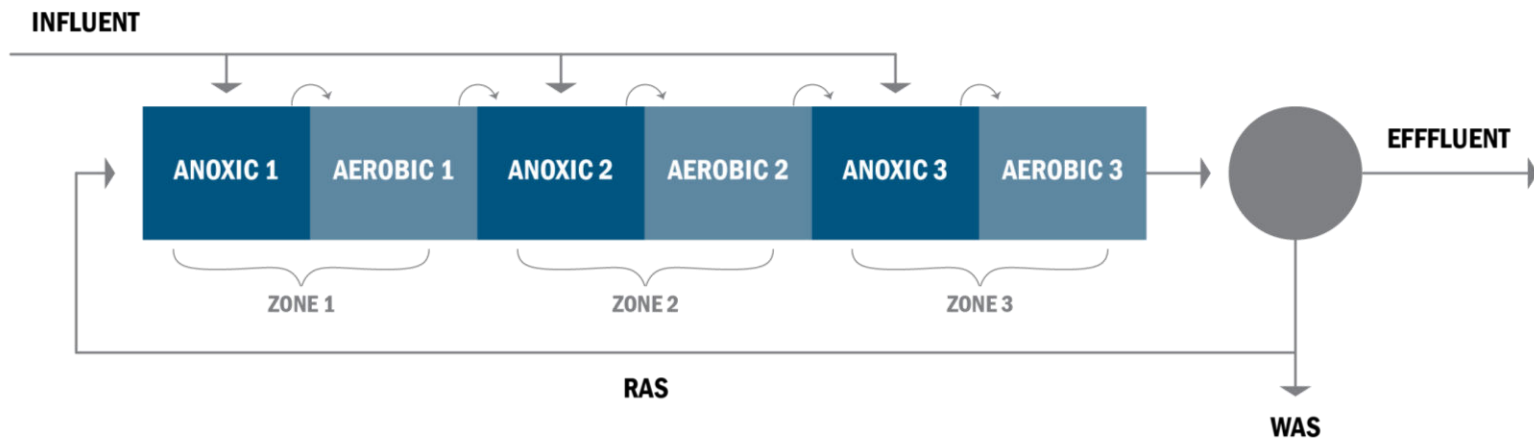
- A2/O Process

- (M)LE Process preceded by initial anaerobic stage
- Removes TN and TP



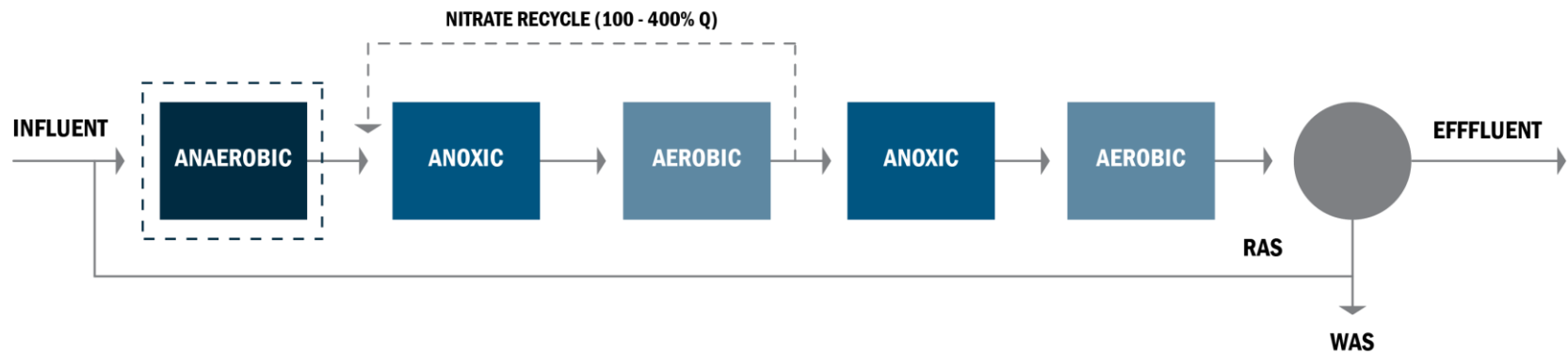
# BNR Process Descriptions

- Step Feed Process
  - Alternating anoxic and aerobic stages



# BNR Process Descriptions

- Bardenpho (Four Stage) and Modified Bardenpho Processes
  - Continuous flow, suspended growth system
  - Anoxic, aerobic, anoxic, aerobic
  - Modified process includes initial anaerobic zone for TP removal



# BNR Process Descriptions

## Sequencing Batch Reactor (SBR)

- Sequenced to simulate the four-stage Bardenpho



## Rotating Biological Contactor Process

- Sequential aerobic and anoxic stage



## Oxidation Ditch

- Looped channels to create anoxic, aerobic and anaerobic zone
- Removes TN and TP



# BNR Process Summaries

- Systems for TN removal
  - Must have aerobic zones for nitrification
  - Must have anoxic zones for denitrification
- Systems for TP removal
  - Must have anaerobic zone free of dissolved oxygen and nitrate

# Design Considerations

- Aeration basin size and configuration
  - HRT
  - F/M Ratio
- Clarifier capacity
  - SRT
  - RAS Rates
  - Additional sludge processing units
- Type of aeration system
  - Bulk liquid DO
  - Impact to floc structure
- Operator skills

# Available Process Control Approaches

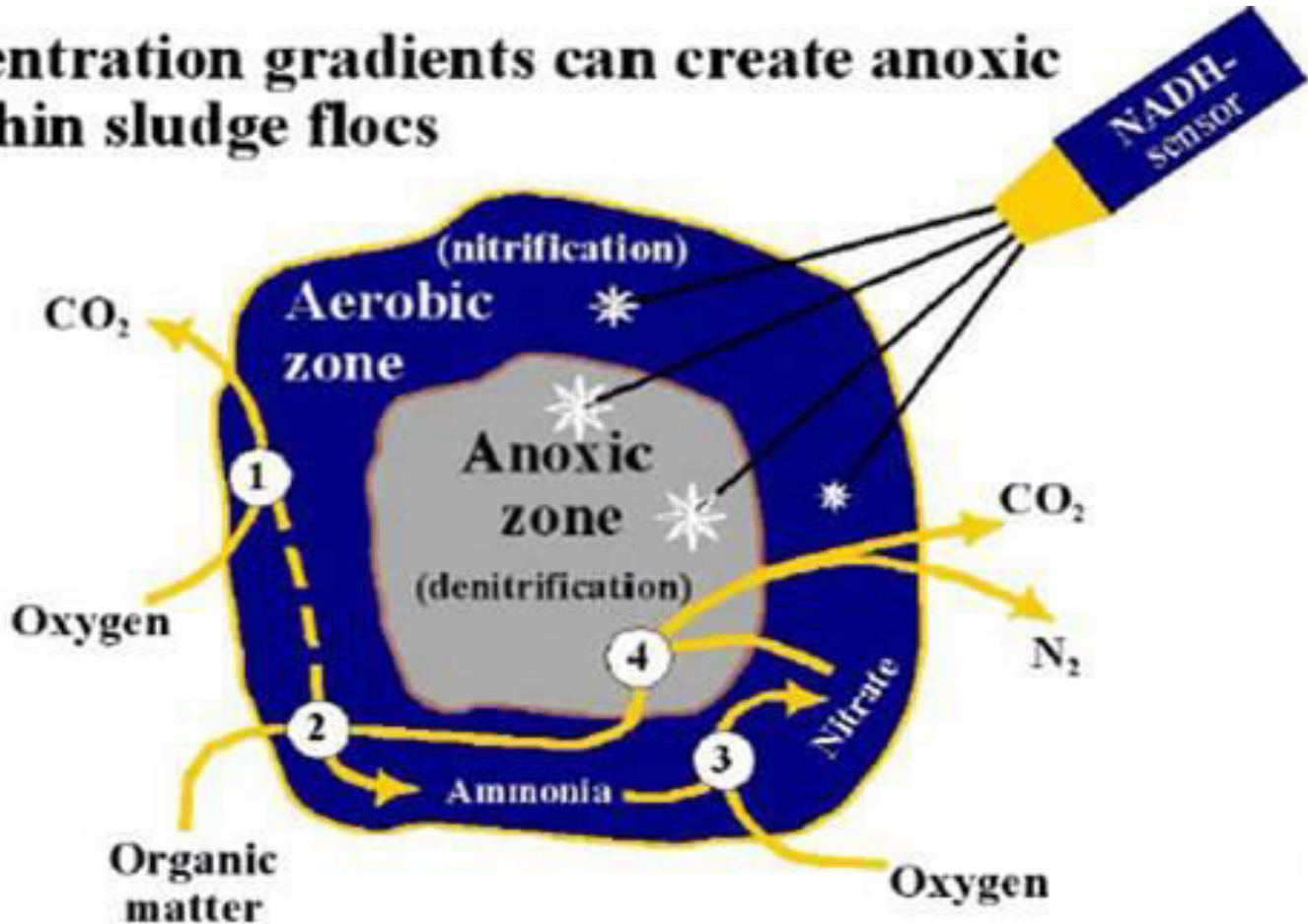
- DO Control (Bulk Liquid)
- Oxidation Reduction Potential Control (Bulk Liquid)
  - Anoxic: negative ORP
  - Aerobic: positive ORP

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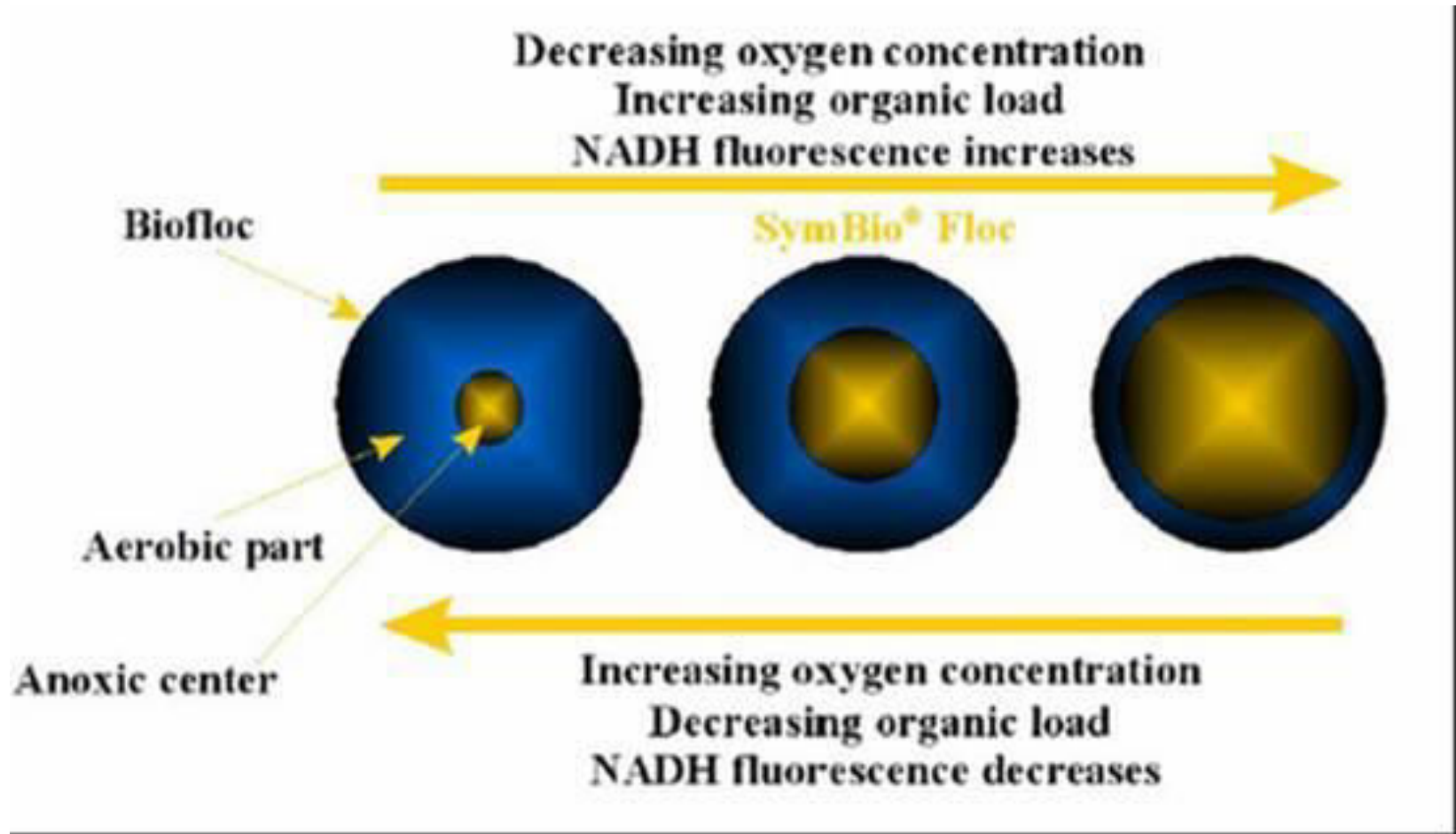
- NADH (Sensors (single tank systems))
  - Measures activity of Nicotinamide Adenine Dinucleotide enzyme within bacterial cells and floc
  - Light Source @ UV340 nm – NADH Emit Signal @ UV 460 nm
  - High NADH Activity: Anaerobic Activity
  - Low NADH Activity: Aerobic Activity
  - NADH Set point/DO Control to achieve simultaneous Nit-Denit within each floc

# NADH Sensor

**DO concentration gradients can create anoxic zones within sludge flocs**



# NADH Sensor



# Benefits of Combined BNR Systems

## Environmental

- Permit Limits
- Toxic Release Inventory
- Toxicity

## Economical

- Energy Recovery (20-30%)
- Alkalinity Recovery
- Evidence of Reduced Sludge Production
- Potential for WQ Credit Trading

## Operational

- Control of Filamentous Organisms
- Improved Settleability

# Performance

Process	Nitrogen Removal	Phosphorus Removal
MLE	Good	None
A <sup>2</sup> /O	Good	Good
Step Feed	Moderate	None
Four-stage Bardenpho	Excellent	None
Modified Bardenpho	Excellent	Good
SBR	Moderate	Inconsistent
Modified UCT	Good	Excellent
Oxidation Ditch	Excellent	Good

# Limit of Technology

BNR Process	Achievable TN Effluent Quality
MLE	10 mg/L
Four-Stage Bardenpho	6 mg/L
Three-Stage Bardenpho	6 mg/L
SBR	8 mg/L
RBC	12 mg/L

Applicable to Small Systems (< 0.1 MGD)

# The Final Word

- Transition from planning to implementation
  - Time is now
- Build or Retrofit?
  - Retrofit may save money but cost effort
- Characterization studies should move into high gear
  - Wastewater
  - Process
  - Personnel
  - Financing Strategies



# Questions?

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