



WRF 4973: Nutrient Removal Optimization Guidelines

Lower Neuse Basin Association/Neuse River Compliance Association 2022 Wastewater Treatment Plant Operators Training Workshop JB Neethling



WRF 4973 Nutrient Optimization



Neuse River Resource Recovery Facility, Raleigh, N.C.

2 August 2022

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- Tung Nguyen, NextGen Water
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- Orange County Sanitation District, Irvine, CA
- · Philadelphia Water, Philadelphia, PA
- Pima County, Tuscon, AZ
- Raleigh, NC



Introduction

Question 1.....

What does it mean to

"Optimize a WRRF?"

Question 1+.....

What does it mean to

"Optimize a WRRF?...

For Nutrient Removal"

What does Nutrient Removal Plant Optimization Mean?

- Optimization a treatment plant typically mean
 - Reduce the operational cost
 - Improve the performance for reducing nutrients
 - Increase the treatment capacity of the facility
- Optimization for nutrient removal includes
 - Improve reliability of a nutrient removal plant
 - Reduce effluent concentration of a nutrient removal plant
 - Remove some nutrients in a WRRF designed for secondary treatment
 - Implement some other means of nutrient removal (Water reuse, sidestream treatment, etc.)

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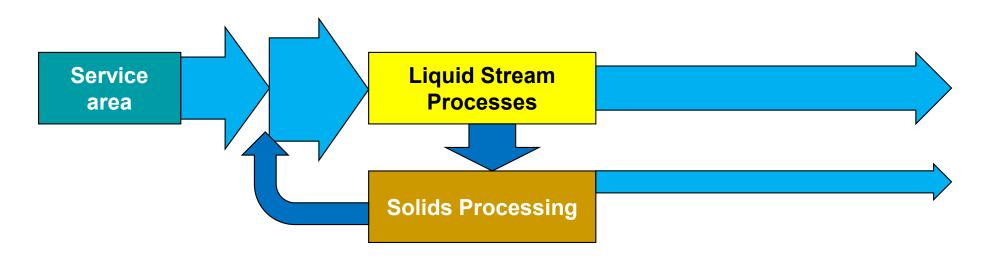
Regulatory Drivers - Examples

Receiving Water/Region	Comment/Goal
San Francisco Bay	 Watershed based nutrient permit – Research funding Monitoring and reporting required Nutrient target limits identified for some utilities
Puget Sound	 Puget Sound Nutrient General Permit Uses annual N loading action levels and treatment performance metrics All known, available, and reasonable technology (AKART) for N removal
Delaware River Watershed	 Delaware River Dissolved Oxygen Partnership (12 municipal dischargers) Focus on NHx reduction
Iowa Nutrient Reduction Strategy	 Mississippi River Basin and down to the Gulf of Mexico Goal: 10 mg TN/L;1 mg TP/L OR 66% TN and 75% TP reduction
Long Island Sound General Permit and Nitrogen Credit Exchange	 Nitrogen originating from New York and Connecticut Credit Exchange Program (2002) N removal optimization studies at WRRFs in the LIS watershed
Chesapeake Bay Watershed General Permit	 Reduce N and P loads to Chesapeake Bay / WLAs to major river basins Watershed-based general permit for 125 dischargers nutrient trading Permit with annual TN and TP mass limits



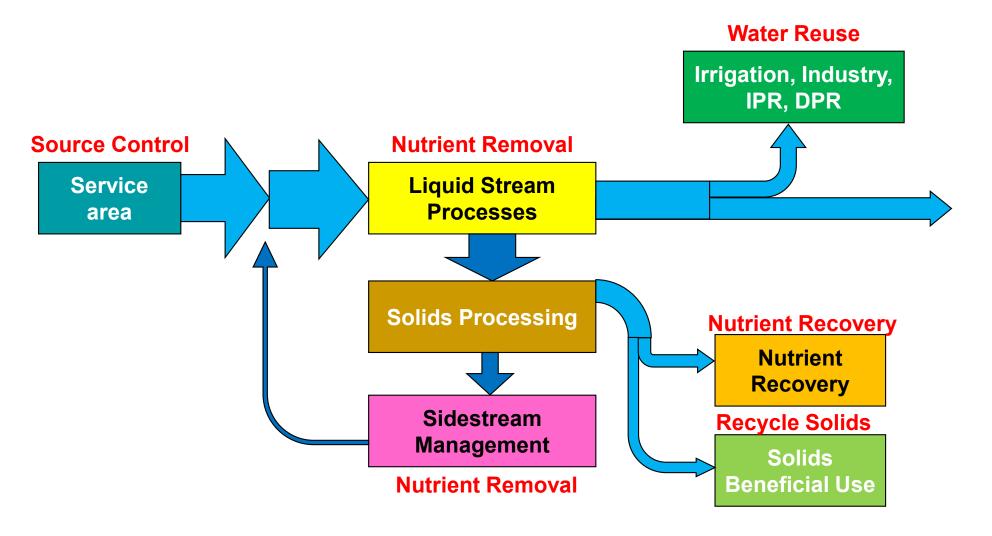
Approach to Nutrient Removal Optimization

Overall Nutrient Fate in a Typical Plant

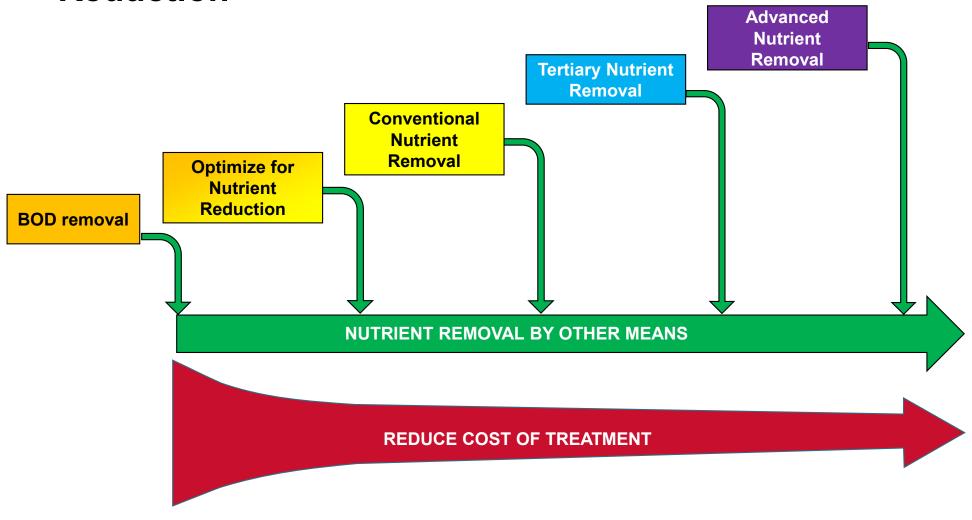


Thickness of line represents the mass flow – the lb/d of N, P, solids, etc.

Consider Overall Nutrient Removal Potential



Nutrient Reduction Pathways – Incremental Nutrient Reduction





What can we do to reduce nutrients AND reduce cost AND improve performance?

Guidance: Decision Tree

Decision Points

Process	Example
Nutrient species	NH4, TN, TP
Current Process	Activated sludge, TF, BNR, lagoon, etc.
Objective	Improve reliability Reduce nutrients Reduce cost
Metric/Benchmark	Yardstick – kWh/MG, \$/lb N, effluent concentration, etc.
Strategies	List potential approaches/strategies to achieve the above goals

Nutrient Removal Treatment Stages (WERF, 2019)

	CNR	TNR	ANR
Primary treatment	Optional Chemical addition for P removal	Optional Chemical addition for P removal	Optional Chemical addition for P removal
Conventional treatment	BNR with suspended growth, biofilm, hybrid	Multistage BNR Chemical addition	Multistage BNR Chemical addition
Tertiary treatment	No	Filtration Chemical addition	Filtration Chemical addition
Advanced Treatment	No	No	Molecular separation, advanced oxidation, biofiltration
Other Features	No Carbon supplement such as ferm fermentation or chemical Side Sidestream management		Carbon supplement such as fermentation or chemical Sidestream management Brine disposal
Performance Range			
Ammonia, mg N/L	2-5	0.5-2	<0.1
TN, mg N/L	8-15	3-8	<0.2
TP, mg P/L	0.5-2	0.03-0.1	<0.01

CNR = Conventional Nutrient Removal; TNR = Tertiary Nutrient Removal; ANR = Advanced Nutrient Removal

Note: Listed performance is based on best judgment for a typical range of effluent. Performance is highly dependent on site-specific conditions (temperature, weather, influent composition, influent strength, industrial contributions, and solids management practices).

Neethling, J.B., Clark, D.L., Stensel, D.H., Sandino, D.H., and Tsuchihashi, R. (2019). "Nutrient Removal Challenge Synthesis Report." WRF Report NUTR5R14g/4827g.

Nutrient Removal Treatment Stages (WERF, 2019)... PLUS

	CNR	TNR	ANR	Secondary Treatment
Primary treatment	Optional Chemical addition for P removal	Optional Chemical addition for P removal	Optional Chemical addition for P removal	Optional
Conventional treatment	BNR with suspended growth, biofilm, hybrid	Multistage BNR Chemical addition	Multistage BNR Chemical addition	Act sludge, TrFilter, Lagoon
Tertiary treatment	No	Filtration Chemical addition	Filtration Chemical addition	No
Advanced Treatment	No	No	Molecular separation, advanced oxidation, biofiltration	No
Other Features	No	Carbon supplement such as fermentation or chemical Sidestream management	Carbon supplement such as fermentation or chemical Sidestream management Brine disposal	BOD and TSS only
Performance Range				
Ammonia, mg N/L	2-5	0.5-2	<0.1	>25
TN, mg N/L	8-15	3-8	<0.2	>30
TP, mg P/L	0.5-2	0.03-0.1	<0.01	>4

CNR = Conventional Nutrient Removal; TNR = Tertiary Nutrient Removal; ANR = Advanced Nutrient Removal

Note: Listed performance is based on best judgment for a typical range of effluent. Performance is highly dependent on site-specific conditions (temperature, weather, influent composition, influent strength, industrial contributions, and solids management practices).

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Decision Points/Sequence in Decision Tree

Small Systems follow a similar structure

Existing process		Unit process	<u>Nutrient</u>	Objective	Evaluate	Strategy
	Casandami	Suspended Growth & Hybrid	Ammonia	Improve Reliability	Benchmark Compare to Metrics	Strategy 1
	Secondary Treatment	Fixed Film	Nitrogen	Reduce Nutrients		Strategy 2
		Lagoon				Strategy 3
		CNR (biological)	Phosphorus	Reduce Cost		
	Conventional	CNR (chemical)	Τησορησίασ			Strategy 4
	Nut Rem	Civit (Gleffical)				Strategy 5
		CNR (bio & chem)				Strategy 6
		TNR (biological)				Oli alegy 0
	Tertiary Nut	TNR (chemical)				
	Rem	TNR (bio & chem)				

CNR Process – Total Nitrogen – SG&Hyb

Conventional Nutrient Removal

Decision Tree Steps: 1→4

 Step 1: Select the Type of Existing Treatment

 Step 2: Select the Nutrient of Interest

 Step 3: Select the Unit Process Type

• Step 4: Select the Objective

2

3

4

NH4-N

TN

TP

Suspended Growth & Hybrid

Improve Reliability

Reduce Nutrient

Reduce Cost

In this case, reducing TN for a suspended growth plant currently providing secondary treatment

Decision Tree Step: 5

CNR Process – Total Nitrogen – SG&Hyb

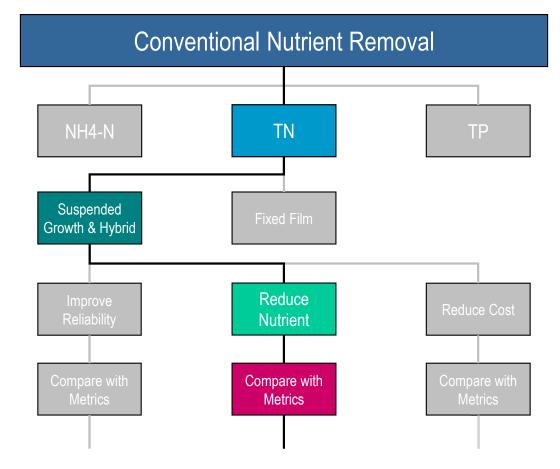
Compare with Metrics:

Evaluate Room for Improvement 2

3

4

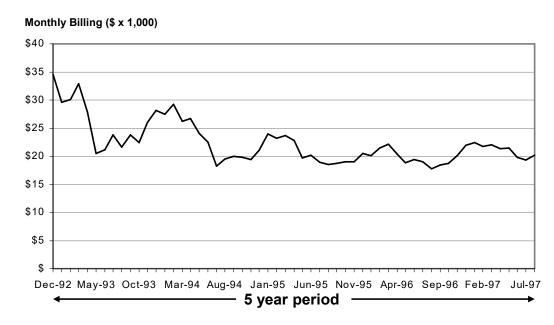
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Example KPI and Metric

A good KPI will:

- Clearly define and identify quantifiable measurements
- Set the performance period weekly, monthly, annual, instantaneous
- Normalize values to key process performance driver
- Adjust for special conditions/periods

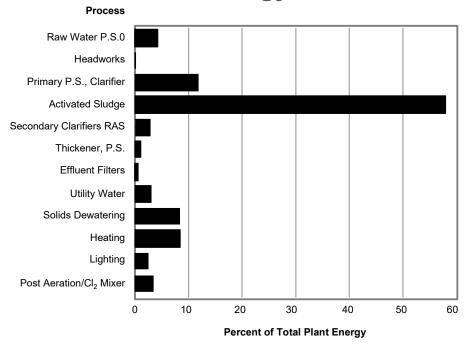


Cost for 4.5 mgd WRRF after installing Energy Management System

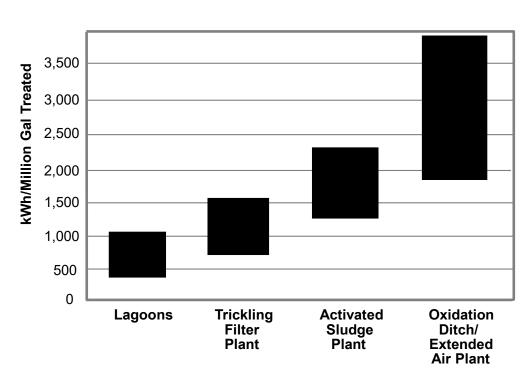
Reardon (1998) Energy Usage Wastewater treatment plants Waterworld Aug 31 1998

Metrics for Comparison

Distribution of Energy Use



Normalized Performance Metric

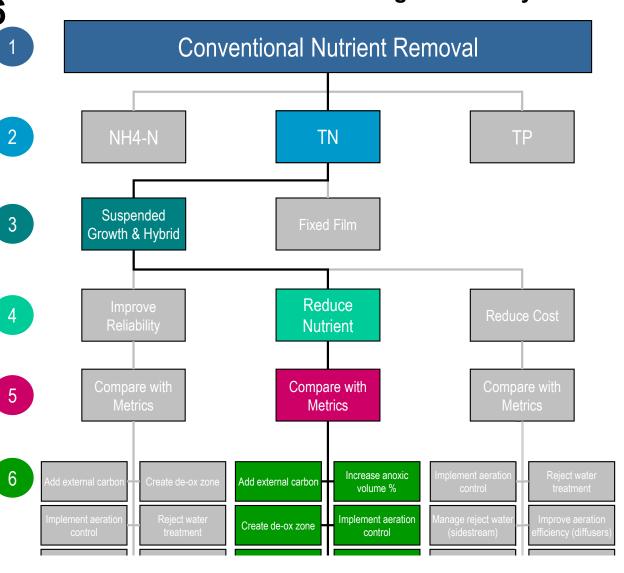


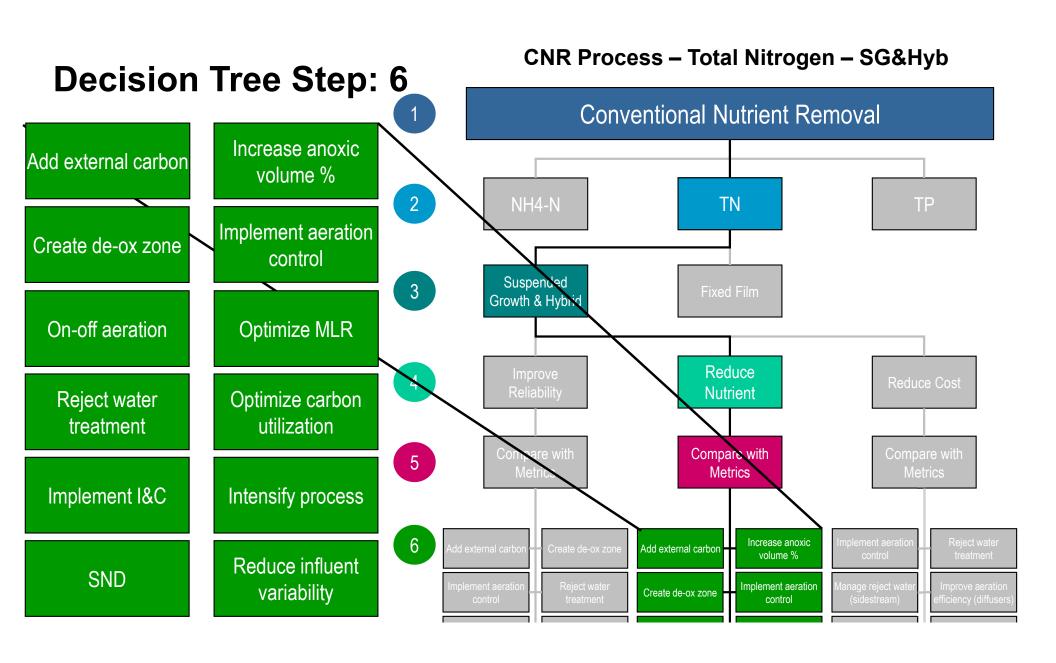
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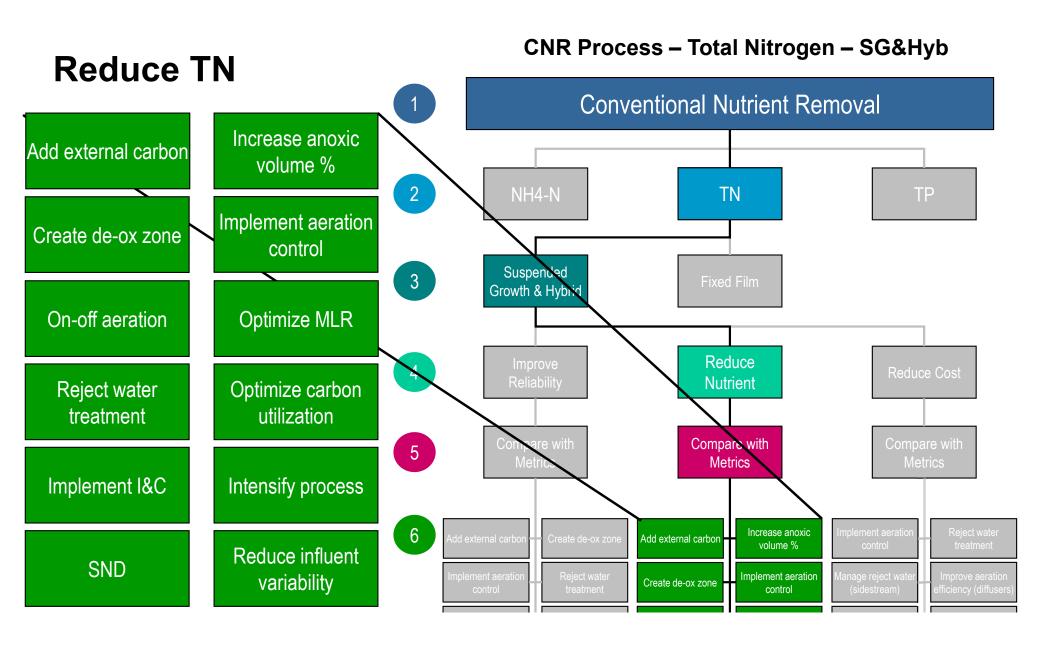
Decision Tree Step: 6

- Find potential strategies
- Additional details provided in corresponding Fact Sheet(s)

CNR Process – Total Nitrogen – SG&Hyb







CNR Process – Total Nitrogen – SG&Hyb Reduce TN **Conventional Nutrient Removal** Increase anoxic Add external carbon volume % 2 Which if these strategies do you know of? Implement aeration Create de-ox zone control 3 Which have you used/operated? On-off aeration Optimize MLR What other strategies can you think of? Optimize carbon Reject water treatment utilization Compare with Compare with 5 Metrics Implement I&C Intensify process 6 Increase anoxic Add external carbon volume % Reduce influent **SND** Implement aeration variability Create de-ox zone

CNR Process – Total Nitrogen – SG&Hyb

TN Removal Cost

Implement aeration control

Manage reject water (sidestream)

On-off aeration

Add external carbon

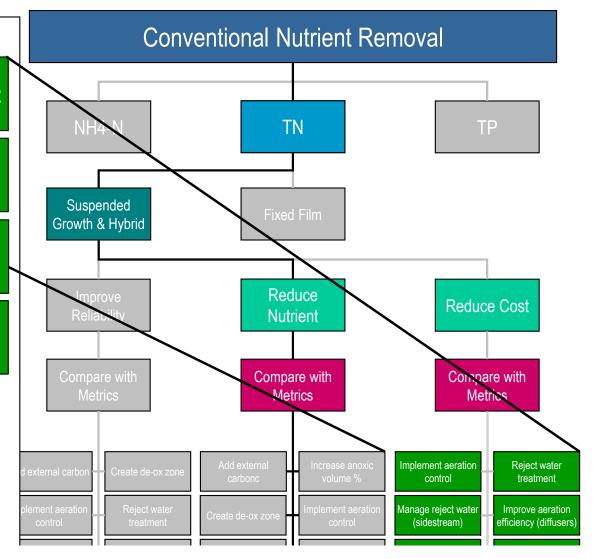
Import carbon

Reject water treatment

Improve aeration efficiency (diffusers)

Implement I&C

Optimize carbon utilization



CNR Process – Total Nitrogen – SG&Hyb

TN Removal Cost

Implement aeration control

Manage reject water (sidestream)

On-off aeration

Add external carbon

Import carbon

Reject water treatment

Improve aeration efficiency (diffusers)

Implement I&C

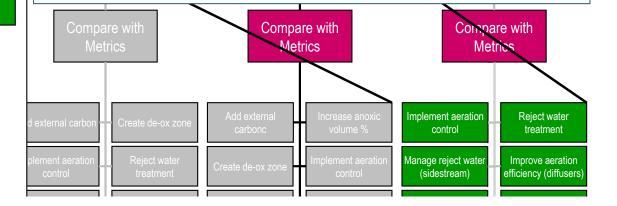
Optimize carbon utilization

Conventional Nutrient Removal

Which if these strategies do you know of?

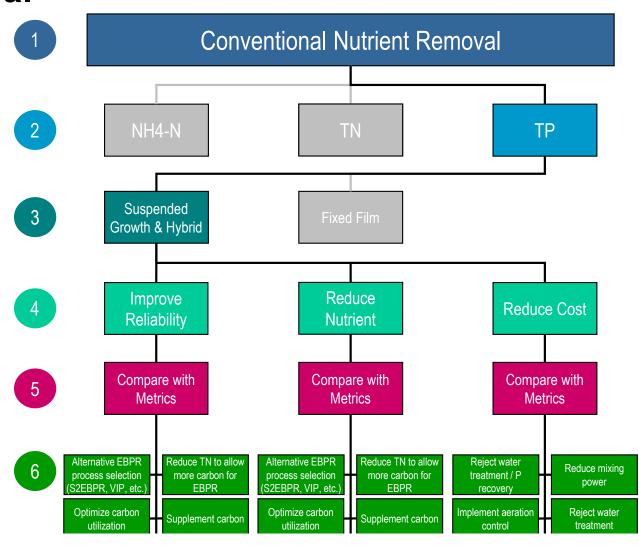
Which have you used/operated?

What other strategies can you think of?

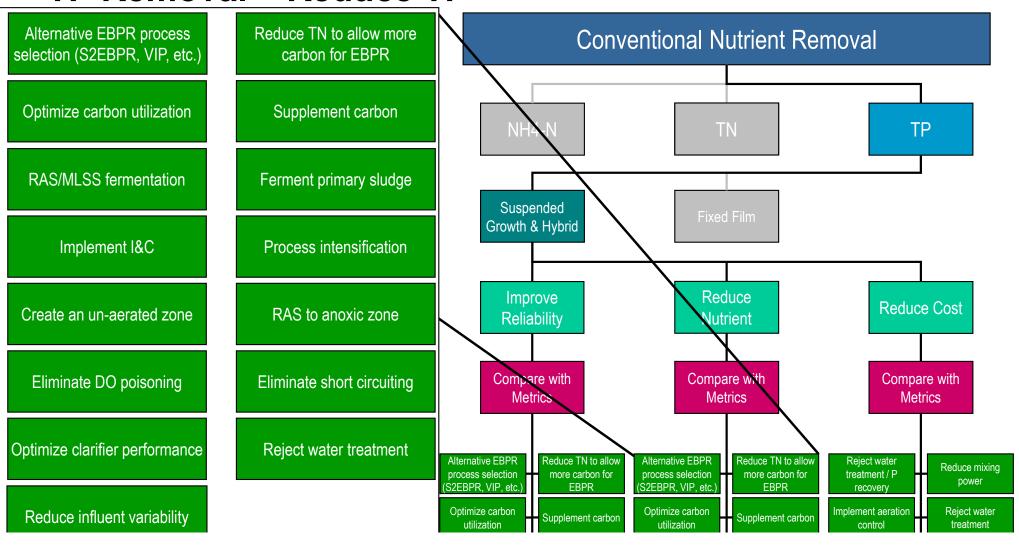


Phosphorus Removal

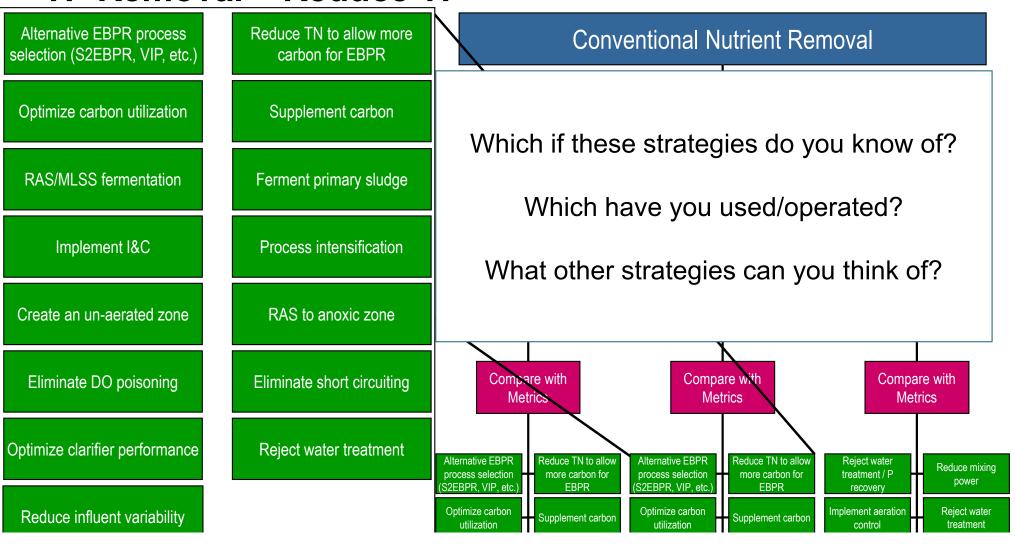
CNR Process – Total Phosphorus – SG&Hyb



TP Removal – Reduce TP CNR Process – Total Phosphorus – SG&Hyb



TP Removal – Reduce TP CNR Process – Total Phosphorus – SG&Hyb



TP Removal - COST

CNR Process – Total Phosphorus – SG&Hyb

Reject water treatment
/ P recovery

Implement aeration control

Manage reject water (sidestream)

Implement I&C

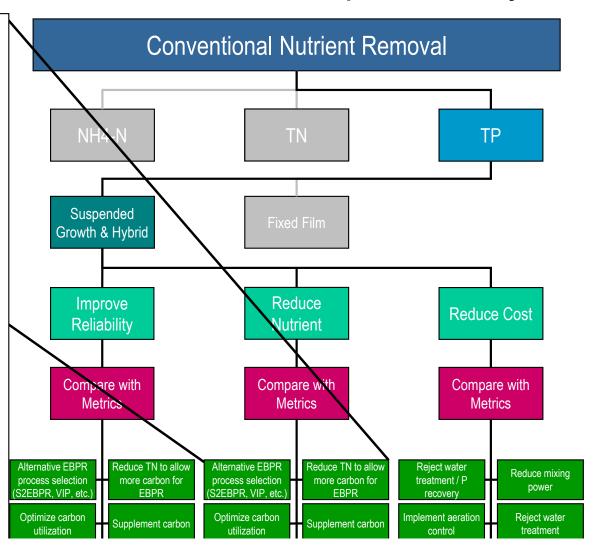
Optimize carbon utilization

Reduce mixing power

Reject water treatment

Improve aeration efficiency (diffusers)

Add external carbon



TP Removal - COST

CNR Process – Total Phosphorus – SG&Hyb

Reject water treatment
/ P recovery

Implement aeration control

Manage reject water (sidestream)

Implement I&C

Optimize carbon utilization

Reduce mixing power

Reject water treatment

Improve aeration efficiency (diffusers)

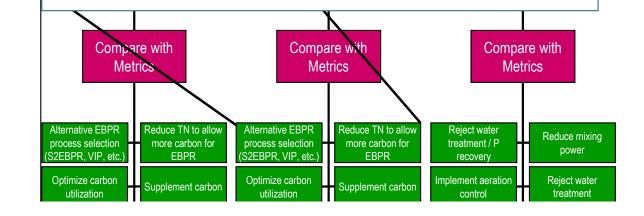
Add external carbon

Conventional Nutrient Removal

Which if these strategies do you know of?

Which have you used/operated?

What other strategies can you think of?



Guidelines for Optimizing Nutrient Removal Plant Performance

Fact Sheets Provide Basic **Information About Strategies**

- Summary of strategies 5-8 page
- Series with increasing level of detail
- Description, typical application of strategy, examples, benefits, limitations, fatal flaws, footprint, references...
- Identify other related fact sheets
- Additional information to inform application

WRF 04973 Fact Sheet —ID 1101

Strategy: Process Intensification

Process Intensification Overview





Guidelines for Optimizing Nutrient Removal Plant Performance

treatment capacity within a basin." The goal is typically to something different (such as achieve nutrient removal), to capacity of a treatment process by retaining more biomass or gain additional treatment capacity

Strategies can broadly be categorized in three groups. The increase the biomass in the system by changing the operati changing the biological process to grow granules, increasing and operating in step feed mode, amongst other options. T changes to operate with more aggressive SRT or reduced D operating in simultaneous nitrification/denitrification mode group of strategies are those that add equipment to the big or biomass carriers including IFAS or MOB, to enhance bion improve the nutrient removal capacity

This fact sheet provides an overview of these strategies. Se

Descriptions/Evaluation

Process intensification strategies include technologies and process configurat increase the treatment performance and/or capacity of existing infrastructure any significant major concrete structures or equipment. Some capital investme required for some of these strategies. Examples of intensification strategies in

- feed operation, adding media for biofilm growth (integrated fixed-film activa IFAS), selective solids separation, etc.
- Modify process operation to achieve nutrient removal by increasing SRT, imp settleability with high F/M selectors, modify operation to simultaneous nitrification/denitrification (SNDN), control changes such as ammonia-bas control (ABAC), etc.
- Modify basins by creating anaerobic/anoxic/aerobic zones for BNR, elimin circuiting in basins, install equipment to promote nutrient removal such as m aerated bioreactor (MABR), etc.
- Reduce loading to BNR process with i enhanced primary treatment (CEPT).

APPLICATION

DESCRIPTION

- · Existing plant with limited space available for expansion or achieving
- Convert existing conventional activated sludge or nitrifying activated sludge achieve some nutrient removal.
- Improve reliability of nutrient removal with increased biomass
- Improve operational ease with increase settleability.

Intensifying opportunities for fixed film processes, such as trickling filters, are r Intensification can be achieved with equipment changes (modifying wetting rate) mechanical airflow/blower, etc.) and by reducing organic loading (using CEPT of

CONSTITUENTS REMOVED

Intensification is used to achieve nitrogen and/or phosphorus removal, increas capacity and improve treatment reliability. See the specific technologies in Tab their specific nutrient removal capabilities and more information





List of Fact Sheet Strategy Groups (2-3 in each group)

Number Series	Strategy Group	Improve Reliability	Reduce Effluent Nutrients	Reduce Operations Cost
1100	Process intensification	✓	✓	✓
1300	Chemical testing and dose optimization	✓	✓	
1400	Carbon management	✓	✓	✓
1500	Instrumentation and control	✓		✓
1600	Reject water (reject water) management	✓	✓	✓
1700	Reduce energy use			✓
1800	Reuse chemical sludge	✓		✓
1900	Change to operational practices			✓
2000	Manage nutrients outside WRRF		✓	
2100	Small systems	✓	✓	
2200	Regulatory strategies			

Add external carbon

Increase anoxic volume %

Create de-ox zone

Implement aeration control

On-off aeration

Optimize MLR

Reject water treatment

Optimize carbon utilization

Implement I&C

Intensify process

SND

Reduce influent variability

Create List of Site-Specific Strategies

- Evaluate applicability to WRRF and create a list of site-specific strategies
- Consider available unused basins, loading conditions, age of infrastructure, environmental factors, investment needs/available funding, etc.
- ADD strategies to the site-specific list:
 - Get staff input (operator, maintenance, lab, process analyst, management, etc.)
 - Engage subject matter experts
 - Use WEF/WRF/professional associations tools
- Refine/Prioritize/Evaluate/Full scale testing





Nutrient Reduction Optimization Example

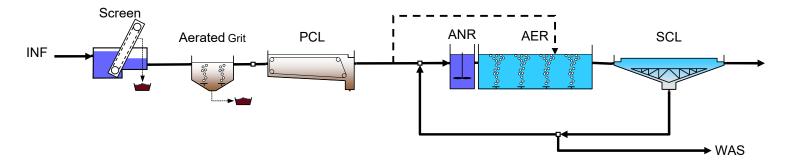
Confidential WRRF

Reduce Nutrient Discharge from a Secondary WRRF



Description of WRRF

- Process: Secondary activated sludge located in moderate climate
 - Operating at 1.5 d SRT
 - MLSS 1500 mg/L
 - Plug flow tanks with step feed for peak wet weather condition
 - Anaerobic selector for settleability does not function well
- Plant loading currently 50% of design
- Anaerobic digestion and dewatering



Decision Tree Application

Secondary Process

2

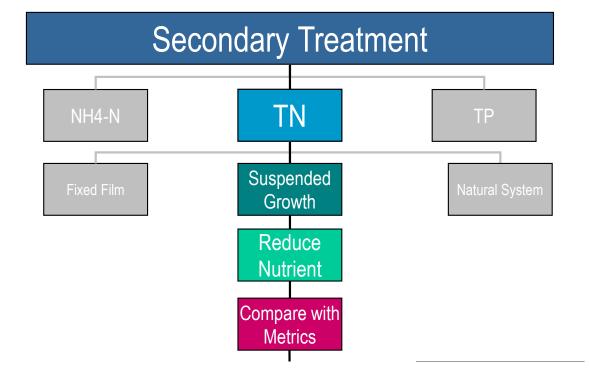
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- Nutrient = TN
- Suspended Growth
- Goal: Reduce nutrients
- Skip metrics permit requirement
- Strategies See #6 to the right in green

Secondary Process - TN - Suspended Growth Process



What strategies can you think of?

Decision Tree Application

- Secondary Process
- Nutrient = TN
- Suspended Growth
- Goal: Reduce nutrients
- Skip metrics permit requirement
- Strategies See #6 to the right in green

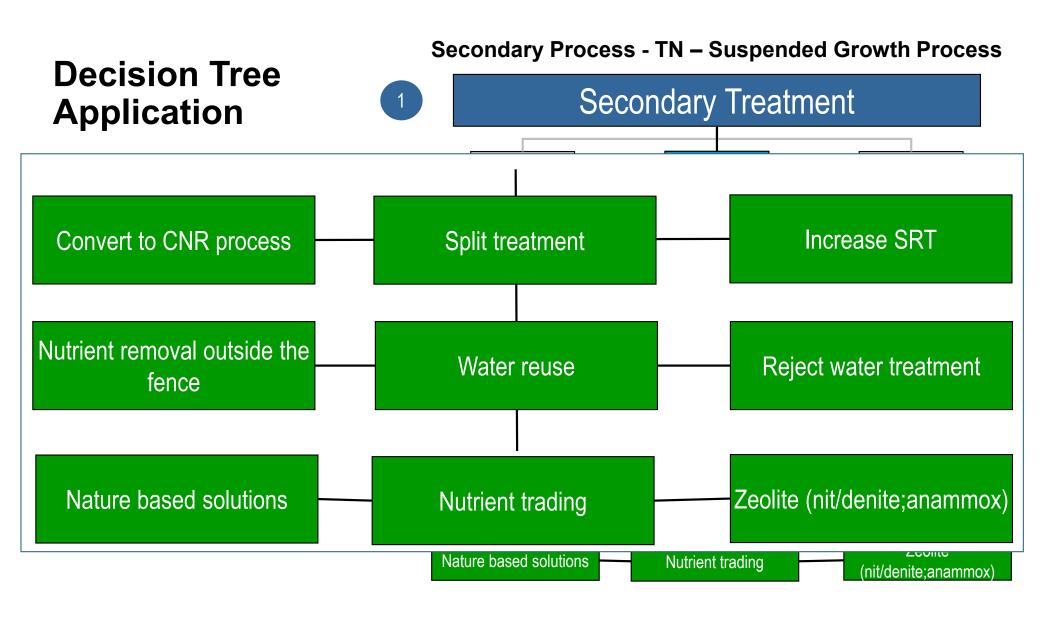
Secondary Process - TN – Suspended Growth Process Secondary Treatment 2 TN NH4-N TP Suspended 3 Growth Reduce **Nutrient** Compare with 5 **Metrics** Convert to CNR process 6 Split treatment Increase SRT Nutrient removal outside Reject water treatment Water reuse the fence

Nutrient trading

Nature based solutions

Zeolite

(nit/denite:anammox)



Initial List of Strategies

No	Strategy	Initial Reaction	Comment
1	Convert to CNR process	Potentially	Need to evaluate
2	Nutrient removal outside the fence	N/A	
3	Nature based solutions	N/A	
4	Split treatment	Possible	Not very attractive to operations
5	Water reuse	N/A	
6	Nutrient trading	Future perhaps	
7	Increase SRT	Potentially	Need to evaluate
8	Reject water treatment	Potential	Anticipate to be costly
9	Zeolite (ion exchange)	N/A	

Eliminate Unattractive Strategies

No	Strategy	Initial Reaction	Comment
1	Convert to CNR process	Potentially	Need to evaluate
2	Nutrient removal outside the fence	N/A	
3	Nature based solutions	N/A	
4	Split treatment	Possible	Not very attractive to operations
5	Water reuse	N/A	
6	Nutrient trading	Future perhaps	
7	Increase SRT	Potentially	Need to evaluate
8	Reject water treatment	Potential	Anticipate to be costly
9	Zeolite (ion exchange)	N/A	

Add Detail and More Site-Specific Strategies

No	Strategy	Detail/Feature	Comment
7	Increase SRT	Reduce wasting and allow MLSS to increase to >3000 mg/L Operating SRT 4-6 days	Required for nitrification. Plant currently at 50% capacity so could increase SRT
1A	CNR option	Increase RAS to return NOx and make Anaerobic selector Anoxic	RAS limited to 80% of influent. Concern with SVI.
1B	CNR option	Install MLR recycle from aerobic to unaerated selector to denitrify	Require investment in pumps/piping – need to evaluate
1C	CNR option	Convert to step feed and create anoxic zone downstream for denitrification	Require basin modification and loss of aerobic volume
8	Reject water treatment	Add deammonification or other process to reduce NHx return flow 20-25%	Potentially costly. Conduct life cycle cost comparison

Selected Solution

Proceed with step-wise implementation

- Implement Strategies 7 and 1A
 - 7: Increase SRT to nitrify
 - 1A: Increase RAS to return NOx and make Anaerobic selector Anoxic and denitrify
- Further evaluate Strategies 1B, 1C, and 8
 - 1B: Install MLR for internal NOx recycle to anoxic zone
 - 1C: Step feed to a second anoxic zone
 - 8: Treat reject water to reduce NHx return
 - These strategies "competes" and requires investment. Do life cycle analysis to select desired option.

WRF Resources

WRF Resources

- WRF 4973 report to be published in 2023
- Webinar series is available for view
 - Thirteen 2-hr sessions
 - Operator/optimization focused webinars in red
- Online:
 - Go to https://www.waterrf.org/
 - Search "4973"
 - Scroll to webinar of choice

No	Webinar	
1	Applied Fundamentals for N and P Removal Optimization	
2	Emerging Technologies for Nutrient Optimization	
3	Beyond Liquid Treatment: Reduce Nutrient Discharge Loads by Other Means	
4	Sidestream Management Optimize WRRF Nutrient Removal	
5A	Instrumentation and Control – Part 1: Sensors	
5B	Instrumentation and Control - Part 2: Controls	
6	Strategies to reduce O&M Cost in Nut Removal WRRFS	
7	Nutrient Reduction from Secondary (BOD WRRFs)	
8	Optimizing Nutrient Removal WRRFs	
9	Nutrient Reduction Approaches for Small Systems	
10	Optimize Nutrient Removal WRRF Operations	
11	Tools to Evaluate Nutrient Optimization in WRRFs	
12	Nutrient Discharge Permitting and WRRF Optimization	

6 Strategies to reduce 0&M Cost in Nutrient Removal WRRFS

WEBCAST 05/26/2021 0 Public Plus

10 Optimize Nutrient Removal WRRF Operations

WEBCAST 08/04/2021 0 Public Plus



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