HDR

WRF 4973: Nutrient Removal Optimization Guidelines

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

JB Neethling

THE Water Research FOUNDATION

WRF 4973 Nutrient Optimization

HDR

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

2 August 2022

WRF Team Participants

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Project Advisory Committee (PAC)

- Gary Johnson (lead)
- Tung Nguyen, NextGen Water
- Ed Kobylinski, Black and Veatch

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Small Community Advisory Team

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- BACWA, San Francisco, CA
- City of Henderson, Henderson, NV
- Des Moines Water Reclamation Authority, Des Moines, IA
- HRSD, Virginia Beach, VA
- LA County Sanitation District, Los Angeles, CA
- 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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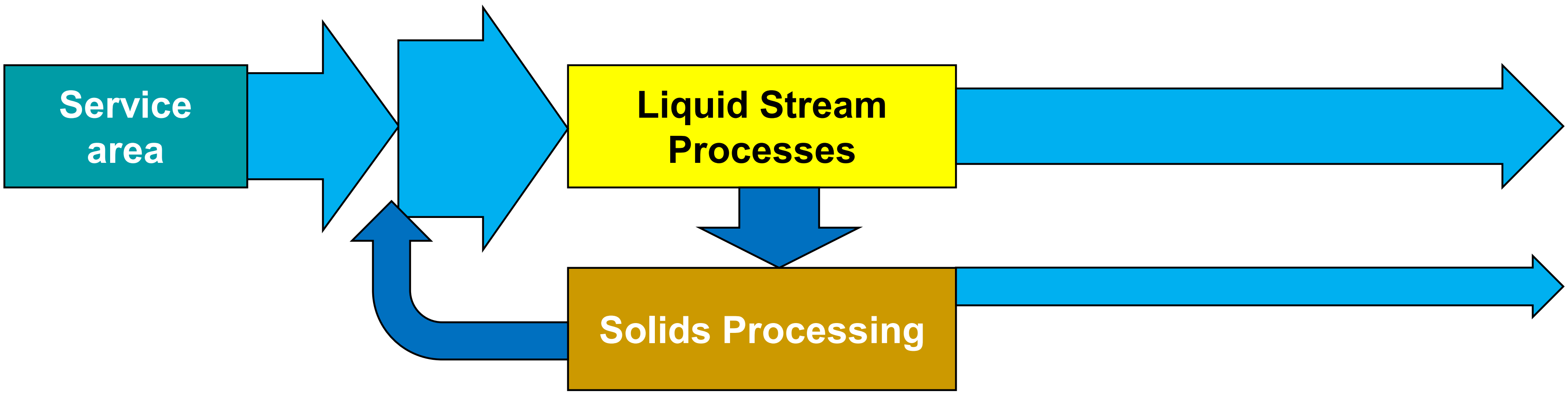
ALL OF THE ABOVE

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

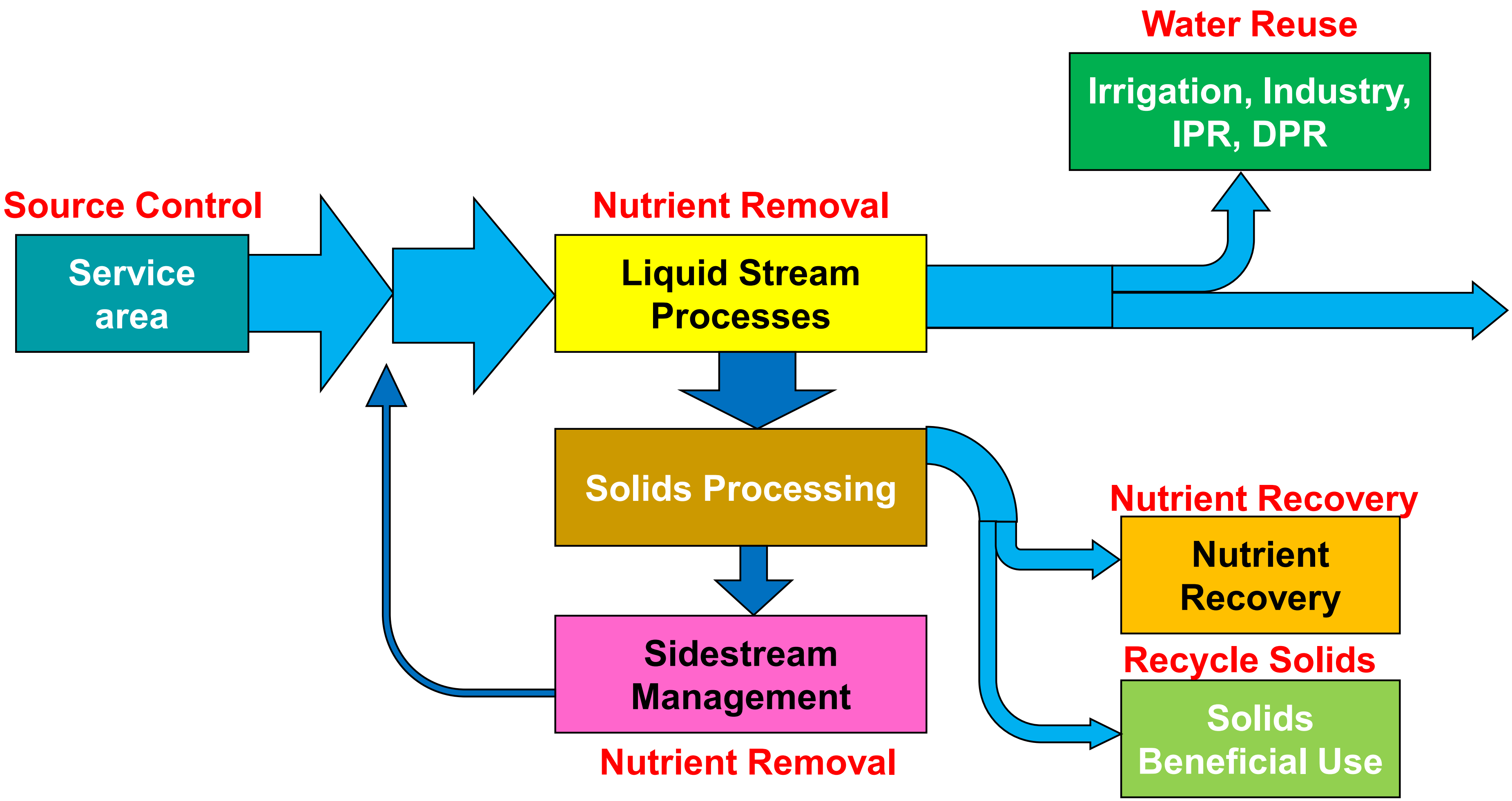
Approach to Nutrient Removal Optimization

Overall Nutrient Fate in a Typical Plant

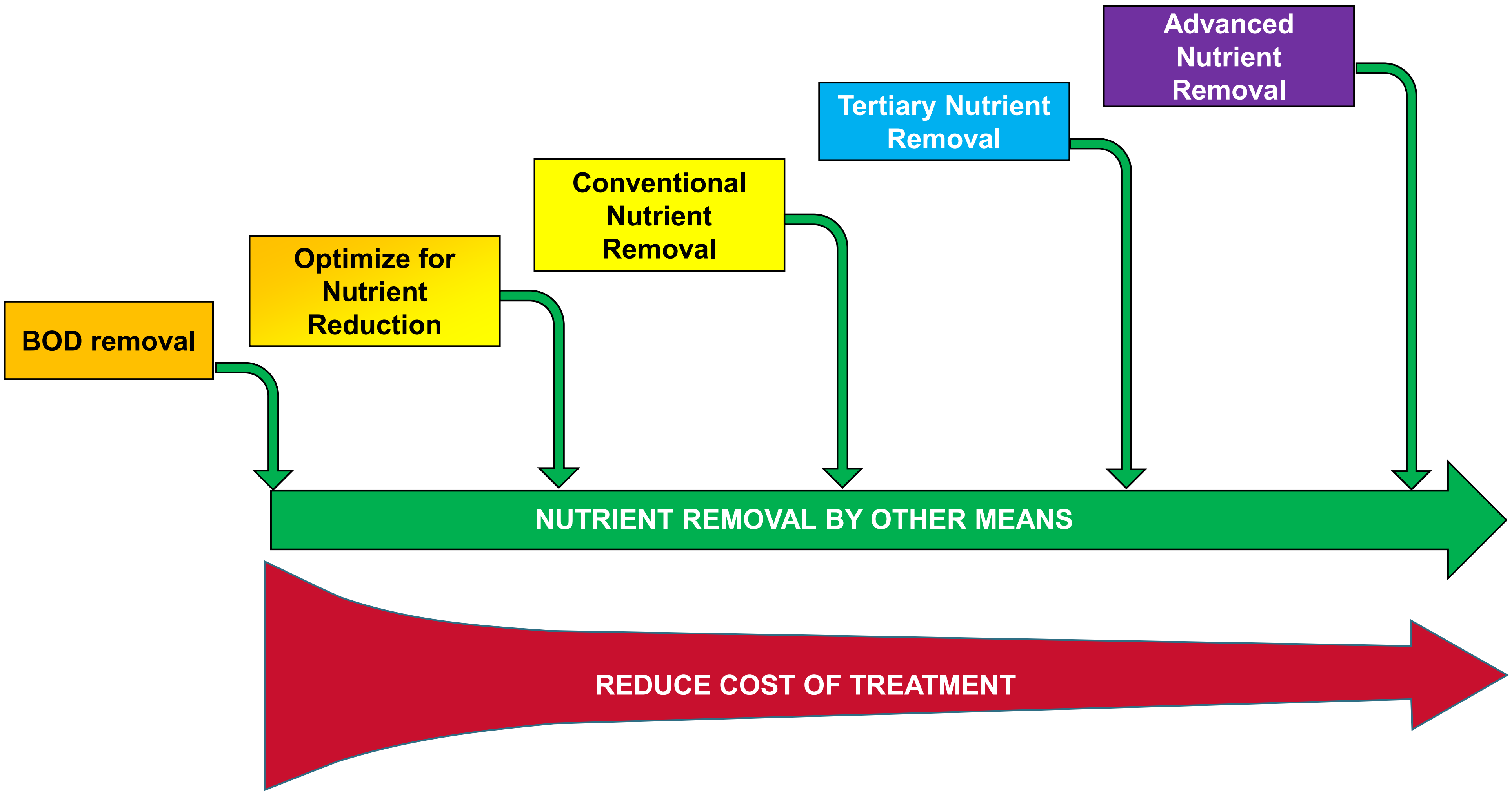


Thickness of line represents the mass flow – the lb/d of N, P, solids, etc.

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 fermentation or chemical 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

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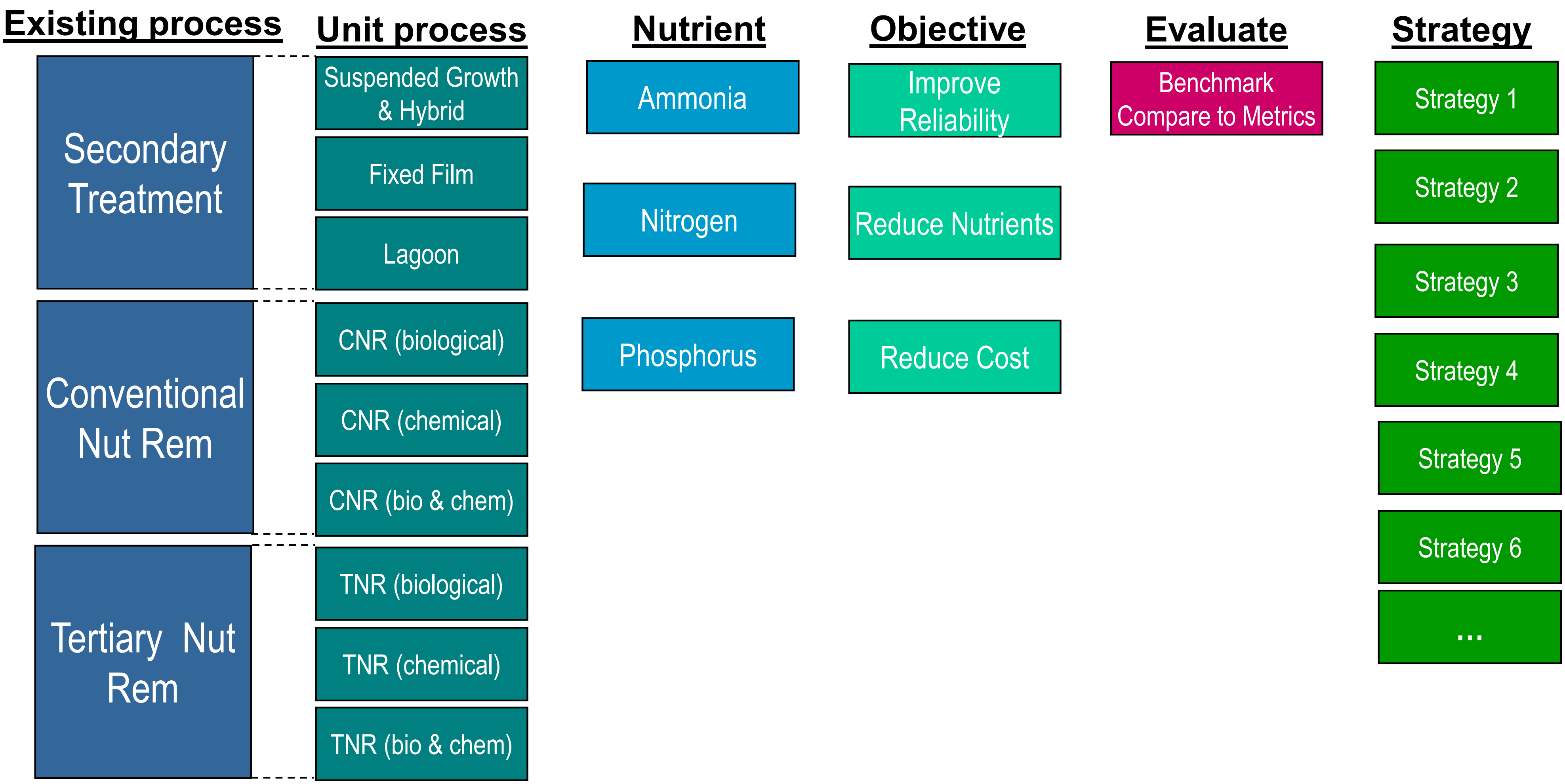
Decision Points/Sequence in Decision Tree

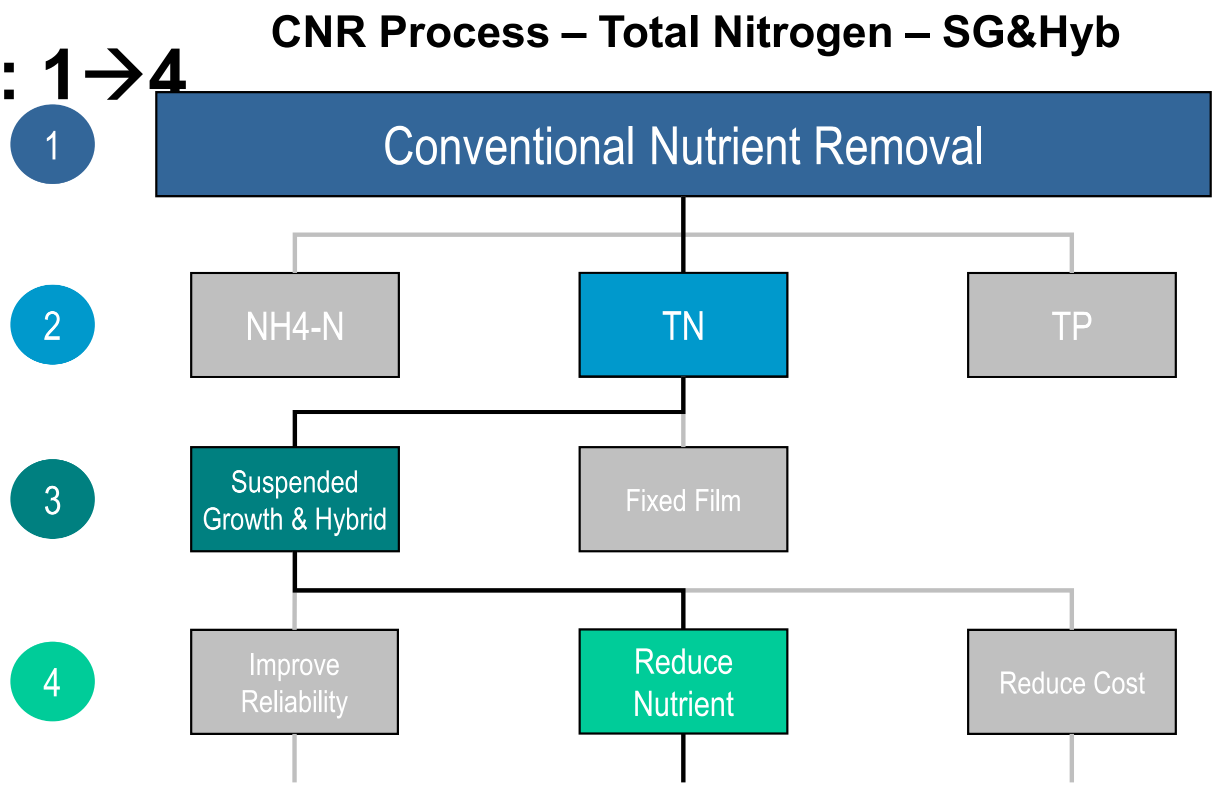
Small Systems follow a similar structure



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

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

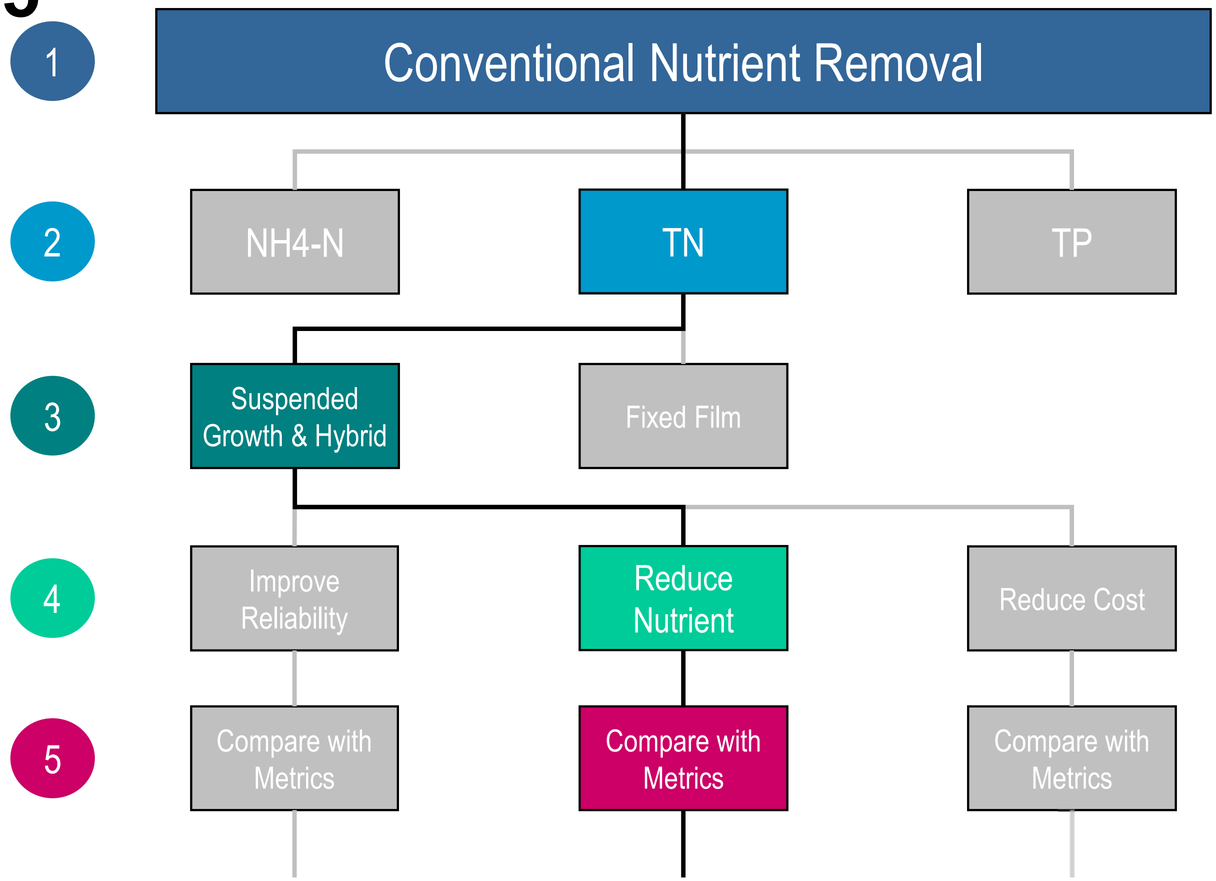


Decision Tree Step: 5

Compare with Metrics:

Evaluate Room for Improvement

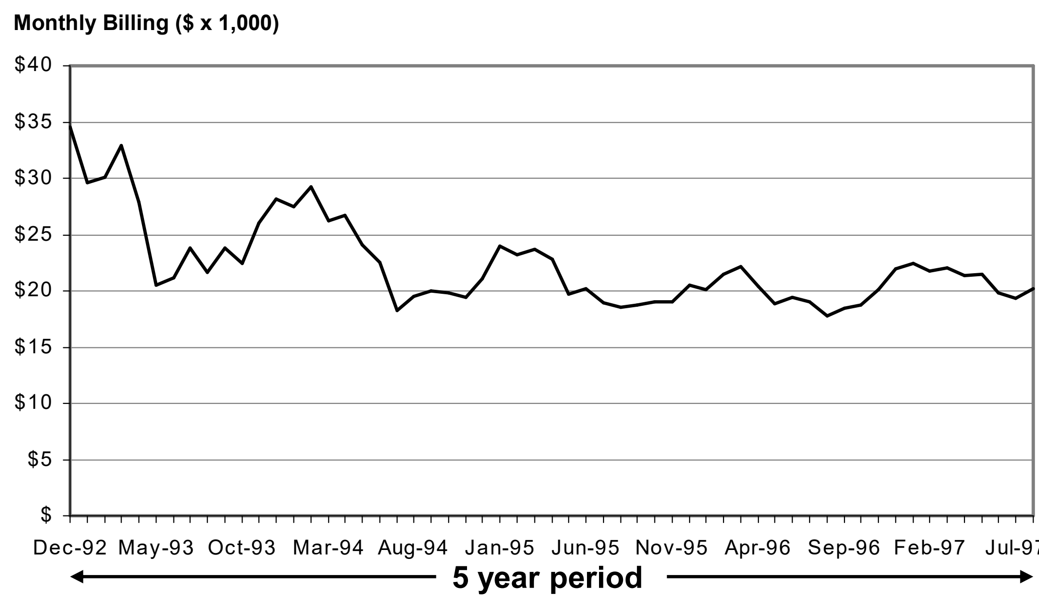
CNR Process – Total Nitrogen – SG&Hyb



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

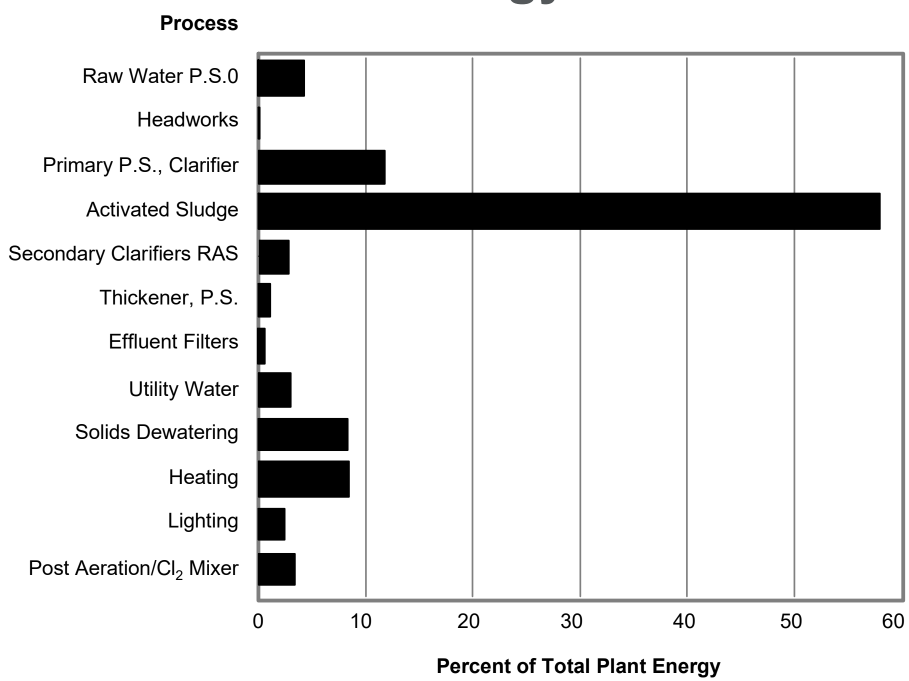


Cost for 4.5 mgd WRRF after installing Energy Management System

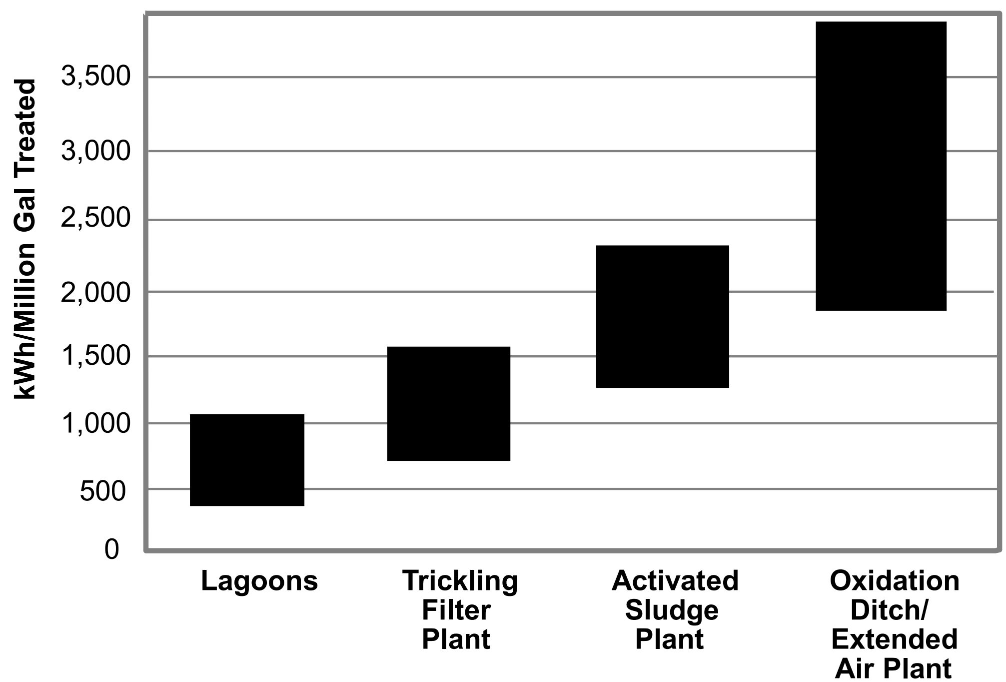
Reardon (1998) Energy Usage Wastewater treatment plants Waterworld Aug 31 1998

Metrics for Comparison

Distribution of Energy Use



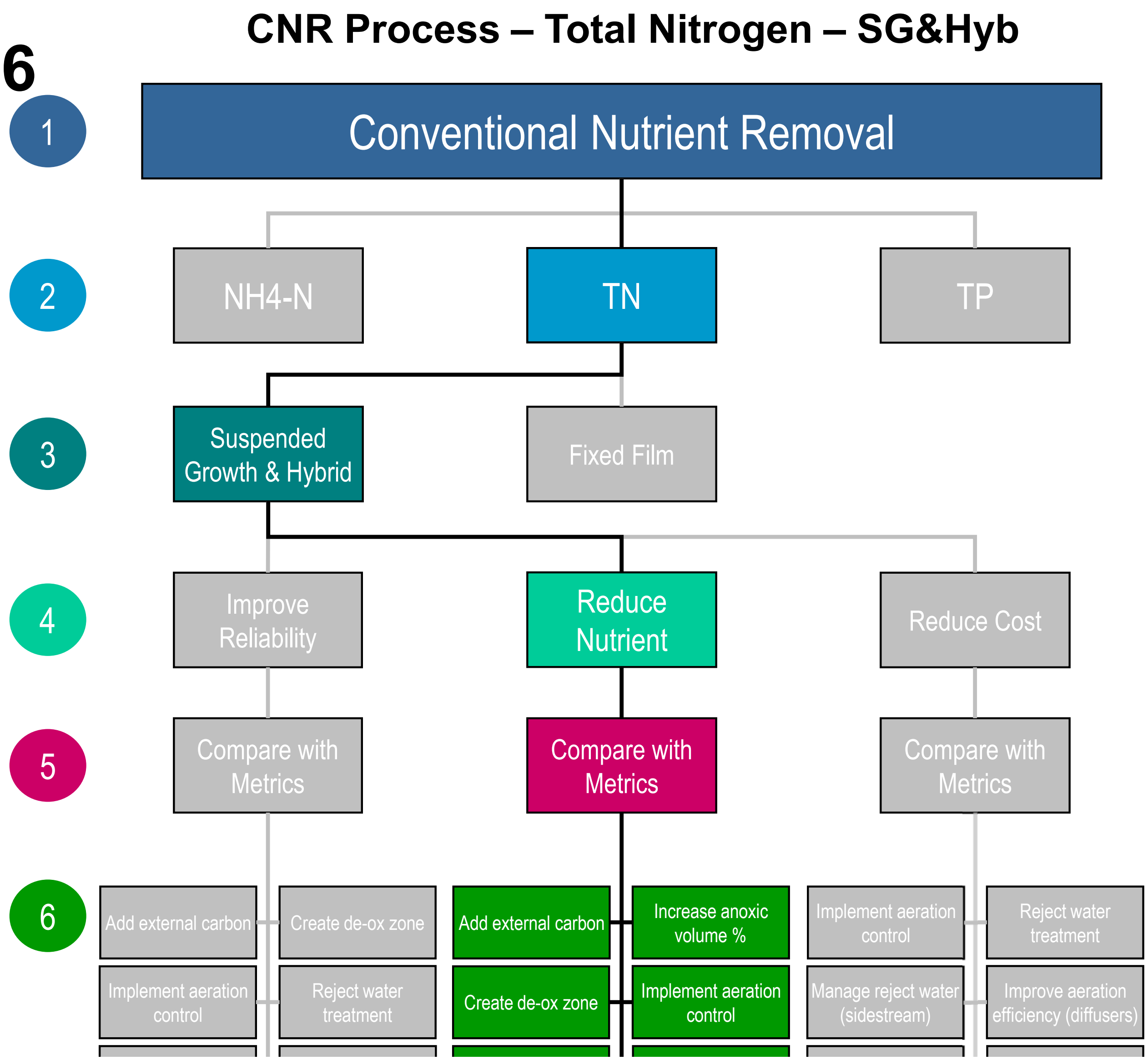
Normalized Performance Metric



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

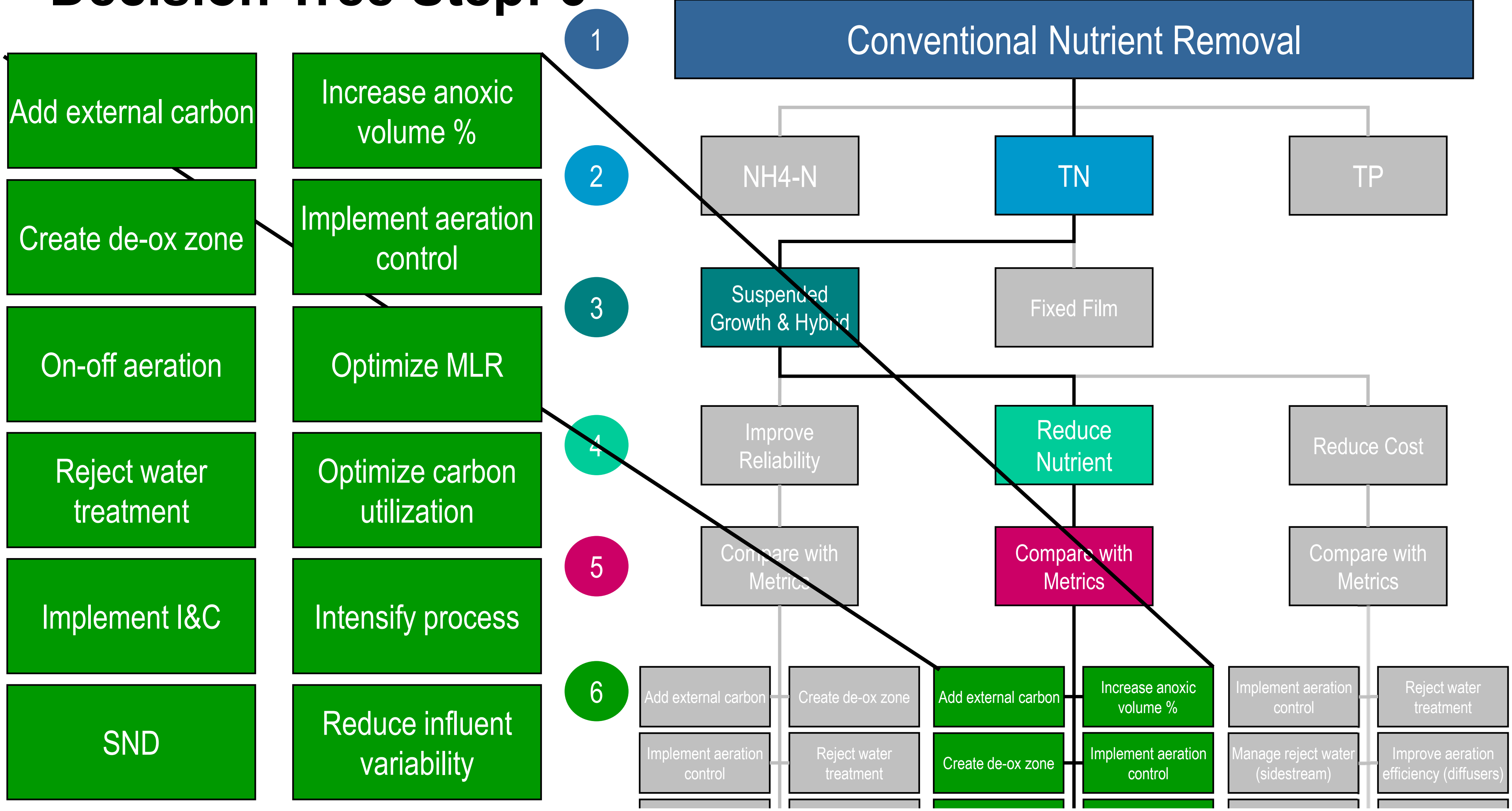
Decision Tree Step: 6

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



Decision Tree Step: 6

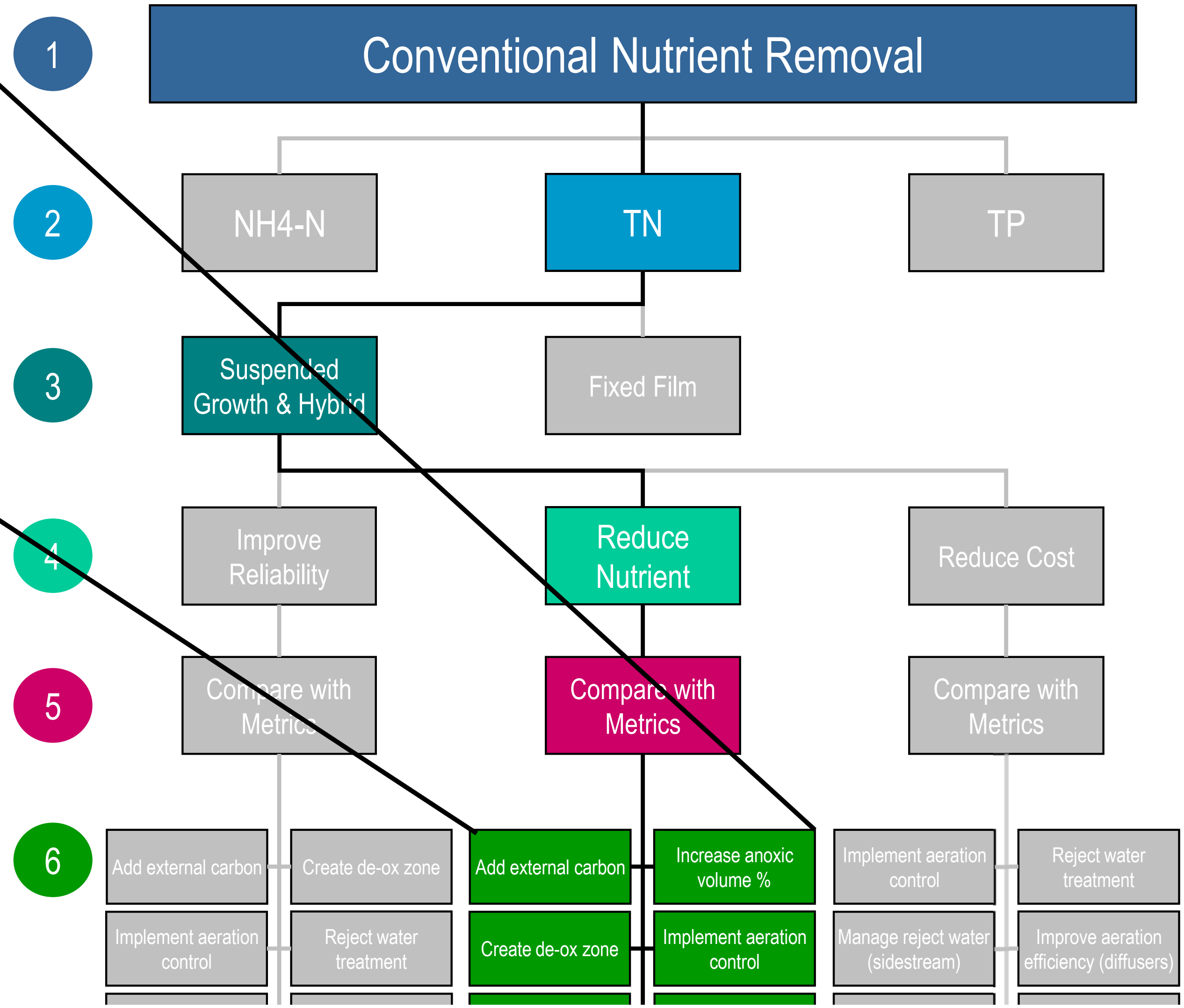
CNR Process – Total Nitrogen – SG&Hyb



Reduce TN

- 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

CNR Process – Total Nitrogen – SG&Hyb



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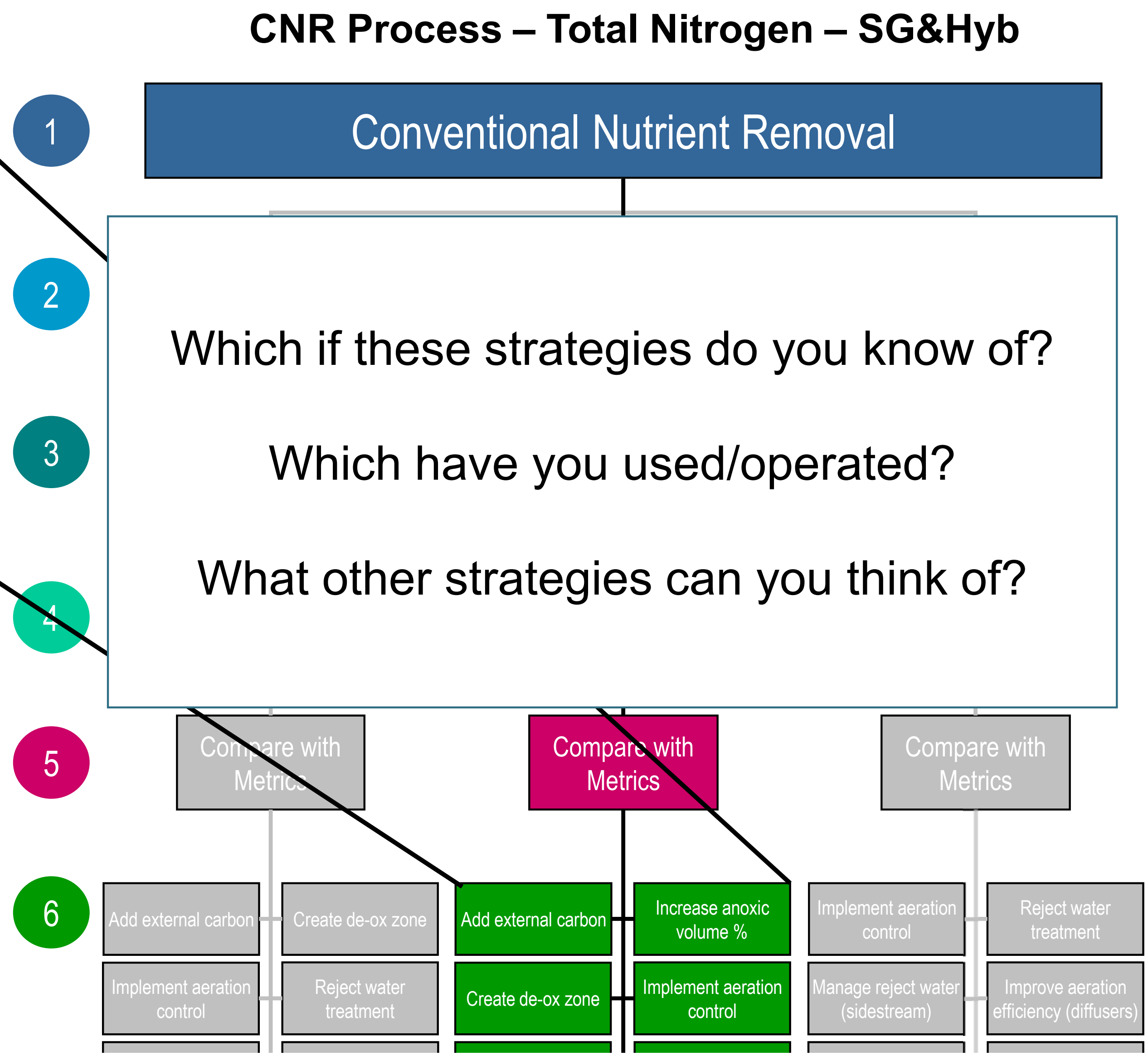


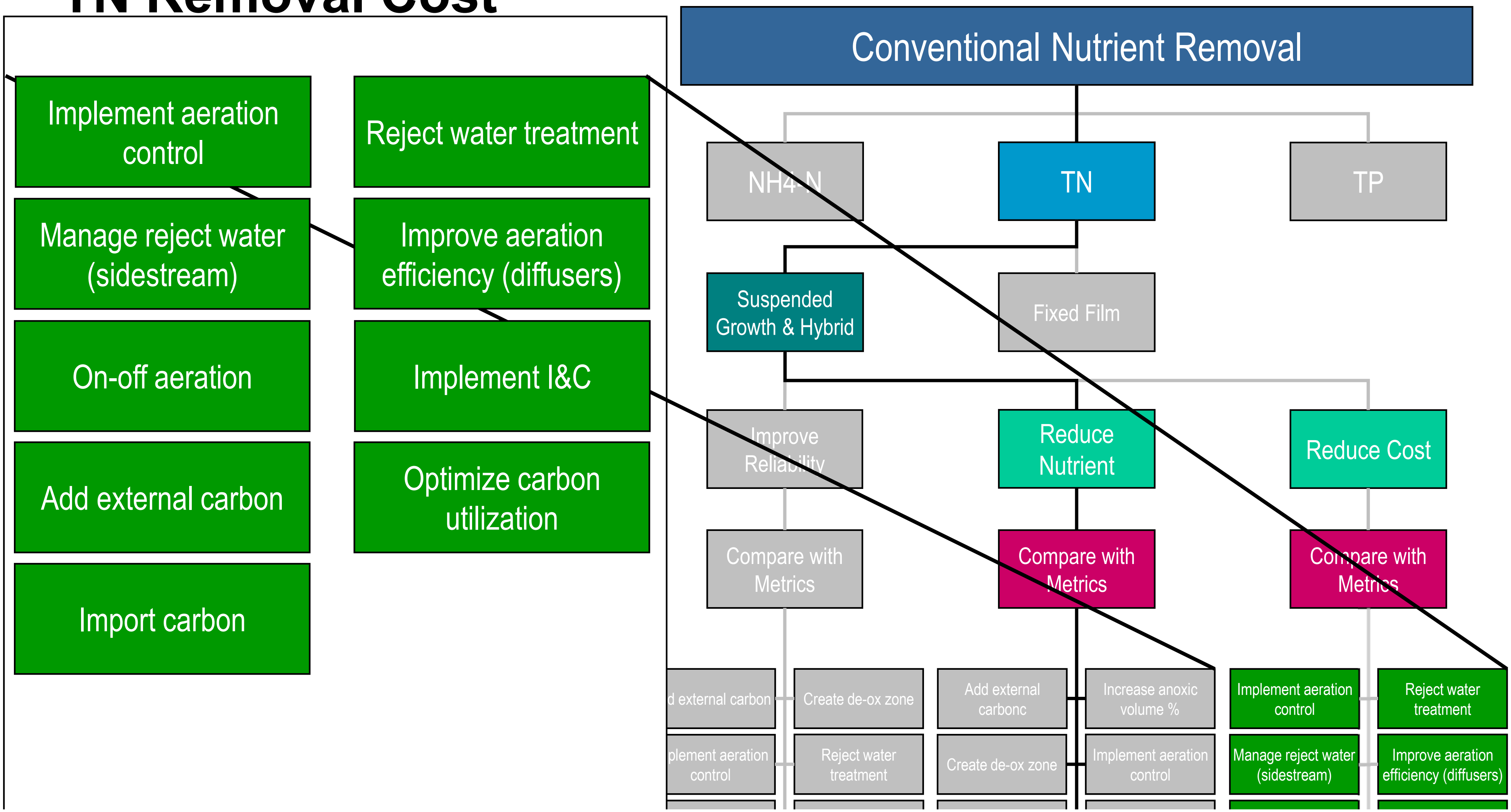
Which if these strategies do you know of?

Which have you used/operated?

What other strategies can you think of?

TN Removal Cost

CNR Process – Total Nitrogen – SG&Hyb



TN Removal Cost

- Implement aeration control
- Reject water treatment
- Manage reject water (sidestream)
- Improve aeration efficiency (diffusers)
- On-off aeration
- Implement I&C
- Add external carbon
- Optimize carbon utilization
- Import carbon

CNR Process – Total Nitrogen – SG&Hyb

Conventional Nutrient Removal

Which if these strategies do you know of?

Which have you used/operated?

What other strategies can you think of?

Compare with Metrics

Compare with Metrics

Compare with Metrics

d external carbon

Create de-ox zone

Add external carbonc

Increase anoxic volume %

Implement aeration control

Reject water treatment

plement aeration control

Reject water treatment

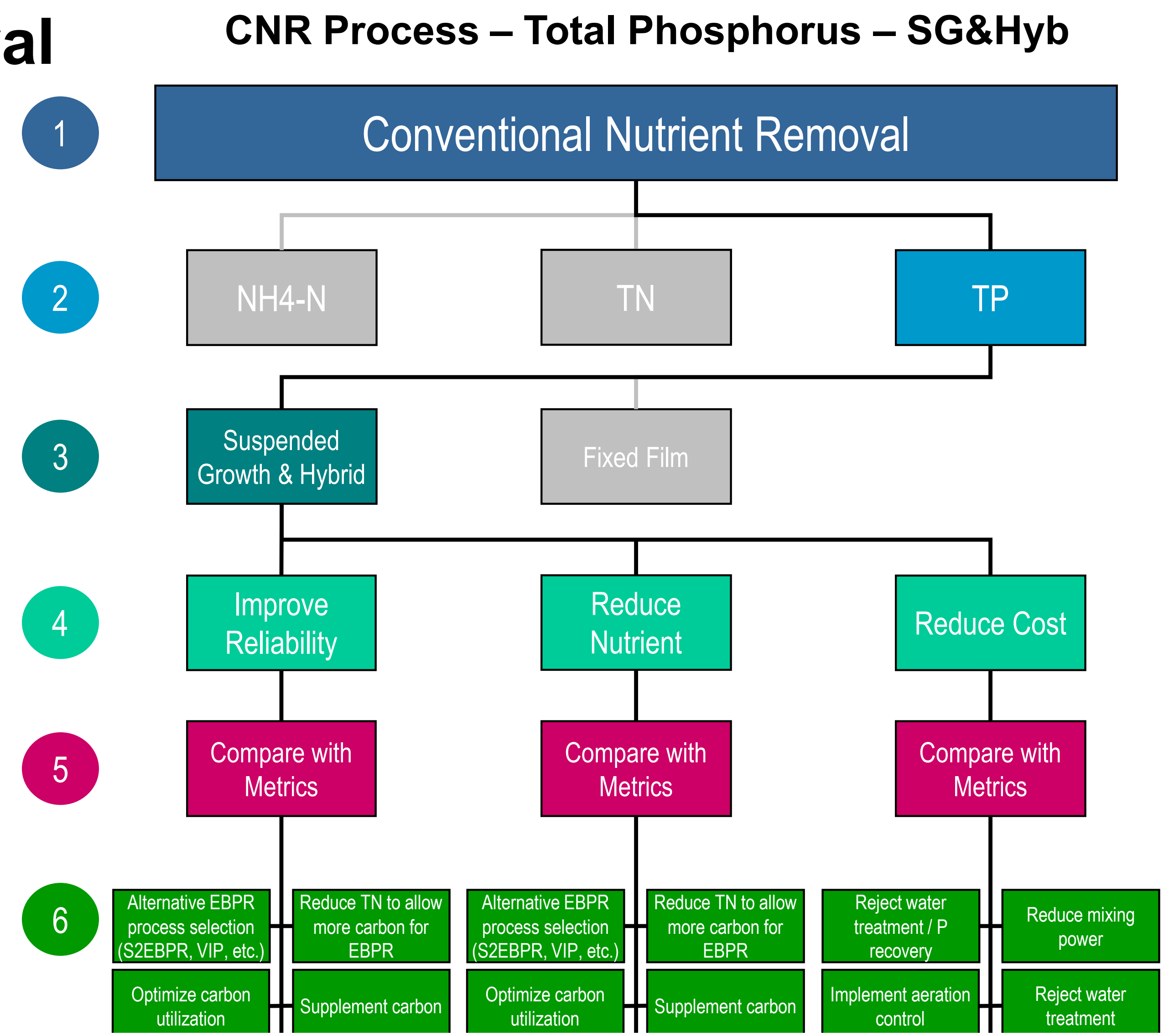
Create de-ox zone

Implement aeration control

Manage reject water (sidestream)

Improve aeration efficiency (diffusers)

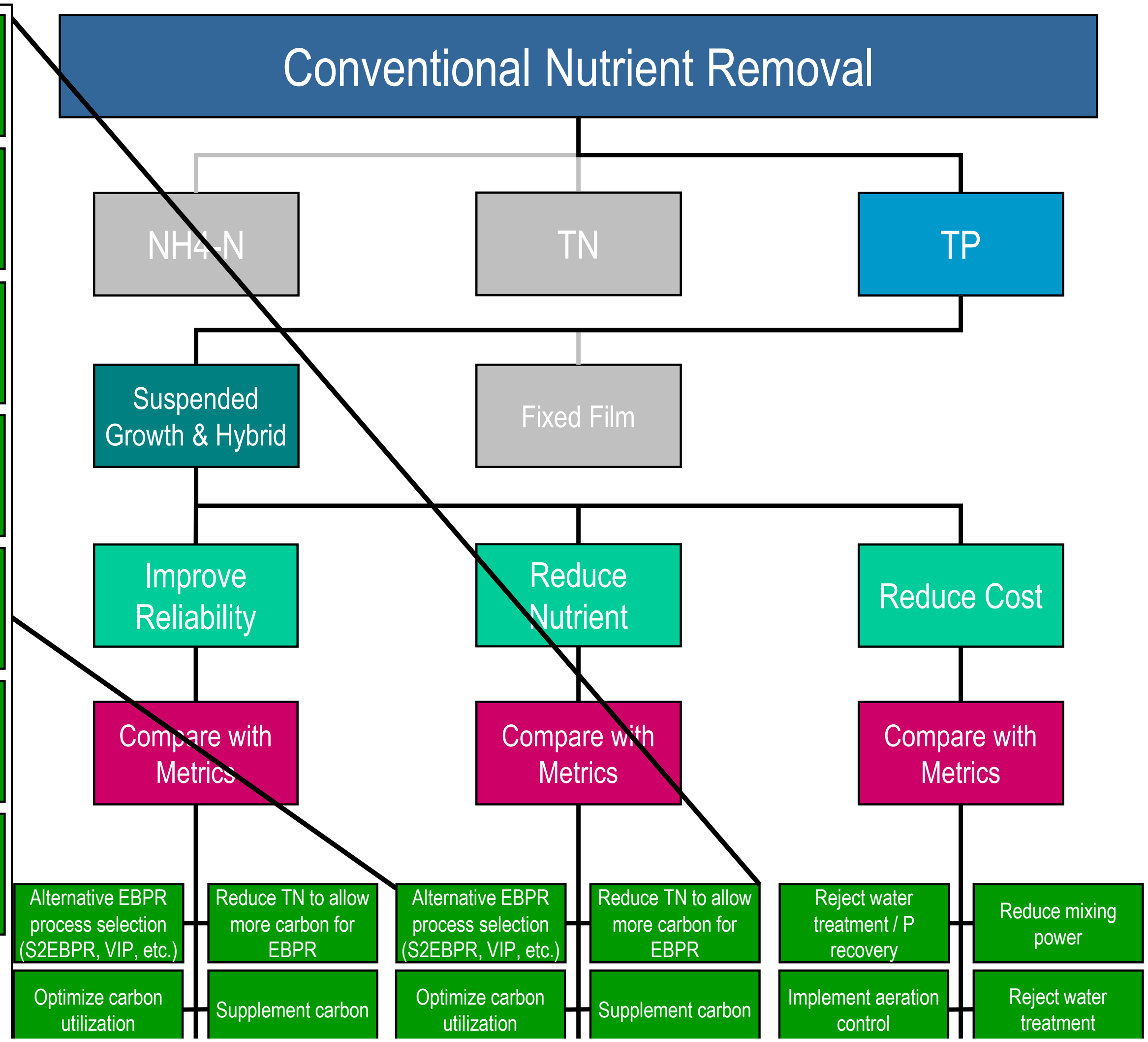
Phosphorus Removal



TP Removal – Reduce TP

- Alternative EBPR process selection (S2EBPR, VIP, etc.)
- Optimize carbon utilization
- RAS/MLSS fermentation
- Implement I&C
- Create an un-aerated zone
- Eliminate DO poisoning
- Optimize clarifier performance
- Reduce influent variability
- Reduce TN to allow more carbon for EBPR
- Supplement carbon
- Ferment primary sludge
- Process intensification
- RAS to anoxic zone
- Eliminate short circuiting
- Reject water treatment

CNR Process – Total Phosphorus – SG&Hyb



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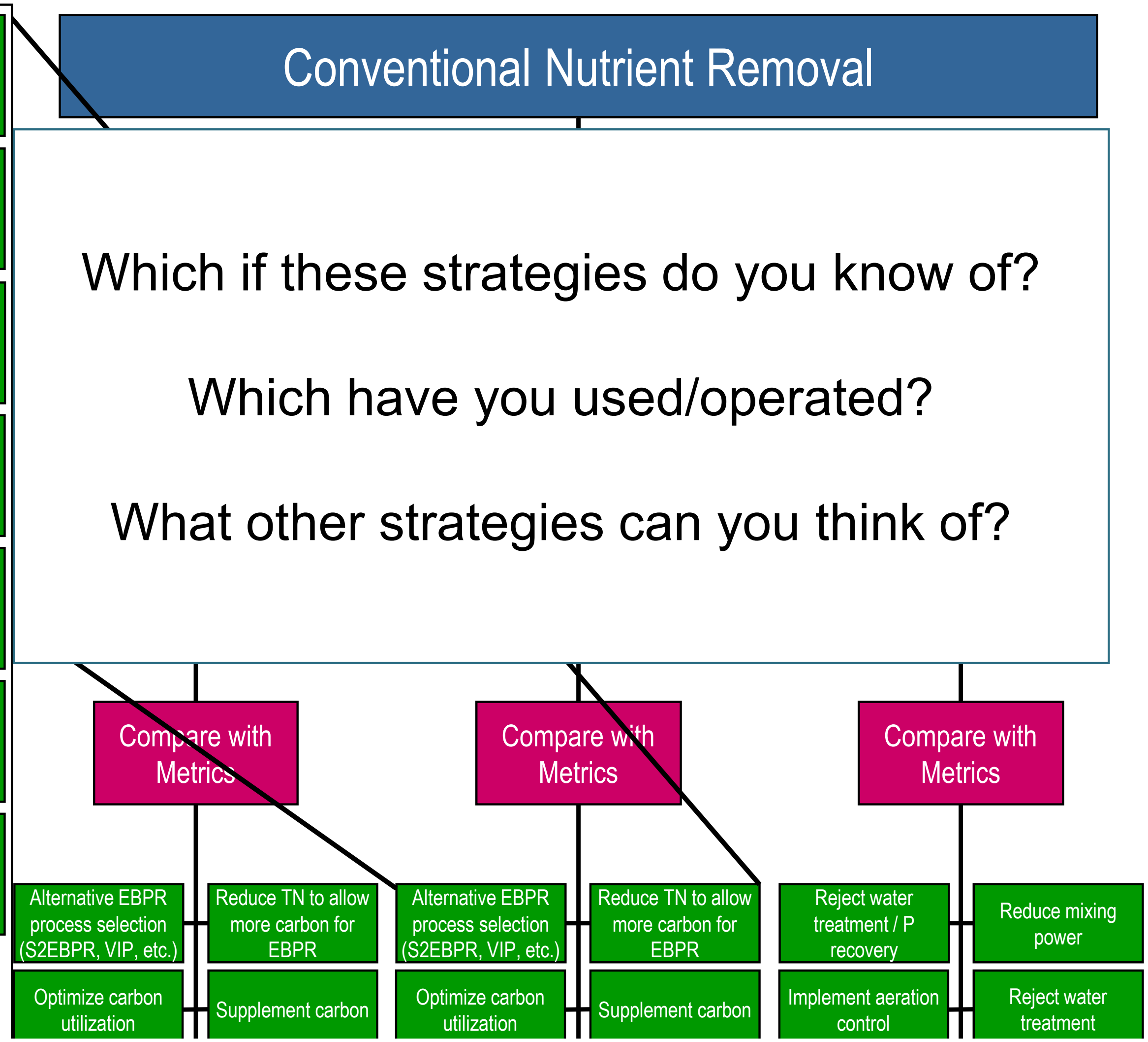
CNR Process – Total Phosphorus – SG&Hyb



Which if these strategies do you know of?

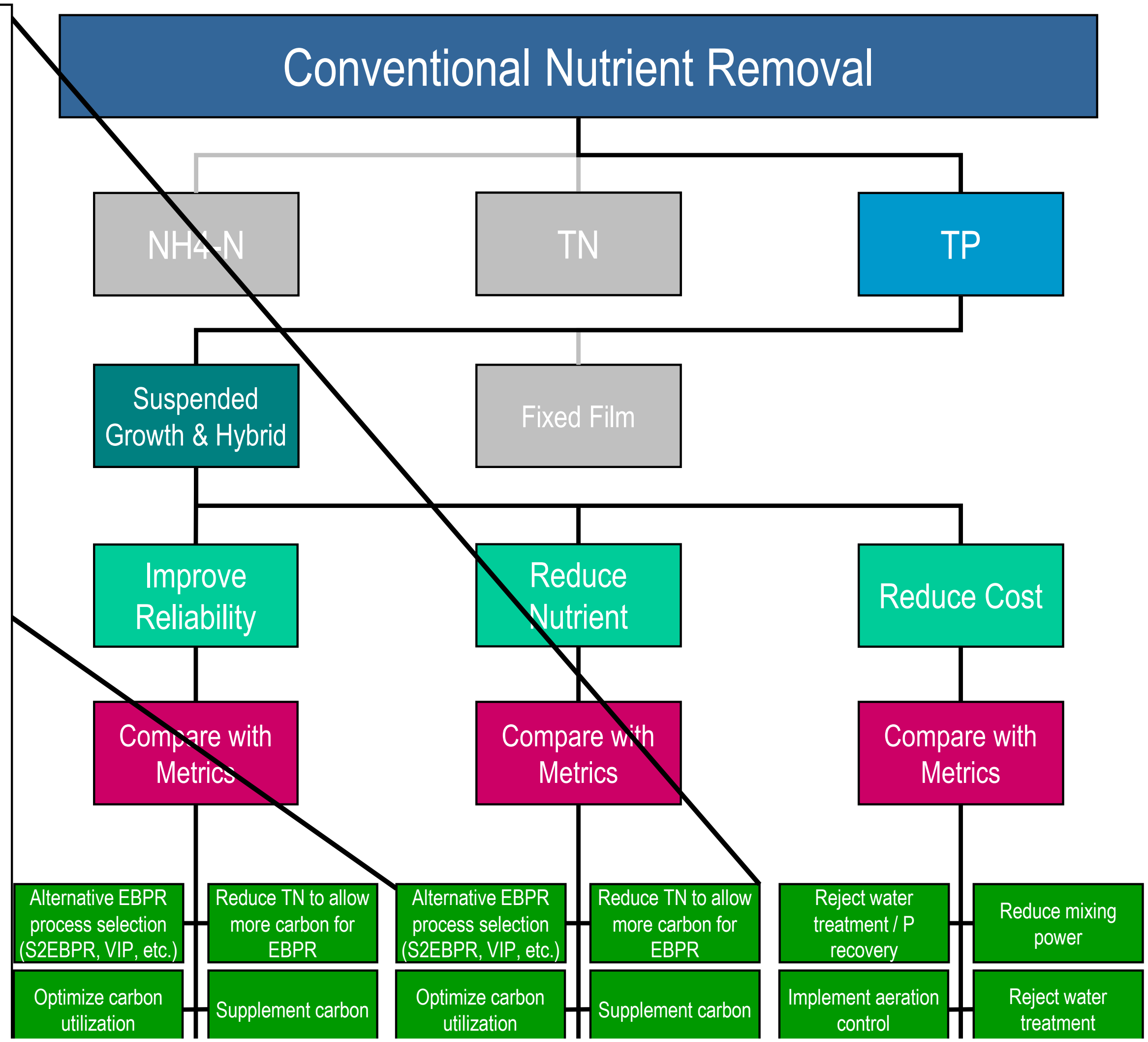
Which have you used/operated?

What other strategies can you think of?

TP Removal - COST

- Reject water treatment / P recovery
- Reduce mixing power
- Implement aeration control
- Reject water treatment
- Manage reject water (sidestream)
- Improve aeration efficiency (diffusers)
- Implement I&C
- Add external carbon
- Optimize carbon utilization

CNR Process – Total Phosphorus – SG&Hyb



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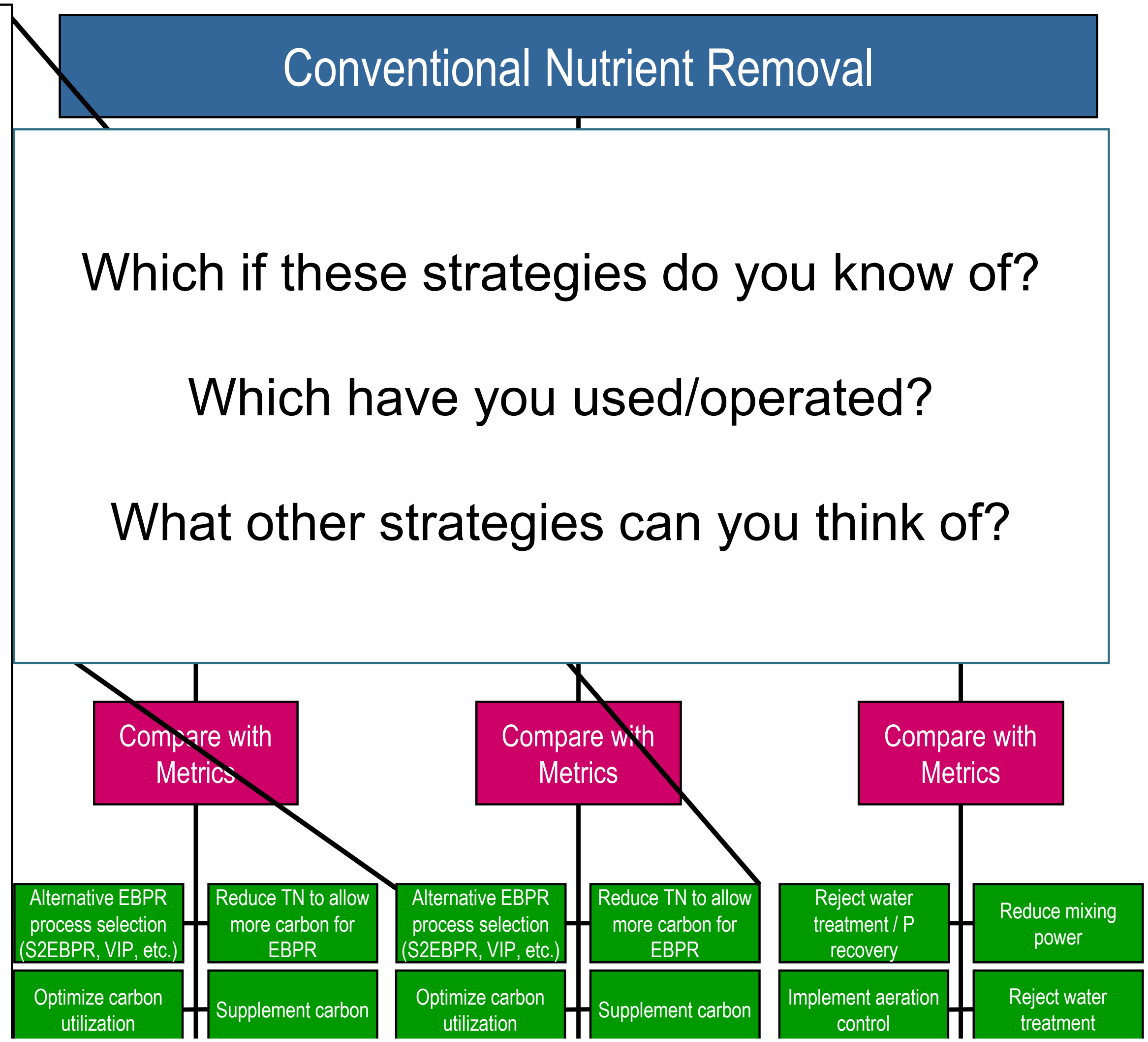


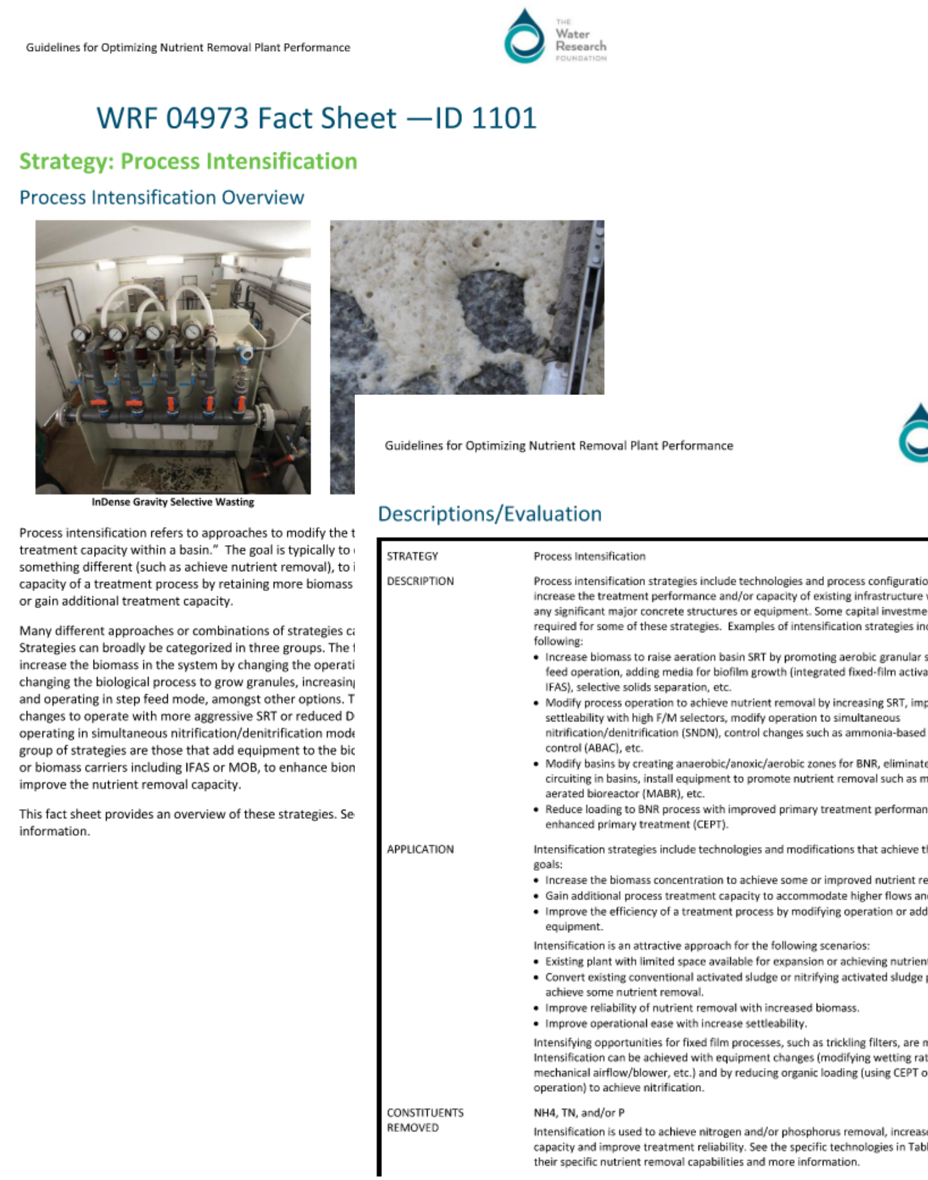
Which if these strategies do you know of?

Which have you used/operated?

What other strategies can you think of?

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



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	--	--	--

Create List of Site-Specific Strategies

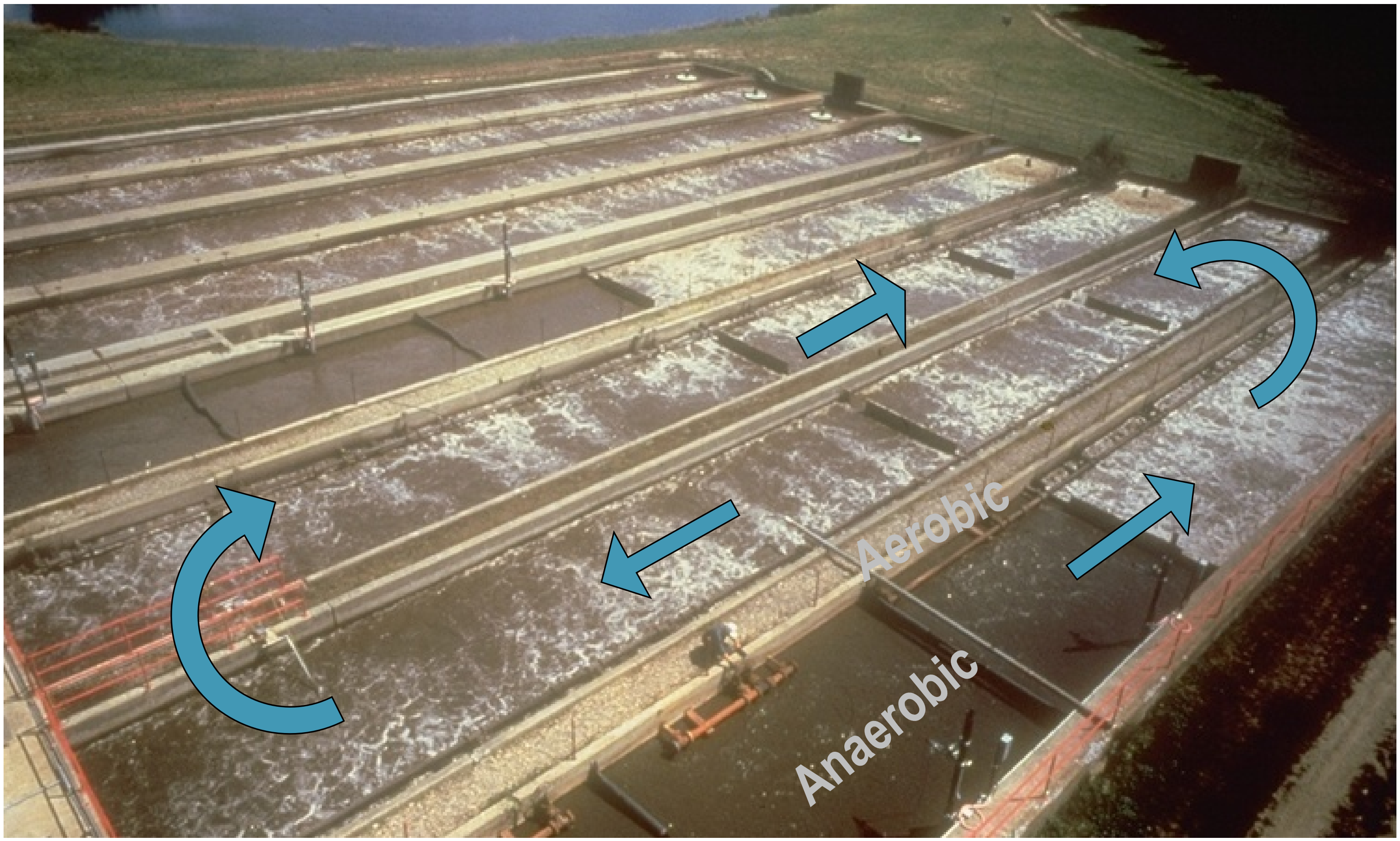
Add external carbon	Increase anoxic volume %
Create de-ox zone	Implement aeration control
On-off aeration	Optimize MLR
Reject water treatment	Optimize carbon utilization
Implement I&C	Intensify process
SND	Reduce influent variability

- 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

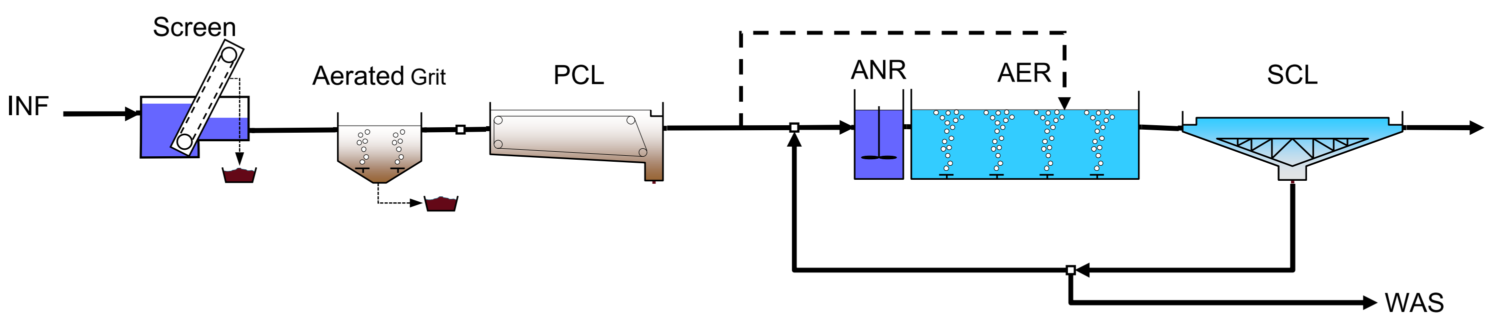
Confidential WRRF

Reduce Nutrient Discharge from a Secondary WRRF



Description of WRRF

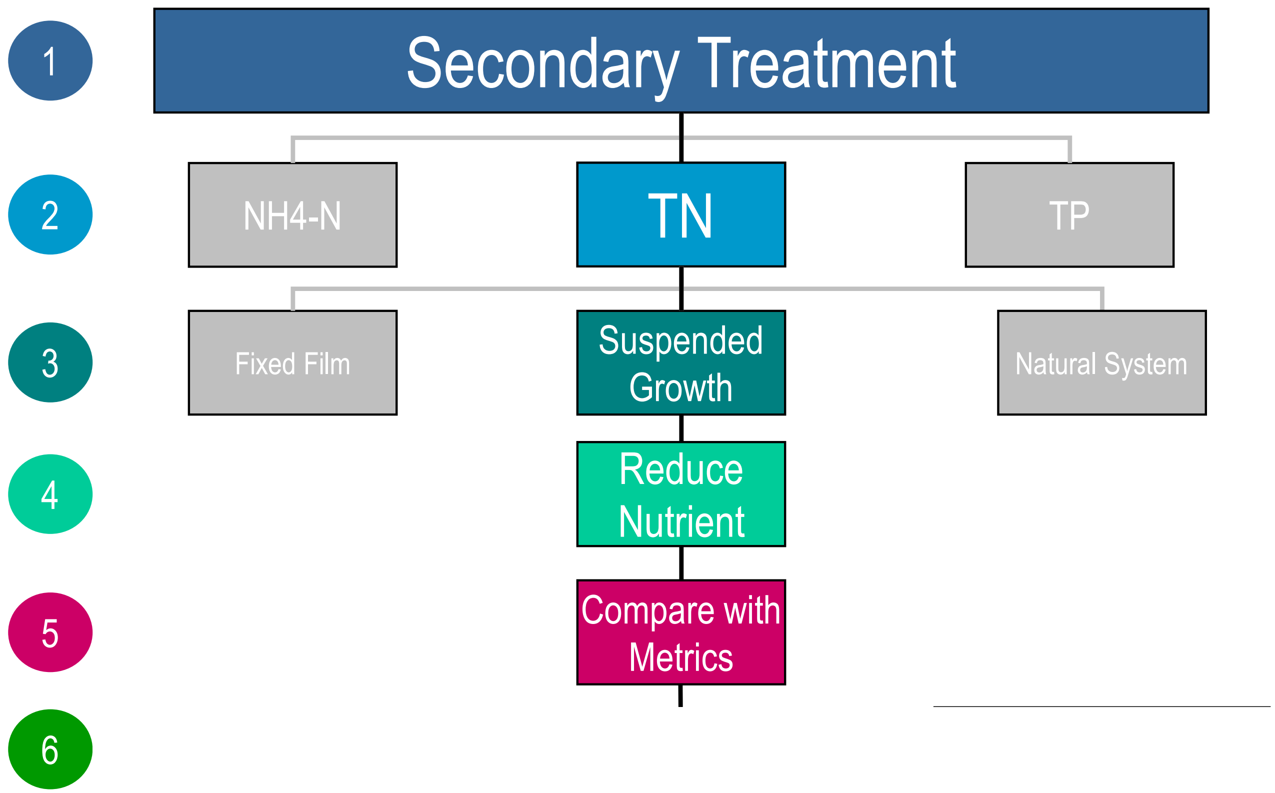
- Process: Secondary activated sludge located in moderate climate
  - Operating at 1.5 d SRT
  - MLSS 1500 mg/L
  - Plug flow tanks with step feed for peak wet weather condition
  - Anaerobic selector for settleability – does not function well
- Plant loading currently 50% of design
- Anaerobic digestion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



Decision Tree Application

- Secondary Process
- 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
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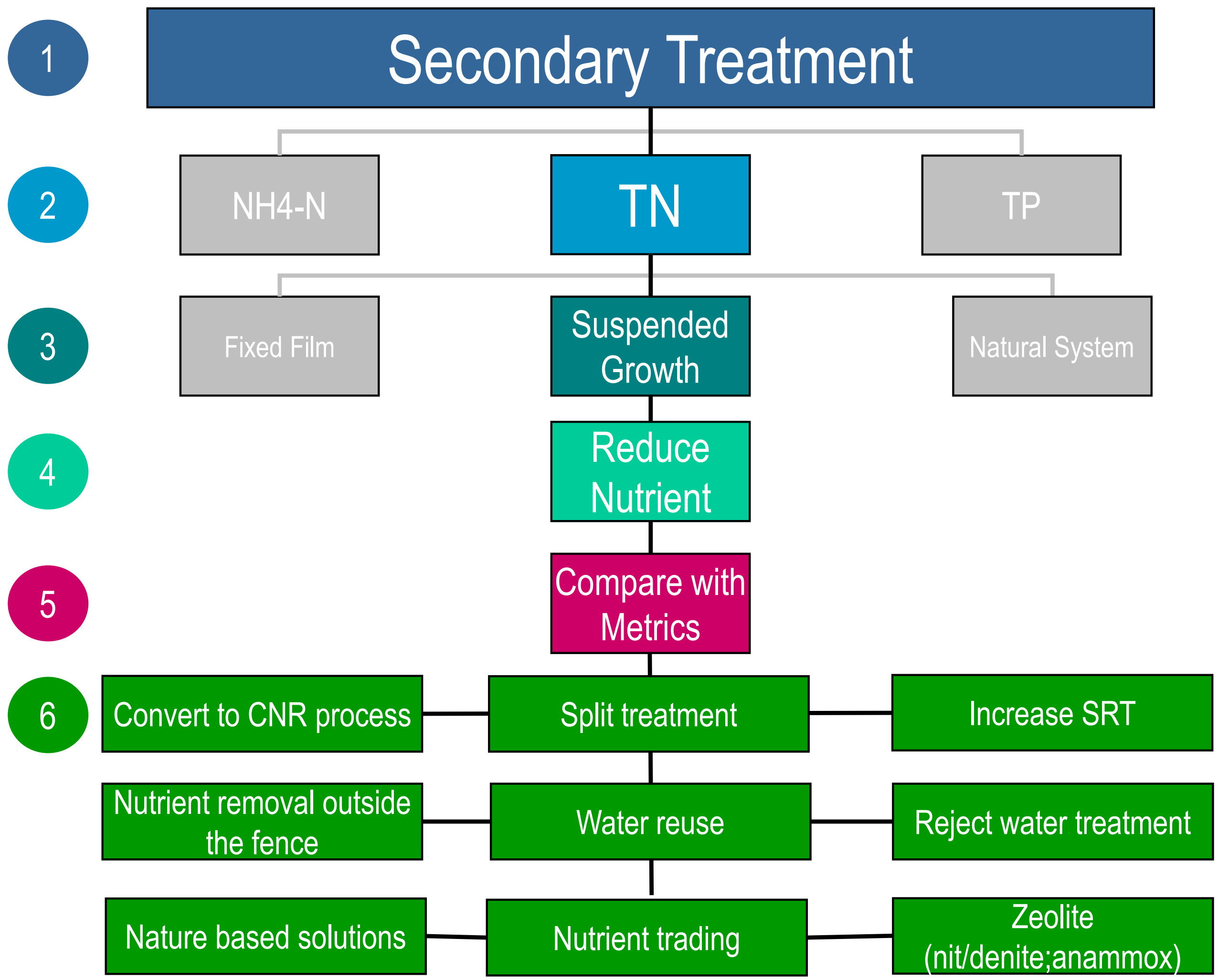
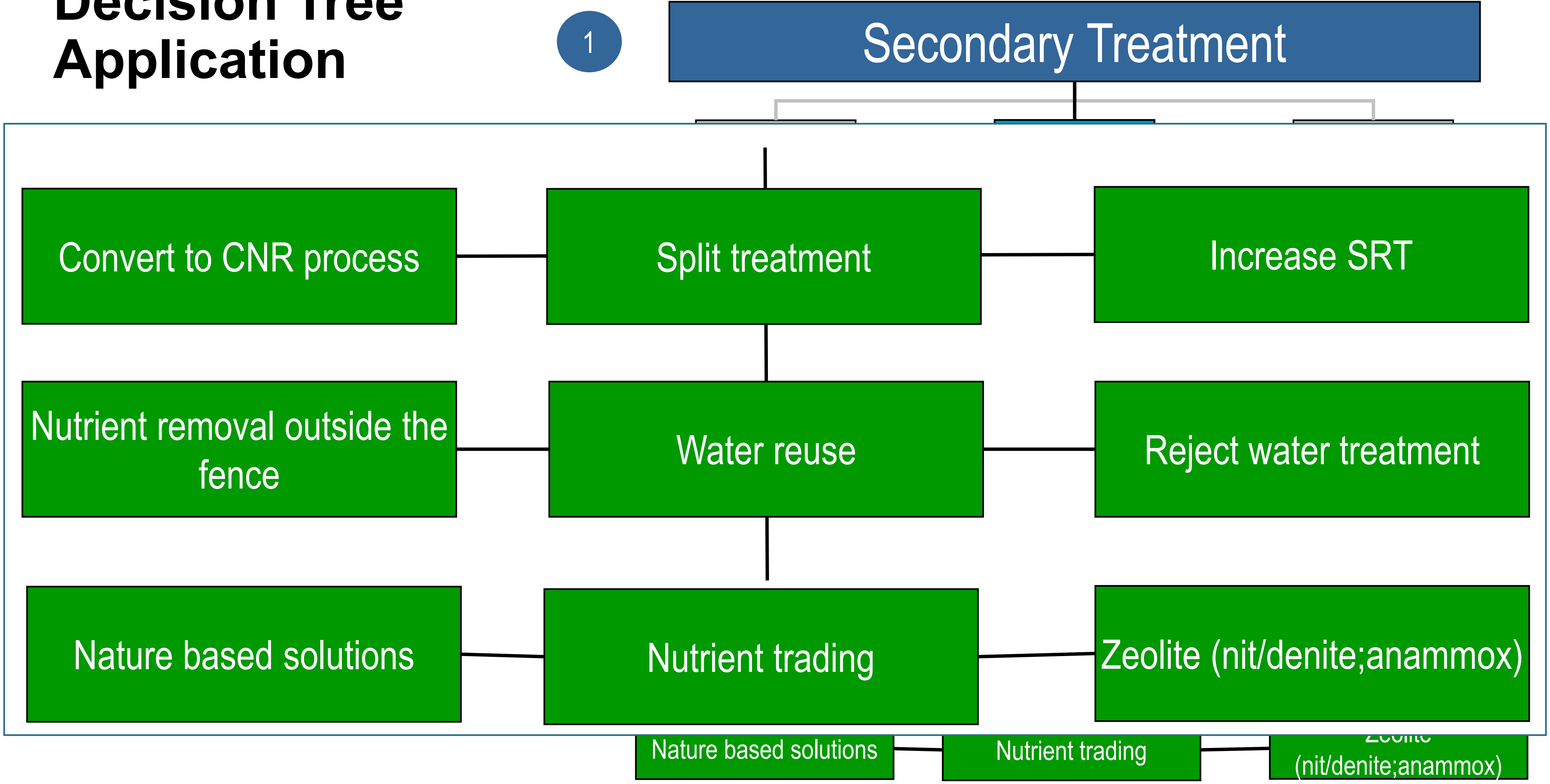
Secondary Process - TN – Suspended Growth Process



Decision Tree Application

Secondary Process - TN – Suspended Growth Process



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 O&M Cost in Nutrient Removal WRRFS

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10 Optimize Nutrient Removal WRRF Operations

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