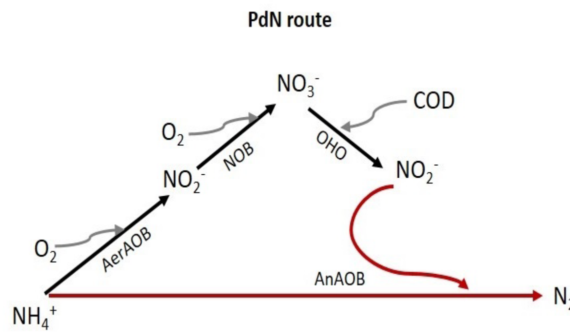
WRF 4973 Fact Sheet: ID 1130

Strategy: Process Intensification

Improve Nutrient Removal in an Existing BNR Process

Simultaneous Nitrification and Denitrification Can Achieve TN Reduction.
Source: HDR Engineering, Inc.



Partial Denitrification/Anammox Process.
Source: Printed with permission from HRSD.

This fact sheet addresses strategies to improve nutrient removal in an existing conventional nutrient removal (CNR) facility, specifically biological nutrient removal (BNR) facilities. The strategies presented here include both optimization strategies that reduce effluent nutrient levels and strategies to improve the reliability of meeting effluent nutrient goals.

Strategies presented in this fact sheet typically require minor investments and operational changes to existing BNR basins to improve nutrient removal efficiency and/or reliability. Many of the strategies are documented in other fact sheets (see Related Fact Sheets in table below). Within the context of optimization, this fact sheet focuses on strategies with a favorable return on investment (to reduce operating costs) that also reduce effluent nutrient concentrations and increase treatment reliability.

Fact Sheet Application Checklist

R = fact sheet relevant to item
PR = fact sheet is potentially relevant to item depending on application, existing conditions, etc.

Category		
	R	Intensification
		Chemical addition
	R	Carbon management
	R	I&C strategies
	R	Sidestream mgmt.
	R	Energy savings
	R	Chemical savings
	R	Operational savings
		Other means of NutRem

Nutrient		
	R	Ammonia
	R	NOx
	R	TN
	R	Ortho-P
	R	TP

Scale (design flow)		
	R	Small (<1 MGD)
	R	Medium (1–10 MGD)
	R	Large (>10 MGD)

Goal		
	R	Improve reliability
	R	Reduce nutrient
		Reduce O&M cost

Group		
	R	Optimize existing CNR
		Optimize existing TNR
		NutRem in secondary plant

Process		
	R	Small
		Pond
		Fixed film (secondary)
		Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
	R	Tertiary NutRem (TNR)
		Other

CAS = conventional activated sludge (BOD only)
NAS = nitrifying activated sludge (without denitrification)
CNR = conventional nutrient removal no chemical/no filter, etc.
TNR = tertiary nutrient removal with chemical, filter, etc.

Technology Summary Evaluation

Footprint	1	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	3–5	Technology ranking based (LIFT) see below*
Energy use	2	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M cost	3	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
Material/consumables	1–3	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1–3	Scale 1–3: minimal/none = 1; some = 2; significant = 3 (e.g., chemical process)

* Technology ranking based on Leaders Innovation Forum for Technology (LIFT) Water Research Foundation (WRF) Technology Development Level (TDL) definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional

Descriptions/Evaluation

Strategy	Improve nutrient removal in an existing CNR process
Description	Improve BNR in an existing BNR process by modifying operation strategy, process configuration, installing new equipment, and other strategies. The possible optimization strategies depend on the current activated sludge process, basin layout, process selection, etc. Some strategies may require additional tankage or take advantage of “unused available” capacity. In water resource recovery facilities (WRRFs) that operate below their rated capacity, the excess “capacity” can be used to optimize nutrient removal. The following approaches are presented in this fact sheet: • Simultaneous nitrification and denitrification (SND): modify operation to allow nitrification and denitrification to occur at the same time • Phased nitrification and denitrification (PNDN): operate with intermittent aeration to achieve sequential nitrification and denitrification in the same basin • Split treatment: a strategy to achieve some nutrient reduction in one or more parallel activated sludge trains while maintaining other trains in biochemical oxygen demand (BOD) mode • Mixed liquor suspended solids (MLSS) fermentation to improve enhanced biological phosphorus removal (EBPR): turning mixers in anaerobic zone off to ferment MLSS and generate volatile fatty acids (VFAs) for improved EBPR • Shortcut nitrogen (N) removal with partial nitritation anammox (PNA) • Shortcut N removal with partial denitrification with anammox (PdNA) • Sidestream nitrification-denitrification (NDN) using existing tankage
Application	Some of these strategies rely on “spare capacity” in existing basins to function in a new way. Others may require more efficient equipment or process controls. In most cases this would involve an existing activated sludge system that has excess capacity (if the WRRF’s current load is below design capacity or if spare/redundant basins are available) or the addition of capacity through intensification strategies i.e., increased biomass (see Fact Sheet 1110).
Constituents removed	Nitrogen and/or phosphorus
Development status*	LIFT TDLs 3–5: BNR zoning is established technology but some recent innovations like return activated sludge (RAS) fermentation, PdNA, or low– dissolved oxygen (DO) nitrification have been demonstrated in full scale but some design and operating criteria remain to be resolved.
O&M considerations	Varies based on selected technology or strategy (see Table 1).
Benefits	Varies based on selected technology or strategy but can include increased nutrient removal and treatment reliability without additional infrastructure, improved effluent water quality, and/or lower operational costs.
Limitations	Existing system must have excess capacity or incorporate an intensification strategy
Design considerations	Design considerations are specific to the existing infrastructure (see Table 1).
Potential fatal flaws	Insufficient excess capacity, intensification not possible
Footprint requirements	None
Residuals	BNR upgrade will reduce nitrogen and/or phosphorus while all other effluent residual levels will be similar. Increasing the solids retention time (SRT) will result in lower solids production.
Cost considerations	Depends on the design approach and existing basin geometry and layout
Past experience	St. Joseph, Missouri: Conversion of trickling filter/activated sludge (TF/AS) plant. Existing aeration basin converted to anaerobic-anoxic-aerobic (A2O). Existing unused aerobic digesters converted to five-stage Bardenpho. Bozeman, Montana; Silverton, Oregon; Columbia Falls, Idaho; Hamilton, Montana: all implemented PNDN.

Publications	Benisch, M., P. Young, and A. Clements. 2019. "Achieving Nitrification and Nutrient Removal through Mainstream Bio-Augmentation from Parallel Plant." Nutrient Removal and Recovery Symposium. Minneapolis, Minnesota: WEF. Bott, C., S. Klaus, and M. Parsons. 2020. "Mainstream Partial Denitrification/Anammox: Results from Operation in a Full-Scale Deep-Bed Filter (informed by pilot-scale MBBR research)" WEFTEC 2020. Macmanus, J., C.B. Bott, H. De Clippeleir, M. Parsons, and S. Klaus. 2021. "Startup and Pilot Testing of MBBR and IFAS Partial Denitrification/Anammox Processes." WEFTEC 2021. Neethling, JB, Bruce Willey, Dan Harmon, Mario Benisch (2007). "Phased Nitrification-Denitrification Provides Flexible Nitrogen Removal." WEF Nutrient Removal Conference, Baltimore, 2007.
Related fact sheets	1101: Process Intensification Overview 1110: Increase Biomass 1140: Optimize BNR Effectiveness 1150: Use of Chemicals to Improve Nutrient Removal
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Note

* Technology ranking based on LIFT WRF TDL definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = Conventional (https://www.waterrf.org/sites/default/files/file/2019-07/LIFT%20Scan%20Application-LIFT%20Link%2BHub_0.pdf : accessed September 2020)

Additional Information

Most WRRFs in operation have some amount of excess capacity beyond what is required for redundancy, which can be used to increase the level of treatment. If such excess capacity is unavailable at a WRRF, intensification strategies can free up capacity for the same purpose.

In some cases, simple changes in operational strategy may be all that is needed. Oxidation ditches, for instance, have excess treatment capacity by design. By separating aeration from mixing, aeration controls can be adjusted to achieve BNR through cyclical aeration or SND through low DO operation.

Table 1. Features of Basin Conversion Strategies.

Feature	SND	PNDN	PNA	PdNA	Split Treatment	RAS or MLSS Fermentation	RAS Nitrification or Sidestream NDN
Modification	Control aeration to achieve SND	Control aeration ON/OFF to achieve sequential nitrification and denitrification	Aeration and SRT control to denitrify via NO_2 and/or anammox	Generate nitrite (NO_2) by adding carbon to partially denitrify nitrate (NO_3), followed by shortcut N removal	Convert one or more trains to nutrient removal and blend with existing WRRF	Intermittently mix in unaerated zones to promote low oxidation-reduction potential (ORP) conditions for fermentation to occur. RAS/MLSS to generate VFA.	Use unused existing tanks to lower recycle ammonia and N loads
Nutrients impacted	Ammonium (NH_4), oxidized nitrogen (nitrate + nitrite) (NO_x), total nitrogen (TN)	NH_4, NO_x, TN	NH_4, NO_x, TN	NH_4, NO_x, TN	NH_4, NO_x, TN	NH_4, NO_x, TN, Ortho-P, total phosphorus (TP)	NH_4, NO_x, TN
Impact on capacity	Small	Small	Small	Small	Some	Small	Can be significant with bioaugmentation
Modifications (potential)	Instrumentation and controls (I&C) Blower control	Blower output (on/off) on timer or I&C. Pulse aerate Mixer (or allow settling)	Blower output (on/off) and I&C	Blower output (on/off) and I&C Carbon addition	Require "spare basins" Convert some trains to BNR	Control on mixers to turn on/off Flow routing through basin likely to change	Adding/ repairing mixers or diffusers and other fixes to repurpose existing tanks

Feature	SND	PNDN	PNA	PdNA	Split Treatment	RAS or MLSS Fermentation	RAS Nitrification or Sidestream NDN
Design Considerations	Minimize air for oxygen demand may be less than required for mixing especially with well settling solids Additional mechanical mixing may be needed Post-aeration recommended to increase DO before final clarifiers	Post-aeration zone required to raise DO Balance air demand from cyclical aeration with blower start/stop limitations ORP can be used as control	Post-aeration zone required to raise DO Balance air demand blower control Nutrient (NO_2, NO_3, NH_4) and ORP can be used as control	Post-aeration zone required to raise DO Balance air demand blower control Nutrient (NO_2, NO_3, NH_4) and ORP can be used as control	Transition from unaerated to aerated zones should include submerged weir wall to prevent surface backflow Baffle walls do not need to be load bearing and can be constructed out of aluminum and even marine plywood when basins are small and spans are short	Covers and odor control recommended for facilities located in areas sensitive to odors Mixing intensity modest to low/interim	Without NDN or alkalinity addition only 50% of the recycle ammonia can be nitrified. Air on/off operation can increase nitrification rate as well as N removal

Abbreviations

A2O	Anaerobic-anoxic-aerobic
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
I&C	Instrumentation and controls
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
MLSS	Mixed liquor suspended solids
N	Nitrogen
NAS	Nitrifying activated sludge
NDN	Nitrification-denitrification
NH_4	Ammonium
NO_2	Nitrite
NO_3	Nitrate
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
ORP	Oxidation reduction potential
PdNA	Partial denitrification with anammox
PNA	Partial nitritation anammox
PNDN	Phased nitrification and denitrification
RAS	Return activated sludge
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SND	Simultaneous nitrification and denitrification
SNR	Secondary nutrient removal
SRT	Solids retention time
TDL	Technology Development Level
TF/AS	Trickling filter/activated sludge
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus

TSS	Total suspended solids
UV	Ultraviolet
VFA	Volatile fatty acid
WRF	The Water Research Foundation
WRRF	Water resource recovery facility