WRF 4973 Fact Sheet: ID 1120

Strategy: Process Intensification

Nutrient Removal in Existing Secondary Process

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

Aeration Tanks Converted to BNR
Source: HDR Engineering, Inc.

This fact sheet addresses strategies to improve nutrient removal in an existing conventional secondary process not designed for nutrient removal. The strategies presented here address nutrient removal in both fixed-film and suspended-growth secondary processes.

Effluent nutrient reduction can be required in a secondary water resource recovery facility (WRRF) process to meet permit requirements based on waste load allocations, or proposed limits on nutrient discharges from WRRFs to cap nutrients into a receiving water to prevent enrichment beyond current conditions. In many places in the country (such as the San Francisco Bay, Puget Sound, Iowa, and others) an effluent nutrient discharge target is set to limit nutrient enrichment beyond current levels.

Some of the strategies presented in this fact sheet may require a capital investment for additional facilities or modifications to the existing infrastructure, and operational changes to reduce the effluent nutrient discharged. Many of the strategies are documented in further detail in other fact sheets (see Related Fact Sheets in table below).

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
	R	Chemical addition
		Carbon management
	R	I&C strategies
	R	Sidestream mgmt.
	R	Energy savings
	R	Chemical savings
	PR	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		Optimize existing CNR
		Optimize existing TNR
	R	NutRem in secondary plant
Process	R	Small
	R	Pond
	R	Fixed film (secondary)
	R	Conventional act. sludge (CAS)
	PR	Nitrifying act. sludge (NAS)
		Conventional NutRem (CNR)
		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	2	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	3–5	Technology ranking based (LIFT) see below*
Energy use	3	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., chem 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	Reduce effluent nutrient discharged in an existing conventional secondary treatment process.
Description	Achieve nutrient removal in an existing WRRF by modifying the secondary process configuration, installing new equipment, and implementing other strategies. Some strategies may require additional tankage or take advantage of "unused available" capacity. This may be available if industry stopped discharge to the WRRF or growth in the service area did not materialize. The following approaches are appropriate for this fact sheet strategy group: • Unused or abandoned facilities could potentially be used to increase treatment process capacity to nitrify, denitrify, and implement enhanced biological phosphorus removal (EBPR) • Increase solids retention time (SRT) to nitrify and denitrify in existing tankage—strategy may reduce the WRRF treatment capacity • If existing WRRF nitrifies, add anoxic zones to remove some nitrogen (N) • Use chemically enhanced primary treatment (CEPT) to reduce organic load to activated sludge or trickling filter and nitrify in process • Recycle nitrified flow to headworks of other location in WRRF to denitrify. Adding nitrate to headworks could eliminate odor concerns • 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 • Chemical addition for phosphorus (P) removal • Export effluent to reuse as landscaping, irrigation of highway medians, parks/recreational areas, cooling, etc. • Produce effluent suitable for industrial reuse • Addition of sidestream treatment • Implement cyclical aeration in a nitrifying process • Remove/treat/recover nitrogen and phosphorus from anaerobic digestion sludge dewatering reject water

Application	Additional treatment capacity or volume is typically required to achieve some nutrient reduction in a secondary treatment plant. Additional "spare capacity" in an existing process could be available as a result of the following:
	• Underloaded WRRFs when industries change or move away, leaving excess capacity available. This "capacity" from reduced load could be used for N removal:
	  ▪ Activated sludge process converted to nitrify and denitrify
	  ▪ Convert trickling filter to nitrify
	• Unused infrastructure that can be repurposed for mainstream or reject water treatment.
	• Water reuse applications that do not return salts/nutrients back to the WRRF.

Constituents removed	Nitrogen and/or phosphorus
Development status*	LIFT TDLs 4–5 for conventional strategies such as increasing SRT and implementing conventional nutrient removal (CNR) technologies. LIFT TDLs 2–4 for implementing emerging strategies such as membrane aerated bioreactor (MABR), partial denitrification with anammox (PdNA), and others (see Table 1).
O&M considerations	Varies based on selected technology or strategy (see Table 1).
Benefits	Nutrient removal with minimal additional infrastructure or short return on investment. Improved effluent water quality. Increasing SRT will reduce biosolids production and reduce solids management operating cost. Changing from BOD to biological nutrient removal (BNR) mode of operation typically improves settleability, simplifies operation, and improves process stability.

Limitations	Existing system must have excess capacity or provide more via intensification strategies. The aeration oxygen requirements increase substantially (30%–100%) for ammonia oxidation and biomass decay (endogenous respiration). Denitrification credit is insufficient to offset the additional oxygen required for nitrification. However, improved oxygen transfer efficiency because of higher alpha factors reduces the increased blower requirement to meet the aeration demands for an overall increase of 10%–40% in blower requirements.
Design considerations	Design considerations are specific to the existing infrastructure (see Table 1).
Potential fatal flaws	Insufficient available unused reactor volume for intensification. Fixed-film processes such as trickling filters are more challenging to convert from BOD to nitrification mode and may require higher capital investment. Site constraints, aging infrastructure, and operational complexities could make modifications impractical.
Footprint requirements	Minimal, unless additional facilities are needed to achieve sufficient treatment capacity. This would involve a capital improvements project.
Residuals	BNR upgrade will reduce nitrogen and/or phosphorus. Other residuals are similar. Increase in SRT will result in lower solids production.
Cost considerations	Depends on specific strategy and facility needs.
Past experience	St. Joseph, Missouri: Conversion of trickling filer activated sludge plant. Existing aeration basin converted to anaerobic-anoxic-aerobic (A2O). Existing unused aerobic digesters converted to 5-stage Bardenpho. Orange County Sanitation District, Plant 1: Convert 91-million-gallon per day (mgd) secondary (BOD removal) WRRF to a 91 mgd step-feed nitrification and denitrification process within the same biological reactor volume (Neethling et al. 2011). King County, Washington: Conducted nitrogen reduction strategies at three WRRFs: Vashon, Carnation, and South Plant (Renton). Rick Butler (Butler et al. 2021). Bozeman, Montana: Convert nitrification-only process to denitrify by implementing phased nitrification and denitrification (PNDN) by turning aeration equipment on and off in sequence to nitrify and denitrification in the same basin (McInnis et al. 2009).
Publications	Butler, R., C. Steinke, and C. Nelson. 2021. “Comparing N-Removal at Three King County Wastewater Treatment Facilities: Vashon, Carnation, South Plant (Renton).” PNCWA. McInnis, A., H. Bartle, T. Adams, and C. Jones. 2009. “Using pH and ORP to Optimize Phased Nitrification-Denitrification Operation.” WEF’s 82nd Annual Technical Exhibition and Conference. Orlando, Florida: WEFTEC. Neethling, J.B., B. Willey, A. Nichols, M. Hetherington, D. Heinz, R. Wade, and W. Sevenandt. 2011. “Converting BOD to Nitrification/Denitrification in Same Reactor While Maintaining Capacity.” WEFTEC 2011.
Related fact sheets	1101: Process Intensification Overview 1110: Increase Biomass 1150: Use of Chemicals to Improve Nutrient Removal 1601: Reject Water (Sidestream) Management Overview 2001: Manage Nutrients outside the WRRF
Date updated	9/10/2022
Contributors	JB Neethling, James Barnard, Stephanie Klaus, Michael Liu, Erika Bailey, Mario Benisch, Justin Macmanus, Adam Hendricks, Anand Patel

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

Many WRRFs in operation have some amount of excess capacity beyond what is required for treatment that can be used to increase the level of treatment. If such excess capacity is unavailable at a WRRF, intensification strategies may be able to achieve the higher treatment level in the same basin volume.

In some cases, simple changes in operation strategy may be all that is needed. Oxidation ditches, for instance, have excess treatment capacity by design using long SRTs. By separating aeration from mixing, aeration controls can be adjusted to achieve BNR by cyclical aeration or simultaneous nitrification and denitrification (SND) through low dissolved oxygen (DO) operation.

Applicable strategies are divided into those applicable for suspended growth/hybrid secondary treatment processes (activated sludge for both conventional activated sludge [CAS] and nitrifying activated sludge [NAS], integrated fixed-film activated sludge [IFAS], etc.) and other BOD-only removal processes that cannot accommodate in-basin SRT increases or the creation of unaerated zones in the secondary process (fixed film, lagoons, etc.) in Table 1 below.

The following approaches for strategies are presented in Table 1 below. Each column in the table represents a different approach:

- Increase SRT
- Nitrification in non-suspended growth processes
- Denitrification options
- Add biological P removal
- Add chemicals for P removal
- Split treatment between parallel trains and convert some trains to remove nutrients
- Nutrient removal beyond liquid treatment

Row 2 in the table identifies the secondary treatment process that could benefit from the strategy group. The secondary treatment processes include the following:

- CAS (conventional activated sludge: BOD removal only)
- IFAS (integrated fixed-film activated sludge)
- NAS (nitrifying activated sludge)
- TF (trickling filter)
- TF/AS (trickling filter/activated sludge)
- Ponds
- Lagoons

Table 1. Features of Strategies for Nutrient Reduction in Secondary (BOD and NAS) WRRFs.

Group of Strategies →	Increase SRT	Nitrify in Non-Suspended Growth Systems	Denitrification Options	Biological Phosphorus Removal	Chemical Phosphorus Removal	Split Treatment	Nutrient Removal Beyond Liquid Treatment
Applicable secondary process type	CAS, NAS, IFAS	TF, TF/AS, ponds, lagoons	CAS, NAS, IFAS	CAS, NAS, IFAS	CAS, NAS, IFAS, TF, TF/AS, ponds, lagoons	CAS, NAS, IFAS TF, TF/AS, ponds, lagoons	CAS, NAS, IFAS TF, TF/AS, ponds, lagoons

Strategy/ modification	Raising SRT increases the biomass and allows nitrifiers to grow. See "Intensification" fact sheet 1101 and "Increase Biomass" fact sheet 1110.
	Unaerated zones required for denitrification to remove oxidized nitrogen (nitrate + nitrite) (NO_x) and reduce total nitrogen (TN).
		Reduce load to process to achieve nitrification by:
		• Reduce BOD load
		  ▪ Reduce flow
		  ▪ Divert BOD (e.g., CEPT)
		• Add submerged aerated fixed-film basin
		  ▪ TF/AS potential
		  ▪ Fixed media in ponds
			Increase SRT (first strategy)
			Anoxic zone in step-feed arrangement provides higher SRT and anoxic basins.
			Recycle NO_x-rich flow to headworks for odor control and denitrification.
				Create anaerobic zone (ANR) to grow polyphosphate-accumulating organisms (PAOs). Strategies include:
				• Shut down aeration in front zone of activated sludge process
				• Add conventional EBPR anaerobic zone for return activated sludge (RAS) and influent
				• Add sidestream anaerobic zone (S2EBPR)
					Add chemicals to precipitate P. Chemicals can be added to:
					• Primary clarifier
					• CEPT treatment
					• Secondary clarifier influent
					• Tertiary filter
					• Sidestream recycle flow
						Reduce load to selected process trains to operate in BNR mode.
						Shift more load to parallel treatment trains.
						Convert one or more trains to nutrient removal and mix in one outfall.
							These strategies remove nutrient outside the liquid treatment processes. Strategies include:
							• Source control to reduce nutrient load entering the WRRF
							• Effluent reuse and nature-based solutions to reduce nutrients discharged to receiving waters
							• In-plant management, treatment of sidestream/ reject water that can add a substantial nutrient load to effluent

Nutrients impacted	Ammonium (NH_4), NO_x (produced)	NH_4, NO_x (produced)	NO_x, TN	NH_4, NO_x, TN, Ortho-P, TP	SRP, TP	NH_4, NO_x, TN, SRP, TP	NH_4, NO_x, TN, Ortho-P, TP

Group of Strategies →	Increase SRT	Nitrify in Non-Suspended Growth Systems	Denitrification Options	Biological Phosphorus Removal	Chemical Phosphorus Removal	Split Treatment	Nutrient Removal Beyond Liquid Treatment
Impact on capacity	Process-specific and highly seasonal/ temperature-dependent. Blower and clarifiers can become capacity limiting.	Reduced capacity likely. Split treatment is a potential option.	Unaerated zones reduce aerobic SRT. Improved settleability adds treatment capacity (higher operating mixed liquor suspended solids [MLSS], lower effluent total suspended solids [TSS]).	Unaerated zones reduce aerobic SRT. Improved settleability adds treatment capacity (higher operating MLSS, lower effluent TSS).	Increase capacity when adding chemical to primary from reduced BOD load to biological process.	Reduced capacity with lower load to portion of plant.	New facilities are typically required. Capacity could even increase with load reductions.
Modifications (potential)	• Aeration system modification • Unaerated zones/mixing • Modified influent flow routing • WAS flow reduced • Blower capacity increase • I&C • Blower control	• Flow routing changes • Increase wetting rate for TF • Upgrades to TF likely (blower fans, liquid distributor changes, etc.)	• Unaerated zones/mixing • Modified influent flow routing • Internal recycles • Blower capacity decrease • Instrumentation and controls (I&C) • Blower control	• Control aeration in front zone to create anaerobic zone • Flow routing through basin likely to change • Adjust mixing speeds in created anaerobic zones	• Chemical feed facilities for storage, pumping, delivery • Chemical feed controls • Chemical mixing at dose point	• Require “spare basins” • Convert some trains to BNR	• Modifications depend on the specific strategy • New treatment facilities would be required for reject water treatment, production of reuse water, or effluent polishing

Group of Strategies →	Increase SRT	Nitrify in Non-Suspended Growth Systems	Denitrification Options	Biological Phosphorus Removal	Chemical Phosphorus Removal	Split Treatment	Nutrient Removal Beyond Liquid Treatment
Design considerations	Change in capacity and hydraulics from process changes.	Assess capacity implications.	Change in capacity and hydraulics from process changes.	Covers and odor control recommended for facilities located in areas sensitive to odors. Mixing intensity modest to low/interim. Struvite potential from EBPR. Reduce DO and NO_x recycle to anaerobic zone.	Finding mixing and dose application points for plant. Delivery routes for chemical deliveries. Chemical storage facilities.	Change in capacity and hydraulics from process changes.	Highly dependent on strategy.

Secondary processes:

1. CAS: conventional activated sludge: BOD removal only
2. IFAS: integrated fixed-film activated sludge
3. NAS: nitrifying activated sludge
4. TF: trickling filter
5. TF/AS: trickling filter/activated sludge
6. Ponds
7. Lagoons

Abbreviations

BOD	Biochemical oxygen demand
BNR	Biological nutrient removal
CAS	Conventional activated sludge: BOD removal only
CEPT	Chemically enhanced primary treatment
CNR	Conventional nutrient removal
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
I&C	Instrumentation and controls
IFAS	Integrated fixed-film activated sludge
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
MABR	Membrane aerated bioreactor
mgd	Million gallons per day
MLSS	Mixed liquor suspended solids
N	Nitrogen
NAS	Nitrifying activated sludge
NH_4	Ammonium
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
PAO	Polyphosphate-accumulating organism
PdNA	Partial denitrification with 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
SRT	Solids retention time
TDL	Technology Development Level
TF	Trickling filter
TF/AS	Trickling filter/activated sludge
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
TSS	Total suspended solids

UV	Ultraviolet
WRF	The Water Research Foundation
WRRF	Water resource recovery facility