WRF 4973 Fact Sheet: 2020

Strategy: Nutrient Reduction outside WRRF

Nature-Based Solutions

Horizontal Levee Provides Nutrient Reduction and Sea-Level Rise Protection.
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Wetlands Can Reduce Nutrients.
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Nature-based solutions (NbS) are a group of technologies and approaches used to reduce nutrients and polish effluent from a water resource recovery facility (WRRF) through natural methods. These technologies include wetlands, lagoons, and horizontal levees, and typically require a low capital investment (excludes the cost for land), have low operating costs, and can remove nutrients. These systems are relatively low rate, and require long detention times and a large amount of land coverage or footprint compared to mechanical treatment systems. Newer developments for NbS technologies aim to reduce their water impoundment and footprint requirements, but the natural system biological processes may have to be enhanced using mechanical equipment to accomplish this.

Wetlands have been used for polishing and storing treated effluent for decades (if not centuries) and have a proven track record for reliably reducing nutrients. Vegetative growth removes nutrients from the water; however, the vegetation must be managed and periodically removed (as needed).

An emerging NbS technology that is gaining traction is the horizontal levee, which relies on the soil matrix to treat the water as it flows through levee berms. As the name implies, the levee is “gradually” sloped compared to a traditional levee. The gradual slope subsequently requires a larger area than traditional levees as the berm height does not necessarily change. The benefits of the gradually sloped levee are (1) more overall area to polish nutrients and other pollutants, (2) ability to restore habitat for multi-benefit uses (e.g., shoreline restoration), and (3) ability to address flooding and sea-level rise. This technology appears to be promising for WRRFs with some available land that also require levee protection.

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		
		Intensification
		Chemical addition
		Carbon management
		I&C strategies
		Sidestream mgmt.
		Energy savings
		Chemical savings
		Operational savings
	R	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		
		Improve reliability
	R	Reduce nutrient
		Reduce O&M cost

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

Process		
	R	Small
	R	Pond
	R	Fixed film (secondary)
	R	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	5	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	3–5	Technology ranking based (LIFT) see below*
Energy use	1	Scale 1–5: 1 = use much less; 3 = use similar to conventional; 5 = use much more
O&M cost	1	Scale 1–5: 1 = cost much less; 3 = cost similar to conventional; 5 = cost much more
Material/consumables	1	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1	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	Nature-based solutions (NbS)
Description	NbS refer to treatment strategies and technologies that use ponds, lagoons, wetlands, soil treatment, and other non-mechanical intensive processes. These are typically applied to polish WRRF effluent. NbS often add secondary benefits as well, such as protection against rising sea levels.
Application	NbS are attractive options when space is available to meet nutrient reduction goals. NbS also have relevant applications in areas prone to the effects of sea-level rise or looking for habitat restoration.
Constituents removed	All nutrients (ammonium [NH_4], oxidized nitrogen [nitrate + nitrite] [NO_x], total nitrogen [TN], soluble reactive phosphorus [SRP], total phosphorus [TP]). Soluble organic nutrients may increase from vegetation decay. Recent studies have also demonstrated the removal of contaminants of emerging concern (CECs) and total dissolved solids (TDS) in these systems.
Development status*	LIFT TDL 3 (horizontal levee) to 5 (wetlands).
O&M considerations	NbS typically require very little attention. Denitrification can be enhanced by providing a carbon source (wood chips or chemicals). Wetlands and algae-based systems require biomass harvesting and management of residuals.
Benefits	Simple, low cost, robust nutrient reduction. Secondary benefits that have been reported include levee protection against rising sea levels and storm events. Partial nutrient reduction can be achieved. The biological system performs best during warm weather, which coincides with the most restrictive nutrient permit limits.
Limitations	Large footprint required. Performance is impacted by weather conditions.
Design considerations	Facilities should be designed to allow for biomass to be easily and efficiently harvested and managed. A proper design should also account for the unlikely chance that a unit may be out of service for a long period of time.
Potential fatal flaws	Relatively large space/footprint requirements compared to mechanical systems.
Footprint requirements	Substantially larger than conventional mechanical treatment.
Residuals	Vegetation must be managed by harvesting and processing residuals.
Cost considerations	NbS require appropriate water retention and flow routing.
Past experience	Lagoons (facultative or aerated): widespread with a particular focus on small communities Zeolite/anammox: Various demonstration-scale studies throughout the San Francisco Bay Area. Free water surface (FWS) constructed wetlands: Mountain View, California (Moorhen Marsh): full-scale FWS that polishes treated wastewater (nitrification, filtration, and disinfection) from Mt. View Sanitary District in the San Francisco Bay Area prior to entering Suisun Bay. Arcata, California (Arcata Marsh and Wildlife Sanctuary): full-scale FWS that polishes treated wastewater (secondary treatment) from the City of Arcata's Wastewater Treatment Facility prior to entering Humboldt Bay. Unit-process open water (UPOW) wetlands: Livermore, California (Discovery Bay): pilot-scale testing focused on water typically fed to an FWS system. Corona, California (Prado Wetlands): half of the Santa Ana River in Riverside County in Southern California is passed through the wetlands. Nitrate removal is the primary treatment goal.

	Denitrifying bioreactor beds: Claremont, Minnesota (agricultural drainage treatment) Decatur, Illinois (agricultural drainage treatment) Davis, California (pilot-scale denitrification polishing treated wastewater) Horizontal levees/Ecotone/wetland levees: Oro Loma, California: demonstration-scale facility with full-scale construction slated for 2024 Palo Alto, California: demonstration-scale facility that has been ongoing since 2016
Publications	Cecchetti, A, A. Stiegler, K. Graham, and D. Sedlak. 2020. "The horizontal levee: a multi-benefit nature-based treatment system that improves water quality and protects coastal levees from the effects of sea level rise." Water Research X. https://doi.org/10.1016/j.wroa.2020.100052. Christianson, L.E., C. Lepine, P.L. Sibrell, C. Penn, and S.T. Summerfelt. 2017. "Denitrifying woodchip bioreactor and phosphorus filter pairing to minimize pollution swapping." Water Research. 121(15):129–139. https://doi.org/10.1016/j.watres.2017.05.026. Grismer, M.E. and R.S. Collison. 2017. "The Zeolite-Anammox Treatment Process for Nitrogen Removal from Wastewater—A Review." Water. 9(11)901. https://doi.org/10.3390/w9110901. Hughes, J., K. Williamson, and D. Austin. 2015. "Low-Energy Nitrogen Removal in Intensified Wetlands." WEF's 88th Annual Technical Exhibition and Conference. Chicago, Illinois: WEFTEC. Ilyas, H. and I. Masih. 2017. "The performance of the intensified constructed wetlands for organic matter and nitrogen removal: A review." Journal of Environmental Management. 198(Pt 1):372–383 DOI:10.1016/j.jenvman.2017.04.098 Jasper, J.T., M.T. Nguyen, Z.L. Jones, N.S. Ismail, D.L. Sedlak, J.O. Sharp, R.G. Luthy, A.J. Horne, and K.L. Nelson. 2013. "Unit Process Wetlands for Removal of Trace Organic Contaminants and Pathogens from Municipal Wastewater Effluents." Environmental Engineering Science, 30(8):421–436. https://www.liebertpub.com/doi/10.1089/ees.2012.0239. Jasper, J.T., Z.L. Jones, J.O. Sharp, and D.L. Sedlak. 2014. "Nitrate Removal in Shallow, Open-Water Treatment Wetlands." Environmental Science and Technology, 48(19):11512–11520. https://doi.org/10.1021/es502785t. Kadlec, R.H. and R.L. Knight. 1996. "Treatment Wetlands." CRC Press, Lewis Publishers, Boca Raton, Florida. Leverenz, H.L., K. Haunschild, G. Hopes, G. Tchobanoglous, and J.L. Darby. 2010. "Anoxic treatment wetlands for denitrification." Ecological Engineering 36:1544–1551. Lopez-Ponnada, E.V., T.J. Lynn, M. Peterson, S.J. Ergas, and J.R. Mihelcic. 2017. "Application of denitrifying wood chip bioreactors for management of residential non-point sources of nitrogen." Journal of Biological Engineering. 11(16):1–14 DOI 10.1186/s13036-017-0057-4.
Related fact sheets	2001: Manage Nutrients Outside the WRRF
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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

Table 1 contains a summary of some common NbS technologies.

Table 1. Nature-Based System Features for Various NbS Types.

Feature	Ponds/Lagoons		Constructed Wetlands		Denitrifying Bioreactor Beds	Zeolite/Anammox	Horizontal Levee/ Ecotone/Wetland Levees
	Facultative	Aerated	FWS	UPOW			
Process	Facultative lagoons are not mechanically mixed or aerated (typically 4'–8' deep). Synergy between algal and bacterial growth with zones that range from aerobic (typically at the surface; except during inversion periods) and anaerobic (most of the water column).	Similar configuration as facultative except mechanical aeration and/or mixing is included. This additional accelerates treatment, whereby carbonaceous biochemical oxygen demand (cBOD) and solids are biologically treated throughout the water column.	Water flows over a vegetated soil surface from an entrance to an outlet point (e.g., marshes). The water is exposed to the atmosphere to enhance oxygen transfer to provide dissolved oxygen (DO) for biological treatment. Plant growth encouraged for physical treatment and nutrient uptake.	Constructed wetland systems that are designed to promote photo- and microbiologically mediated natural water treatment processes. Such systems are considerably shallower than FWS to exploit sunlight photolysis. Plant growth encouraged like FWS.	Employs a submerged zone containing wood chips to foster denitrification. The wood chips serve as both a microbial biofilm support and a source of dissolved organic carbon needed for biological denitrification.	Water flows through a bed of zeolite where total ammonia nitrogen (TAN) is removed via ion exchange and sorption, followed by flowing through an outlet point. The zeolite bed is recharged biologically that includes nitritation/ nitrification, followed by denitrification/ denitritation.	Gradually sloped levee system with subsurface NbS treatment features. The system has the potential to address flooding/sea-level rise, nutrient polishing, and habitat restoration.
Pretreatment	Primary	Screenings and degritted (preferred)	Primary, secondary, or tertiary (most prevalent)	Primary, secondary, or tertiary	Secondary or tertiary (preferred)	Secondary or tertiary (preferred)	Secondary or tertiary (preferred)
Nutrient removal	• TAN and TN (limited to low loaded systems) • Marginal TP removal via assimilation	• TAN and TN • Marginal TP removal via assimilation (unless chemicals and/or polishing filters added following NbS)	• TAN and TN (requires both shallow/deeper water zones to foster aerobic and anoxic conditions) • Marginal TP removal via assimilation (unless metals salts added for physical/chemical removal)	• TAN and TN (requires both shallow/deeper water zones to foster aerobic and anoxic conditions) • Marginal TP removal via assimilation (unless metals salts added for physical/chemical removal)	• Limited to Denitrification (feed stream should be nitrified unless woody material used with high cation exchange capacity to sorb TAN) • Limited TP (unless metals salt added for physical/ chemical removal)	• TAN and TN • Marginal TP removal via assimilation	• TAN and TN (limited to low loaded systems) • Marginal TP removal via assimilation

Feature	Ponds/Lagoons		Constructed Wetlands		Denitrifying Bioreactor Beds	Zeolite/Anammox	Horizontal Levee/ Ecotone/Wetland Levees
	Facultative	Aerated	FWS	UPOW			
Advantages	• Established technology with 1,000s of installations across the country • Low minor maintenance • Low operational costs	• Established technology • Low footprint requirements • Ability to modify aeration for optimal TAN and TN reduction • Reliable design criteria compared to other NbS technologies	• Established technology • Most common constructed wetland technology • Low operational costs • Habitat restoration and wildlife habitat	• Innovative technology that offers numerous benefits (nutrient removal, CECs, filtration, etc.) • Ability to remove CECs by use of photo-mediated treatment • Low operational costs • Habitat restoration and wildlife habitat	• Established technology • Relies on readily available substrates • Substrate provides the carbon source for biological denitrification • Relatively minor maintenance • Low operational costs • Wide-ranging applications (e.g., agricultural runoff)	• Established technology for ammonia removal (innovative status for anammox step) • Two versions (low- and high-rate) provide design flexibility • Efficient TN removal via biological pathway • Ability to reliably treat biosolids reject streams	• Protection from flooding/sea-level rise • Habitat restoration • Nutrient polishing (focus on TN) • Polishing for CECs • Potential for brine reject treatment (ongoing studies) • Offers numerous multi-benefits compared to other NbS technologies
Disadvantages	• Large footprint required • High algal loads exiting the process that require subsequent handling • Little operational control • Marginal nutrient removal (limited to assimilation) • High methane emissions formation potential	• High energy demand to mix/aerate • Typically, less efficient oxygen transfer than mechanical plants (e.g., activated sludge) • Potential to form nitrous oxide and methane emissions	• Must maintain and harvest plants • Large footprint • Hydraulics can be challenging to control and can result in short-circuiting	• Limited installations • Must maintain and harvest plants • Larger footprint than FWS (because of shallow feature) • Hydraulics can be challenging to maintain and result in short-circuiting	• Prefers nitrified feed stream) • Most installations are for agricultural drainage; municipal waste streams limited to small/specialized systems (e.g., highway rest stops) • Pretreatment is key to providing reliable treatment	• No full-scale installations for anammox step (zeolite is proven) • Compact version has relatively high energy demand from external aeration supply • Pretreatment (solids removal) for long-term reliable performance	• Few installations; limited design criteria for polishing wastewater • Relatively large footprint for flood protection (because of gradual slope) • Nutrient removal limited to polishing (focus is on other multi-benefits)

Abbreviations

BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
cBOD	Carbonaceous biochemical oxygen demand
CEC	Contaminant of emerging concern
CNR	Conventional nutrient removal
DO	Dissolved oxygen
FWS	Free water surface
I&C	Instrumentation and controls
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
NAS	Nitrifying activated sludge
NbS	Nature-based solutions
NH_4	Ammonium
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SRP	Soluble reactive phosphorus
TAN	Total ammonia nitrogen
TDL	Technology Development Level
TDS	Total dissolved solids
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
UPOW	Unit-process open water
UV	Ultraviolet
WRF	The Water Research Foundation
WRRF	Water resource recovery facility