Nutrient Removal Technology Performance

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Stages of Wastewater Treatment

Treatment Stage	Removal/Treatment	Examples
Preliminary	Debris, grit, rags…	Screen, grit
Primary	Solids, particles, TSS, BOD	Primary Clarifier
Secondary	Organics, soluble/particulate	Activated Sludge, Trickling Filter
Tertiary	Pathogens, turbidity (reuse)	Filter, Disinfection
Advanced	Solutes, TDS, “molecules”	RO, EDR

Stages of Wastewater Treatment

Stage	Removal/Treatment	Examples
Preliminary	Debris, grit, rags…	Screen, grit
Primary	Solids, particles, TSS, BOD	Primary Clarifier
Secondary	Organics, soluble/particulate **Nutrients?**	Activated Sludge, Trickling Filter
Tertiary	Pathogens, turbidity (reuse) **Nutrients?**	Filter, Disinfection
Advanced	Solutes, TDS, “molecules” **Nutrients?**	RO, EDR

Nutrient Removal Stages

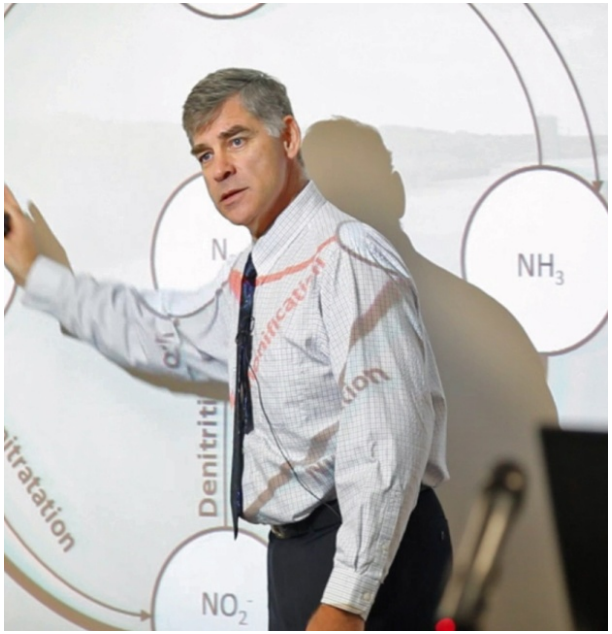
Secondary Nutrient Removal (SNR)	Nutrient removable with a modified secondary treatment process
Tertiary Nutrient Removal (TNR)	Maximize nutrient removal by adding chemicals, filters, and other tertiary processes
Advanced Nutrient Removal (ANR)	Ultimate nutrient removal using Reverse Osmosis, EDR, and other molecular exclusion processes

Treatment Processes in Nutrient Removal Stages

	SNR	TNR	ANR
Primary treatment	Optional Chemical P removal	Optional Chemical P removal	Optional Chemical P removal
Secondary treatment	BNR Trickling Filter plus	Multistage BNR Chemical addition	Multistage BNR Chemical addition
Tertiary treatment	None	Filtration Chemical addition	Filtration Chemical addition
Advanced Treatment	None	None	RO, EDR, advanced oxidation
Other Features	None	Fermentation Sidestream control	Fermentation Sidestream control Brine disposal

Performance Expectation for Nutrient Removal Stages

	SNR	TNR	ANR
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




Secondary Nutrient Removal

Secondary Nitrogen Removal Processes

- Single Stage Nitrification-Denitrification
- Simultaneous/Combined Nitrification Denitrification
- Sequential BOD-Nitrification-Denitrification

- Biological Options
  - Suspended Growth
  - Fixed Biofilm

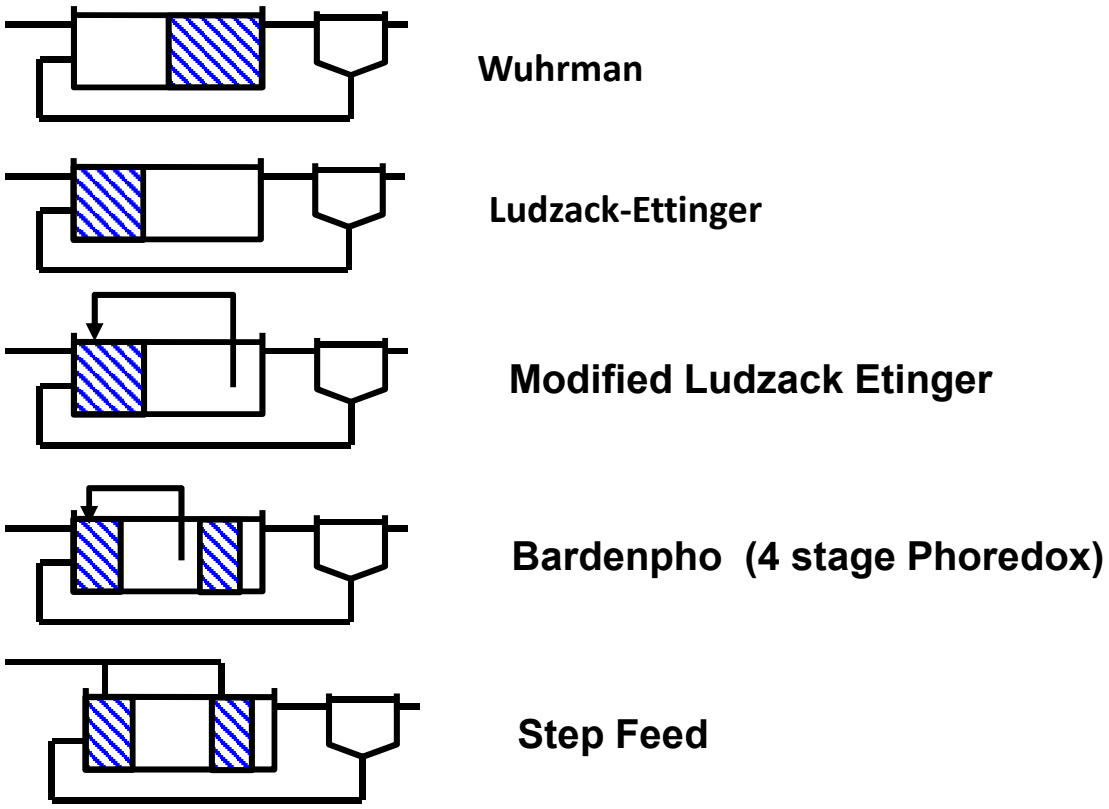
Biological Nutrient Removal Processes

Activated Sludge Reactor to Secondary Clarifier

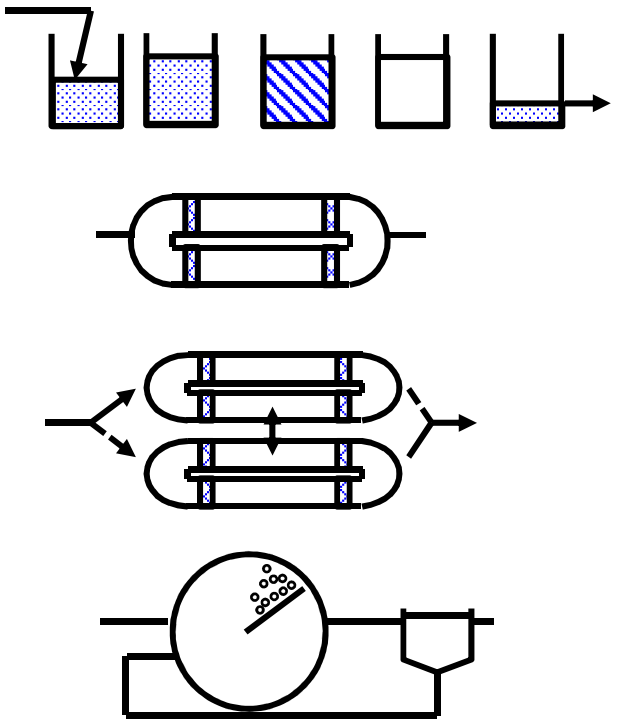
Effluent

MLE Process

Nitrogen Removal Processes - Classic Zoned



Nitrogen Removal Simultaneous



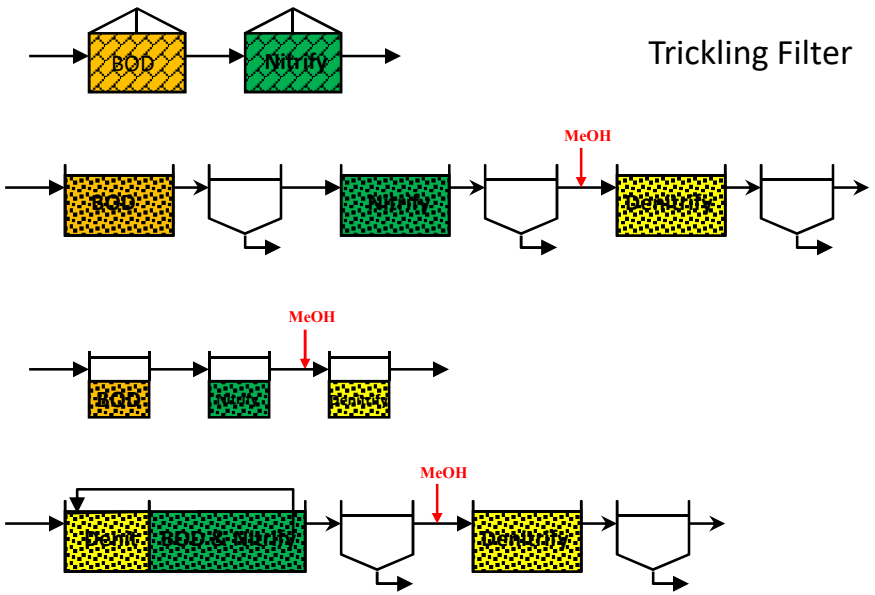
SBR

Oxidation Ditch

Biodenitro
– Cyclic Aeration

Schreiber

Nitrogen Removal – Fixed Film



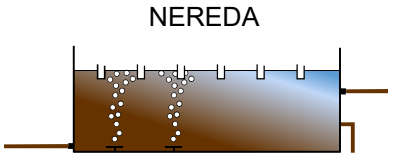
Trickling Filter

MBBR

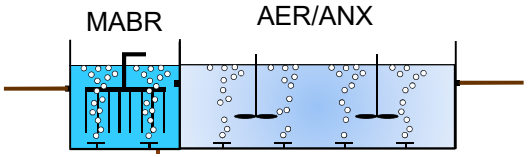
BAF – Biologically Active Filter

MBBR (2)

Secondary Nitrogen Emerging Processes



Granular Activated Sludge



Membrane Aerated BioReactor

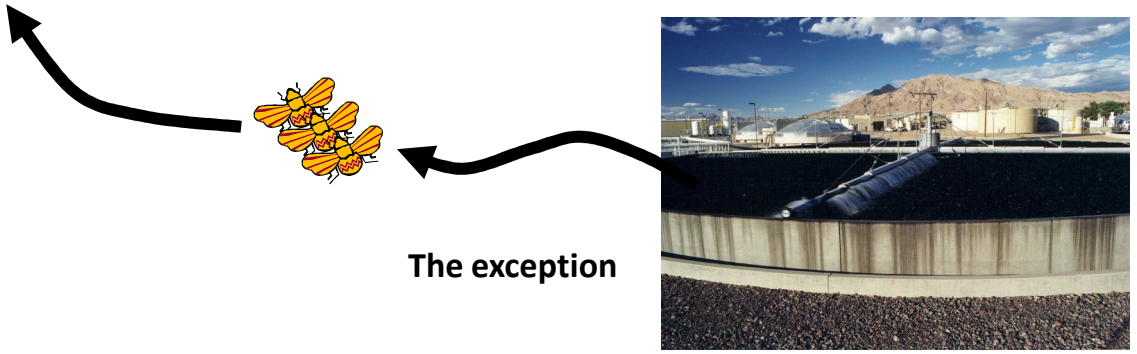
Secondary Phosphorus Removal Processes

- Biological Phosphorus Removal
  - Suspended Growth
  - Fixed Film/Hybrid
- Chemical Phosphorus Removal
  - Metal salt – Alum or Ferric
  - Other – Lime, Struvite
  - Location – Primary, Secondary process

Las Vegas Alum Dose

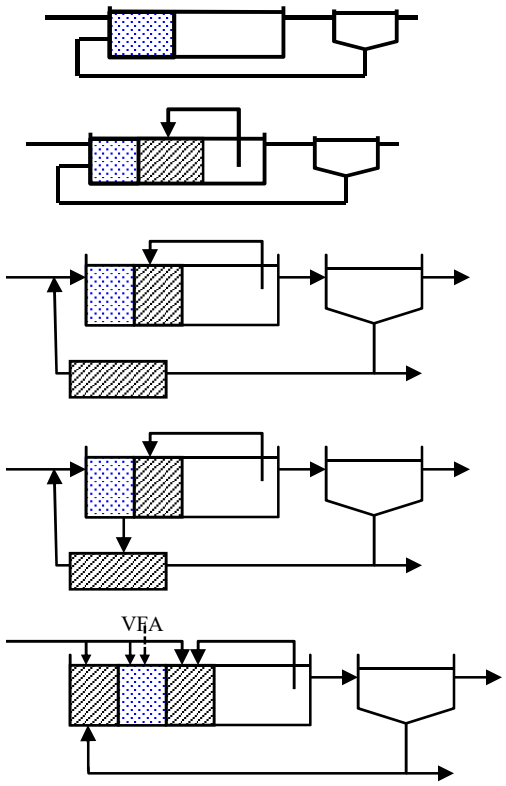
Fundamental Principle of Phosphorus Removal

There is no airborne (gaseous) form of phosphorus



The exception

Biological Phosphorus Removal Zoned Design



Phoredox (AO)

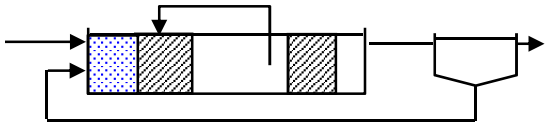
3-stage Phoredox (A2O)

Johannesburg

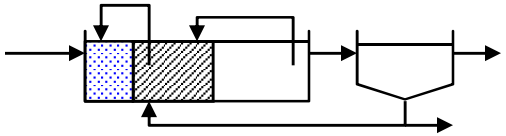
Modified Johannesburg

West Bank

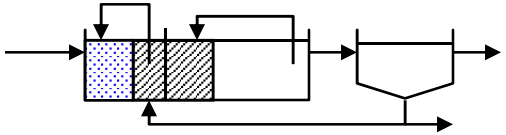
Biological Phosphorus Removal Zoned Design



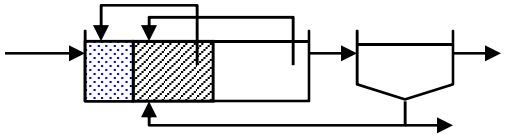
Modified (5-stage) Bardenpho



UCT



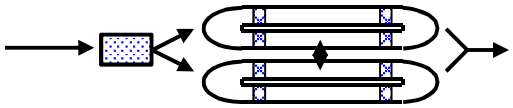
Modified UCT



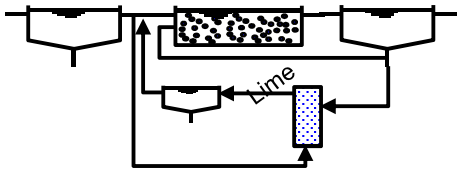
VIP (Virginia Initiative Process)

Biological Phosphorus Removal Mixed Design

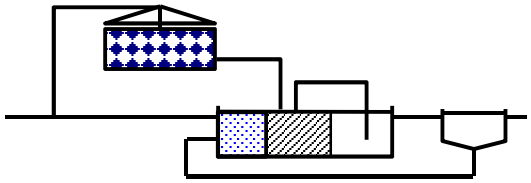
SBR



Biodenipho

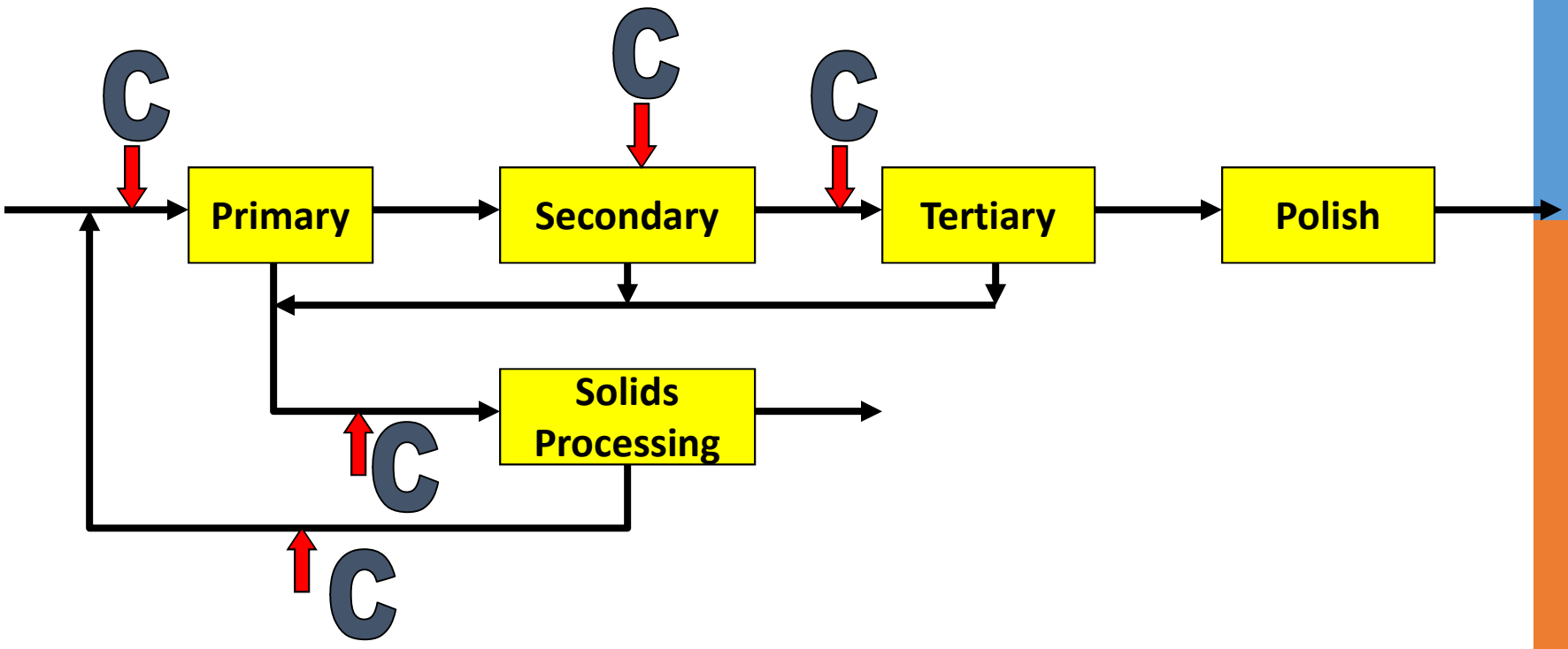


PhoStrip



Trickling Filter with EBPR

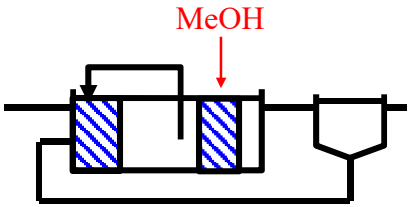
Chemical Phosphorus Removal



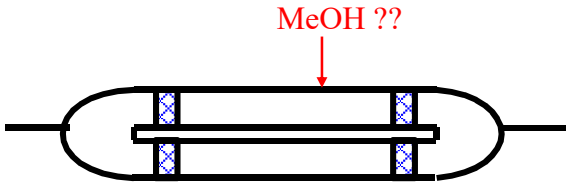
Tertiary Nitrogen Removal

- Suspended Growth Expansion
  - Post Anoxic Zone
  - SNDN
- Tertiary Nitrogen Removal
  - Denitrifying Filters
  - Fluidized Bed
- Carbon addition
  - Methanol
  - Other organics
  - Waste products

Tertiary Nitrogen Suspended Growth Processes

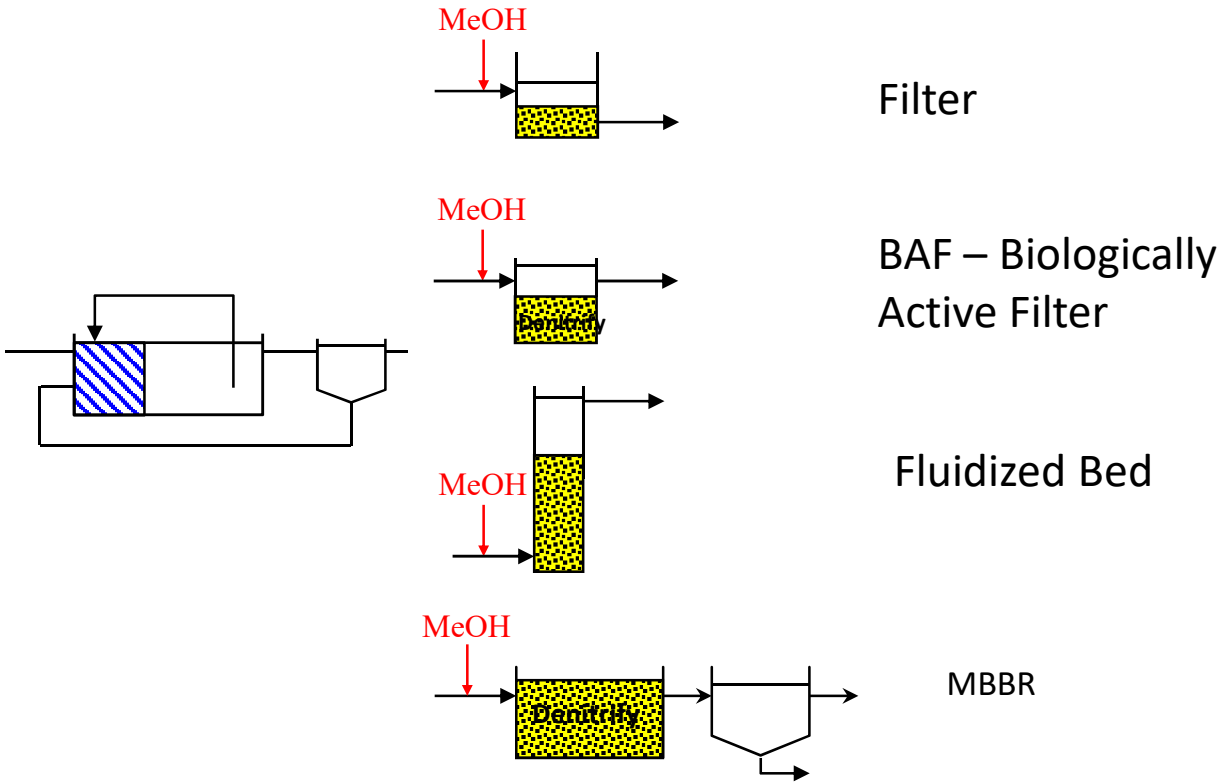


Bardenpho (4 stage Phoredox)



Oxidation Ditch (expanded)

Tertiary Nitrogen Removal Options



Filter

BAF – Biologically Active Filter

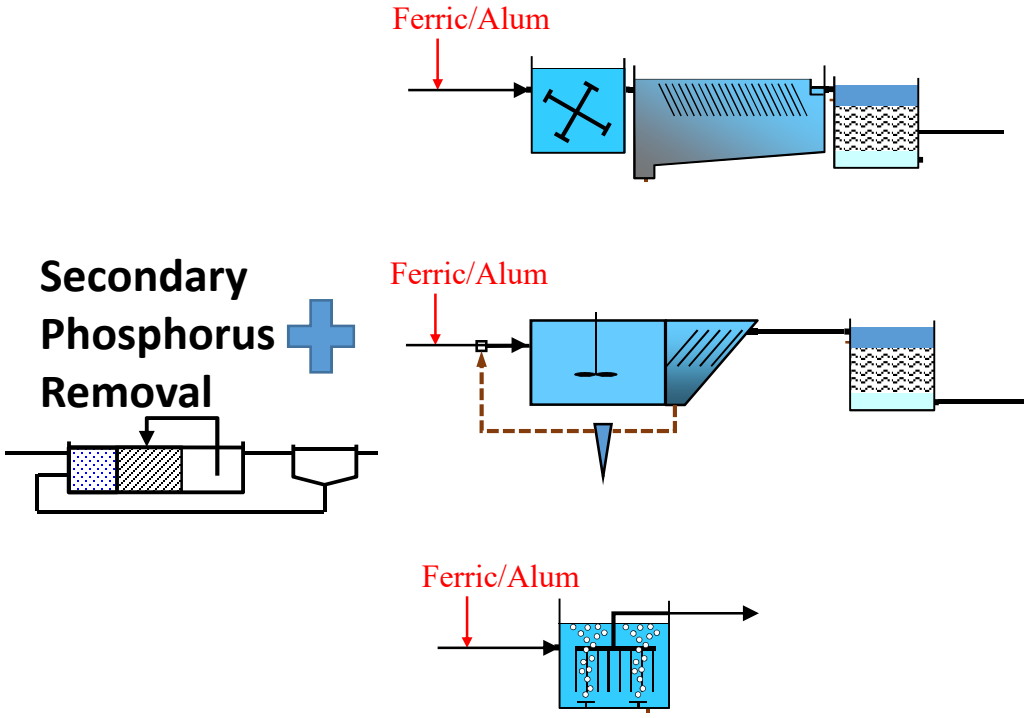
Fluidized Bed

MBBR

Tertiary Phosphorus Removal Processes

- Fermentation/carbon addition
- Chemical addition
- Filtration

Tertiary Phosphorus Removal



Secondary Phosphorus Removal

Flocculation /Sedimentation /Filtration

Ballasted Sedimentation /Filtration

Microfiltration

Typical effluent Filtration Technologies for chemical phosphorus removal

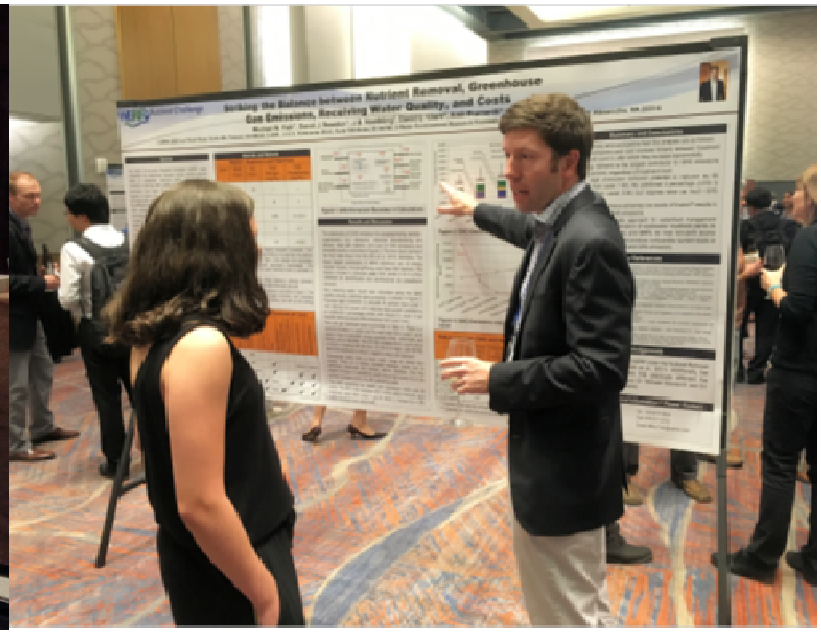
Dual Media Filters
City of Las Vegas

Cloth Media Disk at Sonoma Plants

Deep mono-media Filters (West Basin)

Continuous backwash filter – Ione, CA

Submerged Membranes (West Basin)



Water Environment & Reuse Foundation (WE&RF) Nutrient Challenge

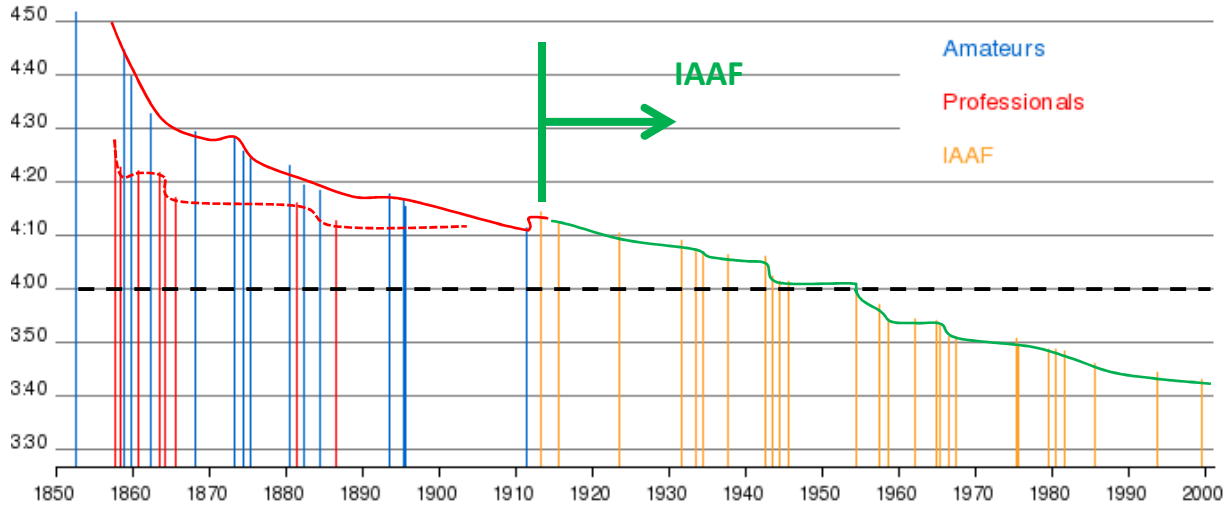
Water Environment & Reuse Foundation (WE&RF) Nutrient Challenge

www.werf.org/nutrients

Go to **KNOWLEDGE AREAS: Nutrients**
>50 completed and ongoing projects

- Objectives
- Provide science-based solutions and recommendations that:
  - (1) support utility decisions to use sustainable wastewater nutrient removal technologies to meet various receiving water body requirements and other wastewater treatment goals (e.g., climate change, sustainability, cost-effectiveness, reliability), and
  - (2) inform regulatory decision making that is moving toward increasingly higher levels of nitrogen and phosphorus removal.

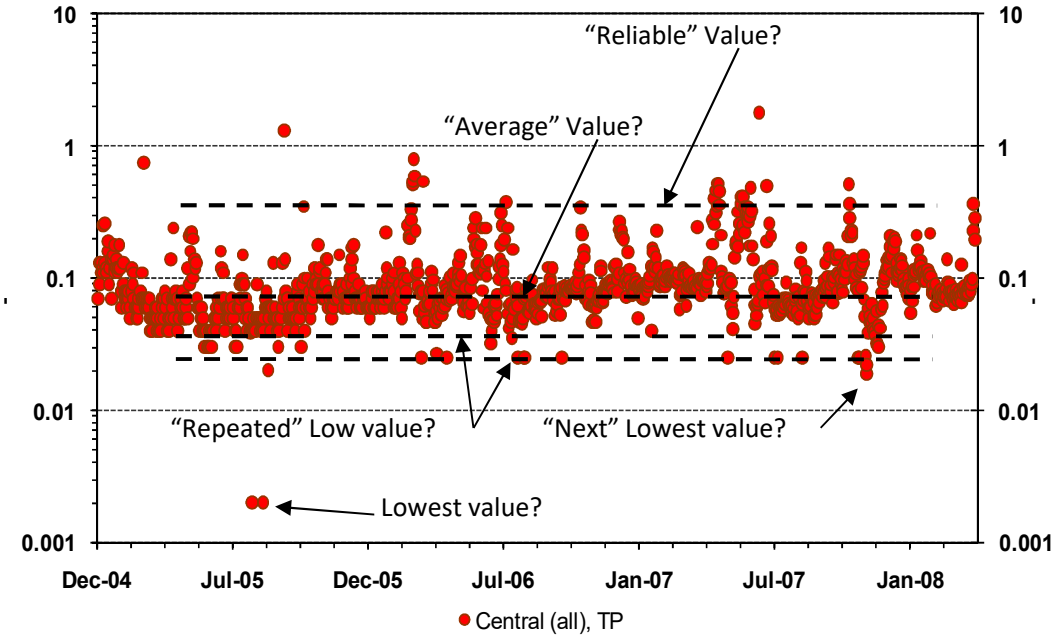
Fastest Mile Runners



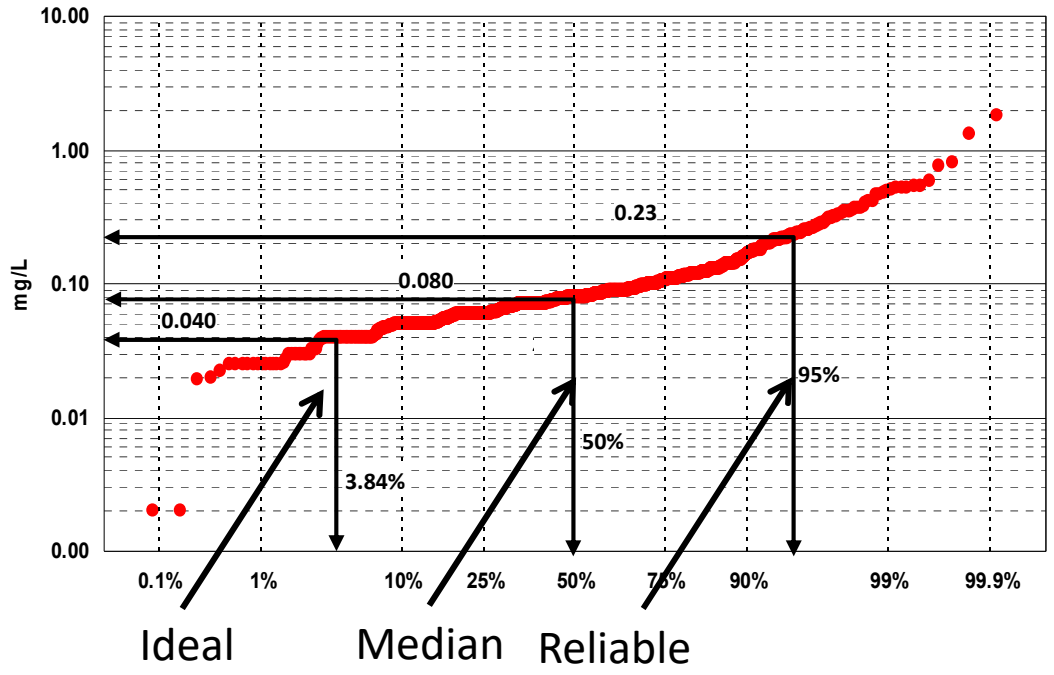
- May 6, 1954: Roger Bannister (3:59.4)
- June 21, 1954 John Landy (3:58.0)
- July 7, 1999: Hicham El Guerrouj (3:43.13)

http://en.wikipedia.org/wiki/Mile_run_world_record_progression

What is the “Performance” for This Real-World WWTP Dataset?



Technology Performance Statistics



Neethling et al. (2009) *WEF Nutrient 2009,* Alexandria, VA.

Permit Period and Reliability

Period	Basis (days)	Sample	Permit Percentile (%)	Reliable Percentile (%)	5 yr Excee-dance
Max Day	1	365	99.7	99.9	1.8
Max Week	7	365	98.1	99	2.6
Max Month	30	365	91.8	95	3
Ann Avg	182.5	365	50	80	1

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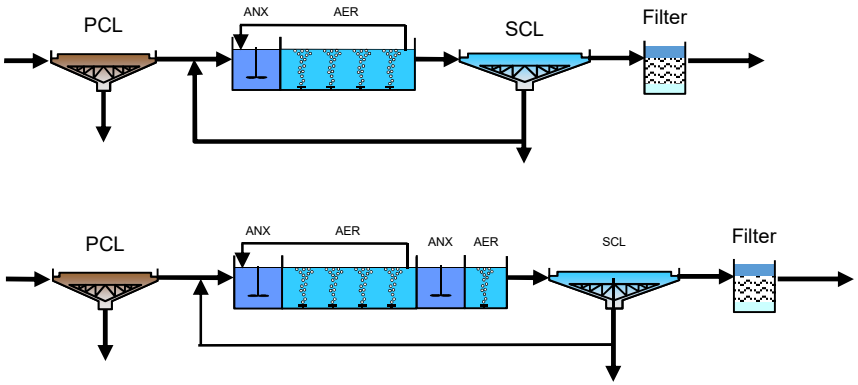
Max Month	30	365	91.8	95	3
Ann Avg	182.5	365	50	80	1

Exceed once a year!

Acceptable Risk?

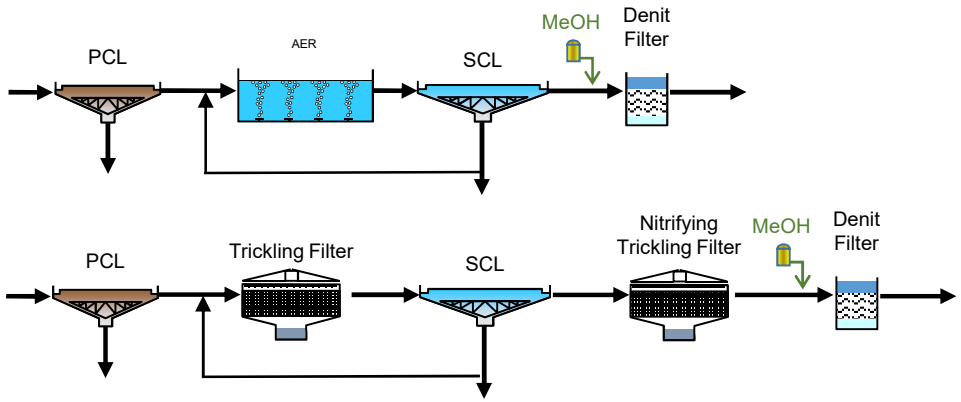
Nitrogen Process Types

- Secondary Nutrient Removal
  - Conventional, multiple cell BNR (MLE, Bardenpho, step feed, etc.
  - Effluent filter (no MeOH)



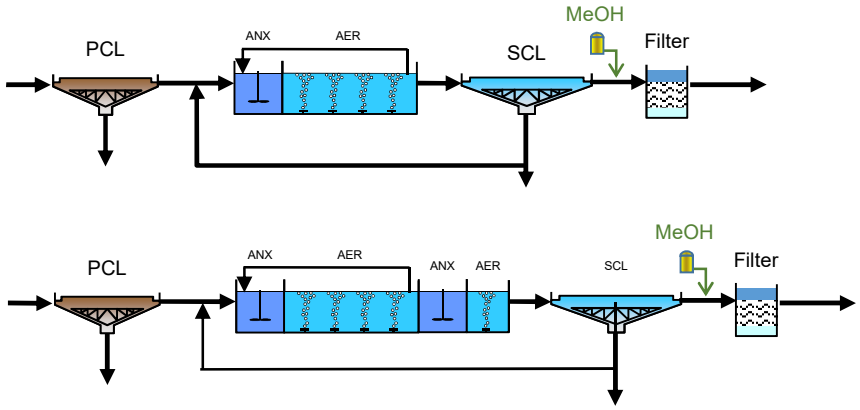
Nitrogen Process Types

- Separate Stage – Secondary/ Tertiary Nutrient Removal
  - Separate processes for nitrification, denitrification
  - MeOH added
  - Filter (denitrification)

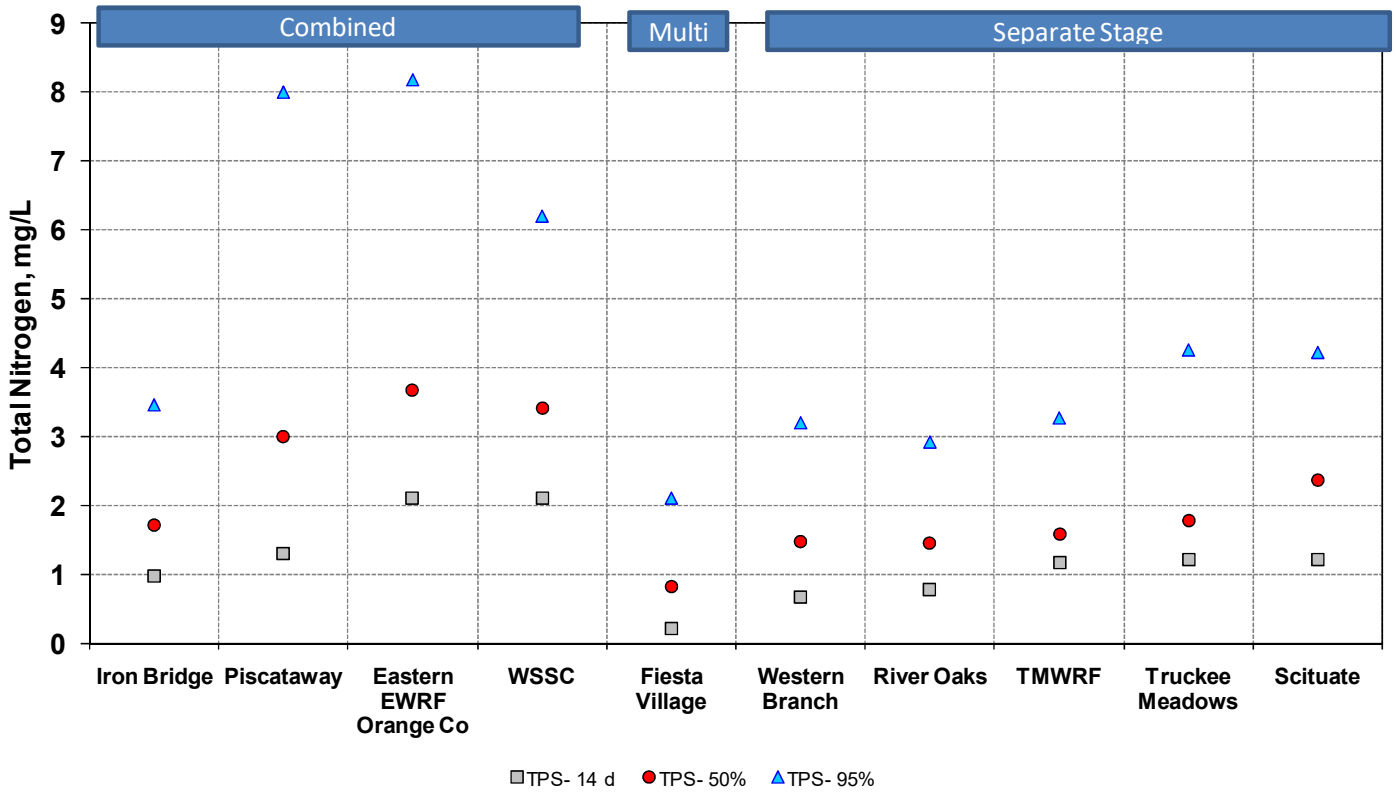


Nitrogen Process Type

- Multiple Stage
  - Conventional plus denitrification filter



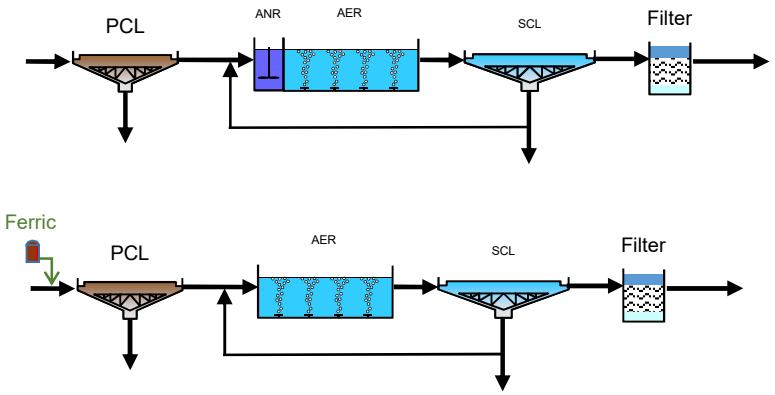
Results: Total Nitrogen – by Process



Adapted from: Bott, C. and Parker, D. (2010) WEF/WERF Study Quantifying Nutrient Removal Technology Performance, WERF NUTRIR06h; Personal Sources

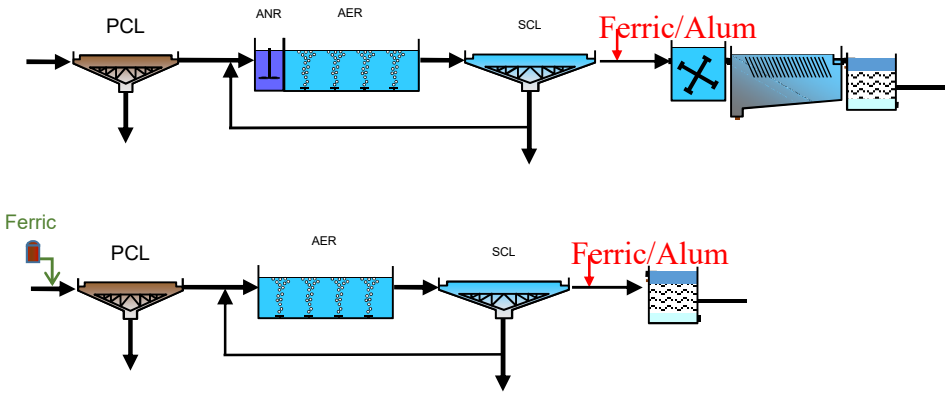
Secondary “plus” Phosphorus Removal

- 1B = Biological Phosphorus Removal with filter polishing
- 1C = Single Chemical Phosphorus Removal with filter polishing



Tertiary Phosphorus Removal

- 2B = Multistage Biological with Chemical polishing
- 2C = Multistage Chemical with Chemical polishing



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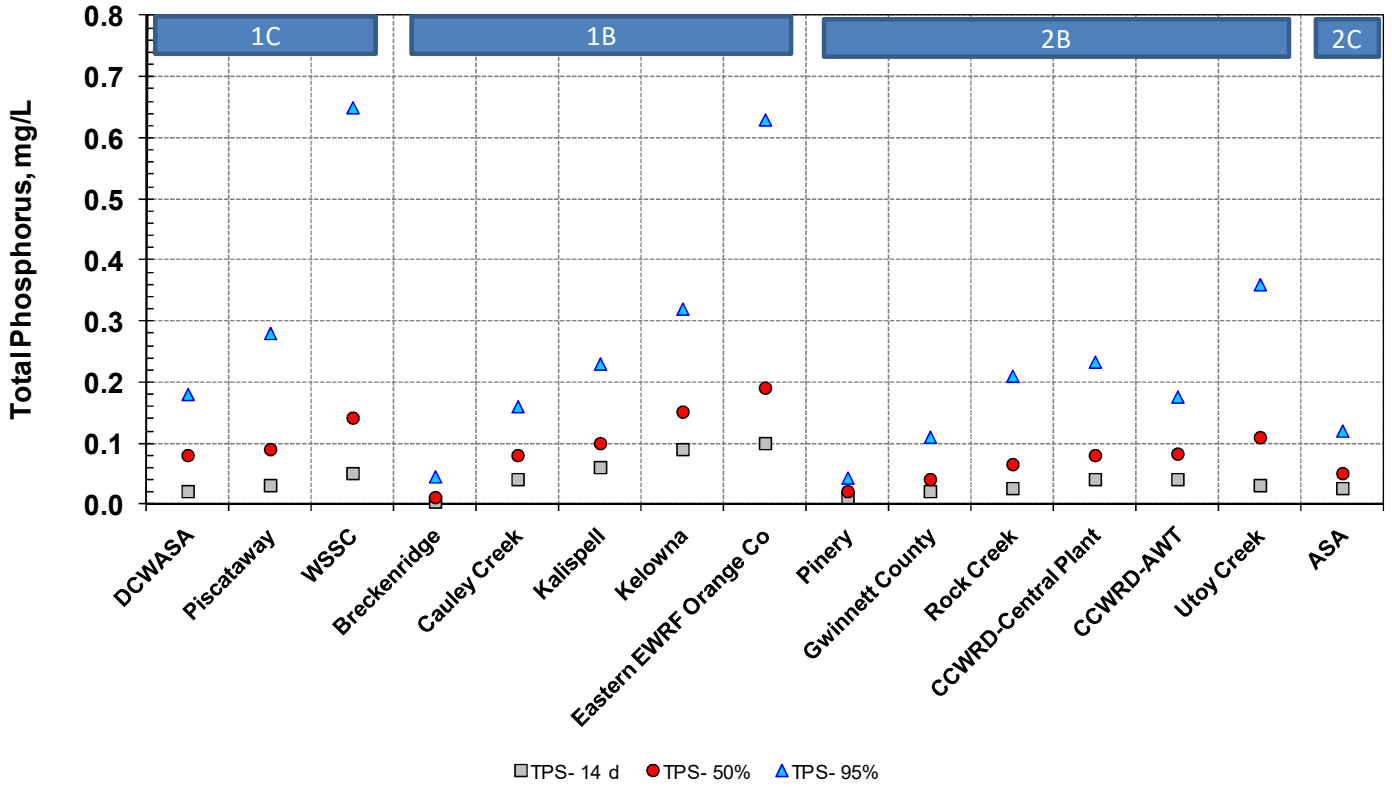

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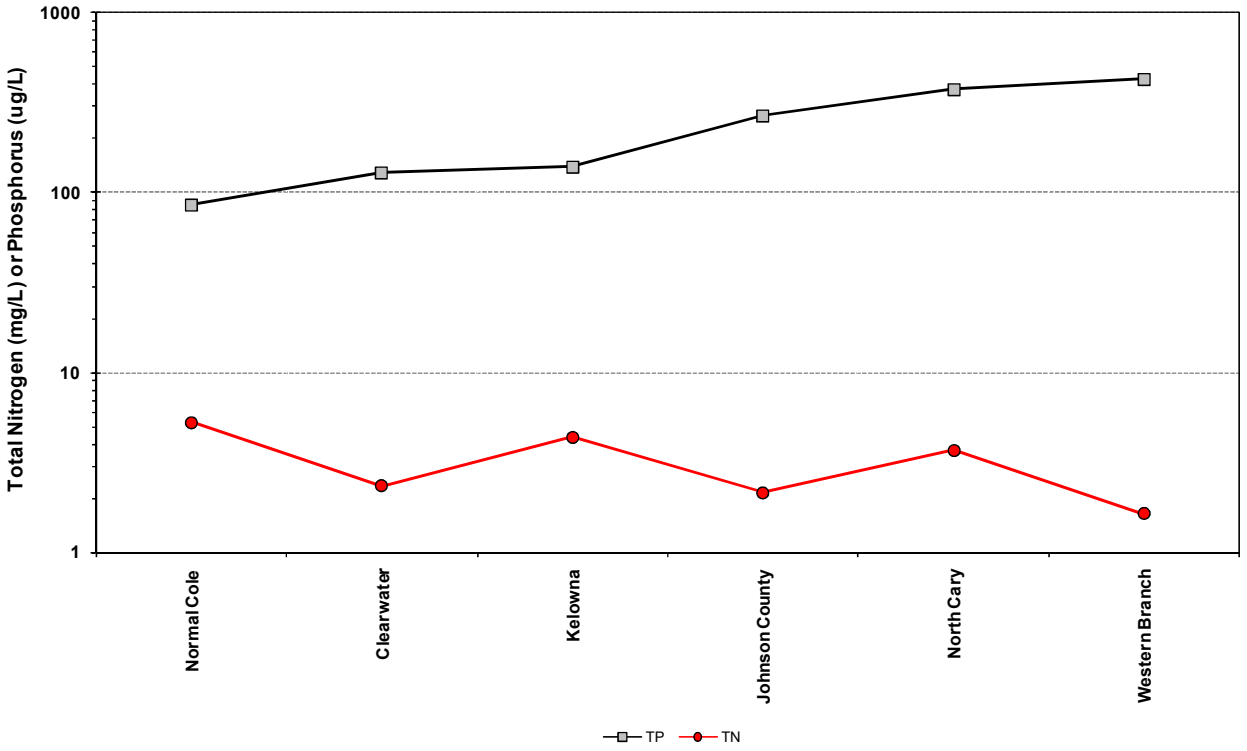
Combined Total Nitrogen and Phosphorus



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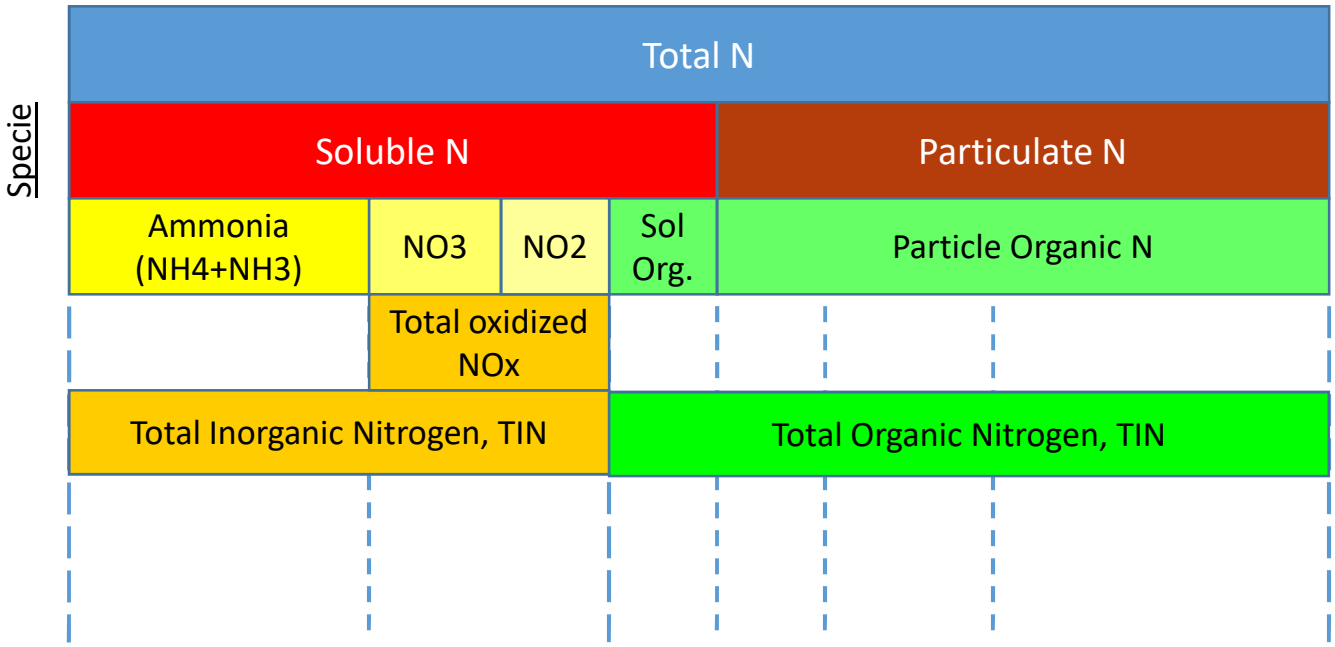
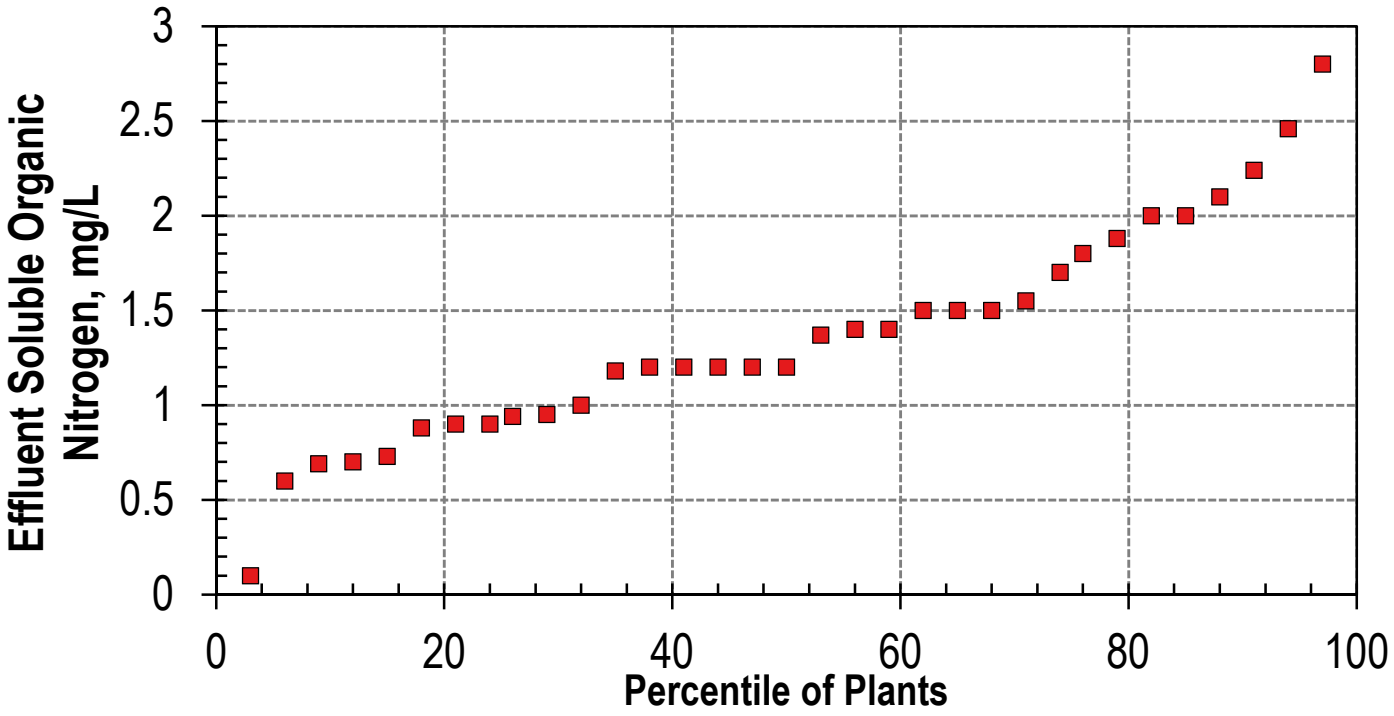
Nitrogen Species

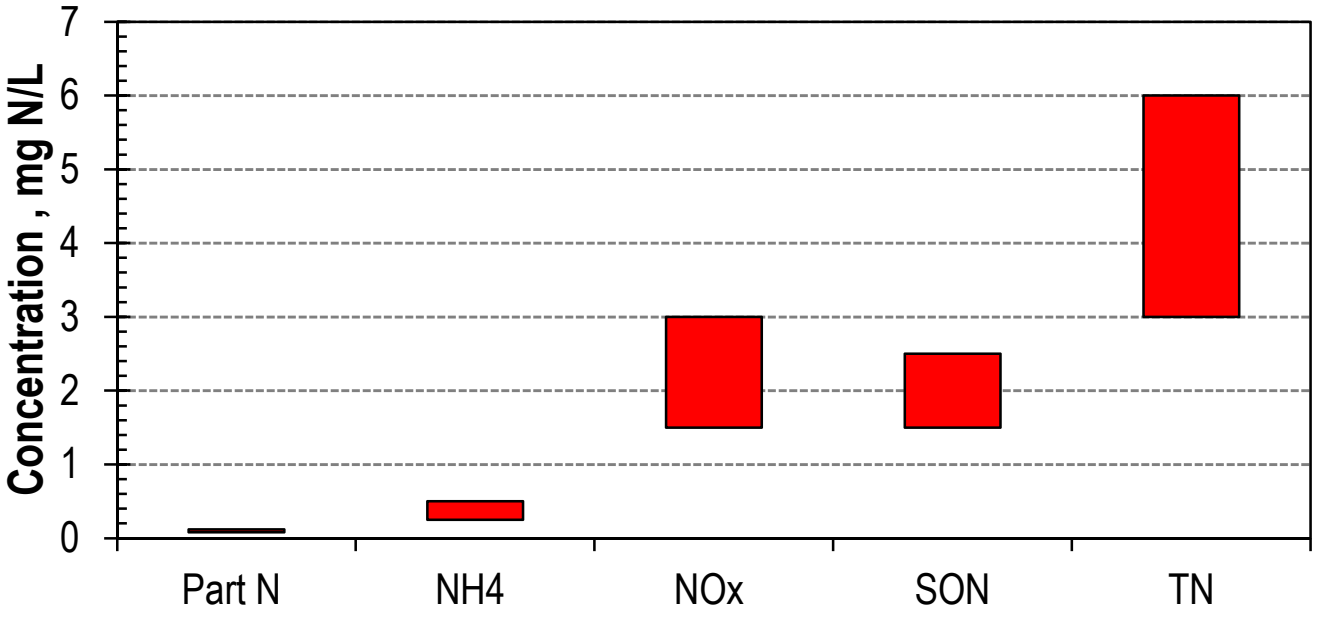


Soluble Organic Nitrogen



Adapted from: Stensel et al, 2007

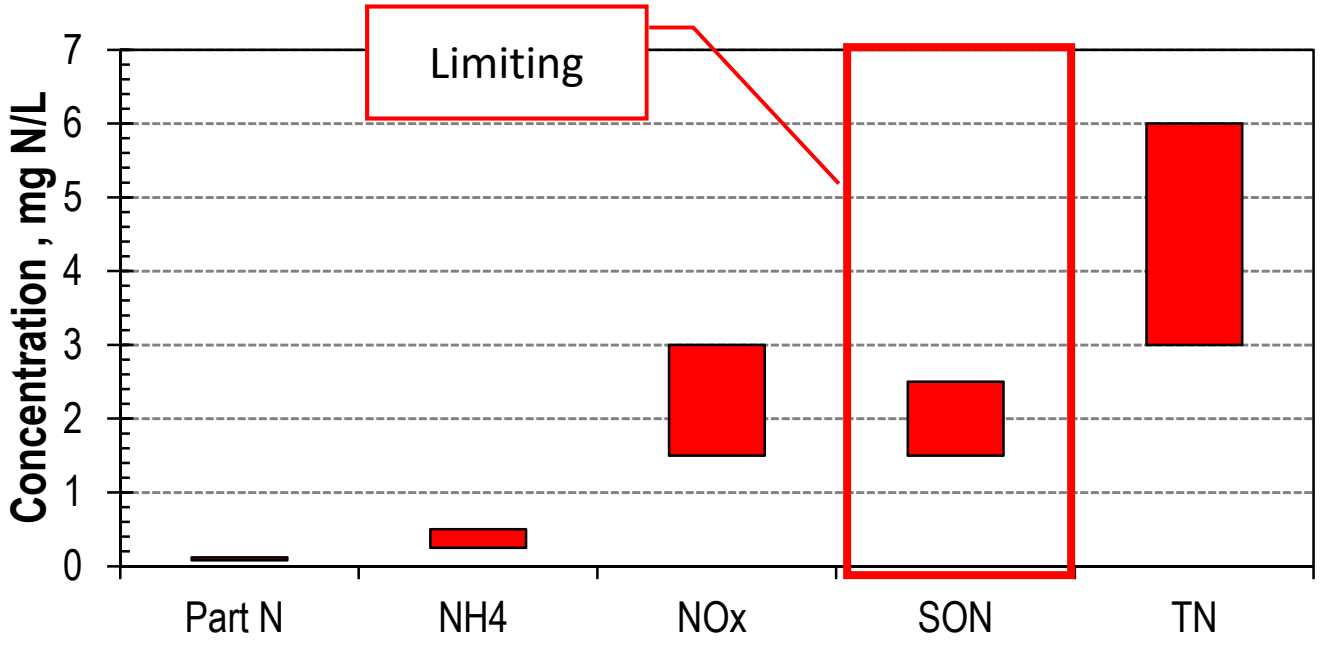
Nitrogen Species in Tertiary Nutrient Removal



Part N=Particulate P
NOx = Nitrate + Nitrite
TN = Total Nitrogen

NH4 = Ammonia N
SON = Soluble Organic Nitrogen

Nitrogen Species in Tertiary Nutrient Removal



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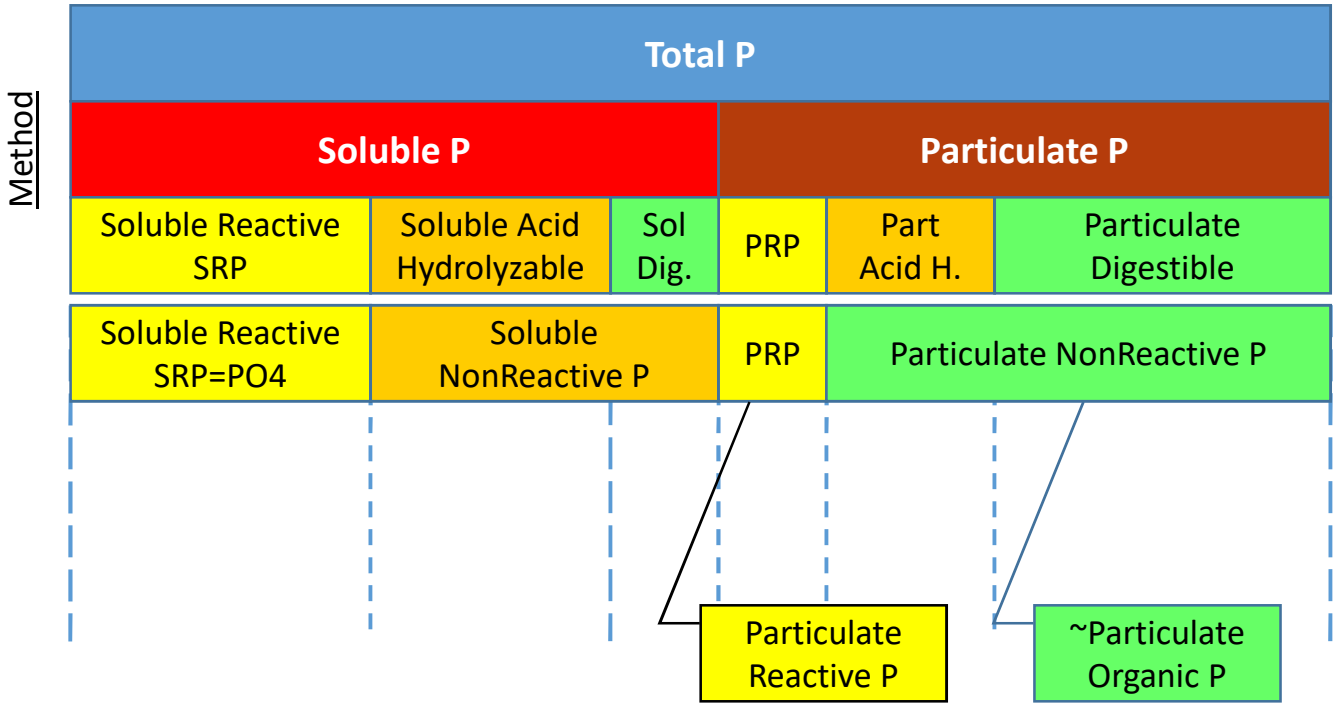
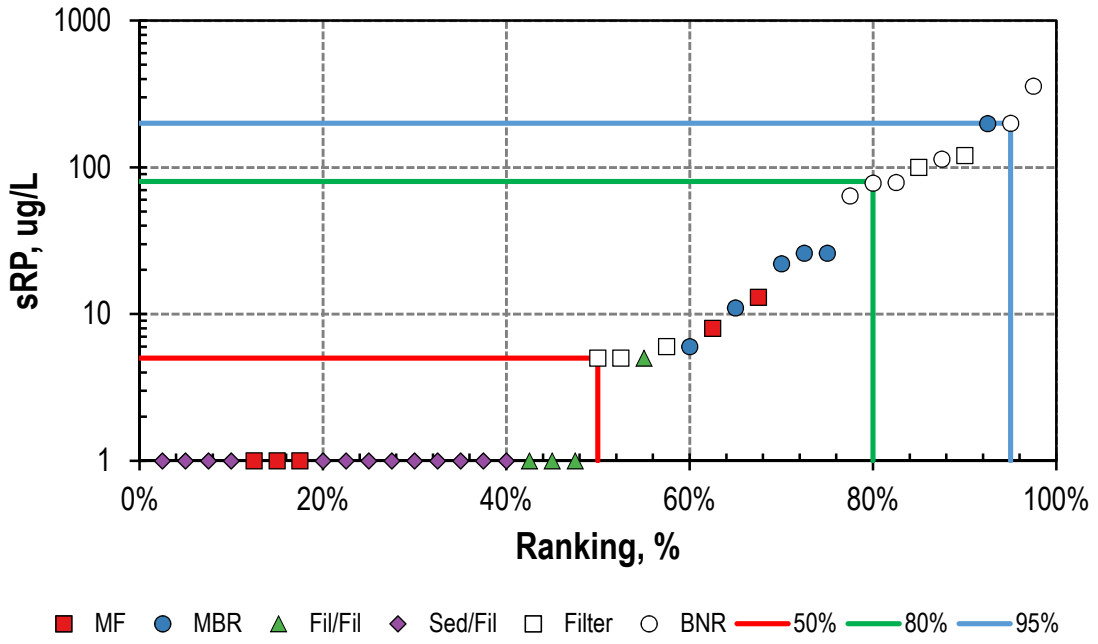
Phosphorus Species Simple

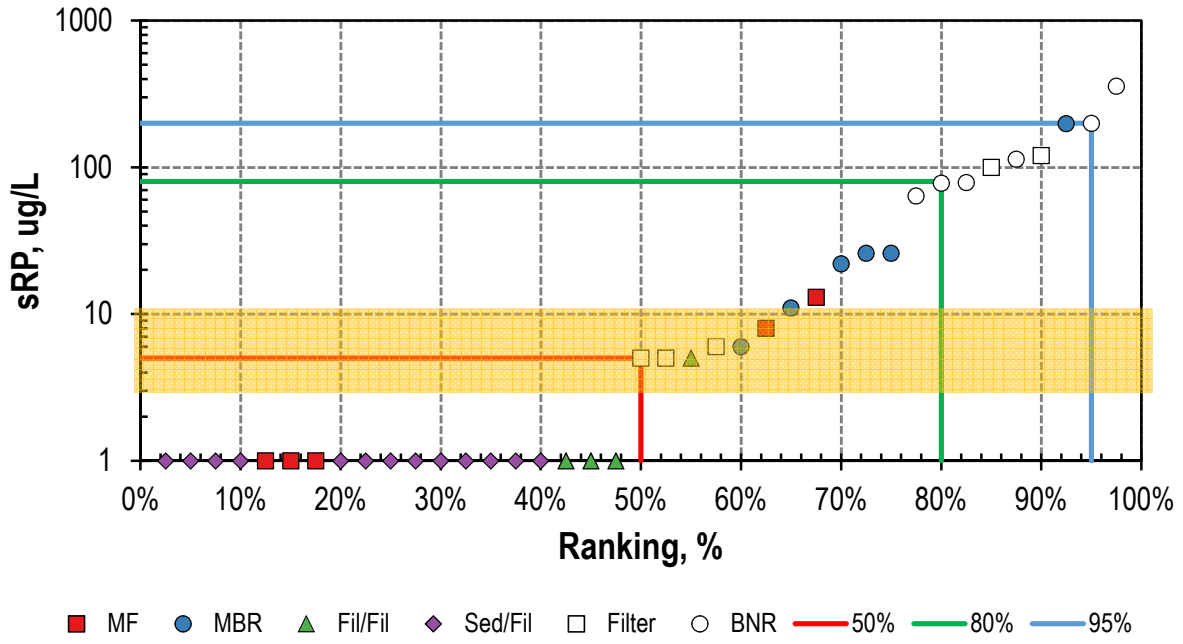


Distribution of sRP



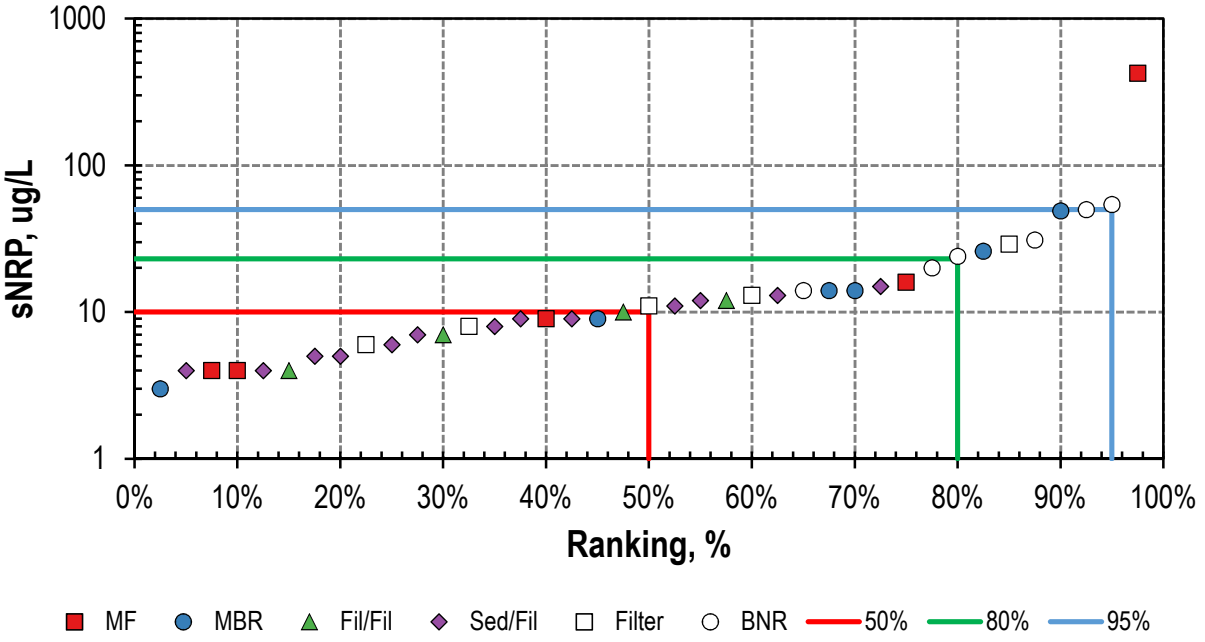
Adapted from: Gu, A. et al. "Phosphorus Fractionation And Removal In Wastewater Treatment-Implications For Minimizing Effluent Phosphorus," WERF Nutrient Removal Study; Draft Report 2012.

Distribution of sRP – Optimal Estimate - 5-15 ug/L



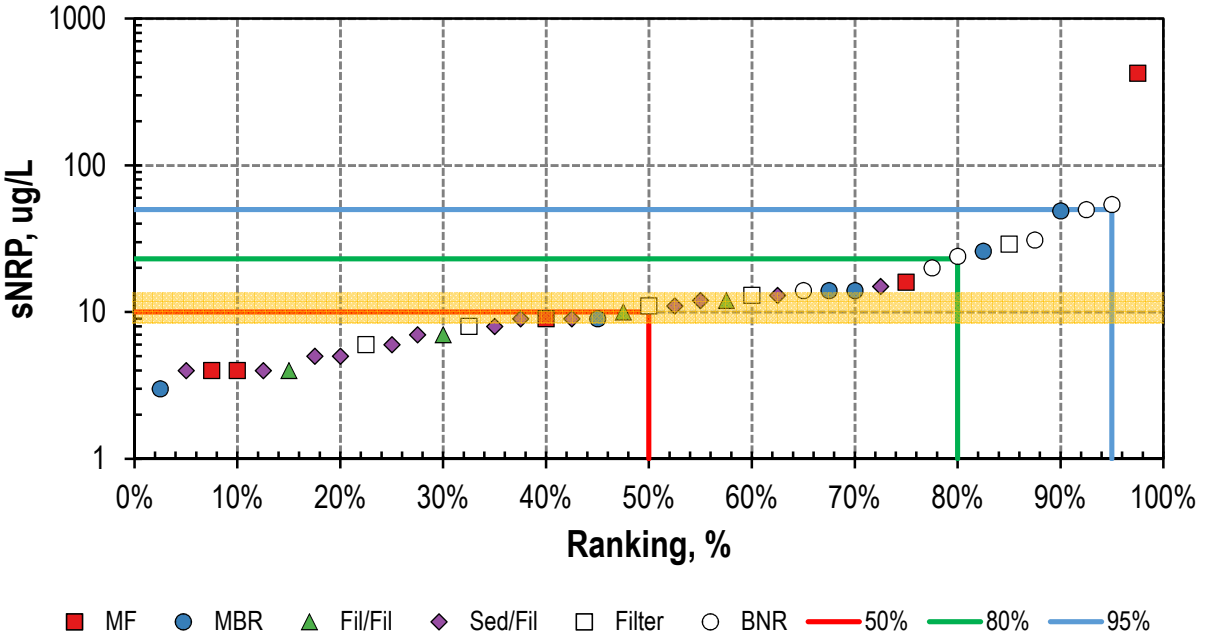
Adapted from: Gu, A. et al. "Phosphorus Fractionation And Removal In Wastewater Treatment-Implications For Minimizing Effluent Phosphorus," WERF Nutrient Removal Study; Draft Report 2012.

Distribution of sNRP



Adapted from: Gu, A. et al. "Phosphorus Fractionation And Removal In Wastewater Treatment-Implications For Minimizing Effluent Phosphorus," WERF Nutrient Removal Study; Draft Report 2012.

Distribution of sNRP – Optimal Estimate – 15-25 ug/L



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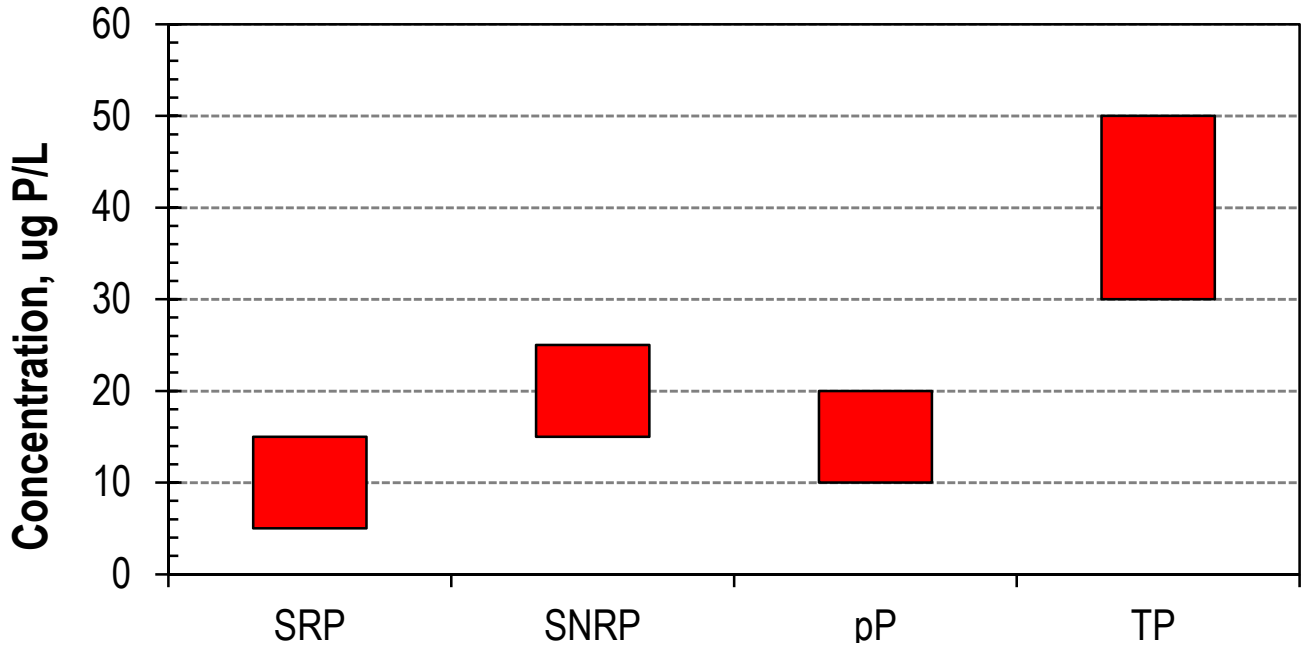
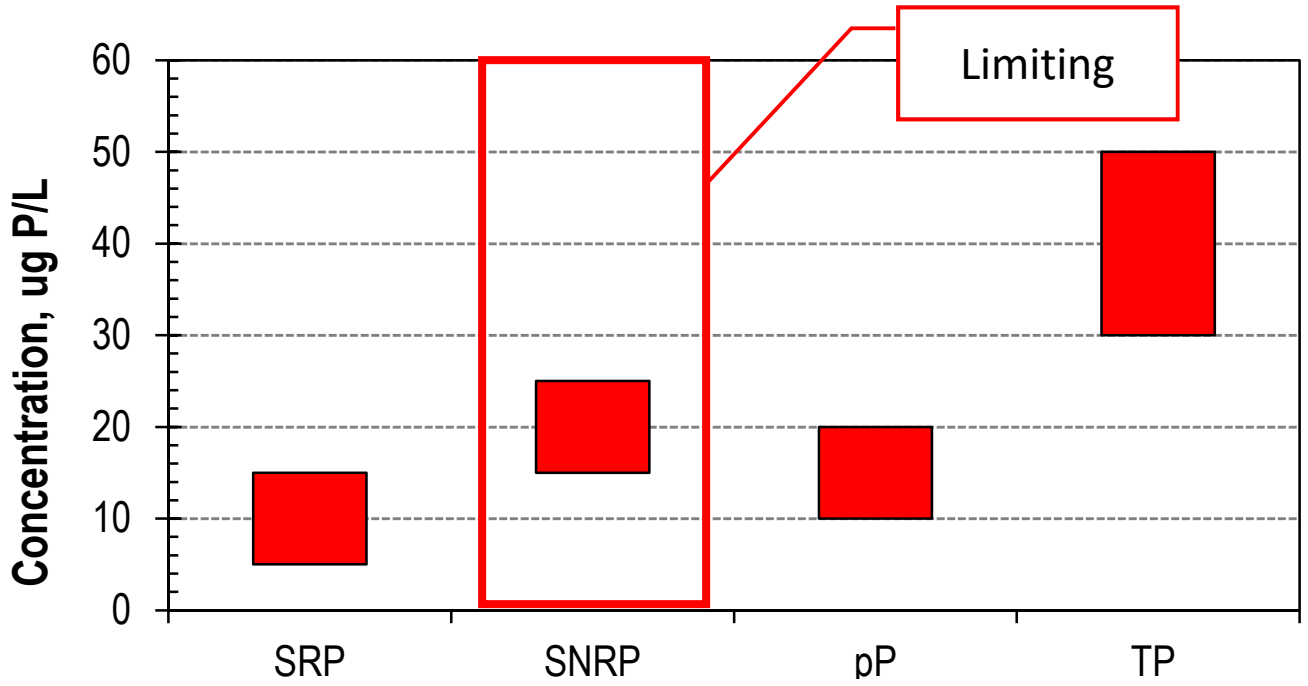
Estimated Optimal P Species in Advanced Treatment



SRP=Soluble Reactive P;
pP=Particulate P

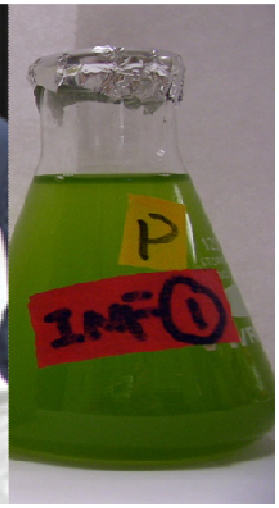
SNRP = Soluble Nonreactive P
TP = Total P

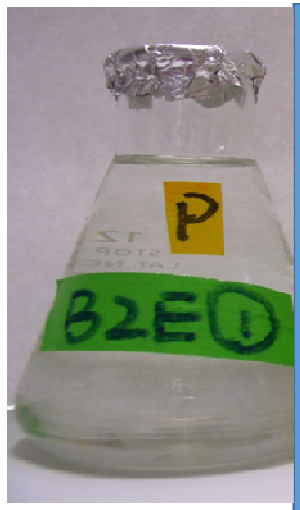
Estimated Optimal P Species in Advanced Treatment



SRP=Soluble Reactive P;
pP=Particulate P

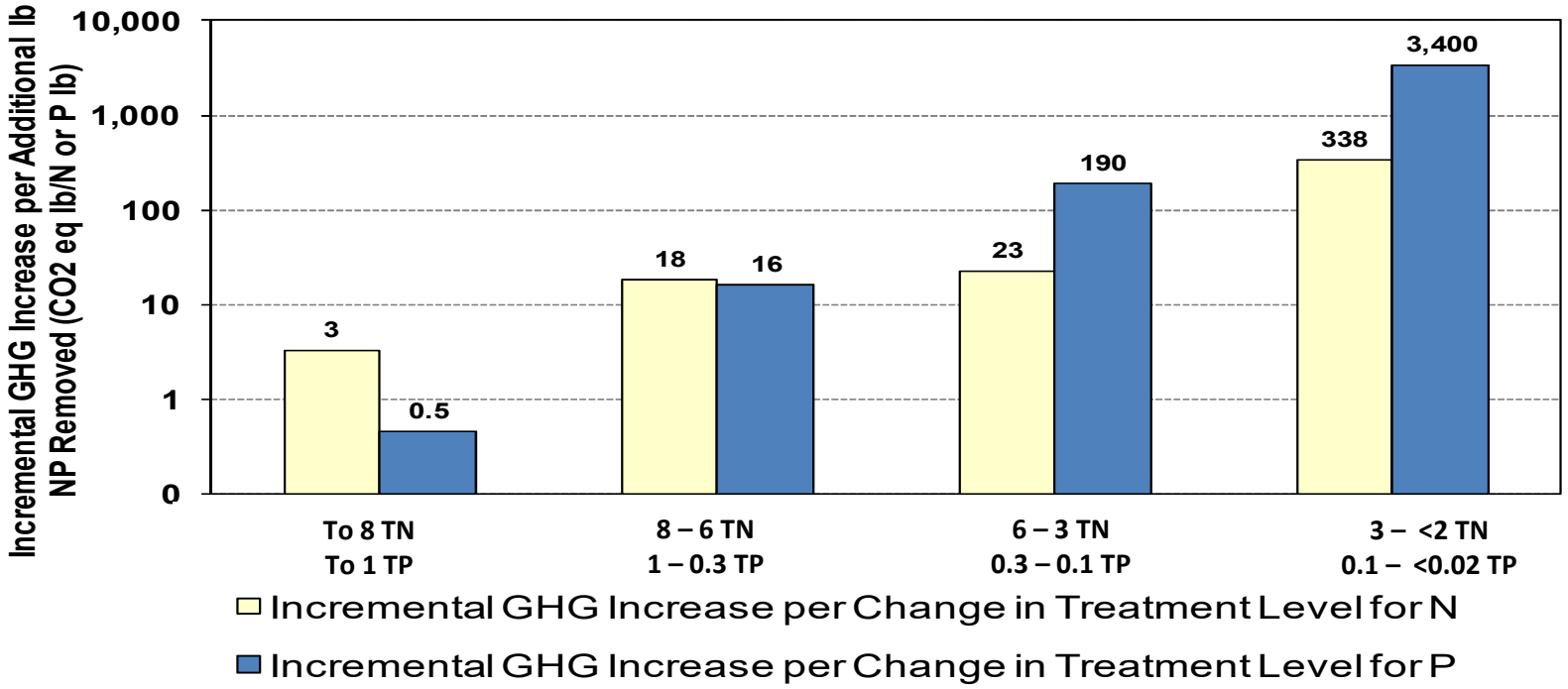
SNRP = Soluble Nonreactive P
TP = Total P





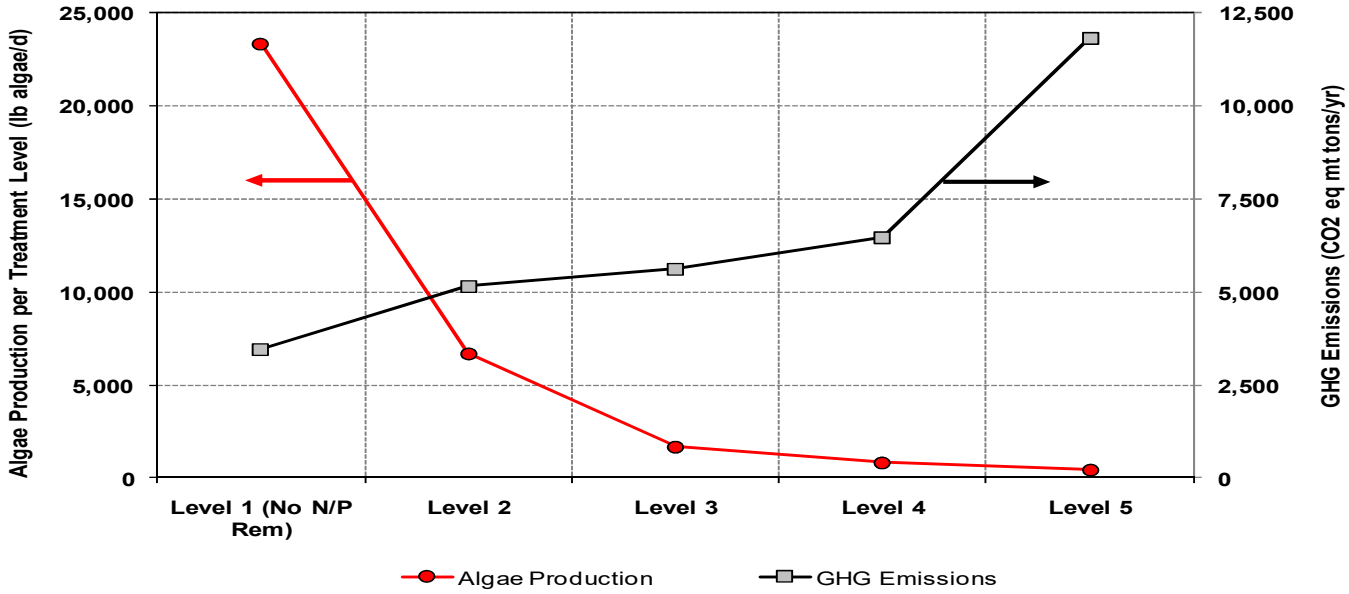
Sustainability

Incremental Greenhouse Gas (GHG) emissions for N and P removal



Adapted from Falk et al., 2011. "Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability" WERF Nutrient Removal Challenge project NUTR1R06n.

Algal Production Potential v. Greenhouse Gas Production

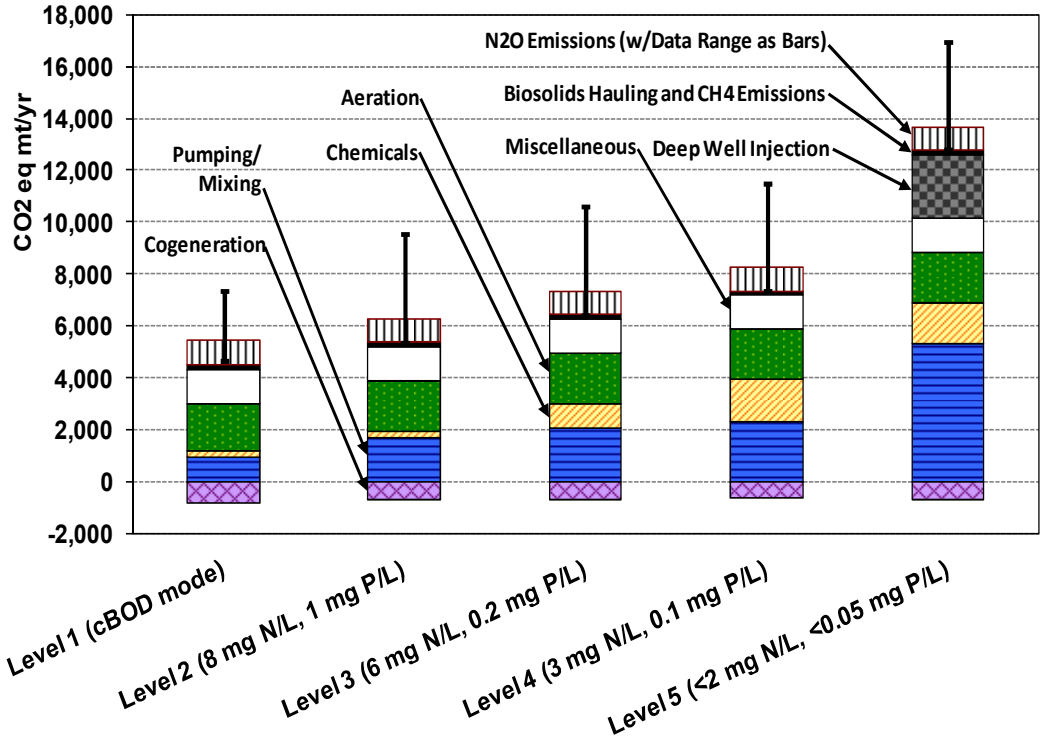


Water Environment Research Foundation (WERF) "*Striking the Balance Between Wastewater Treatment Nutrient Removal and Sustainability*" November 2010

1. *Secondary Treatment (No nutrient removal)*
2. *Biological Nutrient Removal (BNR) TP 1 mg/L TN 8 mg/L*
3. *Enhanced Nutrient Removal (ENR) TP 0.1-0.3 mg/L TN 4-8 mg/L*
4. *Limit of Treatment Technology (LOT) TP <0.1 mg/L TN 3 mg/L*
5. *Reverse Osmosis (RO) TP <0.02 mg/L TN 2 mg/L*

Considering Sustainability in the Design of Low Nutrient Facilities

- NUTR1R06n Striking the Balance between Nutrient Removal in Wastewater Treatment and Sustainability (Falk et al, 2011)
- NUTR1R06v Development of Sustainable Approaches for Achieving Low Phosphorus Effluents (deBarbadillo et al, 2015).
- NUTR1R06R14f Sustainability Evaluation of Nutrient and Contaminants of Emerging Concern Removal Technologies using Life Cycle Assessment (Gu et al, 2016)




WERF Addresses Challenges of Minimizing Effluent Nutrient Concentrations
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Nutrient
Symposium 2015

Summary

Summary

- The WRF Nutrient Removal Challenge investigated WRRF reliability and performance for Secondary and Tertiary Nutrient Removal
- Performance to meet permits reliably is at 80th to 95th percentile
- All nutrient species are not equal in terms of
  - Treatability
  - Water quality impacts
- Soluble organic nutrients (N&P) limits nutrient reduction for SNR and TNR processes
- Soluble organic nutrients (N&P) are slowly available in environment
- Advanced Nutrient Removal dramatically increase GHG emissions and costs (capital and O&M)

Nutrient Removal Technology Performance

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