Enabling Extractive Nutrient Recovery – A Disruptive Nutrient Management Strategy for a Circular Economy

Water Environment Research Foundation
Collaboration. Innovation. Results.

Wendell O. Khunjar, PhD, PE
Ron Latimer, PE

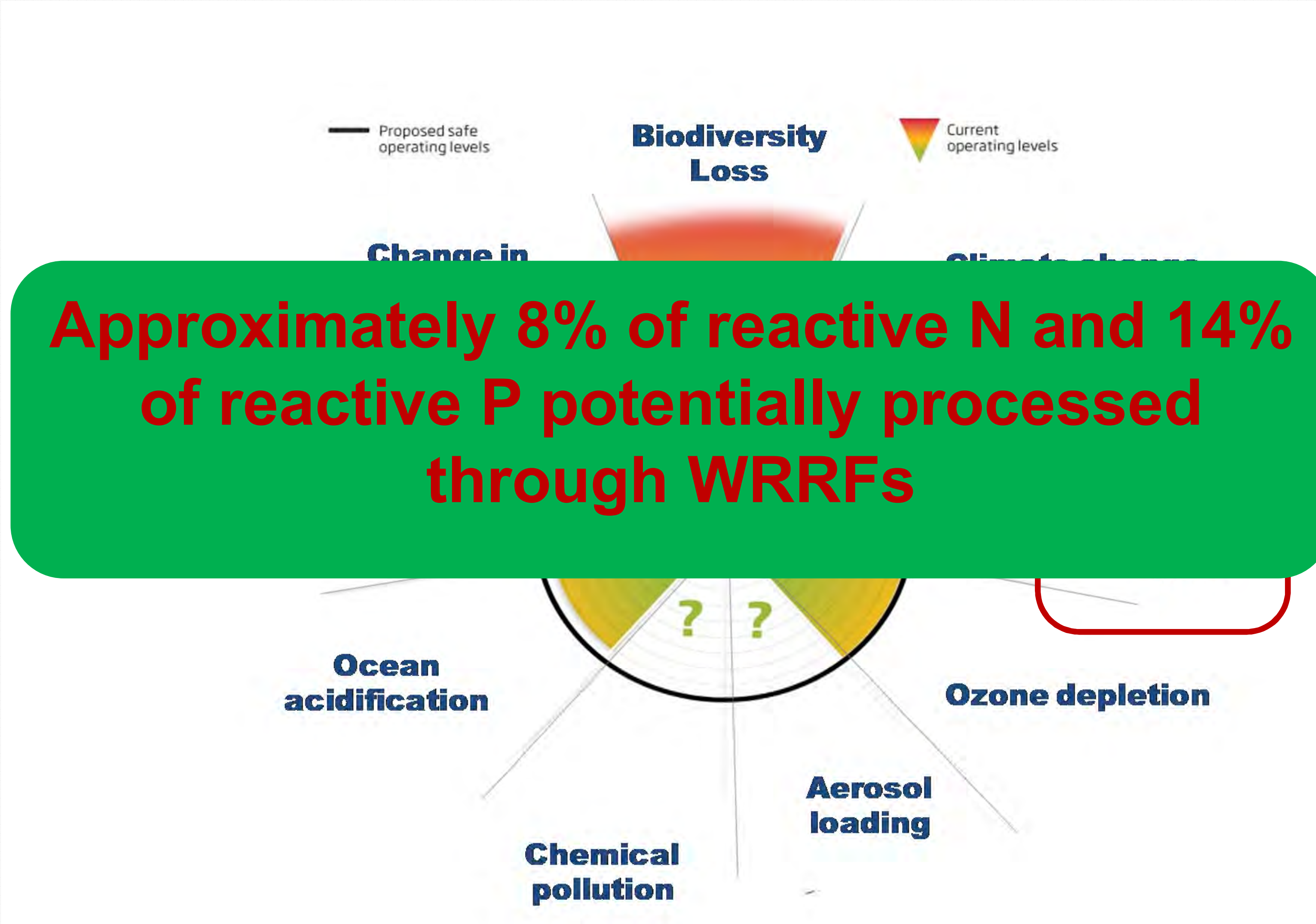
Sam Jeyanayagam, PhD, PE, BCEE

Amit Pramanik, PhD, BCEEM

Acknowledgments

- Joe Rohrbacher, PE – Hazen and Sawyer
- Vivi Nguyen – Hazen and Sawyer
- Ron Latimer, PE– Hazen and Sawyer
- Paul Pitt, PhD PE – Hazen and Sawyer
- Chirag Mehta, PhD – University of Queensland, Australia
- Damien Batstone, PhD – University of Queensland, Australia
- Tim Muster, PhD – CSIRO
- Stewart Burns, PhD - CSIRO
- Ron Alexander – R. Alexander Associates Inc
- Glen Daigger, PhD, PE, BCEE – CH2M
- Todd Williams, PE, BCEE – CH2M

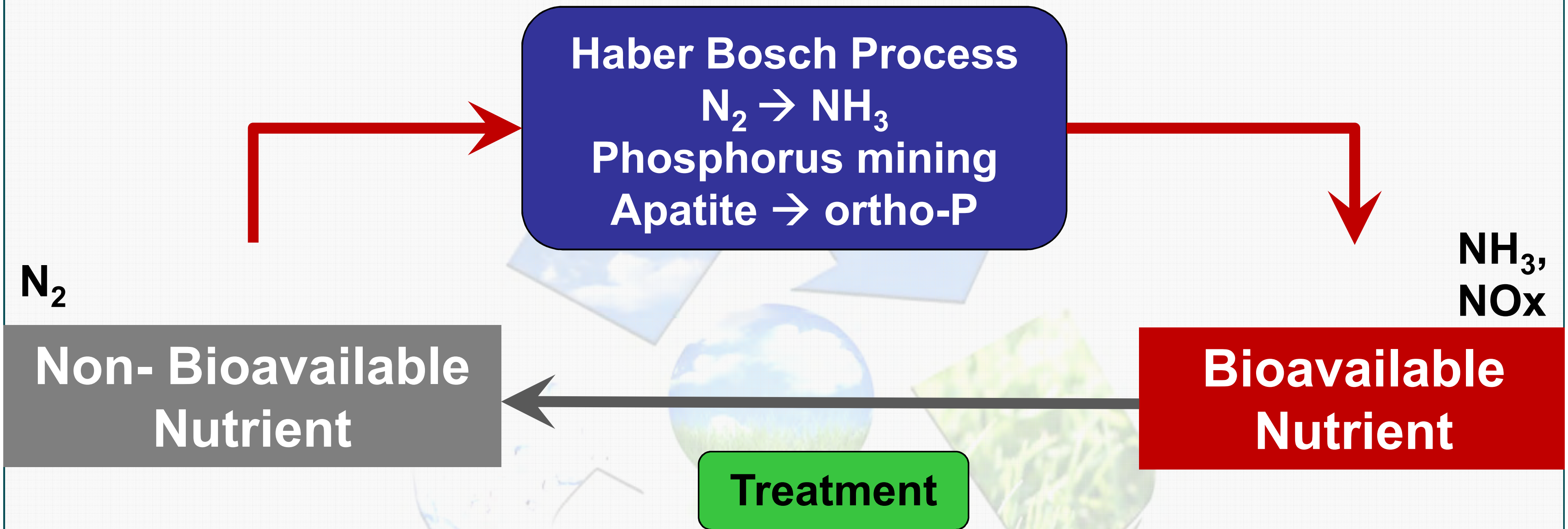
Nutrient planetary boundaries are being exceeded due to increased anthropogenic inputs



Approximately 8% of reactive N and 14% of reactive P potentially processed through WRRFs

1 Adapted from Rockstrom, J., et al. (2009), Nature 461 (7263), 472-5
Adapted from Penuelas, J., et al. (2012), Global Change Biology 18, 3-6

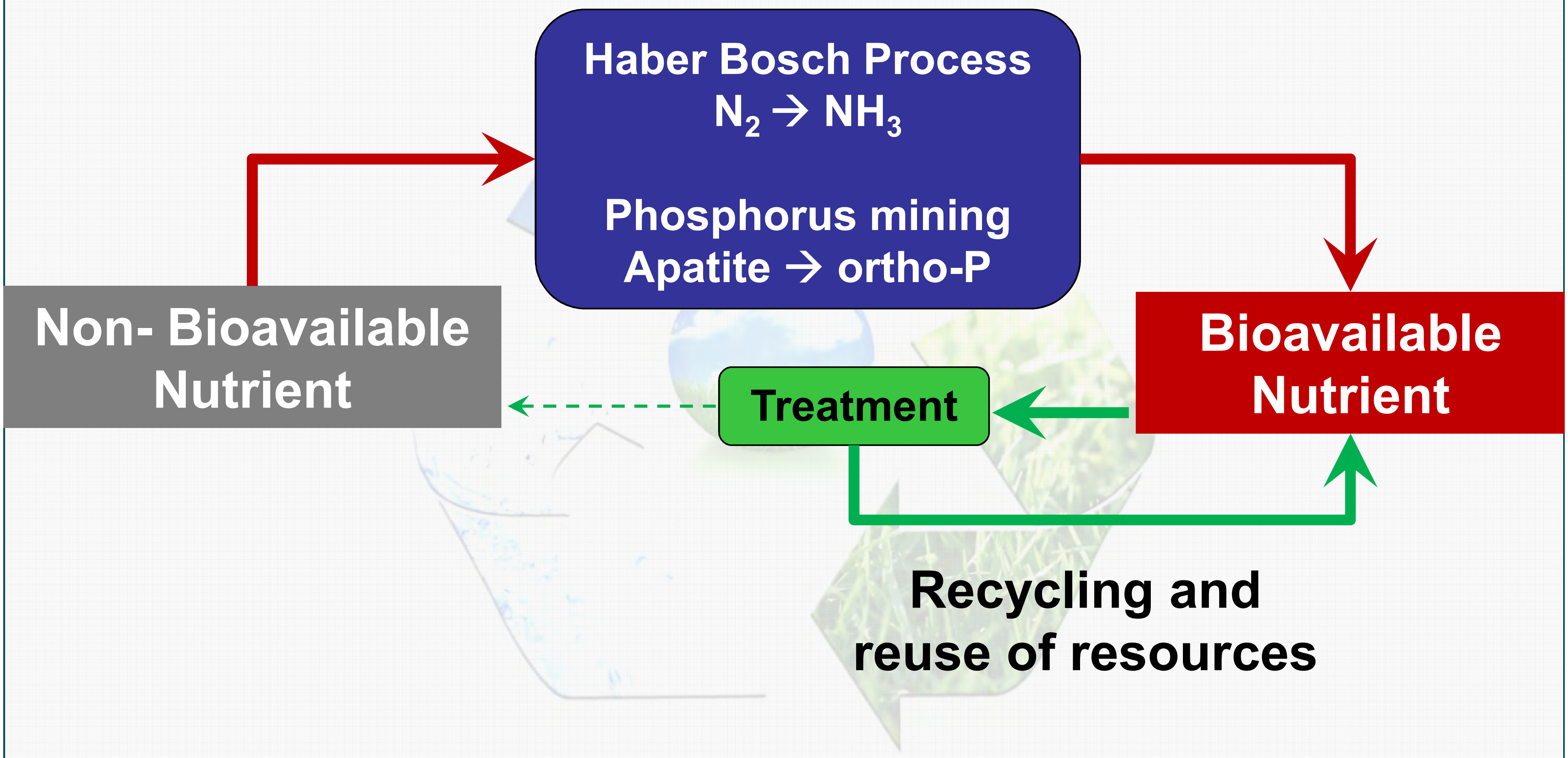
Nutrient usage cycle currently assumes an unlimited supply of resources and energy



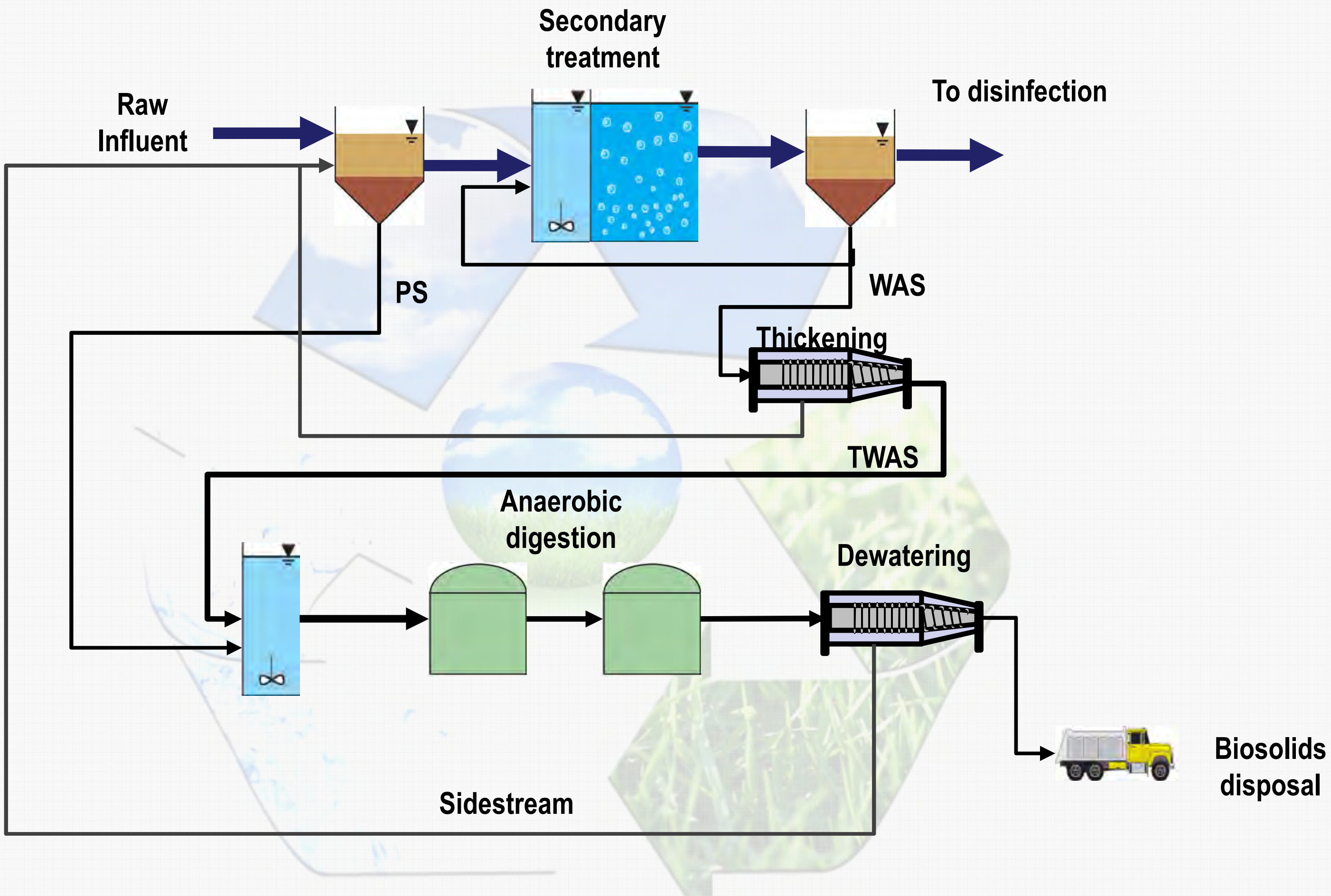
- Nitrogen gas is a renewable resource but is not readily available for plant growth
- Energy required to convert from non-reactive to reactive and vice versa

- Phosphorus is a NON-renewable resource
- Phosphorus resources are declining both in quality and accessibility

Nutrient recovery facilitates the recycling of reactive nutrients



How do we facilitate a transition to nutrient recovery?



Need disruptive and sustaining innovations

Technical, economic and regulatory limitations restrict implementation

Technical

- Technologies are unknown entities.
- Insufficient time and staff to review technologies
- Insufficient data to evaluate technology performance
- Insufficient experience in operating technology
- Unknown maintenance requirements and long-term operational viability

Economic

- Insufficient and/or competing needs for funds
- Unknowns regarding cost of implementation, operating costs, etc.
- Uncertainty with respect to future demand for fertilizer product.
- Competition for product if many utilities adopt the technology

Regulatory

- Lack of regulatory drivers i.e., no effluent nutrient limits.
- Lack of public acceptance

Addressing Technical Considerations

From a technological perspective, a three step framework may be appropriate

Accumulation → **Release** → **Extraction**

Accumulation

- Enhanced biological phosphorus removal (EBPR)
- Algae
- Purple non-sulfur bacteria
- Adsorption/Ion exchange
- Chemical precipitation
- NF/RO

Release

- Anaerobic digestion
- Aerobic digestion
- Thermolysis
- WAS release
- Sonication
- Microwave
- Chemical extraction

Extraction

- Chemical crystallization
- Electrodialysis
- Gas permeable membrane and absorption
- Gas stripping
- Solvent extraction

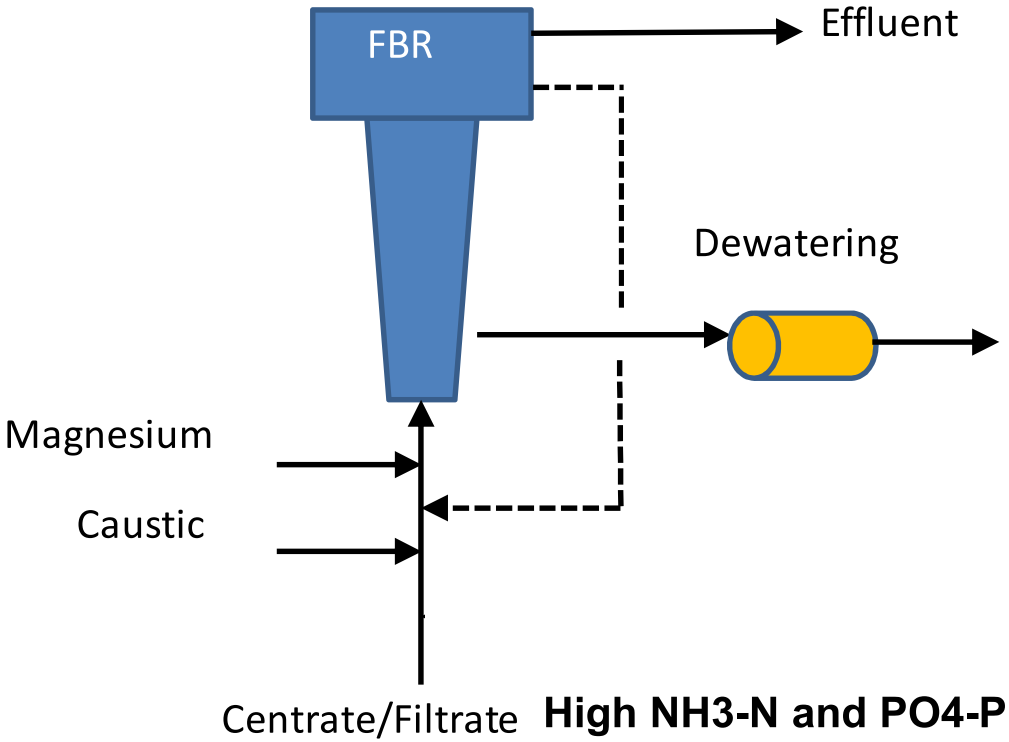
- **Not all systems require all three components**
- **Can optimize each option separately**
- **Can also stage implementation**

More details available in WERF NTRY1R12a and NTRY1R12 m

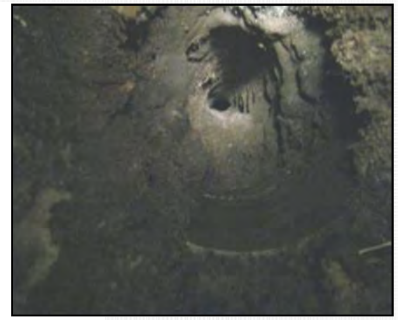
Consider a common scenario in which enhanced biological phosphorus removal is applied

		Nutrient recovery (% recovery efficiency)			Product (% wt nutrient)
		N	P	K	
Accumulation	EBPR	-	√ (15-50%)	-	Sludge (5- 7% P)
Release	Anaerobic digestion	√	√	√	Biosolids
Extraction	Crystallization	√	√ (> 90%)	√	Mg-Struvite (12% P, 5% N), K-struvite, Fe or Ca phosphate

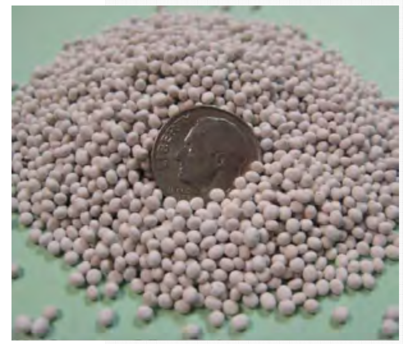
Intentional struvite recovery helps minimize nuisance struvite formation and reduce P recycle



80-90% P removal
15-30% N removal



$MgNH_4PO_4$•6 H_2O

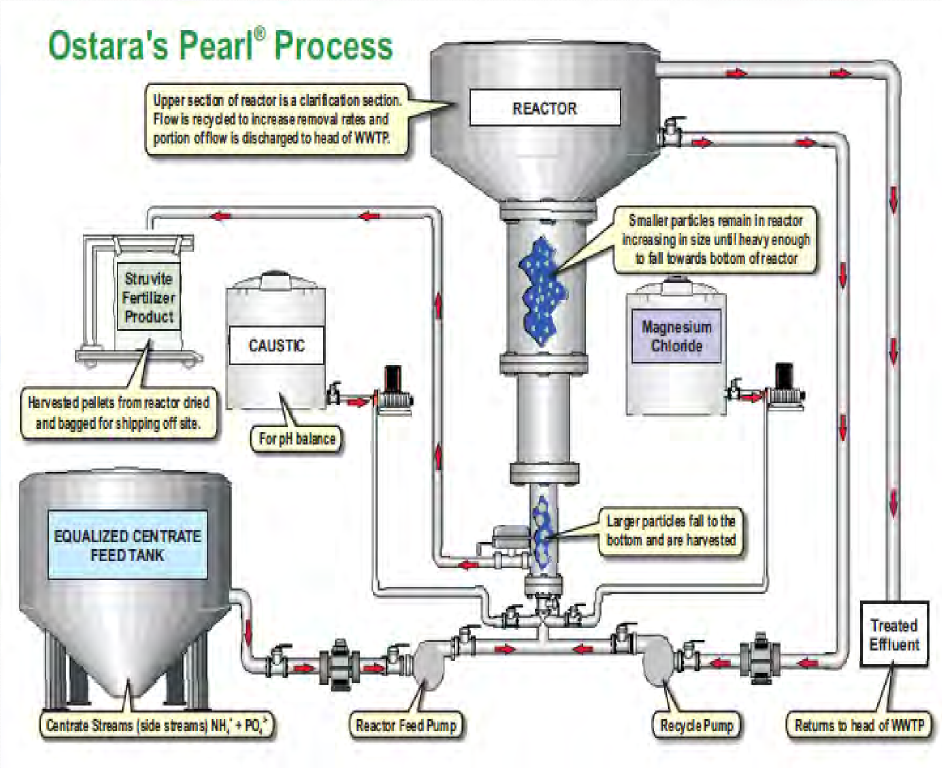


- **Fluidized bed reactor or CSTR used for struvite recovery**
- **High quality, slow release fertilizer – revenue offsets costs**
- **Reduction in ferric/alum – payback on capital**

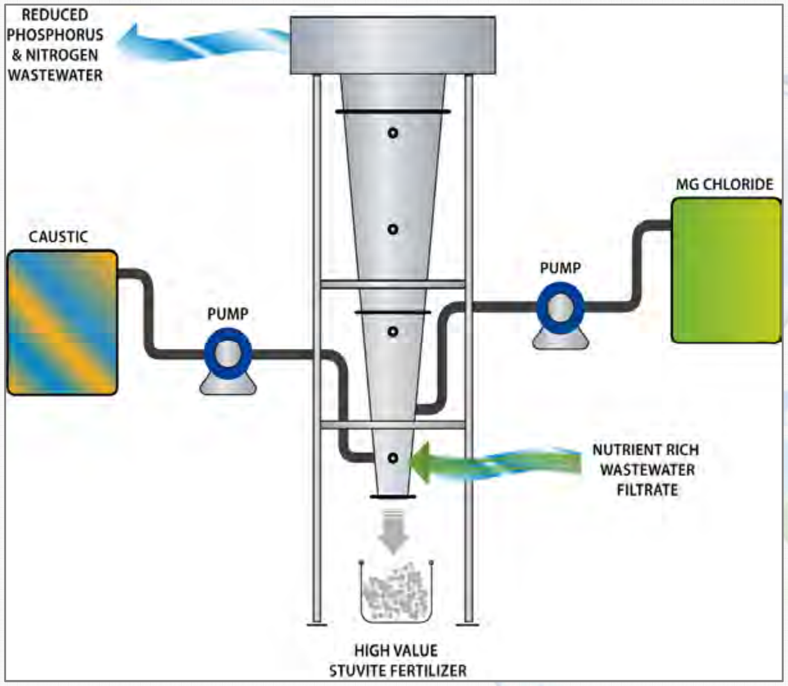
There are several commercial options for struvite recovery

Name of Technology	Pearl®	Multiform Harvest™	NuReSys™	Phospaq™	Crystalactor™	Airprex™
Type of reactor	upflow fluidized bed	upflow fluidized bed	CSTR	CSTR with diffused air	upflow fluidized bed	CSTR with diffused air
Name of product recovered	Crystal Green ®	struvite fertilizer	BioStru®	Struvite fertilizer	Struvite, Calcium-phosphate, Magnesium-phosphate	Struvite fertilizer
% Efficiency of recovery from sidestream	80-90% P 10-40% NH3-N	80-90% P 10-40% NH3-N	>85% P 5-20% N	80% P 10-40% NH3-N	85-95% P for struvite 10-40% NH3-N > 90% P for calcium phosphate	80-90% P 10-40% NH3-N
# of full-scale installations	8	2	7	6	4	3

Ostara Pearl™

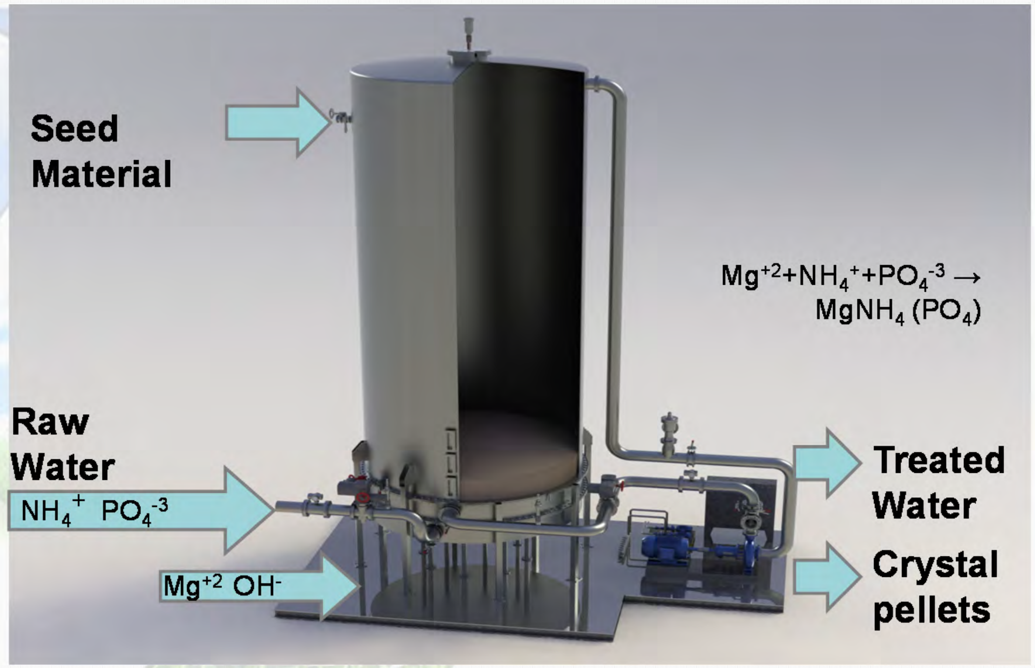


Multiform Harvest



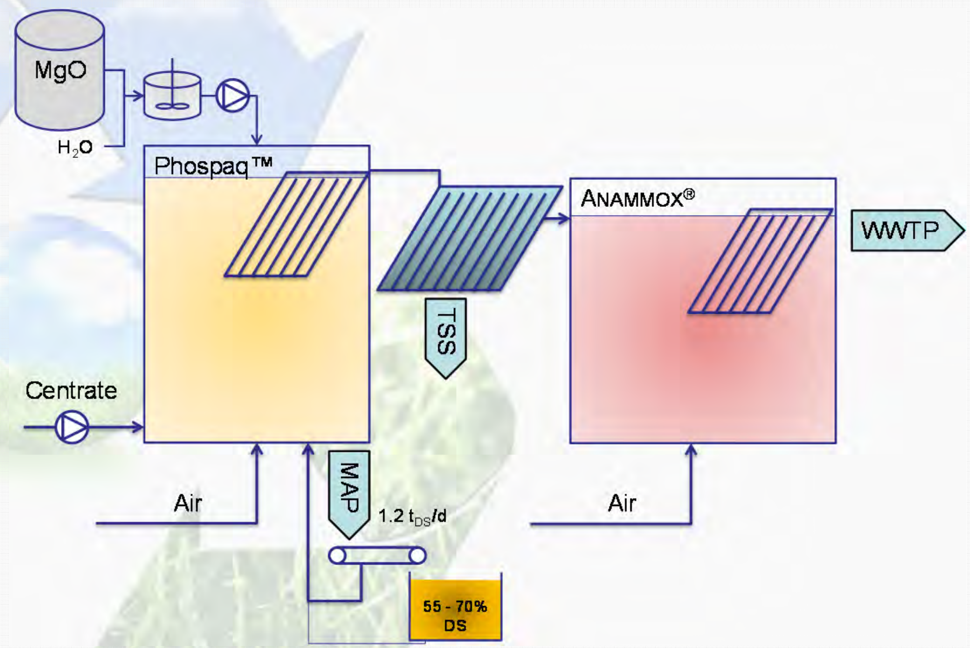
Images courtesy MFH

Crystalactor®



Images courtesy Procorp/Royal HaskoningDHV

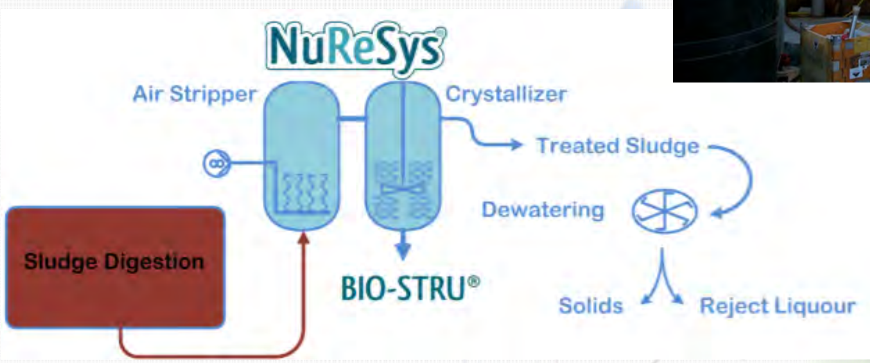
Paques Phosphaq™

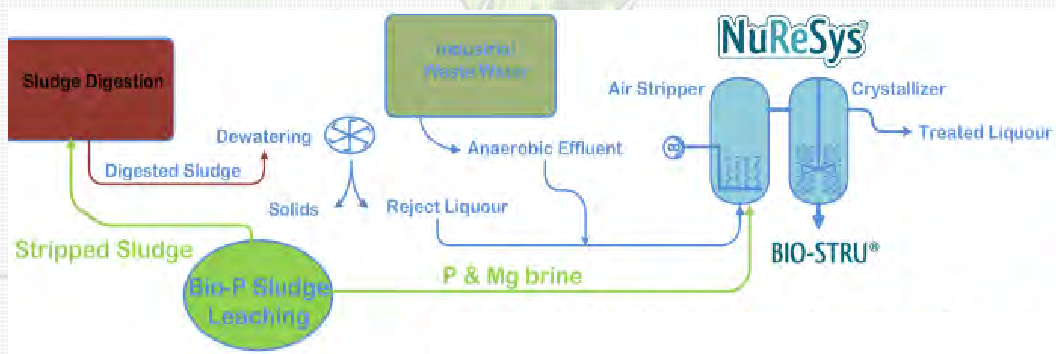


Images courtesy Paques

NuReSys

- **Marketed by Schwing in USA**

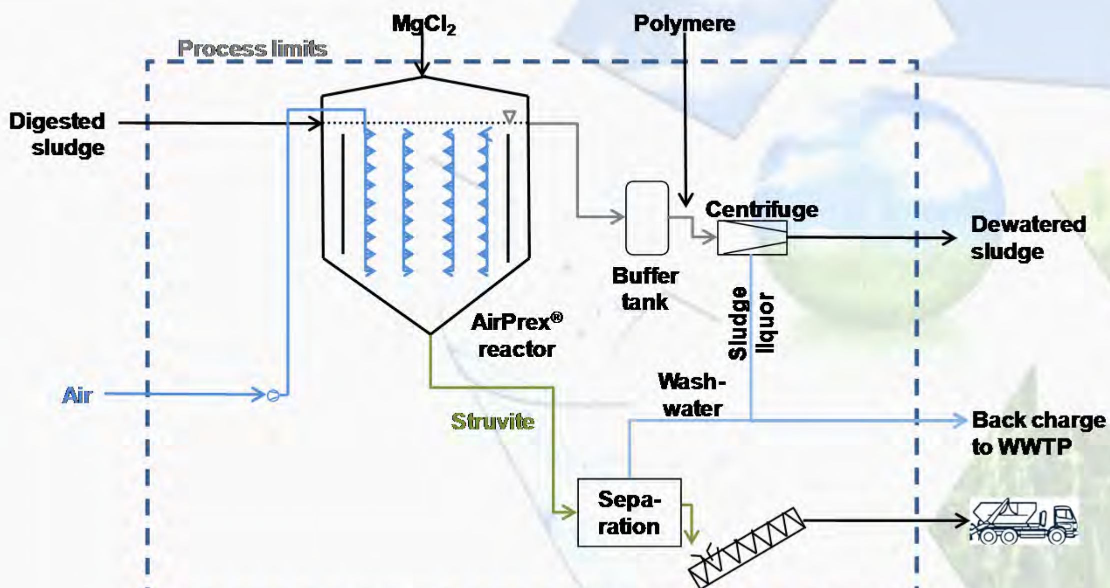




Images courtesy NuReSys bvba

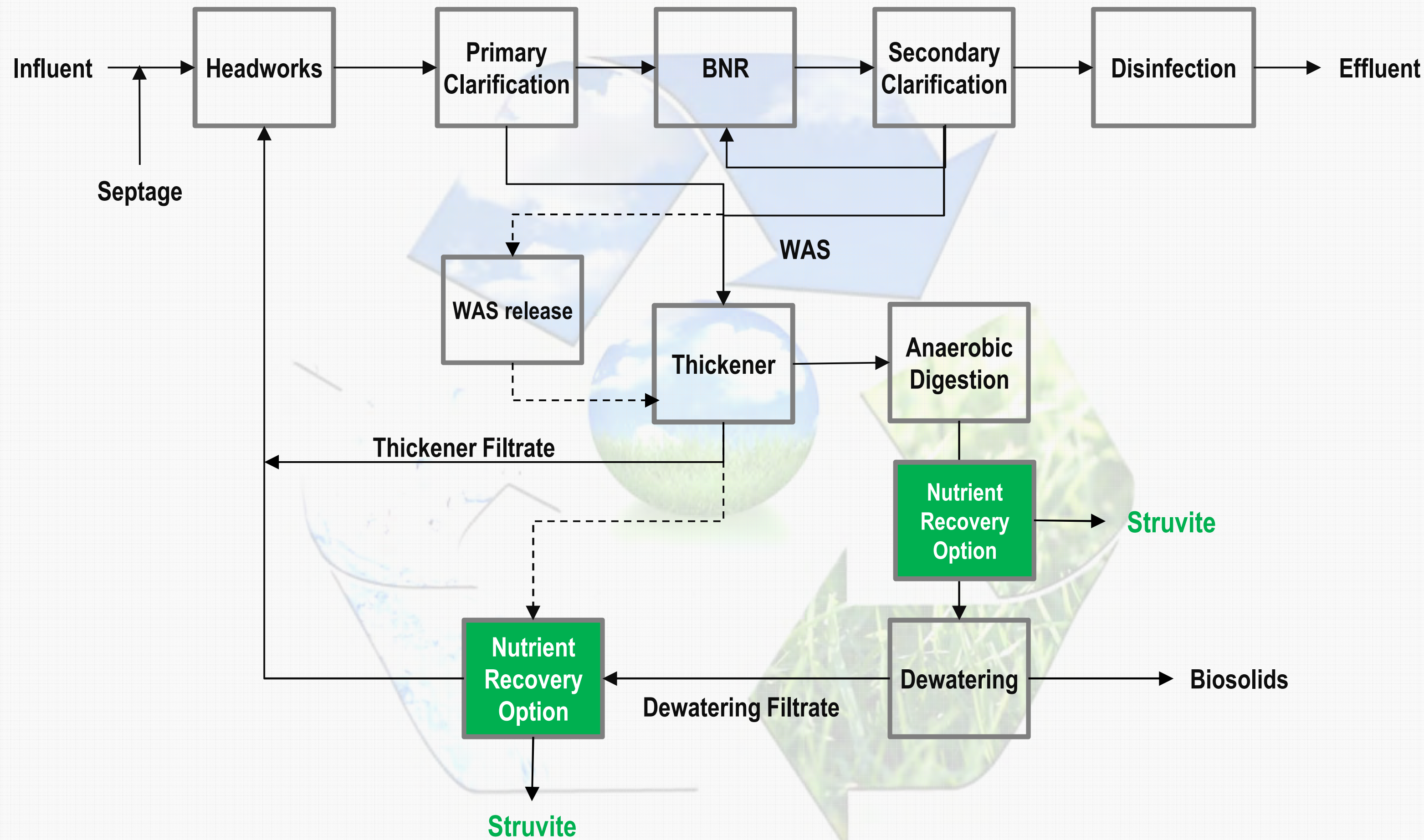
Airprex

- **Marketed by CNP in US**



Images courtesy CNP

Enhanced biological phosphorus removal, anaerobic digestion & nutrient recovery



What about if we use chemical precipitation for mainstream P removal?

		Nutrient recovery (% recovery efficiency)			Product
		N	P	K	
Accumulation	Chemical (Precipitation)	√	√ (> 90 %)	-	Sludge
Release	Anaerobic digestion	√	-	√	Biosolids

- **Release via Anaerobic digestion solubilizes limited amount of P**

		N	P	K	Product
Extraction	Acidification or bioleaching followed by crystallization, liquid extraction , ion exchange	√	√	√	Struvite; diammonium sulfate (DAS), iron phosphate, phosphoric acid, calcium phosphate, biosolids

There are options to allow us to recover nutrients from sludge

Name of Process	Seaborne	Krepro	PHOXNAN
Product recovered	struvite; diammonium sulfate (DAS)	iron phosphate as a fertilizer	phosphoric acid
Process feedstock	sludge	sludge	sludge

- **One full-scale installation of Krepro in Sweden**
- **Regulatory mandate for recycling P is needed to drive implementation of these technologies**

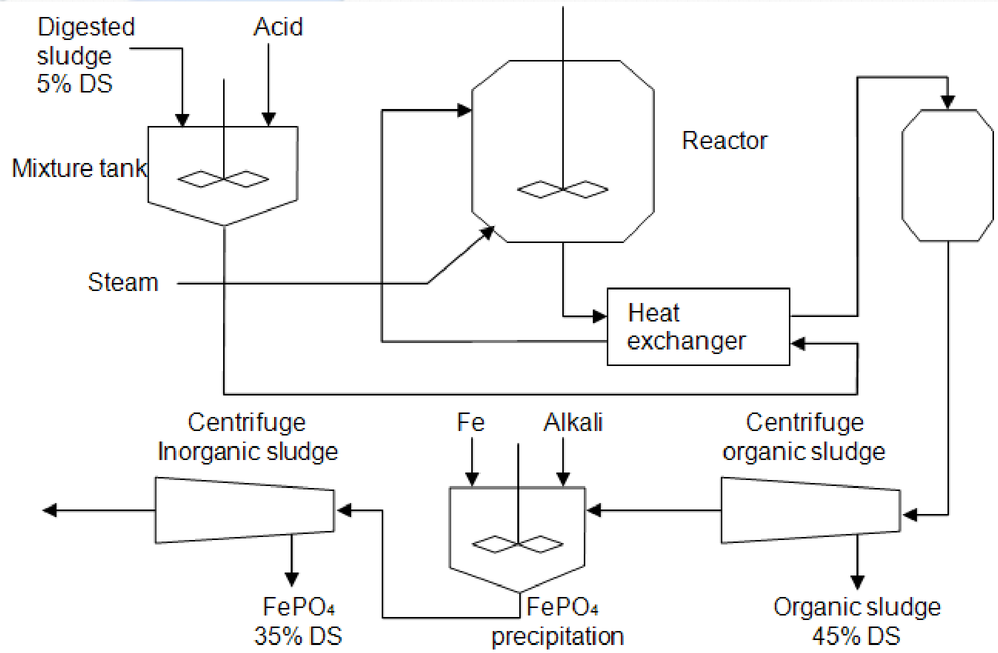
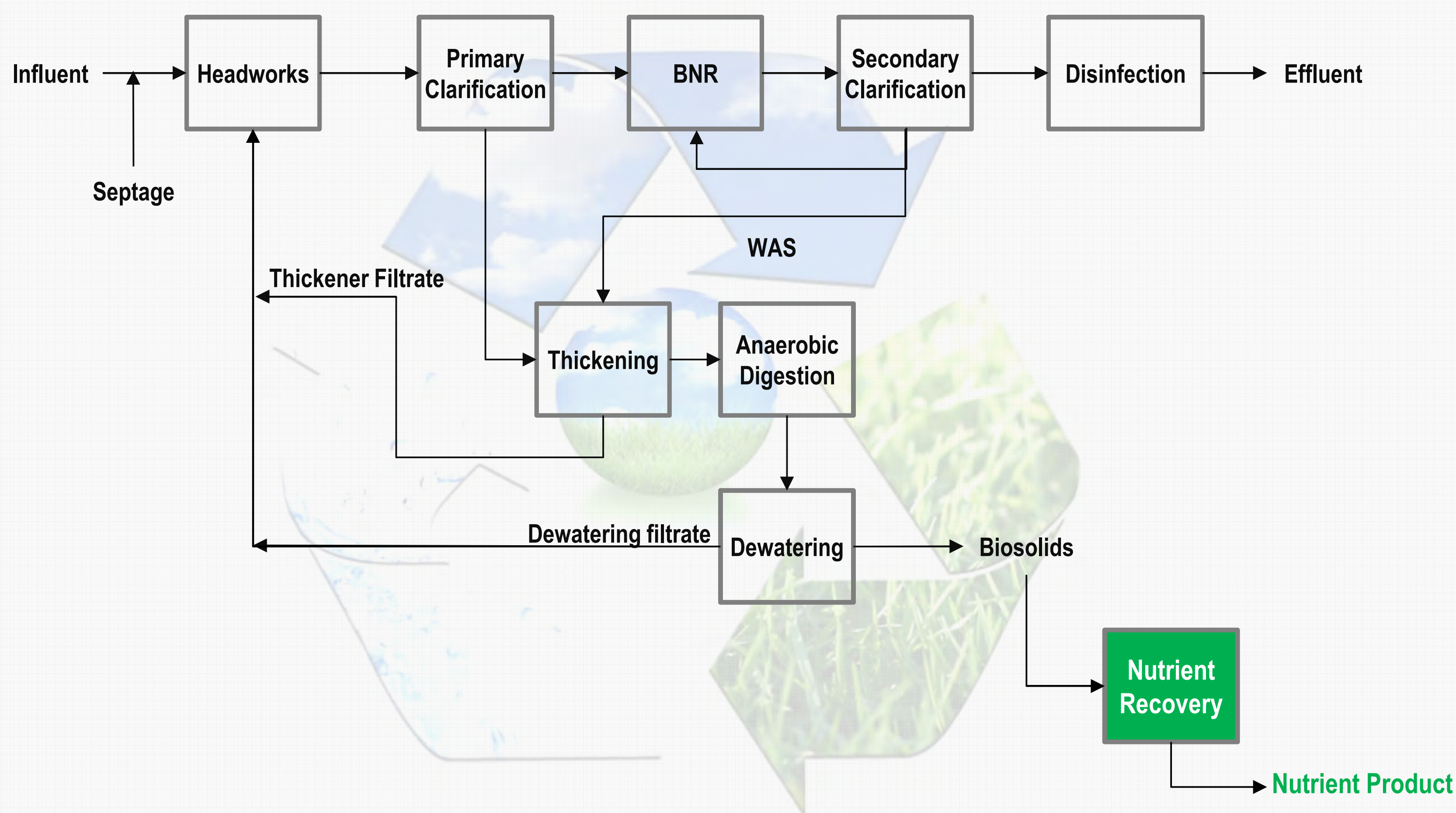


Figure 1. The KREPRO system [11].

Chemical precipitation, anaerobic digestion and nutrient recovery



What about if we use have thermochemical stabilization (i.e., incineration)?

		Nutrient recovery (% recovery efficiency)			Product
		N	P	K	
Accumulation	Biological or Chemical	√	√ (> 90 %)	-	Sludge

- **No release exists so P is bound into ash**

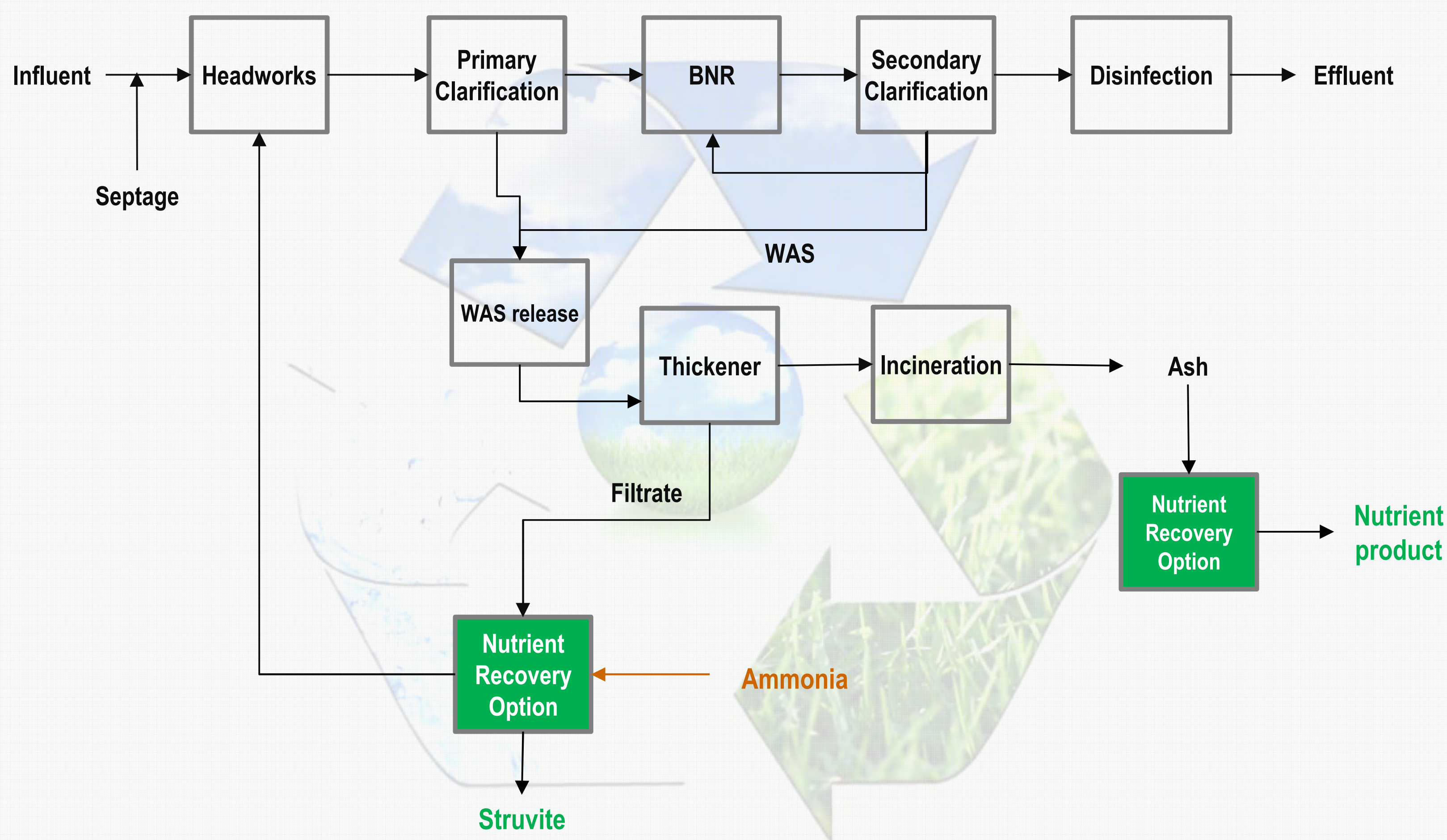
		N	P	K	Product
Option 1 - Release and Extraction	Enhanced WAS Lysis and crystallization	-	√ (20 to 50%)	√	Sludge
Option 2 - Release and Extraction	Acidification of ash followed by crystallization, liquid extraction , ion exchange	√	√	√	Struvite; diammonium sulfate (DAS), iron phosphate, phosphoric acid, calcium phosphate

There are options to allow us to recover nutrients from ash/sludge

Name of Process	SEPHOS	BioCon®	PASH
Product recovered	aluminum phoshate or calcium phosphate (advanced SEPHOS)	phosphoric acid	struvite or calcium phosphate
Process feedstock	sewage sludge ash	sewage sludge ash	sewage sludge ash

- **Post-processing to remove heavy metals may also be required**
- **Few full-scale installations are present**
- **Regulatory mandate for recycling P is needed to drive implementation of these technologies**
- **Ash can also be considered as direct fertilizer amendment**
  - **Consideration needs to be given to the heavy metal content**

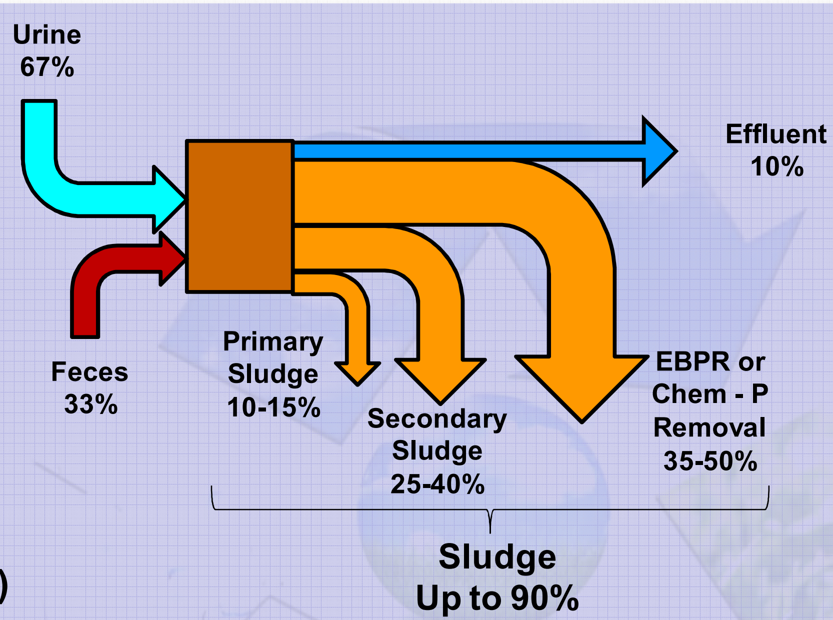
Enhanced biological phosphorus removal, WAS release & nutrient recovery



Addressing Regulatory Considerations

Nutrient recovery is another strategy for removing P from WRRF

P mass balance in WRRF



From Cornel *et al.* (2009)

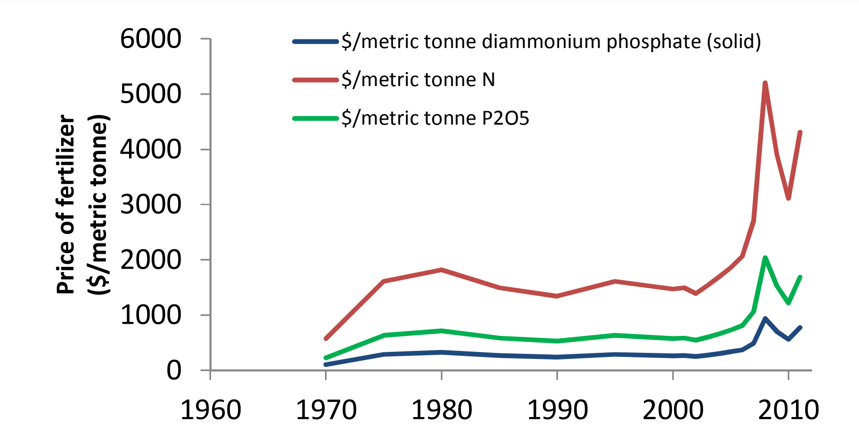
- **Different scenarios**
  - No nutrient limits
  - Nutrient limits on liquid effluent
  - Nutrient limits on liquid effluent and biosolids

Quantifying other benefits (cost and non-cost) can help make the case for nutrient recovery

- **Struvite recovery can:**
  - **Provide factor of safety associated with Bio-P**
    - Minimizes impact of sidestream return
  - **Reduce energy and chemical consumption**
    - Offsets due to reduction in aeration and supplemental carbon
    - Reduction in sludge quantity and hauling costs
  - **Minimize nuisance struvite formation and reduce O&M costs**
  - **Reduce or increase the P content of biosolids**
    - If land application P index limited, removing P in the form of struvite will shift N:P ratio
    - If more P is appreciated, selectively precipitating P into biosolids will increase biosolids P content
  - **Improve sludge dewaterability**
    - Result in higher sludge cake %TS
    - Reduce polymer demand

Addressing Economic Considerations

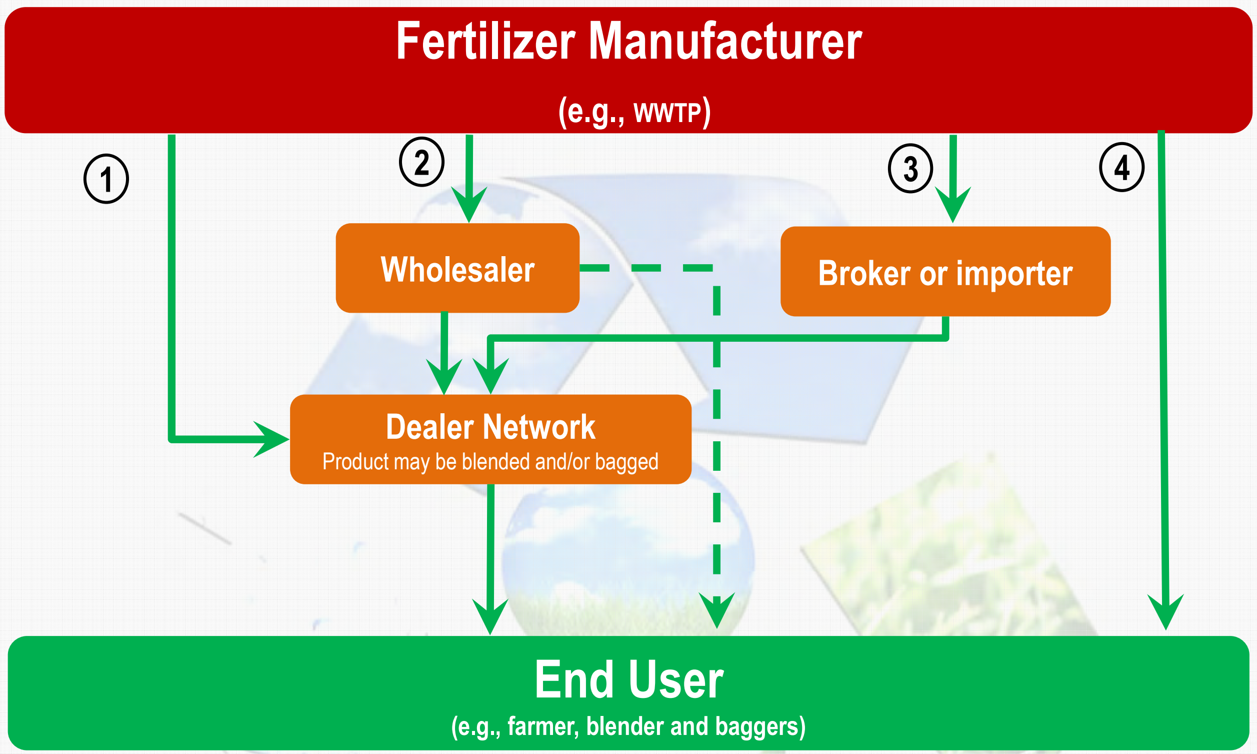
Magnesium struvite is the most commonly encountered product



- **Closest analogues are mono and diammonium phosphate**
- **Based on historical pricing, can expect Mg-struvite value to range from $200 to $600/metric tonne**

Characteristic	Magnesium struvite	Monoammonium phosphate	Diammonium phosphate
Chemical formula	$MgNH_4PO_4$-$6H_2O$	$NH_4H_2PO_4$	$(NH_4)_2HPO_4$
Average price/metric tonne	$200 - $600	$570 - $615	$420 - $680
Grade (N-P-K)	5-29-0	11-52-0	18-46-0
Water solubility at 20 °C	Insoluble - 0.2 g/L	328 - 370 g/L	588 g/L
Application description	Spread on soil	Normally spread of mixed in soil	Normally spread of mixed in soil
Typical application rates*	255 lb/A	142 lb/A	160 lb/A

There are multiple entry points for the nutrient fertilizer market



- **Multiple points of entry into the secondary market**
  - **Most technology providers for struvite production facilitate interaction with the market**
  - **Facility has the choice of entering the market directly**

What are the economics associated with implementing struvite recovery at WRRFs?

Case studies of full-scale facilities available from WERF

- **NTRY1R12b**

- **Developed case studies in 3 categories**
  - Category 1 – Currently operating or constructing struvite harvesting
  - Category 2 – Performed desktop analyses and/or pilot
  - Category 3 – No evaluation but may have piloted

- **Each case study describes:**
  - Nutrient limits,
  - Plant configuration,
  - Challenges faced,
  - Drivers for nutrient recovery,
  - Economics associated with struvite harvesting,
  - Lessons learned where applicable

Plant Designation	Plant 1
Location	Virginia, USA
Current Nutrient limits (mg/L)	TN - 8.0 mg/L AA TP - 2.0 mg/L AA These are treatment goals, the utility has a permit for combined effluent from 7 plants discharging in the James River basin.
Emerging Nutrient limits (mg/L)	Expected 2017 TN reduction to 5.0 mg/L and TP reduction to 1.0 mg/L. Plan to treat with additional supplemental carbon and ferric chloride if needed.
BNR configuration	5-stage BNR
Solids management configuration	Primary sludge + GBT co-thickened. Thickened sludge to anaerobic digesters then centrifuged. Cake is hauled and incinerated.
Biosolids disposal method	Biosolids transported to another plant within utility for incineration
Mainstream Design flow (MGD)	30
Mainstream current operation flow (MGD)	18
Minimum operating temperature (ºC)	12
Effluent nutrient concentrations (June 2011 to February 2013)	TP - 1.5 mg/L TN – 6.5 mg/L (includes periods with 3 and 5 stage BNR)
Sidestream flow (MGD)	0.1
Sidestream nitrogen concentration (mg/L N)	Before implementation of nutrient recovery: 576 After implementation of nutrient recovery: 448
Sidestream ortho-phosphorus concentration (mg/L P)	Before implementation of nutrient recovery: 351 After implementation of nutrient recovery: 54

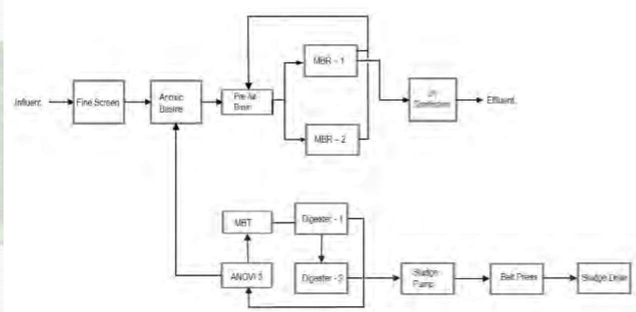


Figure 2-2. Process Flow Diagram

Tool for Evaluating Resource RecoverY developed to facilitate preliminary evaluation

- **Compare struvite crystallization with precipitation with coagulant (i.e., alum or ferric)**

WERF

Business Case Model Criteria | Business Case Model Benefits Selection

README | Start Page | Summarized Results | Plant Mass Balance | Capital and O&M Estimate Results | Business Case Evaluation Results | Do Nothing Financial Model Input | Struvite High Estimate Financial Model Input | Struvite Low Estimate Financial Model Input | Ferric Financial Model Input | Alum Financial Model Input

Title:	Tool for Evaluating Resource Recovery Beta Version 6
Contents:	Fact sheet describing struvite crystallization technology
	Ostara Pearl · Multiform Harvest · Procorp/Royal HaskoningDHV Crystalactor · Nuresys · Paques Phospaq
	Module for estimating capital and O&M costs associated with implementing sidestream P control using struvite recovery
	Module for performing cost benefit analyses of alternatives
Quick reference instructions:	Click on Start Tab
	Enter facility specific data into relevant sections in the each worksheet.
	The user will be guided to enter data in subsequent worksheets using the color code provided in the key below.
	The user can navigate between worksheets using hyperlinks embedded in each worksheet.
	Data Entry Instructions
	Green cell requires data entry by user
	Blue cell indicates calculated value that should not be changed
Detailed Instructions:	Click here for tutorial for using TERRY (not available in this version)
Cite as:	Latimer, R.; Rohrbacher, J.; Nguyen, V.; Khunjar, W. O.; Jeyanayagam, S. Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative (NTRY1R12) - Tool for Evaluating Resource Recovery Beta Version 1; Water Environment Research Foundation: 2013.

Search WERF website for NTRY1R12t

TERRY- P

- **Who can use this tool?**
  - **Utility managers, research and development personnel**
  - **Consultants**
  - **Regulators**
  - **Students**
  - **Public**
  - **Anyone with interest in nutrient recovery**

- **Why use this tool?**
  - **Conceptual level evaluation of nutrient recovery capital and operating cost required**
  - **Helps inform what information is useful for collection**
  - **Informs master planning**

Conclusions

Quantifying other benefits (cost and non-cost) can help make the case for nutrient recovery

- **Struvite recovery can:**
  - **Provide factor of safety associated with Bio-P**
    - **Minimizes impact of sidestream return**
  - **Reduce energy and chemical consumption**
    - **Offsets due to reduction in aeration and supplemental carbon**
    - **Reduction in sludge quantity and hauling costs**
  - **Minimize nuisance struvite formation, reduce O&M costs and regain capacity**
  - **Reduce or increase the P content of biosolids**
    - **If land application P index limited, removing P in the form of struvite will shift N:P ratio**
    - **If more P is appreciated, selectively precipitating P into biosolids will increase biosolids P content**
  - **Improve sludge dewaterability**
    - **Result in higher sludge cake %TS**
    - **Reduce polymer demand**

Next steps for nutrient recovery industry

- Understand true costs/benefits of operating recovery facilities
- Enhance recovery potential of existing facilities
- Explore recovery of other products
- Implement technologies that facilitate multiple benefits
  - P, N, K Carbon, Energy

Questions and Contact Information

Wendell Khunjar
Hazen and Sawyer, P.C.
wkhunjar@hazenandsawyer.com

Ron Latimer
Hazen and Sawyer, P.C.
rlatimer@hazenandsawyer.com

Sam Jeyanayagam
CH2M
Samuel.Jeyanayagam@ch2m.com