WERF

Water Environment Research Foundation

Collaboration. Innovation. Results.

Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative

Case Studies of Facilities Employing Extractive Nutrient Recovery Technologies

Co-published by

IWA PUBLISHING

NTRY1R12b

TOWARDS A RENEWABLE FUTURE: ASSESSING RESOURCE RECOVERY AS A VIABLE TREATMENT ALTERNATIVE

CASE STUDIES OF FACILITIES EMPLOYING EXTRACTIVE NUTRIENT RECOVERY TECHNOLOGIES

Ronald Latimer, P.E.
Joseph Rohrbacher, P.E.
Vivi Nguyen
Wendell O. Khunjar, Ph.D., P.E.
Hazen and Sawyer, P.C

Samuel Jeyanayagam, Ph.D., P.E., BCEE
CH2M

2015

WERF

The Water Environment Research Foundation, a not-for-profit organization, funds and manages water quality research for its subscribers through a diverse public-private partnership between municipal utilities, corporations, academia, industry, and the federal government. WERF subscribers include municipal and regional water and water resource recovery facilities, industrial corporations, environmental engineering firms, and others that share a commitment to cost-effective water quality solutions. WERF is dedicated to advancing science and technology addressing water quality issues as they impact water resources, the atmosphere, the lands, and quality of life.

For more information, contact:
Water Environment Research Foundation
635 Slaters Lane, Suite G-110
Alexandria, VA 22314-1177
Tel: (571) 384-2100
Fax: (703) 299-0742
www.werf.org
werf@werf.org

This report was co-published by the following organization.

IWA Publishing
Alliance House, 12 Caxton Street
London SW1H 0QS, United Kingdom
Tel: +44 (0) 20 7654 5500
Fax: +44 (0) 20 7654 5555
www.iwapublishing.com
publications@iwap.co.uk

Library of Congress Catalog Card Number: 2015943537
IWAP ISBN: 978-1-78040-792-0

Hazen and Sawyer, P.C., CH2M

About WERF

The Water Environment Research Foundation, formed in 1989, is America's leading independent scientific research organization dedicated to wastewater and stormwater issues. Throughout the last 25 years, we have developed a portfolio of more than $134 million in water quality research.

WERF is a nonprofit organization that operates with funding from subscribers and the federal government. Our subscribers include wastewater treatment facilities, stormwater utilities, and regulatory agencies. Equipment companies, engineers, and environmental consultants also lend their support and expertise as subscribers. WERF takes a progressive approach to research, stressing collaboration among teams of subscribers, environmental professionals, scientists, and staff. All research is peer reviewed by leading experts.

For the most current updates on WERF research, sign up to receive Laterals, our bi-weekly electronic newsletter.

Learn more about the benefits of becoming a WERF subscriber by visiting www.werf.org.

ACKNOWLEDGMENTS

The authors acknowledge the staff of all participating utilities for providing assistance in acquiring data for this report.

Research Team

Principal Investigators:
Ron Latimer, P.E.
Wendell O. Khunjar, Ph.D., P.E
Hazen and Sawyer, P.C.

Samuel Jeyanayagam, Ph.D., P.E., BCEE
CH2M

Project Team:
C. Michael Bullard, P.E.
Joe Rohrbacher, P.E.
Paul Pitt, Ph.D., P.E.
Vivi Nguyen
Thomas Worely-Morse
Hazen and Sawyer, P.C.

Julian Sandino Ph.D., P.E., BCEE
Todd Williams, P.E.
Ryan Bercaw, P.E.
CH2M

Stacy Passaro, P.E.
Passaro Engineering, LLC

Project Issue Area Team

Robert Bastian
U.S. Environmental Protection Agency

Rajendra Bhattarai, Ph.D., P.E., BCEE
City of Austin

Katya Bilyk, P.E.
Hazen and Sawyer, P.C.

Charles Bott, Ph.D., P.E., BCEE
Hampton Roads Sanitation District

Heri Bustamante, Ph.D.
Sydney Water Corporation

Mike Connor, Ph.D.
East Bay Dischargers Authority

Leon Downing, Ph.D., P.E.
CH2M

Donald Gray, Ph.D., P.E., DEE
East Bay Municipal Utility District

Willie Harper, Ph.D., P.E.
Air Force Institute of Technology

Robert Humphries, Ph.D.
Strategic Environmental Solutions

Terry Johnson, Ph.D., P.E., BCEE
Water Consulting, LLC

Robert Sharp, Ph.D., P.E.
Manhattan College

Christopher Stacklin, P.E.
Orange County Sanitation District

Beverly M. Stinson, Ph.D., P.E.
AECOM

Water Environment Research Foundation Staff

Director of Research: Amit Pramanik Ph.D., BCEEM
Program Director: Christine Radke, PMP

ABSTRACT AND BENEFITS

Abstract:

Extractive nutrient recovery, defined as the production of chemical nutrient products devoid of significant organic matter, represents a complementary strategy for managing nutrients in multiple waste streams. In this option, energy and resources are used to accumulate and produce a chemical nutrient product that is recyclable and has a resale value that could potentially help offset operating costs while reducing nutrient production from raw materials for agricultural or other uses.

This report presents a compilation of case studies of water resource recovery facilities (WRRFs) at various stages of implementation of extractive nutrient recovery technologies in the form of struvite crystallization. Of the 20 WRRFs identified in this report, six have implemented or are implementing a struvite crystallization facility and seven have performed desktop and/or pilot evaluations. Data from these 13 utilities were used to develop the *Tool for Evaluating Resource Recovery-Phosphorus* (TERRY – Phosphorus), which was used to perform a conceptual level evaluation of implementing struvite recovery at seven other WRRFs.

Data from the full-scale WRRFs that have implemented struvite recovery indicate that sidestream soluble phosphorus removals ranged from 80 to 90%, while ammonia removal ranged from 7 to 30%. Struvite production ranged from 64 to 421 metric tonnes per year and was found to be dependent on the site-specific conditions and technology employed. Drivers for implementing nutrient recovery included reduction in supplemental carbon requirements for nitrogen removal, reduction in aeration requirements, reduction in biosolids production versus conventional treatment alternatives, reduction in costs associated with mitigating nuisance precipitate formation, benefits to sludge dewaterability, and benefits associated with manipulating the N and P content of the biosolids. Quantifying the economic and non-economic benefits of these drivers together with site-specific factors can help drive the implementation of resource recovery systems at full-scale WRRFs.

Benefits:

- Provides a detailed summary of economic and non-economic factors that can favor the implementation of extractive nutrient recovery.
- Presents a framework for performing a comprehensive cost-benefit analysis of implementing extractive nutrient recovery.
- Summarizes detailed costs for full-scale facilities that have implemented extractive nutrient recovery in the form of struvite crystallization.

Keywords: Barriers to adopt existing technologies, nutrient removal/recovery, struvite, nitrogen, phosphorus, extractive nutrient recovery, market assessment, sustainable nutrient management, case studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AADF	Annual Average Daily Flow
A2O	Anaerobic-Anoxic-Oxic
AER	Aerobic
Alk	Alkalinity
ANX	Anoxic
AO	Anaerobic/Aerobic
AWT	Advanced Water Treatment
BCE	Business Case Evaluation
BFP	Belt Filter Press
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CEPT	Chemically Enhanced Primary Treatment
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COPI	Colorado's Phosphorus Index
DAF	Dissolved Air Flotation
DB	Design Build
DBO	Design Build Operate
DBOT	Design Build Operate Transfer
DT	Dry Tons
EBPR	Enhanced Biological Phosphorus Removal
EQ	Equalization
Fe	Iron
FOG	Fats, Oil, Grease
FTE	Full Time Equivalent
GAC	Granular Activated Carbon
GBT	Gravity Belt Thickener
GT	Gravity Thickener
HLD	High Level Disinfection
JHB	Johannesburg
LIFT-TEP	Leaders Innovation Forum for Technology – Technology Evaluation Program
Mg	Magnesium

MLE	Modified Ludzack-Ettinger
MLR	Mixed-Liquor Recycle
N	Nitrogen
NH_3	Ammonia
NH_4	Ammonium
NPC	Net Present Cost
NPV	Net Present Value
NO_3^-	Nitrate
O&M	Operation and Maintenance
P	Phosphorus
PO_4	Phosphate
PS	Primary Sludge
RAS	Returned Activated Sludge
RFI	Request for Information
RFP	Request for Proposal
TERRY	Tool for Evaluating Resource Recovery
TMDL	Total maximum daily load
TN	Total Nitrogen
TP	Total Phosphorus
TPAD	Temperature Phased Anaerobic Digestion
TSS	Total Suspended Solids
UCT	University of Cape Town
UV	Ultraviolet
VFA	Volatile Fatty Acid
WAS	Waste Activated Sludge
WRRF	Water Resource Recovery Facility

EXECUTIVE SUMMARY

ES.1 Project Overview

Implementation of extractive resource recovery technologies at water resource recovery facilities (WRRFs) has been limited to date (2015). WERF's NTRY1R12 research project "Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative" sought to facilitate a more widespread adoption of resource recovery at WRRFs. Three main objectives were defined for this purpose:

1. Characterize factors influencing the adoption of extractive resource recovery systems.
2. Provide guidance on the implementation of extractive resource recovery technologies at water resource recovery facilities (WRRFs) with a special emphasis on phosphorus (P).
3. Experimentally evaluate innovative extractive nutrient recovery technologies with an emphasis on P recovery.

ES.2 Project Approach and Schedule

For Objective 1, the project team performed an extensive review of peer reviewed literature regarding extractive nutrient recovery. The project team also surveyed nine commercial technology providers to supplement existing peer reviewed data. In this survey, the technology providers were asked to provide process principles where applicable, technological (including technical performance) details to the extent possible, prior experiences in the implementation of technology where applicable, and operational and management costs associated with technology implementation as well as research and development efforts to the extent possible. A comprehensive assessment of the chemical nutrient product market and historical pricing was also performed for the United States. The data was compiled into a comprehensive literature review (NTRY1R12a) and an electronic interactive technology matrix (Resource Recovery Technology Matrix – Nutrients).

For Objective 2, the project team surveyed a total of 20 utilities. In this survey, the utilities were asked to self-identify challenges associated with implementing extractive nutrient recovery. Operating data for pilot and full-scale testing were also requested. Data from Objective 2 were used to compile detailed case studies that provide guidance as to the implementation of extractive nutrient recovery via struvite crystallization. Information from these case studies was also used to develop the Tool for Evaluating Resource Recovery (TERRY – Phosphorus). This report presents findings from the second objective.

For Objective 3, researchers at the University of Queensland, Australia, performed research on two innovative concepts focused on enhancing nutrient recovery at WRRFs. The first project involved optimizing phosphorus release and availability during and after solids stabilization. The second project involved quantifying the fate of nitrogen, phosphorus, and potassium in enhanced phosphorus removal systems with a focus on determining whether electrodialysis could be used to recover nitrogen and potassium from sidestreams. Impacts on sludge settleability and dewaterability were also investigated. Results from this phase of research are summarized in report NTRY1R12c – Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative – Innovative Extractive Nutrient Recovery Technologies.

ES.3 Struvite Crystallization Is An Effective Nutrient Management Strategy Technology

Data from pilot and full-scale facilities utilizing struvite recovery have indicated stable removal of soluble phosphorus from 80-90% and ammonia removal ranging from between 7-30%. This degree of treatment is comparable to more conventional phosphorus control strategies such as metal salt addition. It should be noted that all of the facilities summarized in this study considered struvite recovery from liquid sidestreams resulting from solids stabilization processes. There are other recovery options which allow struvite harvesting directly from the digested sludge; however, at the time of this report, no full-scale facilities in North America were intentionally directly recovering struvite from the un-dewatered digested sludge stream.

Struvite production from the WRRFs in this study was reported to range from 64-421 metric tonnes per year. This degree of variability is related to site-specific flow and nutrient characteristics of the liquid sidestreams as well as the technology employed. In all cases considered in this report, the vendors providing the struvite recovery technology contracted with the utility to collect and sell the recovered product as a slow release fertilizer. This business model allows the WRRF to avoid having to directly enter the fertilizer market.

ES.4 A Combination of Cost and Non-Cost Factors Influences the Economic Viability of Implementing Nutrient Recovery

Results from the survey indicated that strict nutrient limits on liquid effluent and biosolids could help drive the implementation of recovery. Additionally, other benefits that argue for implementing nutrient recovery include:

- Mitigating the impact of the sidestream nutrient content on the mainstream nutrient removal process and providing a factor of safety for mainstream EBPR.
- Minimizing nuisance struvite formation and re-gaining infrastructure capacity.
- Reducing chemical and energy costs.
- Reducing chemical sludge production (if metal salt addition is practiced).
- Manipulating the nutrient (phosphorus and nitrogen) content of biosolids.
- Improving sludge dewaterability.

CHAPTER 1.0

Implementation of Extractive Nutrient Recovery At Municipal Water Resource Recovery Facilities

1.1 Background

Nutrient removal from wastewater represents a major demand on resources and expenses for water resource recovery facilities (WRRFs). For instance, electricity costs for aeration can account for between 30 and 80% of total electricity expenditure at WRRFs performing biological nitrogen removal to achieve effluent total nitrogen limits below 8 mg/L (Willis et al., 2012). These needs are expected to increase as more stringent effluent nutrient limits are promulgated in the future. As a result, development of alternative nutrient treatment strategies that allow for effective nutrient removal in an economical manner is needed. Extractive nutrient recovery could represent an alternative strategy for managing nutrients during wastewater treatment. In this option, energy and resources are used to accumulate and produce a nutrient product that has value in a secondary market. Resale of this product can also potentially help plants offset operating costs. Adoption of extractive recovery technologies is contingent on several factors including:

- The recovery process must have equivalent treatment efficiency as conventional treatment alternatives.
- The recovery process must be cost competitive with conventional treatment alternatives.
- Operation of the recovery process should not be overly complicated as compared with conventional treatment alternatives.

As of 2013, there has been slow adoption of extractive nutrient recovery technologies at WRRFs for a variety of reasons. This project seeks to accelerate the adoption by providing utilities with guidance documents and tools. Specifically, three main objectives have been addressed:

- Characterization of factors influencing the adoption of extractive resource recovery systems.
- Development of guidance tools and documents on the implementation of extractive resource recovery technologies at WRRFs.
- Experimental evaluation of extractive nutrient recovery technologies with an emphasis on P recovery.

1.2 Navigating the Challenges Associated with Implementing Extractive Nutrient Recovery

Conducted in 2012, the project team surveyed staff from 20 WRRFs. In this survey, the utilities were asked to self-identify challenges associated with implementing extractive nutrient recovery. Operating data for pilot and full-scale testing were also requested where available. The data were used to compile case studies that provide guidance as to the implementation of extractive nutrient recovery at WRRFs. Key data from these case studies were also collated and used for the development of the Tool for Evaluating Resource Recovery (TERRY – Phosphorus).

It should be noted that the experiences outlined in this report reflect those of systems performing struvite harvesting through chemical crystallization technologies. While the project team focused on this technology, the general approach employed can and will be translated to any alternative extractive nutrient or resource recovery technology.

1.3 Case Studies

A key element of facilitating more rapid adoption of extractive nutrient recovery technology is providing a basis of where the technology has been found to be successful. Data from collaborating utilities that have implemented or evaluated nutrient recovery have been compiled into case studies. The data was gathered from the staff of the utilities in response to a Request for Information. It is presented here to provide the reader a brief understanding of the unique qualities of each installation and evaluation and economic data corresponding with each respective project. These case studies also summarize key operational parameters. They provide insight into costs associated with treatment. Special emphasis was placed on providing case study information for struvite harvesting technologies via chemical crystallization because these technologies have been found to be the most mature extractive nutrient recovery option available. As other technologies mature, a similar approach should be employed to ensure that the lessons learned are conveyed to the industry.

For organizational purposes, the case studies are organized into three categories according to the stage of planning for nutrient recovery:

- Category I: Currently operating a nutrient recovery system (struvite harvesting) or under construction (Chapter 2.0).
- Category II: Completed desktop or pilot evaluation (Chapter 3.0).
- Category III: Has not done any evaluation (Chapter 4.0).

A complete listing of case study facilities is provided in Table 1-1. Case studies associated with Category I are included in Chapter 2.0 of this report. Category II case studies are included in Chapter 3.0 while Category III case studies are included in Chapter 4.0. Drivers for each WRRF are denoted as follows:

- "B" corresponds to a desire to reduce phosphorus in biosolids concentrations.
- "L" corresponds to current or imminent strict nutrient limits (within the one to five year horizon).
- "P" corresponds to a desire to improve the reliability of WRRF performance.
- "S" corresponds to a desire to mitigate nuisance struvite formations.
- "V" corresponds to a desire to mitigate nuisance vivianite formation.
- "E" corresponds to a desire to proactively evaluate and plan for emerging nutrient limits (within the 5-20 year horizon).

Table 1-1. Summary of Case Study Facilities.

Plant Number	Location	Plant Configuration	Size (MGD)	Current Nutrient Limits	Drivers	Category
1	Virginia, U.S.	Liquid: 5-Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	30	TN - 8.0 mg/L AA TP - 2.0 mg/L AA	L, P, S	I
2	Washington, U.S.	Liquid: 3-Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	22	No limits at present; Proactive in reducing TP < 1 mg/L	L, P, S	I
3	Wisconsin, U.S.	Liquid: 3-Stage BNR and UCT process in parallel Solids: Acid Gas Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Gravity Belt Thickeners (GBTs)	57	None	B, S	I
4	Saskatchewan, Canada	Liquid: Modified UCT process Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Sludge Storage Cells	31.7	TP – 1.0 mg/L TN – none	S	I
5	Georgia, U.S.	Liquid: 3 and 5 stage BNR + ferric trim on tertiary filters Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	60	NH3-N – 0.4 mg/L TP – 0.08 mg/L	L, P, S	I
6	Idaho, U.S.	Liquid: MLE, Johannesburg. Conversion to West Bank underway Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	24	NH3-N = 0.398 mg/L (winter); 0.788 mg/L (summer) TP = 0.07 mg/L monthly avg; 0.084 mg/L weekly. (May 1 – Sept 3)	B, L	I
7	North Carolina, U.S.	Liquid: 5 Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	20	TN – 334,851 lb/yr TP – 0.5 mg/L (summer); 2.0 mg/L (winter)	B, L, P, S	II

Plant Number	Location	Plant Configuration	Size (MGD)	Current Nutrient Limits	Drivers	Category
8	North Carolina, U.S.	Liquid: 5 Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	20	TN 334,705 lb/yr; NH_3-N - 1.0 mg/L (summer monthly average), 2.0 mg/L winter monthly average TP 14,053 lb/yr (0.23 mg TP/L)	B, L, P	II
9	Kansas, U.S.	Liquid: 3 Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	12	TN - 8.0 mg/L (annual average goal) TP – 1.5 mg/L (annual average goal)	S	II
10+11	Alberta, Canada	Liquid: Plant 10: AO process, Plant 11: 3-stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Lagoons	132, 26.4	Plant 10: NH_3-N – 10 mg/L (Oct – Jun) and 5 mg/L (Jul – Sept), TP – < 1.0 mg/L (monthly) Plant 11: NH_3-N – 10 mg/L (Oct – Jun) and 5 mg/L (Jul – Sept), TP – < 0.5 mg/L (monthly)	S	II
12	Florida, U.S.	Liquid: Pure Oxygen Activated Sludge Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	143	None	L, S	II
13	Florida, U.S.	Liquid: Pure Oxygen Activated Sludge Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	112.5	None	L, S	II
14	Virginia, U.S.	Liquid: 4 Stage BNR with Filters Solids: Incineration Thickening dewatering: Centrifuges	24	.0 mg/L annual average NH_3--N – 1.0 mg/L monthly average (Apr-Oct) No limit (Nov-Jan) 4.6 mg/L monthly average (Nov-Mar) TP – 0.18 mg/L monthly average	E	III
15	Texas, U.S.	Liquid: UCT Solids: Sludge Storage followed by Landfill No biological stabilization:	11.5	Average NH_4-N = 1.4 mg/L from June – November; Average NH_4-N = 3 mg/L from December – May;	P	III
16	Texas, U.S.	Liquid: Modified Ludzack-Ettinger Solids: Anaerobic Digestion	110	NH_3-N – 3.0 mg/L daily average (Apr-Nov)	L, P, V	III

Plant Number	Location	Plant Configuration	Size (MGD)	Current Nutrient Limits	Drivers	Category
		Digester Sludge Dewatering: Belt Filter Press		4.0 mg/L daily average (Dec-Mar)		
17	Ohio, U.S.	Liquid: Conventional activated sludge Solids: Incineration Thickening dewatering: Belt Filter Press	55	None	E	III
18	Ohio, U.S.	Liquid: Conventional activated sludge Solids: Anaerobic digestion (incineration) Thickening dewatering: Centrifuges	75	NH_3-N – 1.0 mg/L monthly average (June-Oct) 2.5 mg/L monthly average (May) 3.7 mg/L monthly average (Nov – April) TP – No limit currently. P-Index is being implemented in Ohio for land application of biosolids.	E	III
19	Ohio, U.S.	Liquid: Conventional activated sludge Solids: Acid-gas digestion (incineration) Thickening dewatering: Centrifuges	114	NH_3-N – 1.0 mg/L monthly average (June-Oct) 2.0 mg/L monthly average (May) 3.4 mg/L monthly average (Nov – April) TP – No limit currently. P-Index is being implemented in Ohio for land application of biosolids.	L, S	III
20	Colorado, U.S.	Liquid: Modified Ludzack-Ettinger and A2O Solids: Mesophilic anaerobic digestion (incineration) Thickening dewatering: Centrifuges	220	Total Ammonia (begin 1/1/2015) – 2 to 4.6 mg-N/L (30-day avg), 6.2 to 12.7 mg-N/L (Daily Maximum) Nitrite plus Nitrate – 8.68 mg-N/L (weekly average)	B, L, P, S, E	III .

CHAPTER 2.0

CASE STUDIES OF FACILITIES CURRENTLY OPERATING OR CONSTRUCTING AN EXTRACTIVE NUTRIENT RECOVERY SYSTEM

2.1 Overview of Category I Case Studies

This chapter contains six case studies on WRRFs that have either implemented struvite recovery or initiated construction of a struvite recovery process. These processes were implemented or will be implemented to treat liquid sidestream flows resulting from dewatering of stabilized sludge. These larger plants range in size, with mainstream design flows that vary between 20 and 140 MGD. Of the various drivers for nutrient recovery processes, these WRRFs cited mitigating nuisance struvite formation, strict phosphorus effluents limits, limiting the phosphorus concentrations of biosolids in anticipation of stricter limits on the agronomic application rates for biosolids applications, and improving reliability of the mainstream WRRF process as the main drivers. Four of these WRRFs implemented Ostara recovery processes, and the other two selected Multiform Harvest as the technology provider. Table 2-1 summarizes the case studies and gives the respective location, plant configuration, nutrient limits and size for each facility. A detailed discussion of the site-specific drivers and lessons learned from the implementation process is provided within each case study.

Table 2-1. Summary of Case Study Facilities Currently Operating or Constructing an Extractive Nutrient Recovery System.

Plant Number	Location	Plant Configuration	Current Nutrient Limits	Size (MGD)
1	Virginia, U.S.	Liquid: 5-Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	TN - 8.0 mg/L AA TP - 2.0 mg/L AA	30
2	Washington, U.S.	Liquid: 3-Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	No limits at present; Proactive in reducing TP < 1 mg/L	22
3	Wisconsin, U.S.	Liquid: 3-Stage BNR and UCT process in parallel Solids: Acid Gas Mesophilic Anaerobic Digestion Digested Sludge Dewatering: GBTs	None	57
4	Saskatchewan, Canada	Liquid: Modified UCT process Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Sludge Storage Cells	TP – 1.0 mg/L TN – none	31.7
5	Georgia, U.S.	Liquid: 3 and 5 stage BNR + ferric trim on tertiary filters Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	NH3-N – 0.4 mg/L TP – 0.08 mg/L	60
6	Idaho, U.S.	Liquid: MLE, Johannesburg. Conversion to West Bank underway Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press?	NH3-N = 0.398 mg/L (winter); 0.788 mg/L (summer) TP = 0.07 mg/L monthly avg; 0.084 mg/L weekly. (May 1 – Sept 3)	24

2.2 Plant 1 Case Study

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 (P) recovery: 576 After implementation of nutrient (P) recovery: 448
Sidestream ortho-phosphorus concentration (mg/L P)	Before implementation of nutrient (P) recovery: 351 After implementation of nutrient (P) recovery: 54

Plant 1 uses a 5-stage BNR process with supplemental carbon addition to meet 8 mg/L total nitrogen and 2 mg/L total phosphorus annual average discharge limits (Figure 2-1). The influent to the facility has traditionally contained high nitrogen (43 mg/L; 2011 to 2013 average) and phosphorus (7.8 mg/L; 2011 to 2013 average) concentrations due to industrial contributions. Solids handling consists of anaerobic digestion of co-thickened primary and waste activated sludge followed by centrifuge dewatering. Prior to the most recent upgrade, dewatering centrate contributed an abnormally high phosphorus loading on the mainstream process (30% of total load), resulting in frequent process upsets. The last major upgrade, completed in 2011, encompassed process modifications to improve the plant's nitrogen and phosphorus removal including conversion to 5-stage BNR, dewatering centrate equalization, struvite recovery via Ostara's Pearl™ Process, and supplemental carbon addition. A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 2-2.

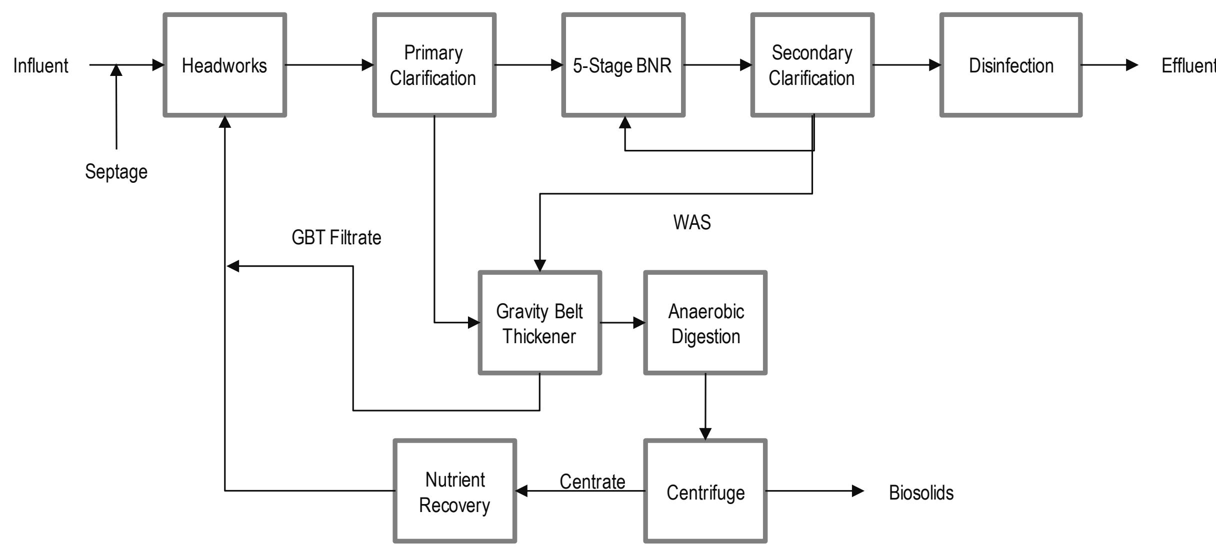

Figure 2-1. Plant 1 Process Flow Diagram.

Table 2-2. Drivers Associated with Extractive Nutrient Recovery for Plant 1.

Driver	Causes	Implemented Solutions
Stringent nutrient limits	• Regulations – sensitive discharge location.	• Continue bio-P. • Centrate equalization. • Engineering pilot study and Business Case Evaluation to evaluate alternative solutions (ferric treatment vs. nutrient recovery) • Implemented Ostara nutrient recovery in 2010. • Chemical addition to sidestream and mainstream as a backup. • Centrate equalization to reduce the impact of intermittent dewatering.
Nuisance struvite in dewatering centrifuges and piping	• Bio-P followed by anaerobic digestion.	
Unstable Bio-P performance	• Significant industrial influent P-load, which contributes to a significant sidestream load. • Low influent BOD/TP ratio. • Industrial contributor overwhelmed biological phosphorus removal capacity. • Intermittent dewatering causes diurnal swings in nutrient recycle loads.	

2.2.1 Implementation of Sidestream Nutrient Control

To attenuate nuisance struvite formation at this facility, the plant previously performed maintenance by hydro-jetting piping and associated equipment. In an attempt to reduce the impact of the sidestream nitrogen and phosphorus loads on the mainstream process and minimize nuisance struvite formation post dewatering, Plant 1 considered two major options, ferric addition and struvite recovery via crystallization of phosphorus present in the centrate.

For the ferric alternative, it was assumed that the precipitate would be processed through centrifuges and disposed of through incineration. For phosphorus recovery, two different scenarios were evaluated. In the first, crystallizer equipment from Ostara would be purchased and the operation and maintenance would be the responsibility of the utility (capital option); however, the utility would receive annual credits to cover operational costs for the facility. In the second option, Ostara would finance the construction of the struvite recovery facility and the utility would pay a monthly fee to the equipment vendor. Under the treatment fee option, Ostara would assume all maintenance of the facilities. For both nutrient recovery alternatives, Plant 1 was required to construct a new 4,800-square foot building with walls 30 feet high.

Table 2-3 shows the cost estimates which were used for the Present Cost Comparison between the potential alternatives for this facility. The present worth analysis indicated that both financing options had a positive net worth at the 5% interest rate, meaning either option was less expensive than using ferric chloride in the side-stream to precipitate orthophosphate.

Table 2-3. Net Present Cost Comparison of Alternatives for Plant 1.

	Treatment Fee Option	Capital Purchase Option
Item	**Annual Cost**	**Annual Cost**
Ferric Chloride Chemical Cost	$(290,000)	$(290,000)
Sludge Savings	$(155,000)	$(155,000)
Methanol Savings	$(29,000)	$(29,000)
Oxygen Savings	$(19,000)	$(19,000)
Ostara Paybacks	$(87,850)	$(135,850)
Total Annual Savings	$(580,850)	$(628,850)
Caustic Cost	$25,000	$25,000
Ostara Annual Fee	$444,000	$ -
Total Annual Operating Cost	$469,000	$25,000
Net Annual Savings	$(111,850)	$(603,850)
Present Worth Savings (5%)	$1,394,000	$7,525,000
Present Worth Savings (8.5%)	$1,058,000	$5,714,000
Capital Cost	$1,080,000	$4,143,110
Net Present Worth (5%)	$314,000	$3,382,000
Net Present Worth (8.5%)	$(22,000)	$1,571,000

The actual construction of the Ostara struvite harvesting facility occurred in 2009-2010 using the capital purchase option as part of a larger BNR upgrade project. The method of procurement was as a change order and Ostara was pre-selected. Table 2-4 shows a summary of actual construction costs.

Table 2-4. Plant 1 Construction Cost Breakdown.

Item	Annual Cost
Foundation and Site/Civil work	$780,000
New Building (Includes mechanical, electrical, HVAC, process piping)	$1,460,000
Equipment (Reactors, pumps, product dryer, classifier screen, NaOH chemical feed system, valves, process piping and associated instrumentation/electrical)	$3,220,000
Total	$5,460,000

The Ostara installation at this plant included three Pearl^{TM} 500 reactors with room to add a fourth reactor in the future. The system treats centrate from the dewatering centrifuge, which is first equalized in tanks that were converted from old aerated grit tanks. Overflow from the Ostara system is pumped back to the headworks. Table 2-5 presents the design criteria as well as historical data to date for the Ostara process at this treatment plant.

Table 2-5. Design Criteria for Sidestream Nutrient Recovery System at Plant 1.

Parameter	Value	Average Historical Value (to date) (May 2010-July 2013)
Flow, MGD	0.10	0.08
Sidestream TP, mg/L	600	432
Sidestream PO_4-P	–	383
Sidestream NH_4-N	–	602
% TP removal	60%	50%
% PO_4-P removal	–	84%
% NH_4-N removal	–	25%

2.2.2 Lessons Learned from Full-Scale Implementation

Based on feedback from Plant 1 staff, the following points have been identified as key lessons that should be considered by facilities implementing a full-scale struvite recovery facility

- Locate struvite recovery facility as close to dewatering facilities and equalization tank as possible.
- Avoid traps and use long turn elbows to reduce locations where nuisance struvite accumulation can occur.
- Incorporate acid flushing of lines leading to and from the nutrient recovery facility as part of routine maintenance to help control and remove nuisance struvite buildup.
- Provide flush connections on all pipe runs.
- Use carbon dioxide (CO_2) to help control struvite during dewatering.
- BNR, digester, and dewatering operations impact struvite recovery and vice versa.

2.3 Plant 2 Case Study

Plant Designation	Plant 2
Location	Washington, USA
Current nutrient limits (mg/L)	No nutrient limit exists
Emerging nutrient limits (mg/L)	TMDL for receiving water body expected. Proactive goal is to reduce effluent TP concentrations below 1 mg/L.
BNR configuration	3 Stage BNR (A2O)
Solids management configuration	Primary sludge and thickened WAS are co-digested in two stage anaerobic digesters. Digested sludge is dewatered before final disposal.
Biosolids disposal method	Land Application
Mainstream design flow (MGD)	22 MGD
Mainstream current operation flow (MGD)	13 MGD
Maximum operating temperature (°C; °F)	No information available
Minimum operating temperature (°C; °F)	No information available
Effluent nutrient concentrations (5-year average)	NA
Sidestream flow (MGD)	0.07
Sidestream nitrogen concentration (mg/L)	Before implementation of nutrient (P) recovery: 1,200 After implementation of nutrient (P) recovery: n/a
Sidestream phosphorus concentration (mg/L)	Before implementation of nutrient (P) recovery: 361 After implementation of nutrient (P) recovery: 20

The facility receives domestic wastewater from commercial and residential sources. The influent wastewater flows through fine screens, followed by grit removal and primary clarification. After the primary clarification, wastewater flows to the trickling filter by gravity and then to activated sludge system. Each of the four aeration basins has 1 MGD capacity. Two secondary clarifiers follow the activated sludge process. Effluent is treated with UV before it is discharged. The sludge from the primary clarifiers, and activated sludge system is pumped to three heated and mechanically mixed anaerobic digesters. The digested sludge is dewatered in two centrifuges, and used as soil conditioner and fertilizer in land application. Figure 2-2 shows the solids and liquid process flow streams for the facility. A summary of main drivers for implementing extractive nutrient recovery as well as a list of main considerations are provided in Table 2-6.

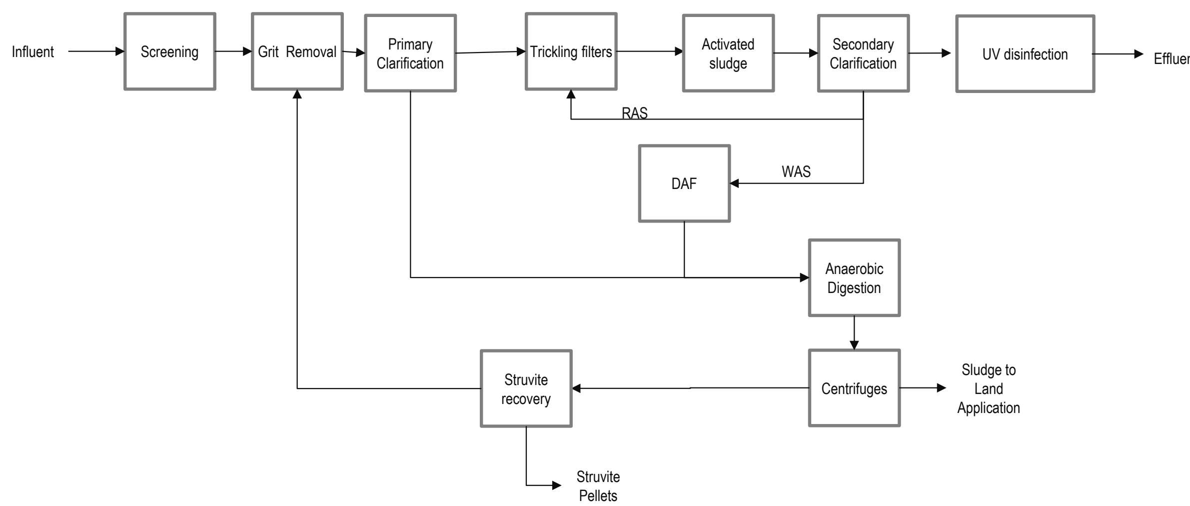

Figure 2-2. Plant 2 Process Flow Diagram.

Table 2-6. Drivers Associated with Extractive Nutrient Recovery for Plant 2.

Driver	Causes	Implemented Solutions
Planned effluent phosphorus limit (1 mg P/L)	• Desire to be proactive in addressing nutrient limits with low cost solutions and lead the effort in the region	• Engineering study with pilot tests, and facility plan amendment that incorporates struvite recovery from sidestream • Full-scale struvite harvesting system
BNR improvements for energy savings	• To reduce ammonia aide stream loading to aeration basins and reduce Centrate dilution water needs	
Nuisance struvite formation in the centrate piping system	• Anaerobic digestion	

2.3.1 Implementation of Sidestream Nutrient Control

During the evaluation of nutrient recovery technologies, proposals from two technology providers were considered and pilot testing was performed. The pilot study achieved the treatment goals with greater than 75% phosphorus removal and approximately 7% nitrogen removal. The removal efficiencies were achieved by varying combinations of operating pH and Mg:P molar ration in the mixed influent.

After the successful implementation of the pilot project, full-scale Multiform Harvest struvite harvesting reactors were installed at the plant. Design parameters are summarized in Table 2-7. Each reactor receives 120 GPM of centrate from the digested sludge dewatering process. The rectors remove 80-90% of the total orthophosphate phosphorus from the centrate before it is returned to the head of the plant. The returned centrate ortho-phosphorus concentration is 20 mg/L.

Table 2-7. Design Criteria for Sidestream Nutrient Recovery System at Plant 2.

Parameter	Value
Flow, MGD	0.3
Influent TP, mg/L	361
% ortho-P removal	75

The total capital cost for the full-scale project was $735,000 and the design cost was $150,000. Estimated monthly operation cost was $250 for power and $2,200 for chemicals. Table 2-8 shows a breakdown of annual operation and maintenance cost for the sidestream nutrient recovery system.

Table 2-8. Plant 2 Annual Sidestream O&M Costs.

Category/Parameter	Anticipated Cost
Chemicals (Mag, caustic)	$25,000
Electricity	$12,000
Cleaning Chemicals	$1,500
Miscellaneous	$600

2.3.2 Lessons Learned from Full-Scale Implementation

Based on feedback from Plant 2 staff, the following lessons have been identified as key points that should be considered by facilities implementing a full-scale struvite recovery facility

- Care must be taken during startup to retain seed material.
- Provide duplicate piping and pumps to minimize downtime during maintenance.
- Eliminate check valves to reduce locations where nuisance struvite accumulation can occur.
- Ensure inlet valve is closed prior to stopping feed pump.
- Use of Struv-Free solution for weekly maintenances helps to relieve nuisance struvite buildup.
- Install large tubing on chemical feed systems to reduce pressure loss.
- Sidestream struvite recovery can delay need for more costly upgrades in the mainstream facility.
- Implementation of nutrient recovery facility can improves public perception of the facility.

2.4 Plant 3 Case Study

Plant designation	Plant 3
Location	Wisconsin, USA
Current nutrient loadings (mg/L)	TP – 2,100 lbs/day (average) TN – 12,900 lbs/day (average)
Future loadings (mg/L)	TN – 19,800 lbs/day TP – 2,900 lbs/day
BNR configuration	Enhanced biological phosphorus removal (EBPR) system with two process configurations being utilized, University of Cape Town (UCT) and the anaerobic/aerobic (A/O) process.
Solids management configuration	WAS from the secondary clarifiers is sent to phosphorus release tanks prior to thickening. The thickened WAS is sent to an acid phase/methane phase digestion process along with thickened primary sludge. Anaerobically digested biosolids is thickened using GBTs and then used for land application. Filtrate streams from WAS and biosolids thickening operations are blended and sent to Ostara struvite recovery process.
Biosolids disposal method	Land application
Mainstream design flow (MGD)	57 MGD (average) and 140 MGD (peak)
Mainstream current operation flow (MGD)	42.9 MGD
Maximum operating temperature (°C; °F)	22°C
Minimum operating temperature (°C; °F)	10°C
Effluent nutrient concentrations (5-year average)	BOD5-3.4, TSS-4.3, NH4-0.14, TP-0.27, NO3-17.1, Cl-392, Fecal Coli-142 MPN/100ml
Sidestream flow (MGD)	WAS = 0.82 MGD WAS thickening filtrate = 0.69 MGD Biosolids thickening filtrate = 0.13 MGD
Sidestream nitrogen concentration (mg/L)	Before implementation of nutrient (P) recovery: 1100 mg/l (digested sludge filt) After implementation of nutrient (P) recovery: 935 mg/l
Sidestream ortho-phosphorus concentration (mg/L)	Before implementation of nutrient (P) recovery: 15 mg/l by virture of ferric chloride dosing to the filtrate return from the digested sludge thickening After implementation of nutrient (P) recovery: 25 mg/l

Plant 3 has an average flow capacity of 57 MGD and a peak flow capacity of 140 MGD. Liquid treatment consists of screening and grit removal, primary clarification, EBPR and ultraviolet (UV) disinfection. Solids treatment consists of primary and waste activated sludge (WAS) thickening, acid gas temperature phased anaerobic digestion (TPAD) and gravity belt dewatering. The facility has recently constructed and started an Ostara struvite harvesting system coupled with phosphorus release and supplementation accomplished by return of acid phase digestion sludge to the phosphorus release tank. Significant phosphorus is released and returned from acid phase digestion back to the phosphorus release tank. Figure 2-3 illustrates a simplified process flow diagram of the facility.

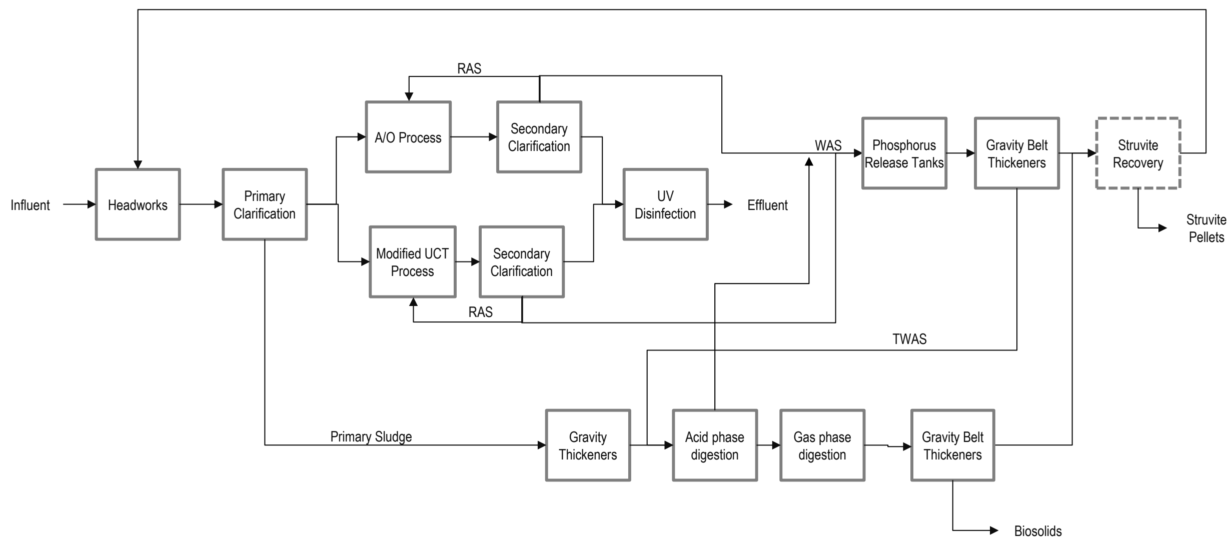

Figure 2-3. Plant 3 Process Flow Diagram.

Table 2-9. Drivers Associated with Extractive Nutrient Recovery at Plant 3.

Driver	Causes	Implemented Solutions
Reduction of P in biosolids	• Recent administrative rule revisions in biosolids P application limits	• Acid phase digestion, phosphorus return and release, and struvite recovery facility
Reduction of nuisance struvite formation in digestion process	• Bio-P followed by anaerobic digesters	

WERF

2.4.1 Implementation of Sidestream Nutrient Control

To address nuisance struvite formation, several alternatives outlined in Tables 2-10 and 2-11 were evaluated. Based on the results from the economic and non-economic evaluation, struvite recovery downstream of the digestion was selected as the preferred option. The facility expects that revenue from fertilizer sales from the struvite recovery will help offset the chemical costs to operate the system. Design criteria for the Ostara facility is provided in Table 2-12.

Table 2-10. Struvite Mitigation Alternatives for Plant 3.

Alternative	Reduces P Loading to main treatment	Mitigation of Digester Struvite	Low Operational Complexity	Reduction in P content of biosolids	Phosphorus Recovery	Proven Technology	Additional Operational Considerations
Poly-Gone Lines	X	X	X			X	Patented chemical. Unknown impact on effluent Total P.
Iron Salt Addition Upstream of Digesters	X	X	X			X	Impact on effluent chloride permit.
Iron Salt Addition to Digesters	X	X	X			X	Impact on effluent chloride permit. Vivianite formation. Hydrogen sulfide removal.
Struvite Harvesting Upstream of Digestion	X	X		X	X		Sensitive to wastewater chemical characteristics.
Struvite Harvesting Downstream of Digestion	X			X	X		Sensitive to wastewater chemical characteristics.

Table 2-11. Comparison of Struvite Mitigation Alternatives for Plant 3.

Alternative	Present Worth Capital Cost	Present Worth O&M Cost	Total Present Worth Cost
Preventative Maintenance of Process Piping and Equipment	–	$1,300,000	$1,300,000
Poly-Gone Lines	$79,000	$1,786,000	$1,865,000
Iron Salt Addition Upstream of Digesters	$845,000	$17,962,000	$18,807,000
Iron Salt Addition to Digesters	$236,000	$17,651,000	$17,887,000
Struvite Harvesting Upstream of Digestion	$19,923,000	$2,815,000	$22,738,000
Struvite Harvesting Downstream of Digestion	$9,021,000	$1,624,000(4)	$10,645,000

Table 2-12. Design Criteria for Sidestream Nutrient Recovery System for Plant 3.

Parameter	Value
Flow, MGD	1.17
Influent TP	6.0 mg/L
Influent PO_4-P	126 mg/L
Influent NH_4-N	175 mg/L
% TP removal	Not specified
% PO_4-P removal	80%
% NH_4-N removal	15%

Treatment through this nutrient recovery process consists of the following:

- WAS from the secondary clarifiers is conveyed to phosphorus release tanks prior to gravity belt thickening. A sidestream of sludge from the acid phase digester is returned to the phosphorus release tank to provide VFAs for phosphorus release plus adding soluble phosphorus released in the acid phase digestion process. The phosphorus rich flow is sent to the struvite recovery reactor.
- Thickener WAS and PS digested and then dewatered by GBTs or centrifuges. The filtrate is sent to the nutrient recovery facility. The biosolids are recycled as fertilizer and applied to agricultural lands.

Estimated savings associated with implementing the nutrient recovery system are summarized in Table 2-13.

Table 2-13. Estimated Saving Attributable to Harvesting Phosphorus at Plant 3.

Item	Current Estimated Savings		Future Estimated Savings	
	Daily lb/d	$ / year	Daily lb/d	$ / year
$FeCl_3$ @ $650 / dt	6,000	$711,750	8,000	$949,000
Biosolids Hauling @ $100 / dt	3,025	$55,200	4,050	$73,900
Reduced GBT Polymer @ $2.7 / dt		$6,750		$9,000
Reduced Aeration from Decreased Ammonia @ $0.08/kWh		$9,200		$12,000
TOTAL ANNUAL SAVINGS		**$782,900**		**$1,043,900**

2.4.2 Lessons Learned from Full-Scale Implementation

Based on feedback from Plant 3 staff, the following points have been identified as key lessons that should be considered by facilities implementing full-scale struvite recovery:

- Polymer costs have increased for WAS thickening since implementation of acid phase recycle.
- Polymer cost savings for digested sludge thickening have not materialized, and concentrations of solids off of the GBTs are lower than prior to process retrofits. A low dose of ferric chloride was re-started on the feed to the digested sludge GBT in order to improve the thickening.
- Creating the correct size material fertilizer requires iteration and optimization of the process.
- When ferric chloride dosing to the digested sludge filtrate recycle stream was discontinued, the hydrogen sulfide concentration in the digester gas increased from <300 ppm by volume to >500 ppm by volume. The hydrogen sulfide and siloxane treatment system was unable to handle the increased loading. A low dose of ferric chloride was resumed, and has been fed directly into the digesters to control the H_2S levels to between 350 and 500 ppm so that the treatment system can remove H_2S to <20 ppm.
- Even though ferric chloride is still being utilized at the same time as struvite harvesting, the costs are less than half of the costs for ferric dosing prior to instituting nutrient recovery.
- Minimizing return sludge rates in the secondary process will increase the feed concentrations to Ostara and reduce chemical costs.

2.5 Plant 4 Case Study

Plant designation	Plant 4
Location	Saskatchewan, Canada
Current nutrient limits (mg/L)	TP – 1.0 mg/L TN – none
Emerging nutrient limits (mg/L)	TP – 0.5 mg/L TN – 10-15 mg/L
BNR configuration	Modified UCT
Solids management configuration	DAF thickened WAS and fermented primary sludge are co-digested before being pumped to short-term storage cells
Biosolids disposal method	Deep cell storage and wet injection on agricultural land
Mainstream design flow (MGD)	31.7 MGD (Average Daily Flow)
Mainstream current operation flow (MGD)	22.45 MGD
Maximum operating temperature (°C; °F)	10°C
Minimum operating temperature (°C; °F)	21°C
Effluent nutrient concentrations (5-year average)	Not available
Sidestream flow (MGD)	0.85 (combined reactor feed)
Sidestream nitrogen concentration (mg/L)	Not available
Sidestream ortho-phosphorus concentration (mg/L)	Not available

Liquid treatment at Plant 4 consists of screening, primary clarification, 3-stage biological nutrient removal (BNR) basins (anaerobic-anoxic-aerobic zones), and UV disinfection. Solids handling consists of mesophilic anaerobic digestion of primary and waste activated sludge (DAF thickened). Methane produced from this system is recovered and used as fuel for boilers or flared. The digested sludge is pumped to sludge storage cells where the sludge is further thickened and stored before removal for liquid injection into farmland. Nuisance struvite formation in the digester complex as well as in pipelines leading to and from the sludge lagoons was identified as the primary drivers for implementation of nutrient recovery at Plant 4 (Table 2-14).

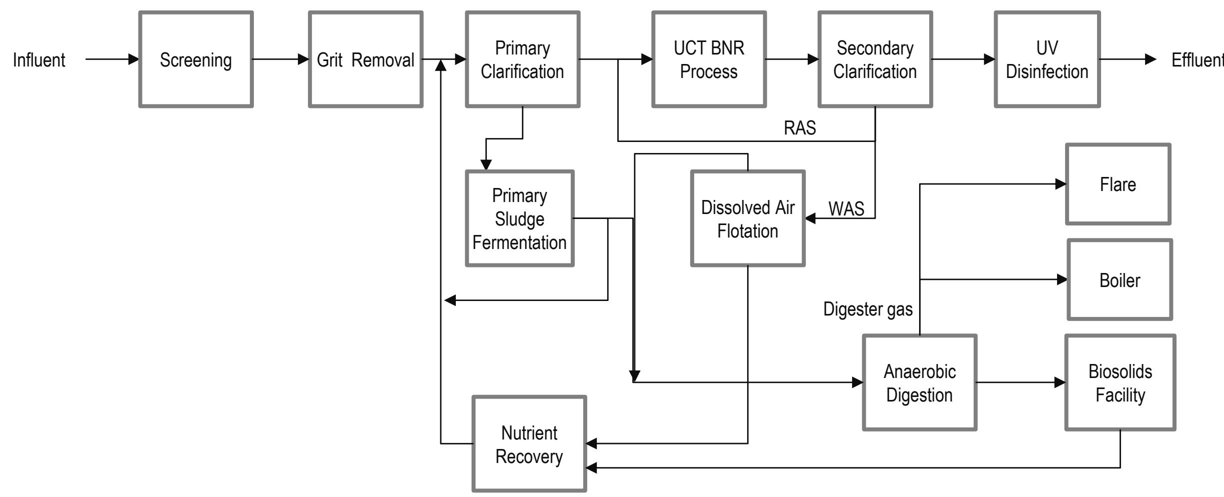

Figure 2-4. Plant 4 Process Flow Diagram.

Table 2-14. Drivers Associated with Extractive Nutrient Recovery for Plant 4.

Driver	Causes	Implemented Solutions
Nuisance struvite formation in pipes, valves and pumps which service the anaerobic digesters and digested sludge lagoons	• Bio-P Removal for phosphorus followed by anaerobic digestion • Receives supernatant from the sludge storage cells, which doubles the P load to the digesters	• Installed glass lined piping and valving to reduce nuisance struvite formation • Implementation of struvite recovery facility

2.5.1 Implementation of Sidestream Nutrient Control

To mitigate nuisance struvite formation, Plant 4 historically used ferric chloride in the digesters to sequester the phosphorus; however, continual repair and replacement of piping and pumps required approximately $250,000 per year. Despite ferric addition, nuisance struvite formation in pipelines steadily increased and in certain cases caused the force-main to over-pressure, requiring emergency closure of the system.

Plant 4 commissioned a struvite mitigation study to reduce side stream nutrient loads and reduce potential for struvite scale build-up. The following options were evaluated:

- **Option 1:** Do nothing.
- **Option 2:** Sidestream chemical phosphorus precipitation of TWAS.
- **Option 3A:** Phosphorus recovery – minimize infrastructure to control struvite formation.
- **Option 3B:** Phosphorus recovery – maximize infrastructure for increased phosphorus revenue potential.

- **Option 4A:** Truck transfer of dewatered undigested WAS cake (15-20%) from WRRF to Organic Processing Facility (complete WAS diversion).
- **Option 4B:** Truck transfer of dewatered undigested WAS cake (15-20%) from WRRF to Organic Processing Facility (minimum diversion for struvite formation control).

An economic evaluation of the options was performed and is summarized in Tables 2-15 and 2-16. Costs were examined for a 25-year period, and an annual discount rate of 5% was assumed. Results from this evaluation indicated that the struvite recovery options would have the lowest net present cost and shortest payback.

Table 2-15. Summary of Struvite Management Costs for Plant 4.

Cost	Option 1	Option 2	Option 3A	Option 3B	Option 4A	Option 4B
Capital	$0	$1.1 M	$1.5 M	$3.0 M	$5.3	$2.9
O&M Cost	$0	-$25,400	-$146,400	-$163,400	–	–
NPV	$0	$0.7 M	-$0.7	$0.5 M	–	–

Table 2-16. Original and Revised Simple Payback Period for Plant 4.

	Option 1	Option 2	Option 3A	Option 3B	Option 4A	Option 4B
Payback Period (years)	N/A	No Payback	13.2	22.9	No Payback	No Payback

The struvite recovery installation at this plant includes one Pearl™ 2000 reactor that is designed to receive input from anaerobically digested sludge storage cell supernatant and filtrate from the WASSTRP™ process. Table 2-17 presents the design criteria used for the Ostara Process at this treatment plant.

Table 2-17. Design Criteria for Sidestream Nutrient Recovery System for Plant 4.

Parameter	Value
Flow, MGD	0.74
Influent PO_4-P	78 mg/L
Influent NH_4-N	250 mg/L
% PO_4-P removal	68
% NH_4-N removal	10

Capital and operating costs associated with the struvite recovery facility are summarized in Table 2-18.

Table 2-18. Estimated Capital and Operating Costs for Struvite Recovery at Plant 4.

Item	Estimated Cost
Capital Cost	$4,450,000
Operating Costs (annual)	$100,000
Expected revenue from struvite sales (~US$ 275 per dry ton)	$66,000 to 99,000

2.5.2 Lessons Learned from Full-Scale Implementation

Based on feedback from Plant 4 staff, the following points have been identified as key lessons that should be considered by facilities implementing full-scale struvite recovery:

- Construction and installation of facility can be impacted by the availability of preferred local contractors. This resulted in construction during the winter period, increasing costs.
- The need to perform a staged commissioning approach whereby reactor startup and operation should be followed by harvesting and then bagging to allow operators to gain familiarity with the system. It is difficult to train staff on equipment that is not fully functional.
- Ensure that control system architecture is compatible with existing infrastructure.
- Lack of second reactor can complicate operation during periods of maintenance.
- WASSTRIP™ process operation during winter needs to be optimized.
- Operation of struvite recovery system has reduced phosphorus loading throughout the plant and has contributed to a reduction of foaming in the digesters and bioreactors.
- DAF performance has improved since commissioning of the process.
- Odor control should be considered for the WAS release tank.

2.6 Plant 5 Case Study

Plant designation	Plant 5
Location	Georgia, USA
Current nutrient limits (mg/L)	NH_3-N – 0.4 mg/L TP – 0.08 mg/L
Emerging nutrient limits (mg/L)	TN – potential for future TMDL
BNR configuration	3 and 5 stage BNR + ferric trim on tertiary filters
Solids management configuration	WAS and primary sludge co-thickening, anaerobic digestion, dewatering centrifuges; gravity thickeners for chemical sludge from tertiary treatment, chemical and biological sludge are dewatered together
Biosolids disposal method	Landfill ($640 per dry ton in 2011)
Mainstream design flow (MGD)	60 MM; 50 AADF
Mainstream current operation flow (MGD)	32
Maximum operating temperature (°C; °F)	26.7°C
Minimum operating temperature (°C; °⁰F)	10°C
Effluent nutrient concentrations (5-year average)	TP - 0.05 mg/L NH_3-N – 0.15 mg/L
Sidestream flow (MGD)	0.21 MGD (average)
Sidestream nitrogen load (lb/day; % of total N load)	900 ppd; 12%
Sidestream phosphorus load (lb/day; % of total P load)	35 ppd*; 1.75%
Method for odor control in collection system	Adding $MgOH_2$ and Bio-oxide at strategic points in the collection system

*A large part of the phosphorus load leaves the plant as struvite crystals in the sludge cake.

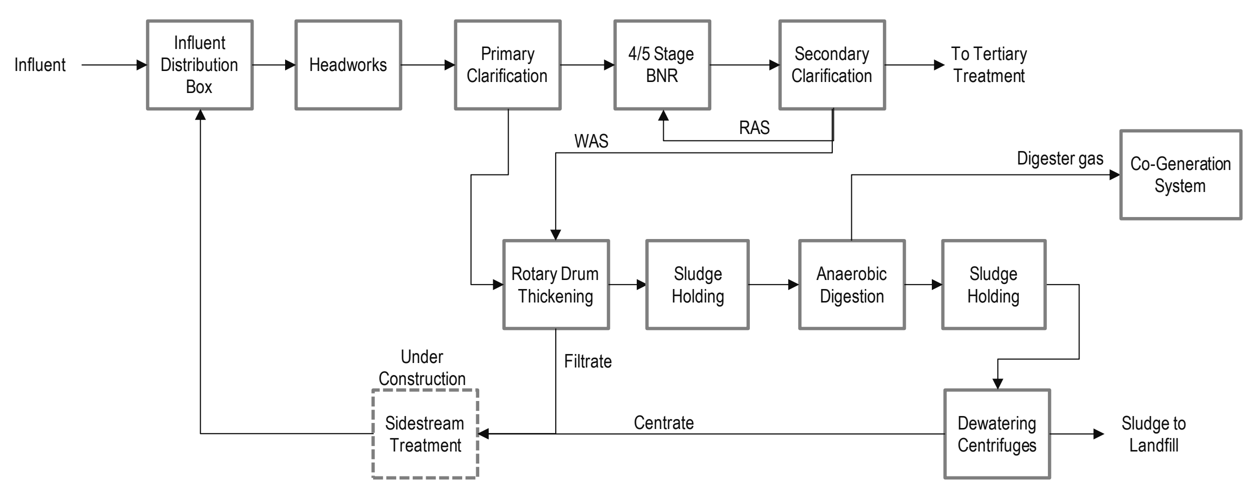

Figure 2-5. Plant 5 Process Flow Diagram.

Existing unit processes at Plant 5 include screening and grit removal, primary clarification, 3-stage and 5-stage BNR activated sludge basins, and secondary clarification. There are 10 activated sludge treatment basins at the plant. Bioreactor basins 1-4 are five-stage BNR and provide anaerobic, primary anoxic, aerobic, secondary anoxic/swing zone (currently aerated), and reaeration zones. The newer basins, Bioreactor basins 5-10, include three stages: anaerobic, anoxic, and aerobic zones.

After secondary treatment the effluent is split into two treatment trains. The first treatment train is rated for 20 MGD and includes tertiary chemical clarification and granular media filtration. The second treatment train is rated for 40 MGD and includes chemical flocculation/clarification and ultrafiltration membrane filtration. The effluent is combined and treated through re-ozonation, granular activated carbon (GAC) filtration, ozone disinfection, and effluent pumping. Solids handling includes waste activated sludge thickening centrifuges, anaerobic digestion, chemical solids gravity thickeners, and dewatering centrifuges. The plant has the flexibility to pump 20 MGD of the effluent approximately 20 miles, combine it with the effluent from a neighboring facility, and discharge into a river. The remaining 40 MGD is pumped to a lake. Figure 2-5 shows the solids and liquids process flow diagram for the facility.

The plant currently uses Bio-P and chemical addition to meet the stringent phosphorus limit. Due to the addition of magnesium for odor control, the facility currently experiences significant nuisance struvite formation. The strategy for managing nuisance struvite formation is by hydrojetting of the dewatering centrate transmission lines and adding Flosperse™, an anti-scalant, ahead of the centrifuges. The annual costs of these maintenance items are shown in Table 2-19. Though it is likely that struvite is forming in the anaerobic digesters, they have never been inspected. A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 2-20.

Table 2-19. Annual O&M Costs Related To Nutrient Control at Plant 5.

Description	Unit Cost	Unit	Qty/year	Annual Cost	Location
Jetting lines every 5 weeks	$5,000	event	10.4	$52,000	Sidestream
Flosperse™	$1,633	month	12	$20,000	Sidestream
Ferric Chloride	$1.31	gallon	135,050	$177,000	Mainstream
Alum	$0.59	gallon	442,380	$261,000	Mainstream
$Mg(OH)_2$	$1.89	gallon	973,820	$1,840,000	Collection System
Total				**$2,350,000**	

Table 2-20. Drivers Associated with Extractive Nutrient Recovery at Plant 5.

Driver	Causes	Implemented Solutions
Stringent effluent P limit	• Regulations – sensitive discharge location	• Bio-P + multipoint chemical addition
Increased influent P-load from receiving additional sludge nutrient load from neighboring Bio-P plant	• County-wide solids management plan	• Engineering pilot study and Business Case Evaluation to evaluate alternative solutions (ferric treatment vs. nutrient recovery)
Nuisance struvite in digester complex and dewatering centrifuges and piping	• Bio-P in addition to MgOH solution in collection system for odor and corrosion control	• Engineering pilot study and Business Case Evaluation to evaluate alternative solutions (ferric treatment vs. nutrient recovery)
Nutrient load impact on mainstream process	• Ammonia breakthrough in future loading conditions	• Previous study recommended centrate equalization with solids handling improvements to lower chemical costs for P removal and reduce PO_4-P and NH_3-N breakthrough

2.6.1 Implementation of Sidestream Nutrient Control

An evaluation of nutrient control strategies was completed in 2012 analyzing options contingent on either continuing or discontinuing $Mg(OH)_2$ addition in the collection system. The business case evaluation (BCE) considered only Ostara as the nutrient recovery equipment vendor. This was done to be conservative in the evaluation as Ostara is typically the highest capital cost option in comparison with other vendors. Following the BCE results, the utility issued a Request for Technical Proposals soliciting proposals from qualified vendors. Upon evaluation of the submitted proposals, Ostara was pre-selected as the nutrient recovery system vendor for the project design.

The options evaluated for the BCE were as follows:

1. Nutrient recovery options – Ostara
   a) Continue $Mg(OH)_2$ addition and implement Ostara with WASSTRIP.
   b) Discontinue $Mg(OH)_2$ addition and implement Ostara with WASSTRIP.
   c) Discontinue $Mg(OH)_2$ addition and implement Ostara on centrate.
2. Ferric options
   a) Continue $Mg(OH)_2$ addition and implement ferric feed at digesters for struvite control.
   b) Discontinue $Mg(OH)_2$ addition and implement feed ferric in centrate for P-recycle control.

Table 2-21. Summary of Ostara Capital Costs for Plant 5.

Item Description	Actual Cost*
Nutrient Recovery Facility (includes new building)	$8.81M
1.5 MG Centrate EQ Tank + odor control	$2.03M (3 tanks)
WASSTRIP modifications	$161k
Electrical and Instrumentation	$1.13k
Yard Piping	$109k
Contingency, Contractor OH&P, Taxes, Eng., etc.	$4.25M

*construction cost estimate in 2012 dollars

Table 2-22. Summary of Ferric Capital Costs for Plant 5.

Item Description	Cost
Ferric Feed Facility	
Building (electrical room and pump room)	$120k
Storage tanks (outdoors, no canopy)	$170k
Chemical feed pumps	$150k
1 MG Centrate EQ Tank + odor control @ 10 yrs	$ 1.5M
Electrical and Instrumentation	$288k
Contingency, Contractor OH&P, Taxes, etc.	$493k

O&M costs were developed from information gathered from Ostara and the utility. Assumptions, unit costs and first year O&M costs are shown in Tables 2-23 through 2-26.

Table 2-23. O&M Unit Costs for Plant 5.

Description	Unit	Unit Cost	Comments
Electrical Cost	$/kWh	$0.065	
Sludge Disposal Cost	$/wet ton	$40.00	Avg. sludge cake concentration = 24%
Ferric Chloride Cost	$/gal	$1.31	Feed rate = 35 lb Fe/dry ton solids
Lime Cost	$/ton	$139.44	Lime Concentration = 25 mg CaO/L
1 FTE	$/hr	$38	

Table 2-24. First Year O&M Costs per Ostara Option at Plant 5.

Item	Description and Assumptions	Ostara WASSTRIP with Magnesium Addition
Lime cost	Lime is added for alkalinity if $Mg(OH)_2$ is omitted Dosages per historical plant usage rates Cost provided by the utility	$0.00
NH_3-N, blower savings	Savings from reduced NH_3-N in recycle stream	-$7,800
NH_3-N, alkalinity savings	Savings from reduced NH_3-N in recycle stream	$0.00
Sludge savings	Savings from reduced sludge production	-$92,100
Product buyback	Fertilizer gross sales	-$263,000
Energy	Rate provided by the utility Usage provided by Ostara	$25,000
Labor	1 FTE to operate Ostara facility	$61,000
Maintenance	Provided by Ostara	$49,000
$Mg(Cl)_2$	Provided by Ostara	$0.00
NaOH	Provided by Ostara	$28,000
Ostara reimbursement	Reimbursement for operations costs	-$100,000
Total O&M		**-$200,000**

**Data for Alternatives 1b and 1c not shown

Table 2-25. First Year O&M Cost per Ferric Option at Plant 5.

Item	Description and Assumptions	Ferric at Digesters Mag
Lime cost	Lime is added for alkalinity if $Mg(OH)_2$ is omitted Dosages per historical plant usage rates Cost provided by the utility	$0.00
Ferric cost	Dosages per historical plant usage rates Cost provided by the utility	$669,000
Operations Labor	½ full time equivalent (FTE) to operate ferric facility	$40,000
Maintenance	Ferric facility annual maintenance = 1% of capital cost	$15,000
Energy	Energy cost assumed negligible for Ferric facility	$0.00
Total O&M		**$724,000**

**Data for Alternatives 1b and 1c not shown

Table 2-26 shows the net present cost (NPC) summary. Results show that Option 1a: Nutrient Recovery with WASSTRIP is the lowest cost option over the period analyzed.

Table 2-26. Net Present Costs for Plant 5.

	Ostara WASSTRIP Mag	Ferric at Digesters Mag
Total Capital Costs	$ 13.75M	$ 4.60M
Year 1 Capital Costs	$ 9.75M	$ 1.52M
Year 1 O&M	$ (200,000)	$ 724,200
Total Net Present Cost	**$ 7.04M**	**$ 20.55M**

Based on results from the economic evaluation, this facility is currently constructing a nutrient recovery facility utilizing Ostara's system including WASSTRIP™. Nutrient recovery startup is expected to be in the late fall of 2014. The facility is designed to house two Pearl™ 2000 reactors with room to add a third reactor in the future with all ancillary equipment. In addition to the building, three 500,000 gallon storage tanks will be constructed for dewatering centrate and thickening filtrate storage. One unique aspect of this system is that it will not require additional magnesium chloride which is typically required in other Ostara installations because the utility adds magnesium hydroxide to the collection system for odor and corrosion control. This magnesium makes its way to the treatment plant and will be consumed in the struvite precipitation process, providing a large operational cost savings.

Table 2-27. Summary of Ostara System Design Performance Parameters for Plant 5.

Parameter	Current	Year 10	Year 20
Treatment capacity per reactor, gpd	726,235	690,966	543,952
Proposed number of reactors, units	1	2	2
Effluent PO_4-P, mg/L	18	27	34
Phosphorus removed, ppd	492	765	1,187
Effluent NH_3-N, mg/L	189	117	129
Ammonia removed, %	19	28	31
Nitrogen removed, ppd	223	346	537
Struvite production rate, tons/yr	641	996	1545
Process target pH	7.75	8	8

*Design parameters obtained from Ostara's response to Request for Technical Proposals

2.7 Plant 6 Case Study

Plant designation	Plant 6
Location	Idaho, USA
Current nutrient limits (mg/L)	Ammonia-Nitrogen = 0.398 mg/L (winter); 0.788 mg/L (summer) TP = 0.07 mg/L monthly avg; 0.084 mg/L weekly. (May 1 – Sept 3)
Emerging nutrient limits (mg/L)	n/a
BNR configuration	Current: North Plant – MLE; South Plant – JHB Future (under construction): North & South Plants - West Bank configuration
Solids management configuration	WAS and primary sludge thickening, anaerobic digestion, and dewatering.
Biosolids disposal method	Land Application to utility owned biosolids application site
Mainstream design flow (MGD)	24 MGD
Mainstream current operation flow (MGD)	14.3 MGD
Maximum operating temperature (°C; °F)	15.2°C
Minimum operating temperature (°C; °F)	24.1°C
Effluent nutrient concentrations (2007-2012)	TP – 4.69 mg/L NOx – 17.2 mg/L NH_3 – 0.396 mg/L (0.438 mg/L latest reading - Excursion)
Sidestream flow (MGD)	WAS filtrate – 0.48 MGD Digester filtrate – 0.078 MGD
Sidestream nitrogen load (lb/day; % of total N load)	50 mg/L in WAS filtrate (200 ppd) 1,100 mg/L in digester filtrate (716 ppd)
Sidestream phosphorus load (lb/day; % of total P load)	180 mg/L in WAS filtrate (721 ppd) 390 mg/L in digester filtrate (254 ppd)

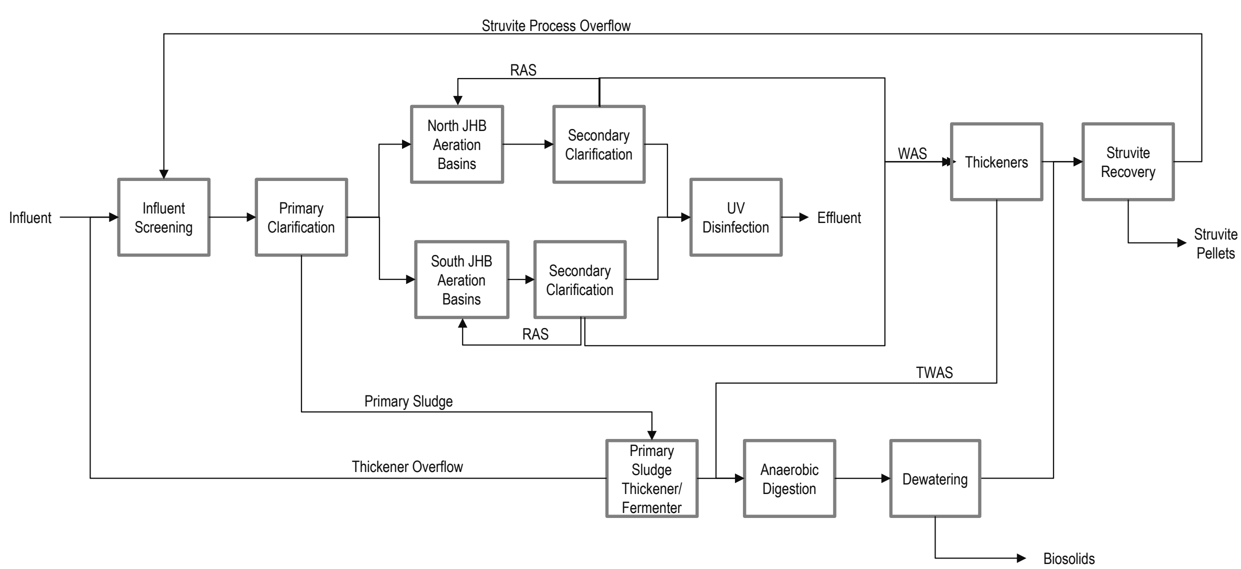

Figure 2-6. Plant 6 Process Flow Diagram.

Secondary treatment at this wastewater treatment facility is provided through two separate north and south plants. The North Plant uses the MLE process with two aeration basins consisting of anoxic reactors followed by aerobic reactors. A mixed-liquor recycle (MLR) is utilized within the aeration basins to maintain a suitable anoxic environment. The primary goal of the anoxic reactors is to improve the settleability of the sludge as opposed to denitrify the sludge. The South Plant includes aeration basins capable of operating in either Johannesburg (JHB) mode to provide enhanced biological phosphorus removal (EBPR) or with strictly anoxic reactors before the aerobic reactors. Ongoing construction will convert both plants to the West Bank configuration.

Since this facility must meet a very stringent effluent TP limit, sidestream treatment of WAS and digester flows was identified as a strategy for improving process reliability. The facility was also interested in utilizing an environmentally friendly approach for sidestream treatment. A summary of the primary drivers behind implementing nutrient recovery is provided in Table 2-28.

Table 2-28. Drivers Associated with Extractive Nutrient Recovery for Plant 6.

Driver	Causes	Implemented Solutions
Low Effluent P Limit	• Stringent Regulations on Phosphorus Effluent Concentration	• Struvite recovery facility
Reduction of nutrient concentration in biosolids	• Bio-P increases P content of the biosolids	

2.7.1 Implementation of Sidestream Nutrient Control

This facility is utilizing the design build delivery method to incorporate a sidestream nutrient recovery process from Multiform Harvest to help manage the reactive phosphorus removal from the WAS and digester filtrates. A summary of costs associated with the project is provided in Table 2-29.

Table 2-29. Costs Associated with Extractive Nutrient Recovery at Plant 6.

Cost	Multiform Harvest Struvite Recovery
Capital	$3,681,695
Chemical Costs	$322,584
Anticipated Revenue for struvite sale	$190,000

The struvite harvesting system that will be implemented at this plant will process both WAS and digester filtrate. The system will include three WAS filtrate reactors, one digester filtrate reactor, and one stand-by reactor. Each recovery reactor will be capable of treating 0.18 MGD. The harvesting system will also include storage tanks and chemical metering pumps to provide ammonia, magnesium chloride, and caustic. A heater conveyor will then dry the struvite to meet pathogen reduction requirements prior to sending the final product off-site for further processing. The struvite harvesting system is projected to produce 6,959 lbs/day under average conditions. Design criteria utilized for this system are summarized in Table 2-30.

Table 2-30. Design Criteria for Sidestream Nutrient Recovery System at Plant 6.

Parameter	Value
Flow, MGD	0.56
Influent PO_4-P	180 mg/L WAS filtrate 390 mg/L digester filtrate
Influent NH_4-N	50 mg/L WAS filtrate 1,100 mg/L digester filtrate
% PO_4-P removal	75

2.8 Summary of Lessons Learned from Full-Scale Implementations

Since WRRFs lack experience with struvite recovery, the wastewater industry needs to use the initial feedback presented here as a guide for future nutrient recovery projects. The above experiences are summarized and presented in the following sections.

2.8.1 General Impacts of Struvite Recovery on WRRFs

Plant-wide, struvite recovery impacted BNR, digester and dewatering processes, due to the reduced phosphorus loadings. To the benefit of WRRF operators, struvite recovery reduced foaming in bioreactors and digesters and increased DAF performance. These experiences suggest that WRRFs will need to optimize mainstream processes after the startup of struvite recovery and that WRRFs can expect some processes to improve due to the reduced phosphorus loading in the plant.

2.8.2 General Design Considerations

Struvite crystallization requires a high concentration of nutrients, and therefore, WRRFs need to locate recovery facilities as close to the dewatering facilities and equalization tanks as possible. To minimize struvite formation in the side stream process, WRRFs need to minimize the installation of traps, check valves, small tubing, and short run elbows. Instead, WRRFs should use and install flush connections, large tubing, and long run turns, which will facilitate cleaning during maintenance and will minimize struvite formation. Installing a second reactor, duplicate piping and additional pumps minimizes downtime during maintenance and ensures that excess phosphorus is not returned to the headworks.

2.8.3 Start Up

WRRFs need to implement the start-up process in stages to facilitate training and learning for operators, as training staff on non-functional equipment resulted in a poor understanding of optimizing the nutrient recovery process. Operators also need to give extra care to the initial startup process, as variations in this sensitive process can cause the loss of seed material.

2.8.4 Operations and Maintenance

Regular acid flushing as part of a routine maintenance plan controls and removes nuisance struvite. For example, the weekly use of Struv-Free minimized the formation of struvite in one plant. During dewatering, the addition of carbon dioxide can control struvite formation, as the reduced pH inhibits struvite precipitation. Before stopping feed pumps, operators recommend closing the inlet valves to minimize struvite formation in the piping. During the winter, the WRRF in Canada struggled to optimize the WASSTRIP™ process, which suggests that extremely cold weather negatively affects this process; however, none of the plants in the United States reported problems with colder weather.

2.9 Case Study for Technology Providers

To greater understand the differences between struvite recovery technologies, five struvite recovery companies provided a conceptual design for a hypothetical facility with the following problem statement:

Case Study Plant A

Plant A is a 24 MGD facility that currently runs at ~ 12 MGD. The facility receives primarily domestic wastewater. Plant A meets a TN < 5 mg/L and TP < 0.5 mg/L using a 5-stage BNR process with enhanced biological phosphorus removal (Figure 2-7). The facility performs anaerobic digestion and dewaters the sludge using centrifuges. The sidestream is currently returned to the head of the plant and can intermittently upset the EBPR process. The facility experiences struvite formation in the digesters, centrifuges, and pipelines to and from this equipment. The plant currently uses ferric chloride to bind up the soluble orthophosphate and to prevent the formation of struvite. The addition of ferric chloride also minimizes the impact of the sidestream phosphorus load on the mainstream processes. A summary of plant flow characteristics is provided in Table 2-31.

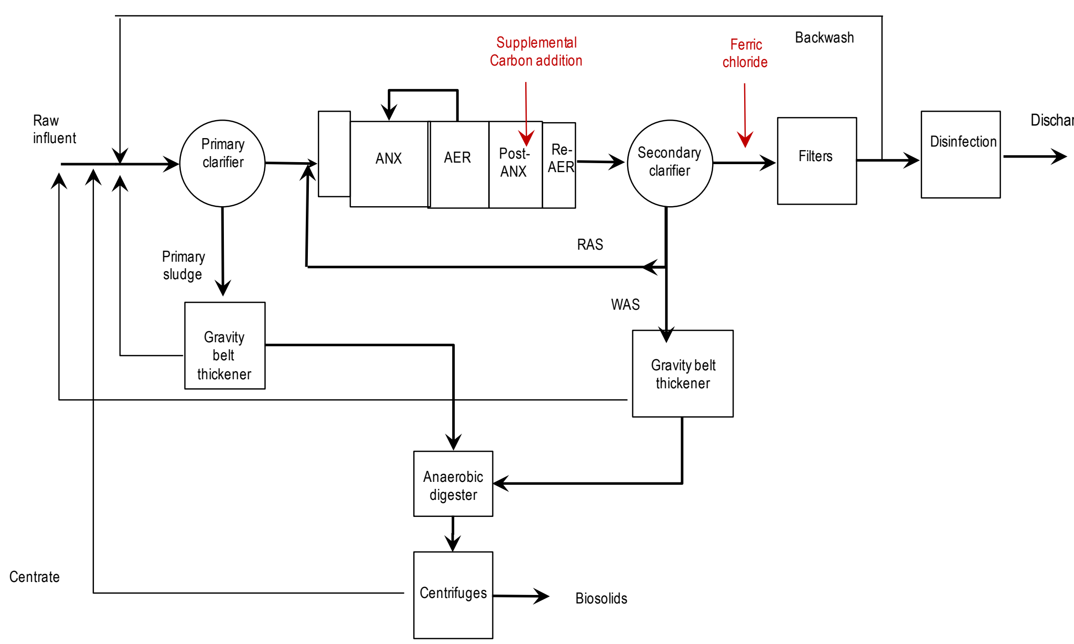

Figure 2-7. Case Study Process Flow Diagram.

Table 2-31. Case Study Wastewater Characteristics and Nutrient Mass Balance.

	Flow (MGD)	TSS (mg/L)	TP (mg/L)	PO_4-P (mg/L)	NH_3-N (mg/L)	Alk[1] (mg $CaCO_3$/L)	pH[1]
Influent	12	232	6.0			150	7.3
Final Effluent	11		0.44				
Primary Sludge	0.1	14,400	199		27		
WAS	0.18	6,900	365		1		
Digester Influent	0.06	46,800	1,480	3.7	14		
Digested Sludge	0.06	29,800	1,480	683	800		
Dewatering Centrate	0.03	710	702	683	800	2,600	7.46
Sludge Cake	0.01	183,300	5,500	683	800	2,600	7.46

The facility desires a solution to this issue and requests a conceptual level design of a nutrient recovery facility for this purpose. As part of the conceptual design, technology providers were asked to include:

1. Scope of supply; If complete system is not included in preferred scope of supply, list other requirements for complete and functioning system
   a. Process flow diagram
   b. Sample plan view layout and overall height requirement
2. Equipment rated capacity and size
3. Physical dimensions and equipment weight
   a. Photos of similar sized systems are encouraged
4. Expected performance
   a. Effluent PO4-P (mg/L), PO4-P removal %, Phosphorus removed (kg P/day)
   b. Effluent NH3-N (mg/L), NH3-N removal %, Nitrogen removed (kg N/day)
   c. Struvite production rate (metric tonne/year)
5. Final product handling and storage
6. Proposed method for disposal of product and typical duration of service
7. Expected operations and maintenance requirements
   a. Electrical power (kWh/day), Natural gas (therms/day), Labor (O&M), chemicals (kg/year)

2.10 Results from Conceptual Design

A summary of system characteristics is provided in Table 2-32. From this summary it can be seen that struvite recovery systems cluster into two groups based on estimated P recovery potential.

1. Group 1 (Ostara, Multiform Harvest, Paques, and Procorp) – For these systems, P recovery estimates were greater 90%, and struvite production ranged from 300 to 421 metric tonnes per year. These processes are relatively similar and employ single reactors.
2. Group 2 (NuReSys and SH+E) – For these systems, P recovery was estimated to range from 50 to 65%, with struvite production rates ranging from 64 to 251 metric tonnes per year. Both NuReSys and SH+E employ dual tanks in there processes, compared to the group 1 processes, which use single reactors. Interestingly, all of the providers except SH+E recover struvite from the sidestream, whereas the Airprex™ process recovers struvite directly from digested sludge.

Table 2-32. Summary of Responses from Technology Providers.

Name of Technology	Pearl®	Multiform Harvest Struvite Technology	Phospaq	Crystalactor®	NuReSys	Airprex
Technology Provider	Ostara	Multiform Harvest	Paques	Procorp	Nuresys	SH+E
Product Recovered	Magnesium Struvite					
Estimated Struvite Production Rate (metric tonne struvite/year)	318	Not reported	421	364	251	64
Estimated % efficiency of P recovery from sidestream	90	90	97	97	53	65
Reactor Configuration	Not reported	Two reactors 26 feet height 8.5 feet diameter	One reactor 13,210 gal 23 ft height	Two reactors 30 ft height, 4 ft diameter	pH stripper (9200 gal) Reactor (5283 gal) 23 ft height	22,419 gal (24 ft height, 14 ft diameter)
Electrical Requirements	Not reported	40,000 kWh/year for pumping 550 kWh/year for harvesting	60 kWh/day (aeration)	447 kWh/day	120 to 160 kWH/day	143 kWh/day
Labor	Not reported	Not reported	18h/wk	1 FTE	Not reported	0.5 to 1 hr per day
Chemicals	Not reported	330 lb Mg/day 448 lb NaOH/day 88 lb NH3/day	518 lb MgO/day	550 lb Mg/day 170 lb NaOH/day	1322 lb MgCl2/day 132 lb NaOH/day	1358 lb MgCl2/day

These technology providers quoted varying estimates for the total amounts of recoverable struvite. Except for Airprex™, all of the processes used the dewatering centrate sidestream with a total daily orthophosphate loading of approximately 171 pounds per day. Since these processes require differing concentrations of chemicals, differing electrical requirements, and differing reactor configurations, the total production of struvite varies between the technology providers.

2.11 Conclusions from Full-Scale Implementations

Struvite recovery provides WRRFs with a cost effective treatment alternative that meets strict phosphorus effluent limits and minimizes nuisance struvite formation. Implementation of nutrient recovery can delay the need for costly upgrades to the mainstream facility and can improve the public perception of the facility. Of these six facilities that implemented struvite recovery processes, four installed Ostara processes and two installed Multiform Harvest processes. The design estimates for orthophosphate removals ranged from 68-80%, while the actual reported removals ranged between 80-90%. For ammonia removal, the designed removal ranged between 7-25%, with actual reported removals ranging between 7-19%. Based on the above data there was no discernable performance differences between Ostara and Multiform Harvest; however, as more WRRFs initiate struvite recovery programs better performance trends and guidelines will emerge.

For the case study, the Paques technology provider quoted the highest estimated total volume of struvite production with the Phosphaq™ process. The SH+E group with the AirPrex™ process estimated the lowest production of struvite from the case study plant; however, in this process the struvite is crystalized and precipitated with digester effluent and not dewatering sidestream liquor. Since each technology provider requires differing inputs to produce differing struvite volumes, each WRRF should evaluate all of these options to determine the best performing technology for their WRRF.

CHAPTER 3.0

CASE STUDIES OF FACILITIES THAT HAVE COMPLETED A DESKTOP AND/OR PILOT EVALUATION OF EXTRACTIVE NUTRIENT RECOVERY

3.1 Overview of Category II Case Studies

This chapter contains case studies on seven WRRFs that have completed desktop or pilot evaluations of an extractive nutrient recovery process. These plants range in size with mainstream design flows between 20 to 143 MGD. Similarly to the WRRFs described above, these WRRFs mainly cited concerns with nuisance struvite formation and strict effluent phosphorus limits and impending phosphorus biosolids application limits. Table 3-1 summarizes the case studies and gives the respective location, plant configuration, nutrient limits, and size for each facility. A detailed discussion of the site-specific drivers and lessons learned from the implementation process is provided within each case study.

Table 3-1. Summary of Case Study Facilities That Have Completed a Desktop and/or Pilot Evaluation of Extractive Nutrient Recovery.

Plant Number	Location	Plant Configuration	Current Nutrient Limits	Size (MGD)
7	North Carolina, U.S.	Liquid: 5 Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	TN – 334,851 lb/yr TP – 0.5 mg/L (summer); 2.0 mg/L (winter)	20
8	North Carolina, U.S.	Liquid: 5 Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	TN 334,705 lb/yr; NH3-N - 1.0 mg/L (summer monthly average), 2.0 mg/L winter monthly average TP 14,053 lb/yr	20
9	Kansas, U.S.	Liquid: 3 Stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Belt Filter Press	TN - 8.0 mg/L (annual average goal) TP – 1.5 mg/L (annual average goal)	12
10+11	Alberta, Canada	Liquid: Plant 10: AO process, Plant 11: 3-stage BNR Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Lagoons	Plant 10: NH3-N – 10 mg/L (Oct – Jun) and 5 mg/L (Jul – Sept), TP – < 1.0 mg/L (monthly) Plant 11: NH3-N – 10 mg/L (Oct – Jun) and 5 mg/L (Jul – Sept), TP – < 0.5 mg/L (monthly)	132, 26.4
12	Florida, U.S.	Liquid: Pure Oxygen Activated Sludge Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	None	143
13	Florida, U.S.	Liquid: Pure Oxygen Activated Sludge Solids: Mesophilic Anaerobic Digestion Digested Sludge Dewatering: Centrifuge	None	112.5

3.2 Plant 7 Case Study

Plant designation	Plant 7
Location	North Carolina, USA
Current nutrient limits (mg/L)	TN – 334,851 lb/yr TP – 0.5 mg/L (summer); 2.0 mg/L (winter)
Emerging nutrient limits (mg/L)	2016: TN - 97,665 lbs/yr (2.15 mg/L in 2031) TP - 10,631 lbs/yr (0.23 mg/L in 2031) 2036: TN - 68,503 lbs/yr (0.94 mg/L at buildout) TP - 3,816 lbs/yr (0.05 mg/L at buildout) Land application TP limit anticipated
BNR configuration	5-stage BNR
Solids management configuration	Primary sludge + GBT-thickened WAS to anaerobic digesters then belt filter press. Cake is hauled and land applied.
Biosolids disposal method	The current cost of sludge disposal through land application is approximately $70 per dry ton.
Mainstream design flow (MGD)	20
Mainstream current operation flow (MGD)	8.81 (1/1/2002-1/31/2013)
Maximum operating temperature (°C; °F)	28.5°C
Minimum operating temperature (°C; °F)	10.3°C
Effluent nutrient concentrations	TP - 0.27 mg/L (1/1/2002-1/31/2013) TN – 3.50 mg/L (1/1/2002-1/31/2013)
Sidestream flow (MGD)	1.1 MGD
Sidestream nitrogen load (lb/day; % of total N load)	473 ppd; 19%
Sidestream phosphorus load (lb/day; % of total P load)	147 ppd; 30%
Method for odor control in collection system	Bioxide

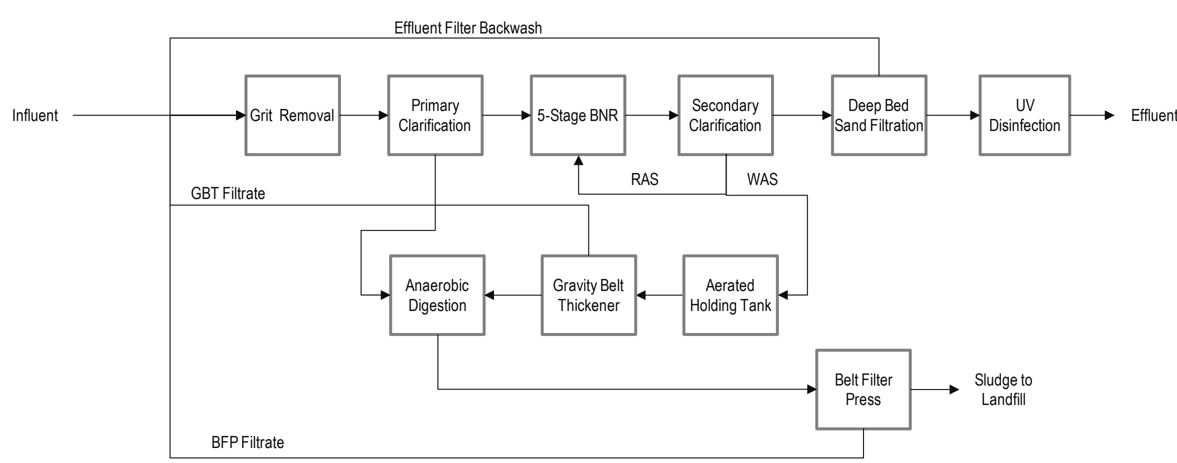

Figure 3-1. Plant 7 Process Flow Diagram.

The liquid processes at Plant 7 include screening, grit removal, primary clarification, biological nutrient removal (BNR), secondary clarifiers, deep bed sand filters, and ultraviolet disinfection for treatment of the wastewater. Waste solids from the secondary clarifiers are processed through GBTs and then combined with primary sludge from the primary clarifiers. The combined solids are then anaerobically digested prior to belt filter press dewatering and land applied as a Class B biosolids product. The plant has an alum feed system but rarely has to use it for phosphorus compliance.

It is likely that regulatory changes in the future will limit phosphorus loading to land application sites in North Carolina. Sidestream phosphorus recovery gives an additional outlet stream for the phosphorus to leave the plant. In addition to a strict phosphorus effluent limit, limitations of the agronomic application rate of phosphorus in the region are one of the main drivers for consideration of sidestream phosphorus treatment at this plant. A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 3-2.

Table 3-2. Drivers Associated with Extractive Nutrient Recovery for Plant 7.

Driver	Causes	Implemented Solutions
Stringent nutrient limits	• Regulations – sensitive discharge location	• Bio-P + multipoint chemical addition
Inadequate amount of land for biosolids disposal in the near future	• NC Dept. of Agriculture moving toward P-based loading program	• Master Plan evaluation on sidestream nutrient control options including resource recovery and Class A product formation
Large load contributions of N and P from the sidestreams	• Bio-P in combination with anaerobic digestion cause high nutrient loads in recycle streams	• Master Plan evaluation on sidestream nutrient control options
Some nuisance struvite formation in belt filter presses	• High nutrient loads in recycle streams pushes struvite formation reaction toward precipitation	• Chemical addition for P-reduction

3.2.1 Evaluation of Sidestream Nutrient Control

As part of the 2011 Master Plan for this facility, phosphorus treatment options were evaluated. Struvite recovery and alum addition were the alternatives which were considered in the evaluation. Two companies were considered for struvite recovery. In addition, a proprietary process was considered in combination with one of the manufacturers that allows for additional struvite recovery by removing phosphorus prior to anaerobic digestion. The following costs were considered as part of the evaluation.

- Alum chemical addition cost per dry ton of $376.
- A ratio of 1 pound of aluminum per pound of phosphorus was used.
- Disposal of additional biosolids (aluminum orthophosphate) $70/DT; was inflated three-fold to $210/DT to account for anticipated increase in land application restrictions.
- Labor $40 per hour.

Table 3-3 summarizes the development of the Net Present Worth for all three alternatives based on 20 years of operation. The payback for the Manufacturer 1 (without proprietary pre-digestion treatment) and Manufacturer 2 versus Alum Addition are 15 and five years, respectively. With the WAS release treatment the payback is 12 years.

Table 3-3. Summary of Costs and Savings Categories Considered in Economic Evaluation for Plant 7.

Description	Without Proprietary Pre-Digestion Treatment Manufacturer 1	Without Proprietary Pre-Digestion Treatment Manufacturer 2	With Proprietary Pre-Digestion Treatment Manufacturer 1
Total Capital Cost	$4,210,000	$1,570,000	$4,550,000
Net Present Costs (Savings less Capital)	$(1,250,000)	$(2,480,000)	$(1,840,000)

3.3 Plant 8 Case Study

Plant designation	Plant 8
Location	North Carolina, USA
Current nutrient limits (mg/L)	TN 334,705 lb/yr TP 14,053 lb/yr NH_3-N 1.0 mg/L summer monthly average 2.0 mg/L winter monthly average
Emerging nutrient limits (mg/L)	TN 185,345 lb/yr (2011- 5.64 mg/L; 2031 – 3.95 mg/L; 3.04 buildout) TP 14,053 lb/yr (2011 – 0.43 mg/L; 2031 – 0.30 mg/L; 0.23 buildout)
BNR configuration	5-stage BNR
Solids management configuration	WAS is gravity thickened then TWAS and primary sludge are co-digested anaerobically; digested sludge is dewatered with belt filter presses; cake is hauled and land applied as Class B product.
Biosolids disposal method	The current cost of sludge disposal through land application is approximately $70 per dry ton.
Mainstream design flow (MGD)	20
Mainstream current operation flow (MGD)	9.54 (1/1/2002-1/31/2013)
Maximum operating temperature (°C; °F)	30°C
Minimum operating temperature (°C; °F)	9.7°C
Effluent nutrient concentrations (5-year average)	TP - 0.47 mg/L TN – 7.49 mg/L NH3-N – 0.14 mg/L
Sidestream flow (MGD)	1.1 MGD
Sidestream nitrogen load (lb/day; % of total N load)	519 lb/d; 21%
Sidestream phosphorus load (lb/day; % of total P load)	134 lb/d; 25%
Method for odor control in collection system	Bioxide

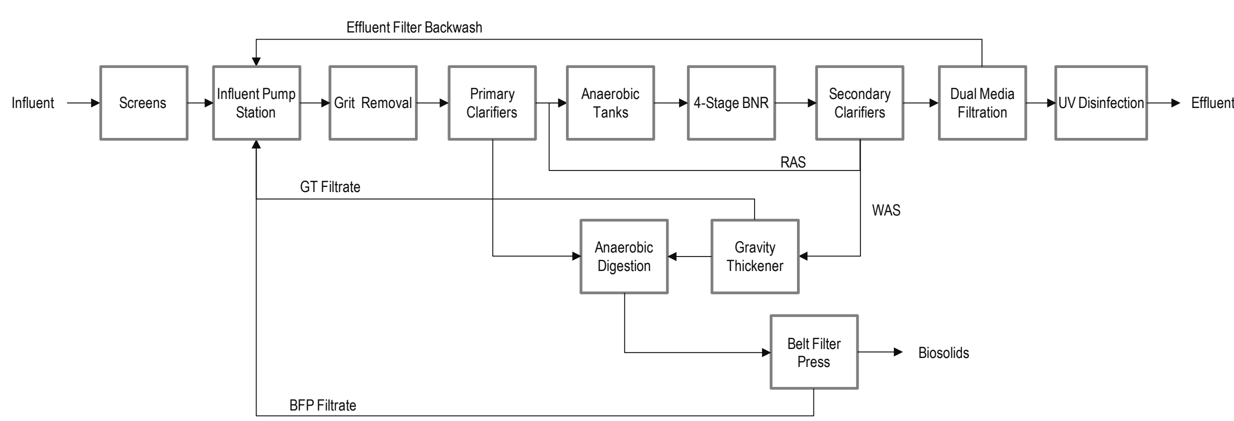

Figure 3-2. Plant 8 Process Flow Diagram.

The liquid processes include screening, grit removal, primary clarification, biological nutrient removal (BNR), secondary clarifiers, chemical flocculation, traveling bridge filters, and ultraviolet disinfection for treatment of the wastewater. Solids are produced by the primary and secondary clarifiers and are processed through gravity thickening (for the waste activated sludge only), anaerobic digestion, and belt filter press dewatering before being ultimately disposed of via land application. A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 3-4.

Table 3-4. Drivers Associated with Extractive Nutrient Recovery for Plant 8.

Driver	Causes	Implemented Solutions
Stringent nutrient limits	• Regulations – sensitive discharge location	• Bio-P + multipoint chemical addition
Inadequate amount of land for biosolids disposal in the near future	• NC Dept. of Agriculture moving toward P-based loading program	• Master Plan evaluation on sidestream nutrient control options
Large load contributions of N and P from the sidestreams	• Bio-P in addition to anaerobic digestion causes high nutrient loadings in recycle streams	• Master Plan evaluation on sidestream nutrient control options

3.3.1 Evaluation of Sidestream Nutrient Control

Phosphorus treatment options were also evaluated as part of the utility's 2011 Master Plan. Struvite recovery and alum addition were the alternatives which were considered in the evaluation. In addition, a proprietary process was considered in combination with one of the manufacturers that allows for additional struvite recovery by removing phosphorus prior to anaerobic digestion. The following costs were considered as part of the evaluation.

- ♦ Alum chemical addition cost per dry ton of $376.
- ♦ A ratio of 1 pound of aluminum per pound of phosphorus was used.
- ♦ Disposal of additional biosolids (aluminum orthophosphate) $70/DT; was inflated three-fold to $210/DT to account for anticipated increase in land application restrictions.
- ♦ Labor $40 per hour.

Table 3-5 summarizes the development of the Net Present Worth for all three alternatives based on 20 years of operation. The payback for the Manufacturer 1 (without proprietary pre-digestion treatment) and Manufacturer 2 versus Alum Addition are 25 and 22 years, respectively. With the pre-digestion treatment the payback is 28 years.

Table 3-5. Summary of Cost and Savings Categories Considered in Economic Evaluation of Plant 8.

Description	Without Proprietary pre-Digestion Treatment Manufacturer 1	Without Proprietary pre-Digestion Treatment Manufacturer 2	With Proprietary pre-Digestion Treatment Manufacturer 1
Total Capital Cost	$4,600,000	$1,960,000	$4,940,000
Net Present Costs (Savings less Capital)	$1,700,000	$290,000	$1,620,000

3.4 Plant 9 Case Study

Plant designation	Plant 9
Location	Kansas, USA
Current nutrient limits (mg/L)	TN - 8.0 mg/L (annual average goal) TP - 1.5 mg/L (annual average goal)
Emerging nutrient limits (mg/L)	< 1.5 mg/L
BNR configuration	Pre-anoxic followed by anoxic and aerobic zones and secondary clarifiers
Solids management configuration	WAS and PS from the plant and other facilities are thickened before digestion; digested sludge is dewatered and biosolids are land applied
Biosolids disposal method	Land application
Mainstream design flow (MGD)	14.4 MGD (average) and 30 MGD (peak)
Mainstream current operation flow (MGD)	12 MGD
Maximum operating temperature (°C; °F) 5-year average	27°C
Minimum operating temperature (°C; °F) 5-year average	5°C
Effluent nutrient concentrations (5-year average)	TKN – 1.54 mg/L TP – 2.0 mg/L
Sidestream flow (MGD)	0.073 MGD
Sidestream nitrogen load (lb/day; % of total N load)	NH_3 – 304.61 lb/day, 6.0% of TKN load (2007-2012) TKN – 377.71 lb/day, 7.3% of TKN load (2007-2012)
Sidestream phosphorus load (lb/day; % of total P load)	PO_4 – 103.57 lb/day, 11.4 % of TP load (2007-2012) TP – 115.75 lb/day, 12.7% of TP load (2007-2012)

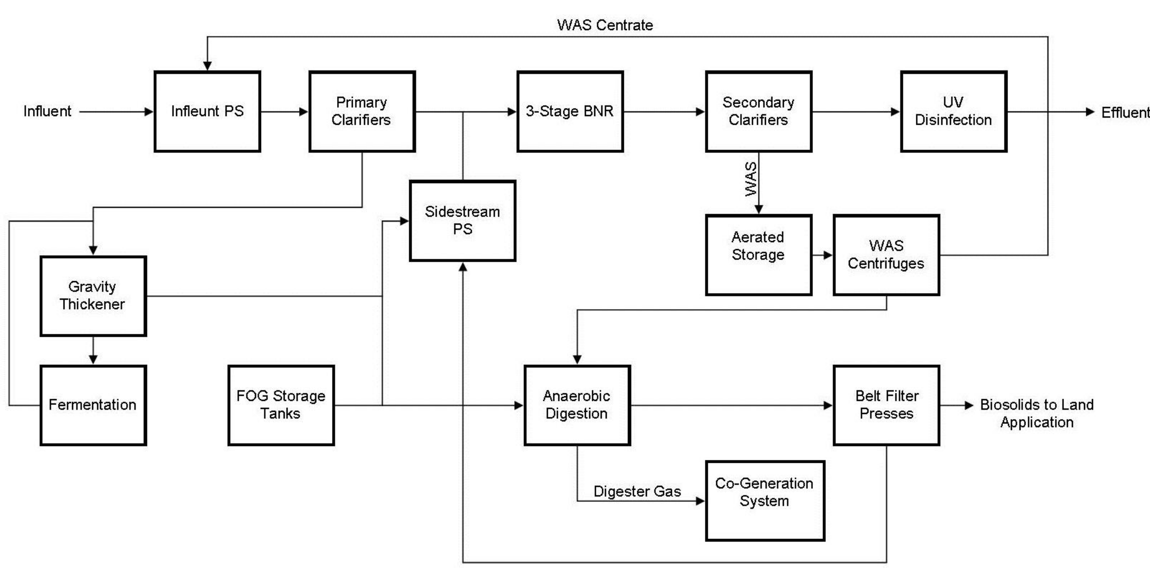

Figure 3-3. Plant 9 Process Flow Diagram.

Existing unit processes at the plant include headworks, primary clarification, biological nutrient removal (BNR) basins (anaerobic-anoxic-aerobic zones), secondary clarifiers, UV disinfection, and effluent discharge. The primary sludge is sent to a gravity thickener and then to a fermenter. Sludge from the secondary clarifiers is pumped to an air mixed WAS storage tank. Feed pumps then send the sludge to thickening centrifuges. After the centrifuges, the centrate flows by gravity back to the influent pump station. Thickened WAS is blended with thickened primary sludge in the digesters.

The anaerobic digestion at this facility is a two stage process including three primary digesters and one secondary digester. Sludge flows from the primary digesters to the secondary digester by gravity through each digester's control box. The secondary digester's sludge is pumped to the solids processing building for dewatering. The digested sludge is dewatered using two standard belt filter presses (BFPs). The dewatered sludge from the BFPs is transported by a belt conveyor to a truck loading station. The truck hauls the sludge to one of the land application sites. The supernatant from the WAS gravity thickener and BFP filtrate is sent to a sidestream pump station which sends the supernatant back into the main treatment process downstream of the primary clarifiers.

This treatment plant currently encounters struvite scaling to a limited extent. The plant staff initiates periodic cleaning to manage the scaling issue. To date this has not been a serious O&M concern; however, planned future operational changes, including activating the EPBR process and receiving thickened sludge from another BNR plant, will alter the recycle stream characteristics. A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 3-6.

Table 3-6. Drivers Associated with Extractive Nutrient Recovery for Plant 9.

Driver	Causes	Implemented Solutions
Management goals	• Desire to be innovative and proactively address emerging issues	• Evaluate struvite recovery system
Nuisance struvite scaling in reactors and piping	• Anaerobic digestion • Receiving additional sludge from other facility	• Evaluate ferric addition and struvite recovery system

3.4.1 Evaluation of Sidestream Nutrient Control

Planning-level cost estimates were developed for the three phosphorus recovery alternatives (Ostara, Multiform Harvest, and Procorp) to provide an indication of order of magnitude cost. It should be noted that in-depth process analysis, design optimization, procurement, and phased implementation are likely to provide several opportunities to realize cost savings. Table 3-7 summarizes the cost development for the evaluation. The cost estimates were based on information provided by the vendors and the following assumptions:

- All costs in 2011 dollars
- Installation and piping: 50% of equipment cost
- Real discount rate: 2.1%
- Planning horizon: 20 years
- O&M Costs based on present average conditions
  - New building sized to accommodate equipment, accessories, and product storage
  - Building cost: $300 per square foot
  - Labor requirements to operate the facility: 4 hrs/day, 364 days/year
  - Labor rate with benefits: $25.40/hr
  - Electrical power cost: $0.06/kWh
- Chemical costs:
  - Magnesium Chloride: $240/dry ton
  - Magnesium Hydroxide: $425/dry ton
  - Sodium Hydroxide: $887.84/dry ton
  - Sand: $150/dry ton

Table 3-7. Summary of Costs for Nutrient Recovery Options at Plant 9.

		Ostara	Multiform Harvest	Procorp
Capital Cost[1]		$8,905,000	$2,787,000	$5,051,000
Operation & Maintenance Cost	Annual	$46,000[2]	$98,000	$108,000
	Present Worth	$741,000[2]	$1,583,000	$1,743,000
Life Cycle Cost		$9,646,000[2]	$4,370,000	$6,794,000

1 All capital costs include equipment, building, installation, and piping. Cost of equalization facility not included.
2 Does not include chemical costs.

3.5 Plants 10 and 11 Case Study

Plant designation	Plant 10 and 11
Location	Alberta, Canada
Current nutrient limits (mg/L)	Plant 10: NH_3-N – 10 mg/L (Oct – Jun) and 5 mg/L (Jul – Sept), TP – < 1.0 mg/L (monthly) Plant 11: NH_3-N – 10 mg/L (Oct – Jun) and 5 mg/L (Jul – Sept), TN – 15 mg/L, TP – < 0.5 mg/L (monthly)
Emerging nutrient limits (mg/L)	TP - < 0.5 mg/L
BNR configuration	Plant 10: BPNR: Anaerobic – Aerobic Plant 11: Anaerobic – Anoxic – Aerobic
Solids management configuration	Gravity thickened PS and DAF thickened WAS are digested at Plant 10. The PS is fermented, subsequently the waste fermenter sludge and DAF thickened WAS are digested at Plant 11. Digested sludge from both facilities is sent to lagoons where be sludge is dewatered by gravity settling. The lagoon supernatant is recycled to the head of Plant 10
Biosolids disposal method	Land Application
Mainstream design flow (MGD)	Plant 10 = 132 MGD Plant 11 = 26.4 MGD
Mainstream current operation flow (MGD)	Plant 10 = 96.4 MGD Plant 11 = 19.5 MGD
Maximum operating temperature (°C; °F)	18°C
Minimum operating temperature (°C; °F)	11°C
Effluent nutrient concentrations (2007 to 2011)	Plant 10 – NH_3-N – 0.42 mg/L; TP = 0.49 mg/L (2007 to 2011) NH_3-N – 0.88 mg/L; TP = 0.50 mg/L (2012) Plant 11– NH_3-N – 0.85 mg/L; TN – 8.22 mg/L; TP = 0.21mg/L (2011), NH_3-N – 0.21 mg/L; TN - 7.29 mg/L; TP = 0.11 mg/L (2012)
Sidestream flow (MGD)	DAF subnatant = 0.85 Lagoon supernatant = 0.56
Sidestream nitrogen load (lb/day; % of total N load)	DAF subnatant + Lagoon supernatant = 4945 lb/day; 13.62% of Total N Load (to Plant 10)
Sidestream phosphorus load (lb/day)	DAF subnatant + Lagoon supernatant = 1710 lb/day (to Plant 10)

Liquid treatment at Plants 10 and 11 consists of bar screens, grit chambers, primary clarifiers, bioreactors, secondary clarifiers, and UV disinfection. For solids processing, unit processes include: dissolved air flotation (DAF), primary sludge fermenters, gravity thickeners, mesophilic anaerobic digesters, and the sludge lagoons. Digested sludge from both Plants 10 and 11 is pumped to the sludge lagoons and is ultimately applied on farmlands. The liquid stream from the lagoon is pumped back to the head of Plant 10 where it mixes with the influent flow and undergoes the subsequent treatment processes. Figures 3-4 and 3-5 show the solid and liquid process flow diagram for both facilities.

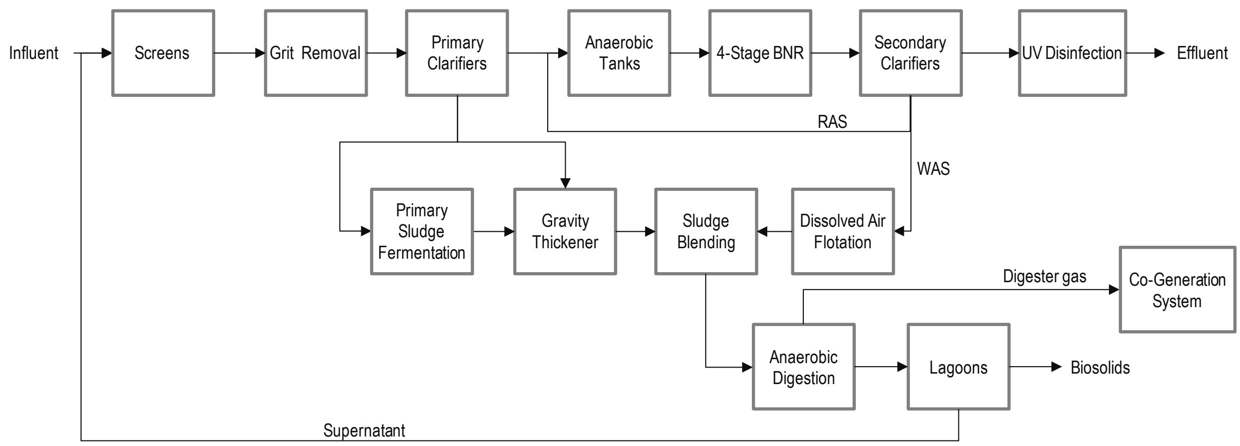

Figure 3-4. Plant 10 Process Flow Diagram.

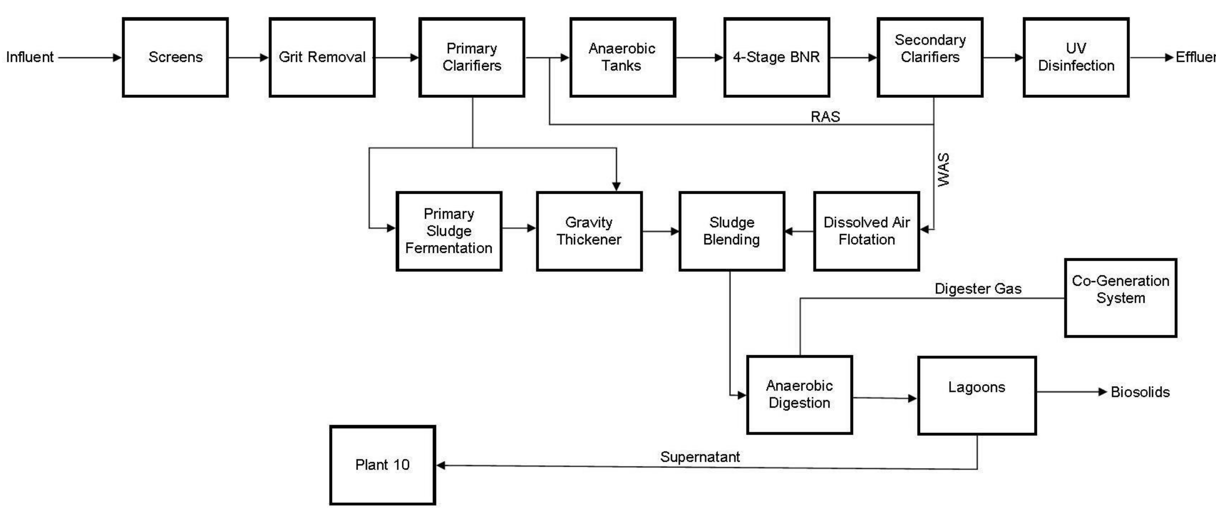

Figure 3-5. Plant 11 Process Flow Diagram.

The use of Bio-P at Plants 10 and 11 results in high phosphorus concentrations in the sludge stream, which leads to the formation of struvite scale deposits in sludge treatment infrastructure from digestion onwards and to the cycling of phosphorus within the BNR process. Due to the high operational costs associated with nuisance struvite formation, the facilities desired a solution which would reduce costs, increase treatment plant reliability, and enhance environmental sustainability. A summary of the main drivers for implementing extractive nutrient recovery as well as a list of the main considerations is provided in Table 3-8.

Table 3-8. Drivers Associated with Extractive Nutrient Recovery at Plants 10 and 11.

Driver	Causes	Implemented Solutions
Implementation of Bio-P at Plants 10 and 11	• Expected change in regulations – sensitive discharge location	• Addition of Alum has reduced amount of bioavailable P in the biosolids
Nuisance struvite in biosolids treatment structure resulting in increased capital and operational expenditure	• Bio-P at Plants 10 and 11	• Addition of Alum has reduced the amount of struvite formation • Client is planning to introduce WASSTRIP™ and Pearl™ process by Early 2016

3.5.1 Evaluation of Sidestream Nutrient Control

This utility evaluated the implementation of a centralized facility at Plant 10 to mitigate nuisance struvite formation as well as the use of alum to control sidestream P loads. Costs associated with alum addition were estimated as follows:

- Chemical procurement: $1.13M/year.
- O&M: $25,000/year.
- Chemical sludge disposal cost: $2.9M/year.

These costs were also categorized as costs that would be avoided by using a struvite recovery process.

The evaluation of struvite recovery indicated that the recovery option would result in financial benefits related to:

- Reduced operating costs.
- Reduced maintenance costs.
- Revenue from fertilizer: $304,000.

Table 3-9 shows the estimated capital costs associated with implementing an Ostara nutrient recovery facility at Plant 10 while Table 3-10 provides an estimate of operational costs associated with the nutrient recovery facility. Although the project is favorable when compared to conventional alum addition, funding was not immediately available. As the result, implementation has been delayed until alternate financing can be acquired.

Table 3-9. Summary of Capital Costs for the Nutrient Recovery Technology at Plant 10.

Capital Cost Item	Capital Cost
Ostara no WAS Strip	$8,500,000
Ostara with WASSTRIP	$12,600,000
Engineering, Procurement, construction and project management, commissioning	$1,500,000
Permitting	$60,000
Contingency	$600,000
Total	$14,800,000

Table 3-10. Summary of Annual O&M Cost for the Nutrient Recovery Technology at Plant 10.

Item	Cost
WASSTRIP (Including Odor Control)	
Power	$48,900
Maintenance (parts and labor)	$5,500
Operating labor	Included in Pearl® estimate
Total	**$54,400/year**
Pearl	
Power	$47,700
Maintenance (parts and labor)	$114,500
Sodium hydroxide	$109,500
Operating labor	$100,000
Magnesium chloride	Free-issued by Ostara
Total	**$371,700**

3.6 Plant 12 Case Study

Plant designation	Plant 12
Location	Florida, USA
Current nutrient limits (mg/L)	None
Emerging nutrient limits (mg/L)	December 31, 2018 – Ocean outfall discharges must meet AWT standards: 5-5-3-1 (TSS, CBOD, TN, TP) December 31, 2025 – 60% of annual average daily outfall flow (AADF) must be converted to reuse. Reuse nutrient criteria varies depending on final use.
BNR configuration	Two pure oxygen activated sludge plants operating in parallel
Solids management configuration	Prior to treatment in the digesters, all the waste sludge from the clarifiers is concentrated. Concentrated sludge is pumped directly into a two-stage anaerobic digester system where temperatures are maintained at approximately 90°F. Anaerobic digestion is maintained for at least 15 days. Digested sludge is dewatered in centrifuges, with approximately 50% of the centrate currently directed to the head of the plant and 50% of the centrate directed to the influent of the Plant 2 secondary clarifiers
Biosolids disposal method	Land application
Mainstream design flow (MGD)	143 AA; 286 Peak Hourly
Mainstream current operation flow (MGD)	116
Maximum operating temperature (°C; °F)	Not available
Minimum operating temperature (°C; °F)	Not available
Effluent nutrient concentrations (5-year average)	TP – 1.21 mg/L NH_3-N – 21.6 mg/L
Sidestream flow (MGD) (5/1/2009-5/31/2010)	0.76
Sidestream nitrogen load (lb/day; % of total N load)	6,065 lb NH_3-N/d; 34%
Sidestream phosphorus load (lb/day; % of total P load)	444 lb PO_4-P/D; 19%

This wastewater facility consists of two high purity oxygen plants that are operated in parallel. Both plants are similar in design, with each plant consisting of grit removal, pure-oxygen activated sludge reactor, screening, final settling tank (clarifiers), and chlorination components. The facility is currently permitted to discharge 143 MGD AADF and is rated to treat a peak hourly flowrate up to 286 MGD.

Currently, liquid treatment for each plant consists of screening and grit removal, pure oxygen reactors, and clarification. Solids handling system at the facility comprises of concentrators, digesters, and centrifuges. Prior to treatment in the digesters, all the waste sludge from clarifiers is concentrated. Concentrated sludge is pumped directly into a two-stage anaerobic digester system where the solids are stabilized for at least 15 days. Digested sludge is dewatered in centrifuges, with approximately 50% of the centrate currently directed to the head of the plant and 50% of the centrate directed to the influent of the Plant 2 secondary clarifiers. Figure 3-6 shows the solids and liquids process flow diagram for the facility.

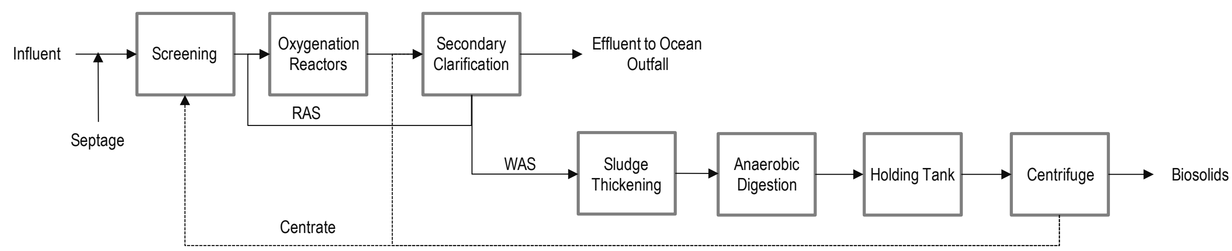

Figure 3-6. Plant 12 Process Flow Diagram.

Currently, the utility feeds ferric sulfate ($Fe_2(SO_4)_3$) to the influent of the centrifuges as a short term fix for resolving struvite precipitation issues as well as improving the solids capture rate (ferric chloride has also been tried). This solution costs $47,000 per month. Plant staff is also feeding gas scrubber water and chlorinated flushing water to the centrate in order to reduce the pH and reduce struvite precipitation. A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 3-11.

Table 3-11. Drivers Associated with Extractive Nutrient Recovery for Plant 12.

Driver	Causes	Implemented Solutions
Nuisance struvite in digesters and dewatering centrate lines	• Anaerobic digestion	• Add ferric upstream of centrifuges • $40,000/ month for ferric addition
Future stringent effluent limits	• Establishment of Numeric Nutrient Criteria in Florida	• Evaluation of sidestream nutrient control

3.6.1 Evaluation of Sidestream Nutrient Control

A desktop evaluation was completed in 2011 to compare long term alternatives for struvite control. The alternatives evaluated were:

- Continued addition of ferric sulfate.
- Struvite production.

Table 3-12 summarizes the capital and O&M costs used in development of the economic evaluation for ferric sulfate addition. The following assumptions were used for this alternative:

- New ferric feed facility (canopy style building) with pumping equipment, dose controls, chemical tanks and containment area.
- Ferric sulfate at 250 mg/L (25lb/DT as Fe^{3+}) as Fe^{3+} at a cost of $300 per ton of ferric sulfate.
- Power costs for the new ferric sulfate feed facility are negligible.
- Additional operational labor to upkeep/monitor the new facility is assumed to cost $40k/yr.
- $5,000 per year is assumed for maintenance of chemical feed equipment.
- No additional maintenance costs due to struvite are assumed.

Table 3-12. Costs Associated with Ferric Sulfate Addition at Plant 12.

Cost Item	Ferric Addition
Total Capital Cost	$1,000,000
Annual O&M	$535,000
20 Year Present Worth[4]	$10,700,000
Net Present Worth (2011 dollars)	$11,700,000

Notes:
1 Capital costs do not include engineering fees or contractor overhead and profit
2 Assumes power costs are negligible
3 Assumes no additional maintenance costs due to struvite precipitation
4 Assumes 6% interest and 6% escalation

Table 3-13 summarizes the capital and O&M costs used in development of the economic evaluation for struvite recovery. For the cost evaluation, Ostara's capital purchase and fee based option was analyzed. Following is a list of assumptions for this alternative:

- One Pearl® 2000 reactor (and corresponding equipment) was assumed at a capital cost of $3,000,000. For the fee base option, it was assumed that a $30,000 per month (for 20 years) fee was paid to Ostara to cover the capital cost of the Pearl® reactor.
- A new pre-fabricated metal building (3,900 sf) to hold two (one future) Ostara's Pearl® 2000 reactor.
- A $250 per ton of Crystal Green® product purchase price was assumed at an estimated 400 tons per year production rate.
- A power consumption of 600 kWhr/day at $0.08/kWhr was assumed.
- $40,000 per year is assumed for additional operational labor to upkeep/monitor the process. Most of the labor for this process is during the harvesting of the Crystal Green® product.
- $25,000 per year is assumed for maintenance of the Pearl® equipment.
- No additional maintenance costs due to struvite are assumed.

Table 3-13. Costs Associated with Struvite Recovery Option at Plant 12.

Cost Item	Ostara Pearl® Process	
	Capital Purchase Option	20 Year Fee Based Option
Capital		
Total Capital Cost[1]	$4,900,000	$1,900,000
Total Annual Operating Cost	$(2,000)	$358,000
20 Year Present Worth[2]	$(40,000)	$7,160,000
Net Present Worth (2011 dollars)	$4,860,000	$9,060,000

Notes:

1 Capital costs do not include engineering fees or contractor overhead and profit

2 Assumes 6% interest and 6% escalation

The results from this evaluation indicated that the struvite recovery options have a lower net present worth than the ferric addition option; however, construction of the project is delayed until funding becomes available. In the interim, the facility is continuing to feed ferric sulfate ahead of the centrifuges to prevent struvite formation.

3.7 Plant 13 Case Study

Plant designation	**Plant 13**
Location	Florida, USA
Current nutrient limits (mg/L)	None
Emerging nutrient limits (mg/L)	December 31, 2025 – 60% of annual average daily outfall flow (AADF) must be converted to reuse. Reuse nutrient criteria vary based on final use.
BNR configuration	Two pure oxygen activated sludge plants operating in parallel that dispose secondary treated effluent through multiple Class I underground injection wells
Solids management configuration	Waste sludge from the clarifiers is concentrated; concentrated sludge is pumped into a two-stage anaerobic digester system where temperatures are maintained at approximately 90 ºF; anaerobic digestion is maintained for at least 15 d; centrifuges dewater digested sludge from the digesters. The sludge cake, approximately 20% solids, is then trucked and spread on sludge drying beds for solar drying. Drainage from the beds is returned to the sewage treatment process through the filtrate pumping station. The centrate from the centrifuges is disposed by gravity to the filtrate pumping station where it is then pumped to the head of the grit chambers.
Biosolids disposal method	Land application
Mainstream design flow (MGD)	112.5 AA; 225 Peak Hourly
Mainstream current operation flow (MGD)	100
Maximum operating temperature (°C; °F)	Not available
Minimum operating temperature (°C; °F)	Not available
Effluent nutrient concentrations (5-year average)	TP – 1.97 mg/L NH_3-N – 18.9 mg/L
Sidestream flow (MGD) (5/1/2009-5/31/2010)	0.51 MGD
Sidestream nitrogen load (lb/day; % of total N load)	3,614 lbs NH3-N/d; 8.8%
Sidestream phosphorus load (lb/day; % of total P load)	650 lbs PO4-P/d; 12.8%

This facility consists of two pure oxygen activated sludge municipal sewage treatment plants operating in parallel that dispose secondary treated effluent through multiple Class I underground injection wells. The facility is currently permitted to discharge 112.5 MGD AADF and rated to treat 225 MGD peak hourly flow. As of 2011, this facility is being upgraded to meet primary drinking water standards (except for pathogen criteria) and high level disinfection (HLD) criteria. Part of this upgrade is to increase the plant's peak flow capacity from 225 MGD to 285 MGD.

Liquid treatment for each plant consists of screening and grit removal, pure oxygen reactors, and clarification The secondary treatment activated sludge process incorporates cryogenic oxygen generation plants, oxygenation tanks (or reactors), and final clarifiers. The solids handling system comprises of concentrators, digesters, centrifuges, sludge drying beds, and composting facilities. Centrifuges are provided for dewatering digested sludge from all digesters. The centrate from the centrifuges is disposed by gravity to the filtrate pumping station where it is then pumped to the head of the grit chambers. Figure 3-7 shows the solids and liquids process flow diagram for the facility.

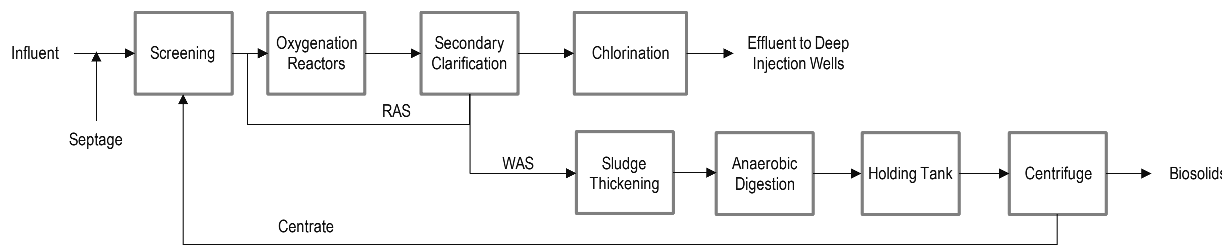

Figure 3-7. Plant 13 Process Flow Diagram.

Plant 13 suffers from nuisance struvite formation. To deal with this, extensive preventative maintenance (jetting out pipe lines) is conducted on a weekly basis while replacement of valves and piping is done on a periodic basis. This maintenance cost is estimated at approximately $35,000 per month (includes material and labor). A summary of the main drivers for implementing extractive nutrient recovery is provided in Table 3-14.

Table 3-14. Drivers Associated with Extractive Nutrient Recovery for Plant 13.

Driver	Causes	Implemented Solutions
Nuisance struvite in digesters and dewatering centrate lines	• Anaerobic digestion	• Manually removed by jetting • $35,000/month for maintenance labor
Future stringent effluent limits	• Establishment of numeric nutrient criteria for Florida	• Sidestream nutrient removal evaluation

3.7.1 Evaluation of Sidestream Nutrient Control

A desktop evaluation completed in 2011 compared long-term alternatives for struvite control. The alternatives evaluated were:

- Continue existing preventive maintenance.
- Addition of ferric sulfate.
- Struvite production via Ostara's Pearl® system.

Alternative 1 consists of continuing existing preventive maintenance at the plant by physically removing struvite accumulation. Following is a list of assumptions for this alternative:

- The preventive maintenance will continue at an estimated cost of $35,000 per month.
- Potential major maintenance rehabilitation projects due to struvite are not included.

Table 3-15. Costs Associated with Preventative Maintenance at Plant 13.

	Continue Existing Maintenance
Capital	$ -
Total Capital Cost	$ -
Total Annual Operating Cost	$420,000
20 Year Present Worth[2]	$8,400,000
Net Present Worth (2011 dollars)	$8,400,000

Notes:
1 Assumes power and operational labor costs are negligible
2 Assumes 6% interest and 6% escalation

Alternative 2 consists of ferric sulfate at the influent to the digested sludge holding tank and the influent to the centrifuges. As part of this evaluation, it was assumed that a new ferric facility will be built. This facility will include a new building (canopy style) with pumping equipment, dose controls, chemical tanks, and containment area. This facility will be designed to feed ferric sulfate but with the flexibility to allow for ferric chloride if the ferric sulfate costs substantially increase. Following is a list of assumptions for this alternative:

- A new ferric feed facility (canopy style building) will be built with pumping equipment, dose controls, chemical tanks, and containment area.
- Ferric sulfate dose at 275 mg/L as Fe^{3+} with an approximate monthly cost of $30,000 (at a cost of $300 per ton of ferric sulfate).
- Power costs attributed to the new ferric sulfate feed facility are negligible.
- $40,000 per year is assumed for additional operational labor to upkeep/monitor the new facility.
- $15,000 per year is assumed for maintenance of chemical feed equipment.
- No additional maintenance costs due to struvite are assumed.

Table 3-16. Costs Associated with Ferric Sulfate Addition at Plant 13.

	Ferric Addition
Total Capital Cost	$900,000
Total Annual Operating Cost	$415,000
20 Year Present Worth[4]	$8,300,000
Net Present Worth (2011 dollars)	$9,200,000

Notes:
1 Capital costs do not include engineering fees or contractor overhead and profit
2 Assumes power costs are negligible
3 Assumes no additional maintenance costs due to struvite precipitation
4 Assumes 6% interest and 6% escalation

Alternative 3 consists of installing Ostara's Pearl® nutrient recovery process. Following is a list of assumptions for this alternative:

- One Pearl® 2000 reactor (and corresponding equipment) was assumed at a capital cost of $3,000,000. For the fee base option, it was assumed that a $30,000 per month (for 20 years) fee was paid to Ostara to cover the capital cost of the Pearl® reactor.
- A new prefabricated metal building (3,900 sf) to hold two (one future) Ostara's Pearl® 2000 reactors.
- A $250 per ton of Crystal Green® product purchase price was assumed at an estimated 730 tons per year production rate.
- An estimated $15,000 per year was assumed for caustic purchase to maintain the target pH in the process.
- A power consumption of 1000 kWhr/day at $0.08/kWhr was assumed.
- $40,000 per year is assumed for additional operational labor to upkeep/monitor the process. Most of the labor for this process is during the harvesting of the Crystal Green® product.
- $25,000 per year is assumed for maintenance of chemical feed equipment.
- No additional maintenance costs due to struvite are assumed.

Table 3-17 summarizes the capital and O&M costs for the struvite recovery option.

Table 3-17. O&M Costs Associated with Struvite Recovery Option at Plant 13.

	Ostara Pearl® Process	
	Capital Purchase Option	20 Year Fee Based Option
Total Capital Cost[1]	$4,900,000	$1,900,000
Total Annual Operating Cost	$(71,000)	$289,000
20 Year Present Worth[2]	$(1,420,000)	$5,780,000
Net Present Worth	$3,480,000	$7,680,000

Notes:

1 Capital costs do not include engineering fees or contractor overhead and profit

2 Assumes 6% interest and 6% escalation

The results from this evaluation indicated that the struvite recovery options have a lower net present worth than the preventative maintenance and ferric addition options; however, construction of the project is delayed until funding becomes available. In the interim, the facility is continuing to perform preventative maintenance to mitigate nuisance struvite formation.

3.8 Conclusions from Desktop and Pilot Evaluations

Due to the need to meet strict phosphorus limits and prevent struvite formation, these seven plants carefully evaluated nutrient recovery options. Of the seven WRRFs, only the WRRF located in Alberta, Canada, decided to implement a nutrient recovery process. Ostara was evaluated and selected as the technology provider, and the WRRF plans to introduce the WASSTRIP™ and Pearl™ processes in 2016. Since this WRRF receives a lagoon supernatant from an additional WRRF and implements a Bio-P process, this WRRF greatly desires to minimize struvite formation. Two of the WRRFs would have preferred to move forward with struvite recovery, but they could not acquire sufficient funds to further pursue the process. In place of struvite recovery, the remaining WRRFs implemented aggressive multipoint chemical addition strategies to meet effluent guidelines and to minimize the sidestream phosphorus concentration. Overall, these desktop and pilot evaluations suggest that struvite recovery is profitable and advantageous for WRRFs with strict phosphorus effluent limits and nuisance struvite formation; therefore, to reduce the overall long-term operational costs, it is recommended that these WRRFs perform pilot evaluations on nutrient recovery processes.

CHAPTER 4.0

CASE STUDIES OF FACILITIES EMPLOYING TERRY – PHOSPHORUS FOR EVALUATING RECOVERY POTENTIAL

4.1 Overview of Category III Case Studies

This chapter contains seven case studies describing WRRFs that have employed TERRY – Phosphorus to evaluate the economic viability of a nutrient recovery process. These plants range in size with mainstream design flows between 11.5 to 220 MGD. Table 4-1 summarizes the case studies and gives the respective location, plant configuration, nutrient limits, and size for each facility.

Table 4-1. Summary of Case Study Facilities Employing TERRY – Phosphorus for Evaluating Recovery Potential.

Plant Number	Location	Plant Configuration	Current Nutrient Limits	Size (MGD)
14	Virginia, U.S.	Liquid: 4 Stage BNR with Filters Solids: Incineration Thickening dewatering: Centrifuges	TN – 3.0 mg/L annual average NH3--N – 1.0 mg/L monthly average (Apr-Oct) No limit (Nov-Jan) 4.6 mg/L monthly average (Nov-Mar) TP – 0.18 mg/L monthly average	24
15	Texas, U.S	Liquid: UCT Solids: Sludge Storage followed by Landfill No biological stabilization:	Average NH4-N = 1.4 mg/L from June – November; Average NH4-N = 3 mg/L from December – May;	11.5
16	Texas, U.S	Liquid: Modified Ludzack-Ettinger Solids: Anaerobic Digestion Digester Sludge Dewatering: Belt Filter Press	NH3-N – 3.0 mg/L daily average (Apr-Nov) 4.0 mg/L daily average (Dec-Mar)	110
17	Ohio, U.S	Liquid: Conventional activated sludge Solids: Incineration Thickening dewatering: Belt Filter Press	None	55
18	Ohio, U.S	Liquid: Conventional activated sludge Solids: Anaerobic digestion (incineration) Thickening dewatering: Centrifuges	NH_3-N – 1.0 mg/L monthly average (June-Oct) 2.5 mg/L monthly average (May) 3.7 mg/L monthly average (Nov – April) TP – No limit currently. P-Index is being implemented in Ohio for land application of biosolids.	75
19	Ohio, U.S	Liquid: Conventional activated sludge Solids: Acid-gas digestion (incineration) Thickening dewatering: Centrifuges	NH_3-N – 1.0 mg/L monthly average (June-Oct) 2.0 mg/L monthly average (May) 3.4 mg/L monthly average (Nov – April) TP – No limit currently. P-Index is being implemented in Ohio for land application of biosolids.	114
20	Colorado, U.S	Liquid: Modified Ludzack-Ettinger and A2O Solids: Mesophilic anaerobic digestion (incineration) Thickening dewatering: Centrifuges	Total Ammonia (begin 1/1/2015) – 2 to 4.6 mg-N/L (30-day avg), 6.2 to 12.7 mg-N/L (Daily Maximum) Nitrite plus Nitrate – 8.68 mg-N/L (weekly average)	220

4.2 Plant 14 Case Study

Plant designation	**Plant 14**
Location	Virginia, USA
Current nutrient limits (mg/L)	TN – 3.0 mg/L annual average (219,280 lb/year) NH3-N – 1.0 mg/L monthly average (Apr-Oct) – No limit (Nov-Jan) 4.6 mg/L monthly average (Nov-Mar) TP – 0.18 mg/L monthly average (13,157 lb/year) These are nutrient limits at 24 MGD annual average flow conditions.
BNR configuration	Chemically enhanced primary treatment, 4-Stage BNR, denitrification filters
Solids management configuration	Primary sludge and WAS are combined and gravity thickened. Co-thickened sludge is pumped to a sludge storage tank then dewatered using centrifuges. Centrifuge cake is fed to a fluidized bed incinerator.
Biosolids disposal method	Land fill
Mainstream design flow (MGD)	24 (average) 48 (peak)
Mainstream current operation flow (MGD) **(January 2011 to September 2013)**	15
Minimum operating temperature (°C; °F)	13°C
Effluent nutrient concentrations **(January 2011 to September 2013 average)**	NH3-N – 0.01 mg/L TN – 2.5 mg/L TP – 0.08 mg/L
Sidestream flow (MGD) **(August 2013 to September 2013 average)**	1.55 MGD
Sidestream nitrogen load **(lb/day; % of total N load)**	552 lb/d; 9%
Sidestream phosphorus load **(lb/day; % of total P load)**	96 lb/d; 11%

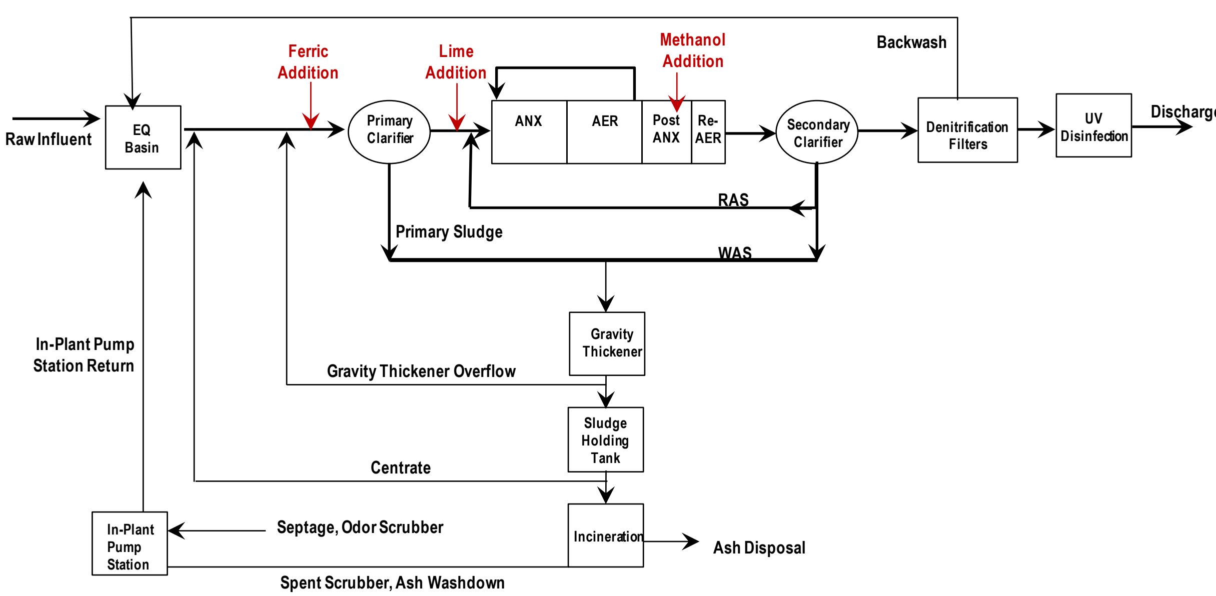

Figure 4-1. Plant 14 Process Flow Diagram.

Plant 14 is a 24 MGD facility that currently treats approximately at 15 MGD using chemically enhanced primary treatment and 4-stage BNR configuration. The facility is required to meet effluent ammonia concentration limits of 1 to 4 mg/L depending on the season and waste load allocations for TN and TP which result in concentrations of 3 and 0.18 mg/L at 24 MGD. The influent to the facility contains approximately 5.8 mg TP/L and the plant effluent contains approximately 0.08 mg TP/L. Solids handling at this facility consists of co-thickening of primary sludge and WAS followed by dewatering and incineration. Primary sludge and WAS are thickened using gravity thickeners. Co-thickened sludge is dewatered using centrifuges. Overflow from the thickeners and centrate from the centrifuges are returned to the primary clarifiers.

Since this facility practices chemically enhanced primary treatment (CEPT) using ferric chloride and does not perform anaerobic digestion of the co-thickened sludge, a significant fraction of the phosphorus treated as this facility is retained within the dewatered cake (619 lb/day). The current sidestream phosphorus load is approximately 11% of the total influent phosphorus load; however, the majority of this phosphorus is not soluble and does not have a significant impact on phosphorus removal at the facility. The facility does not experience nuisance struvite formation and has not previously evaluated nutrient recovery.

4.2.1 Evaluation of Sidestream Nutrient Control

Currently, nitrogen removal at this facility is achieved primarily through biological means whereas phosphorus removal is primarily accomplished via chemical precipitation. A conceptual level evaluation, using TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery on sidestream flows. Recovery of phosphorus from incinerator ash was not considered at this point since the capital and operating requirements for this technology are not well established at present. Future efforts should consider this option.

For the current struvite recovery evaluation, three scenarios were considered. Scenario 1 assumes that current operation would continue and that the struvite recovery facility would treat the gravity thickener overflow and centrate streams. Scenario 2 assumes that the facility has discontinued CEPT and implemented biological phosphorus removal but does not anaerobically stabilize solids. Scenario 3 assumes that the facility has discontinued CEPT, implemented biological phosphorus removal, and implemented anaerobic digestion. These three scenarios were selected for illustrative purposes to demonstrate the impact that changing solids handling processes can have on struvite recovery potential.

4.2.1.1 Scenario 1

In this analysis, the following were assumed:

- The plant would continue to use chemically enhanced primary treatment.
- Anaerobic stabilization is not practiced.
- New buildings and reactors would be required to accomplish nutrient recovery.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-2).

Results from this phase of analyses are summarized in Table 4-2 and indicate limited benefits for implementing struvite recovery under current conditions. This is because the facility practices CEPT, does not currently experience nuisance struvite formation, and is not impacted by the sidestream loads. Under this scenario, there are no significant drivers for recovering struvite.

Table 4-2. Summary of Costs and Struvite Recovery Potential at Plant 14 – Scenario 1.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$4,080,000	$(9,570,000)	93	$6,000
Struvite Recovery from Sidestream Flow – Low Estimate	$450,000	$(5,320,000)	93	$6,000
Ferric Addition to Sidestream Flow	$ -	$(660,000)		
Alum Addition to Sidestream Flow	$530,000	$(1,330,000)		

4.2.1.2 Scenario 2

For Scenario 2, it was assumed:

- The plant would cease chemically enhanced primary treatment.
- The plant would implement Bio-P in the main biological treatment process.
- Enhanced WAS phosphorus release would be practiced.
- Anaerobic stabilization is not practiced.
- New buildings and reactors would be required to accomplish nutrient recovery.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-5).

Results from this phase of analyses are summarized in Table 4-3. These results indicate that implementing Bio-P and enhanced WAS phosphorus release would increase the struvite recovery potential at this facility. Despite this increase in struvite production, the net present cost for implementing struvite recovery is higher than using chemical precipitation for controlling sidestream P loads. This is likely because of the limited amount of struvite that could be recovered from undigested sludge.

Table 4-3. Summary of Costs and Struvite Recovery Potential at Plant 14 – Scenario 2.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$4,650,000	$(7,740,000)	794	$44,000
Struvite Recovery from Sidestream Flow – Low Estimate	$1,560,000	$(4,110,000)	794	$44,000
Ferric Addition to Sidestream Flow	$450,000	$(2,460,000)		
Alum Addition to Sidestream Flow	$450,000	$(3,680,000)		

4.2.1.3 Scenario 3

In this analysis, it was assumed:

- The plant would cease chemically enhanced primary treatment.
- The plant would implement Bio-P in the main biological treatment process.
- Enhanced WAS phosphorus release would be practiced.
- Anaerobic stabilization would be implemented.
- New buildings and reactors would be required to accomplish nutrient recovery.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-5).

Results from this phase of analyses are summarized in Table 4-4. Findings indicate that implementing anaerobic digestion and enhanced WAS phosphorus release significantly increases the amount of struvite that can be recovered. Consequently, implementing struvite recovery under Scenario 3 would have the lowest net present cost versus all alternatives considered. The potential payback period would theoretically range from six to seven years (Figure 4-2). It should be noted that this payback does not include costs associated with implementing anaerobic digestion.

Table 4-4. Summary of Costs and Struvite Recovery Potential at Plant 14 – Scenario 3.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$6,840,000	$(5,280,000)	3,387	$186,000
Struvite Recovery from Sidestream Flow – Low Estimate	$5,660,000	$(3,890,000)	3,387	$186,000
Ferric Addition to Sidestream Flow	$360,000	$(9,260,000)		
Alum Addition to Sidestream Flow	$360,000	$(13,890,000)		

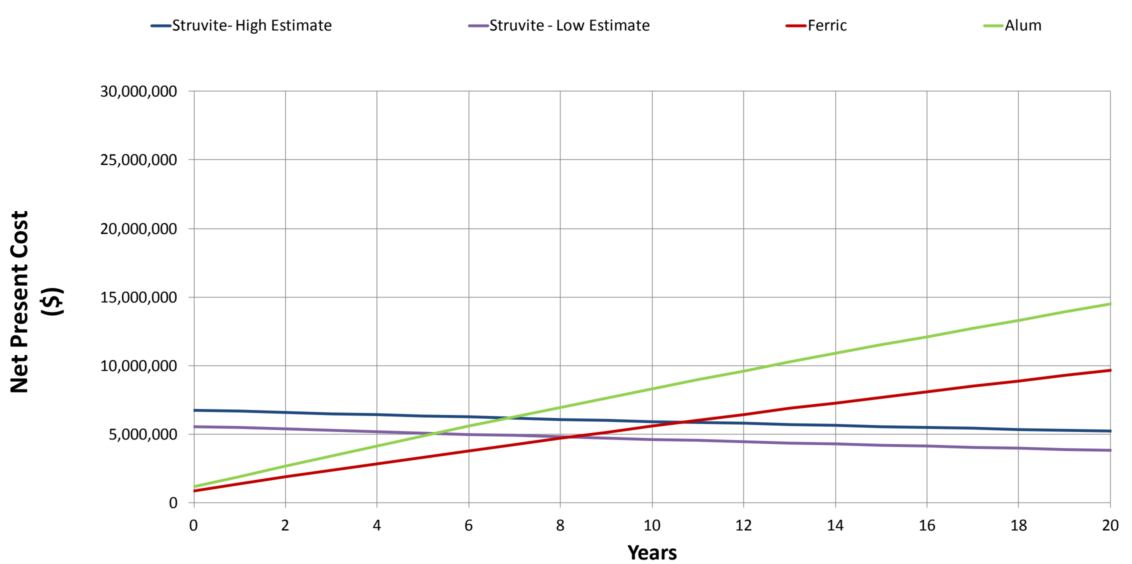

Figure 4-2. Summary of Payback Period Associated with Scenario 3 at Plant 14.

Table 4-5. Plant 14 Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% Al2(SO4)3•14H2O
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% FeCl3
Unit cost for ferric chloride	$ 400	per dry ton
MgCl2 stock concentration	30	% MgCl2
Unit cost for MgCl2	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime (Ca(OH)2) stock concentration	10	% Ca(OH)2
Unit cost for lime Ca(OH)2	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 300	per dry ton

4.3 Plant 15 Case Study

Plant designation	Plant 15
Location	Texas, USA
Current nutrient limits (mg/L)	Average NH4-N = 1.4 from June – November; Average NH4-N = 3 from December – May; 7-Day Average NH4-N = 5 from June – November; 7-Day Average NH4-N = 6 from December – May; Max Day NH4-N = 10; Single Grab NH4-N = 15; Current TP is reporting only, Future limit = 0.5 mg/L.
Emerging nutrient limits (mg/L)	Texas is currently in the process of implementing phosphorus limits, especially in plants which discharge to reservoirs.
BNR configuration	Capetown (UCT)
Solids management configuration	Solids from the plant are stored in three separate Sludge Holding Tanks. Sludge is pumped from the holding tanks centrifuges for thickening prior to disposal of the solids in a landfill. Centrate from the centrifuges is combined with liquid decanted from the Sludge Holding Tanks, backwash from the effluent filters and flow from the Scum Septic Tank.
Biosolids disposal method	Landfill
Mainstream design flow (MGD)	11.5
Mainstream current operation flow (MGD) (2009-2012)	5.3
Maximum operating temperature (°C; °F)	45°C
Minimum operating temperature (°C; °F)	-6°C
Effluent nutrient concentrations (2009-2012 average)	NH4-N – 0.19 mg/L TP – 1.1 mg/L
Sidestream flow (MGD) (2008-2012 average)	n/a
Sidestream nitrogen load (lb/day; % of total N load)	n/a
Sidestream phosphorus load (lb/day; % of total P load)	n/a

n/a – data not available

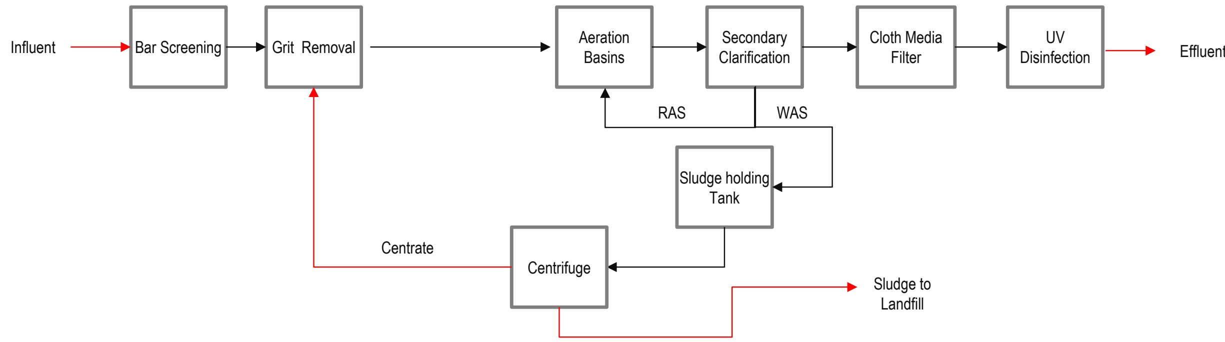

Figure 4-3. Plant 15 Process Flow Diagram.

Plant 15 is an 11.5 MGD facility that currently treats approximately at 5.3 MGD using a UCT configuration. The facility is required to meet effluent ammonia concentration limits of 1.4 to 3 mg/L depending on the season. The influent to the facility contains approximately 4.46 mg TP/L and the plant effluent contains approximately 1.1 mg TP/L. Solids handling at this facility consists of sludge thickening of waste activated sludge (WAS) using centrifuges followed by land application of the thickened sludge. Prior to centrifugation, Plant 15 stores the WAS onsite. The centrate from this process is then returned to the mainstream flow without any sidestream treatment.

At present, this facility does not need to meet a TP limit but it is anticipated that limits will be forthcoming within the next 10 years. Consequently, Plant 15 is interested in determining whether extractive nutrient recovery of struvite would be a viable sidestream process to help the plant meet future TP limits. Within this context, a summary of the main drivers for implementing extractive nutrient recovery is provided in Table 4-6.

Table 4-6. Drivers Associated with Extractive Nutrient Recovery for Plant 15.

Driver	Causes	Implemented Solutions
Nutrient load impact on mainstream process	• Extended solids storage retention time can result in solids stabilization yield nitrogen and phosphorus	• Operations optimization study underway

4.3.1 Costs Associated with Sidestream Nutrient Control

A conceptual level evaluation, using the TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery on sidestream flows. For the current struvite recovery evaluation, the following were assumed:

- The plant would continue to use biological P removal.
- Anaerobic stabilization would not be practiced.
- New buildings and reactors would be required to accomplish nutrient recovery. All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-8).

Results from this phase of analyses are summarized in Table 4-7. They indicate that implementing struvite recovery under current conditions can be a promising alternative for sidestream treatment. Payback analyses indicate that a payback period of 14 years could be observed if a low cost struvite recovery was compared to the alum sidestream treatment option (Figure 4-2). Cumulatively, these results give a good indication that the struvite recovery option can be economically viable at Plant 15; however, a more detailed evaluation is warranted to ensure that the unit costs associated with chemicals, sludge disposal options, struvite resale value etc., are refined. Additionally, these detailed evaluations can consider the potential benefits that might be achieved if biological stabilization were used to increase the amount of P available for recovery.

Table 4-7. Summary of Costs and Struvite Recovery Potential at Plant 15.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$4,930,000	$(7,650,000)	1,127	$42,000
Struvite Recovery from Sidestream Flow – Low Estimate	$2,080,000	$(4,300,000)	1,127	$42,000
Ferric Addition to Sidestream Flow	$430,000	$(3,080,000)		
Alum Addition to Sidestream Flow	$430,000	$(4,780,000)		

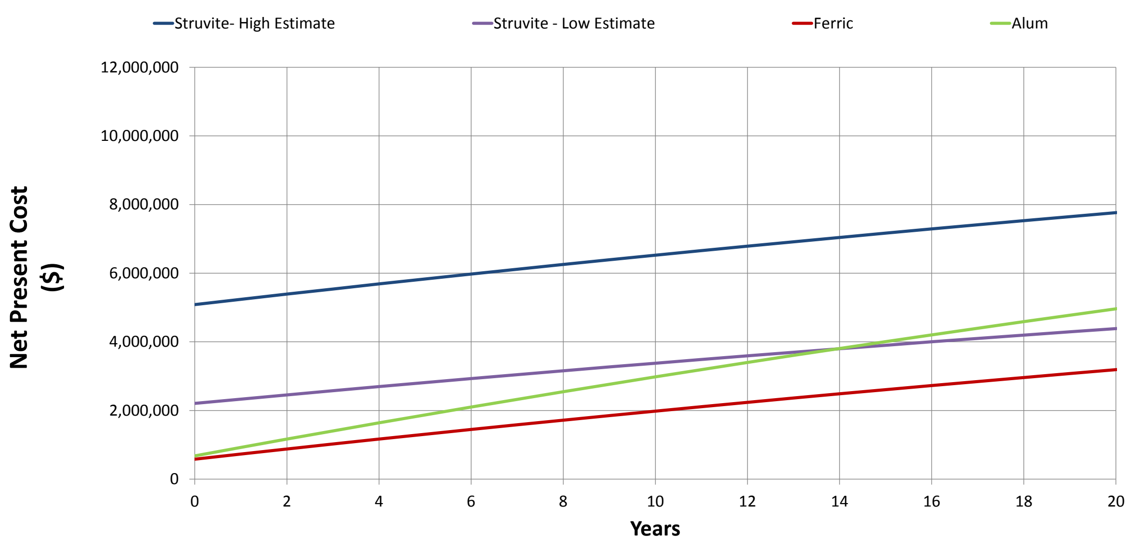

Figure 4-4. Summary of Payback Period for Plant 15.

Table 4-8. Plant 15 – Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% $Al_2(SO_4)_3 \cdot 14H_2O$
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% $FeCl_3$
Unit cost for ferric chloride	$ 400	per dry ton
$MgCl_2$ stock concentration	30	% $MgCl_2$
Unit cost for $MgCl_2$	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime ($Ca(OH_2)$) stock concentration	10	% $Ca(OH)_2$
Unit cost for lime $Ca(OH)_2$	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 200	per dry ton

4.4 Plant 16 Case Study

Plant designation	Plant 16
Location	Texas, USA
Current nutrient limits (mg/L)	NH3-N – 3.0 mg/L daily average (Apr-Nov) 4.0 mg/L daily average (Dec-Mar)
Emerging nutrient limits (mg/L)	Texas is currently in the process of implementing phosphorus limits, especially in plants which discharge to reservoirs.
BNR configuration	Modified Ludzack-Ettinger
Solids management configuration	Primary sludge combined with sludge from another plant (200 MGD) is screened, gravity-belt thickened, then combined with centrifuged-thickened WAS and co-digested; digested sludge is dewatered with belt filter presses; a cogeneration system is online supplementing power for the plant; filtrate from BFPs is treated via a nitrification sidestream treatment system; sludge is land disposed onsite on dedicated land disposal fields
Biosolids disposal method	Onsite Dedicated Land Disposal
Mainstream design flow (MGD)	110
Mainstream current operation flow (MGD) **(January to September 2012)**	69
Maximum operating temperature (°C; °F)	29°C
Minimum operating temperature (°C; °F)	15°C
Effluent nutrient concentrations **(2008-2012 average)**	TP – 2.7 mg/L
Sidestream flow (MGD) **(2008-2012 average)**	4.7 MGD
Sidestream nitrogen load **(lb/day; % of total N load)**	Not available
Sidestream phosphorus load **(lb/day; % of total P load)**	Not available

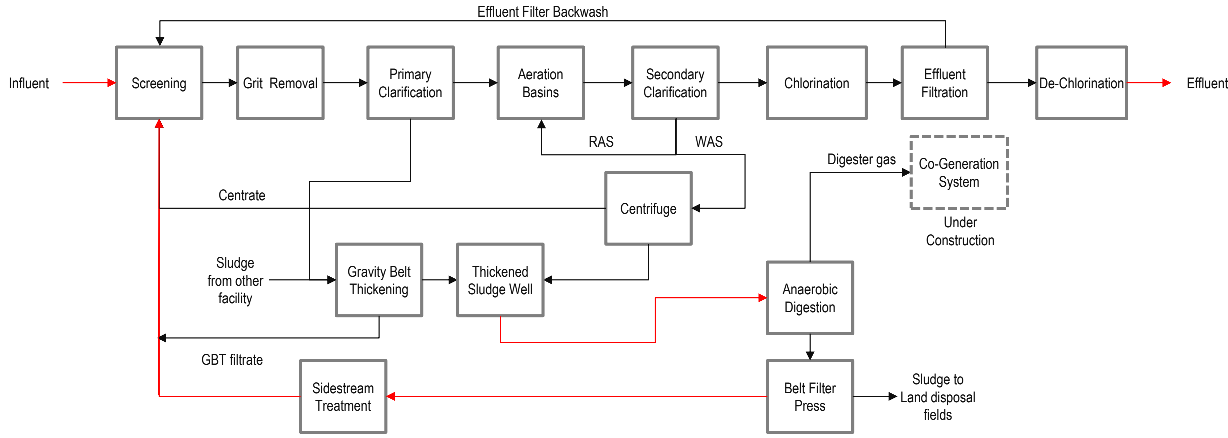

Figure 4-5. Plant 16 Process Flow Diagram.

Plant 16 is a 110 MGD facility that currently treats approximately at 69 MGD using a Modified Ludzack-Ettinger configuration. The facility is required to meeting effluent ammonia concentration limits of 3 to 4 mg/L depending on the season. The influent to the facility contains approximately 5.3 mg TP/L and the plant effluent contains approximately 3 mg TP/L. Solids handling at this facility consists of separate thickening of primary sludge and WAS followed by anaerobic digestion. Plant 16 also receives thickened sludge from another local facility (200 MGD), which is combined and digested. The cumulative digested sludge is dewatered using belt filter presses. The filtrate from this process is then treated using an extended aeration activated sludge process (with lime addition) prior to return of the treated filtrate to the mainstream flow. This sidestream process is used to remove ammonia so that the plant can reliably meet effluent ammonia limits.

At present, this facility does not need to meet a TP limit but it anticipated that limits will be forthcoming within the next 10 years. Consequently, efforts are underway at the second local plant to pilot biological P removal at one-eighth of the existing flow. This would likely result in a net increase in phosphorus in the solids that are processed at Plant 16.

Plant 16 has also experienced nuisance precipitate formation in digester feed piping. This precipitate has been tentatively identified at vivianite (Fe (PO4)2•8(H2O)). Formation of vivianite at Plant 16 is likely due to several factors including:

- Presence of iron in the primary sludge (a carryover of iron addition in the collection system for odor control).
- High TP load in the combined solids.
- Elevated temperatures in the feed piping.

Currently, the plant intends to use recurring replacements of feed headers and moving precipitation into the digester surfaces to address the nuisance vivianite formation. However, as Plant 16 and the other local plant begin to consider biological P removal to address upcoming limits, it is anticipated that the magnitude of nuisance scaling will be exacerbated. Within this context, a summary of the main drivers for implementing extractive nutrient recovery is provided in Table 4-9.

Table 4-9. Drivers Associated with Extractive Nutrient Recovery for Plant 16.

Driver	Causes	Implemented Solutions
Nuisance vivianite formation at Digesters 3-8 header piping	• High phosphorus and iron concentrations in digester feed • Mixing of high and low temperature sludge • High turbulence	• One time replacement cost of header piping ($500,000)
Nutrient load impact on mainstream process	• Anaerobic digestion causes high ammonia loading in return streams	• Sidestream treatment geared toward ammonia reduction
Future TP limit	• Regulations	• Considering biological phosphorus removal

4.4.1 Costs Associated with Sidestream Nutrient Control

A conceptual level evaluation, using TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery on sidestream flows. For the current struvite recovery evaluation, two scenarios were examined.

4.4.1.1 Scenario 1

For this evaluation, the following were assumed:

- The plant would continue to use the existing biological treatment approach.
- Anaerobic stabilization would be continued.
- New buildings and reactors would be required to accomplish nutrient recovery.
- Nutrient recovery would be performed prior to the existing extended aeration sidestream treatment process.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-12).

Results from this phase of analyses are summarized in Table 4-10. They indicate limited benefits for implementing struvite recovery under current conditions. This is due to the low phosphorus concentration in the sidestream.

Table 4-10. Summary of Costs and Struvite Recovery Potential for Plant 16 – Scenario 1.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$5,300,000	$15,150,000)	1,500	$58,000
Struvite Recovery from Sidestream Flow – Low Estimate	$2,790,000	$(12,210,000)	1,570	$58,000
Ferric Addition to Sidestream Flow	$20,000	$(4,310,000)		
Alum Addition to Sidestream Flow	$720,000	$(6,680,000)		

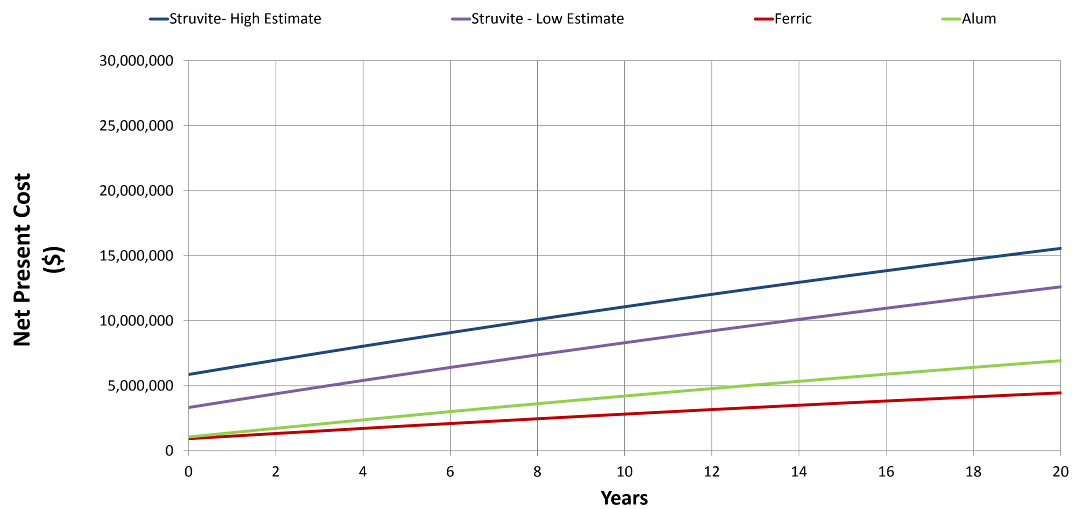

Figure 4-6. Summary of Payback Period for Plant 16 – Scenario 1.

4.4.1.2 Scenario 2

For this evaluation, the following were assumed:

- The plant would implement biological phosphorus removal.
- Anaerobic stabilization would be continued in combination with enhanced WAS release.
- New buildings and reactors would be required to accomplish nutrient recovery.
- Nutrient recovery would be performed prior to the existing extended aeration sidestream treatment process.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-12).

Results from this phase of analyses are summarized in Table 4-11. They indicate that implementing struvite recovery can be a promising alternative for sidestream treatment. Payback analyses indicate that a payback period of between four and 15 years could be observed as compared to the alum or ferric sidestream treatment option (Figure 4-7). Cumulatively, these results give a good indication that the struvite recovery option can be economically viable at Plant 16; however, a more detailed evaluation is warranted to ensure that the unit costs associated with chemicals, sludge disposal options, struvite resale value etc., are refined. Additionally, these detailed evaluations can consider the potential benefits that might be achieved if biological stabilization were used to increase the amount of P available for recovery.

Table 4-11. Summary of Costs and Struvite Recovery Potential for Plant 16 – Scenario 2.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$39,170,000	$(38,320,000)	24,953	$898,000
Struvite Recovery from Sidestream Flow – Low Estimate	$23,300,000	$(19,730,000)	24,953	$898,000
Ferric Addition to Sidestream Flow	$460,000	$(47,220,000)		
Alum Addition to Sidestream Flow	$460,000	$(84,350,000)		

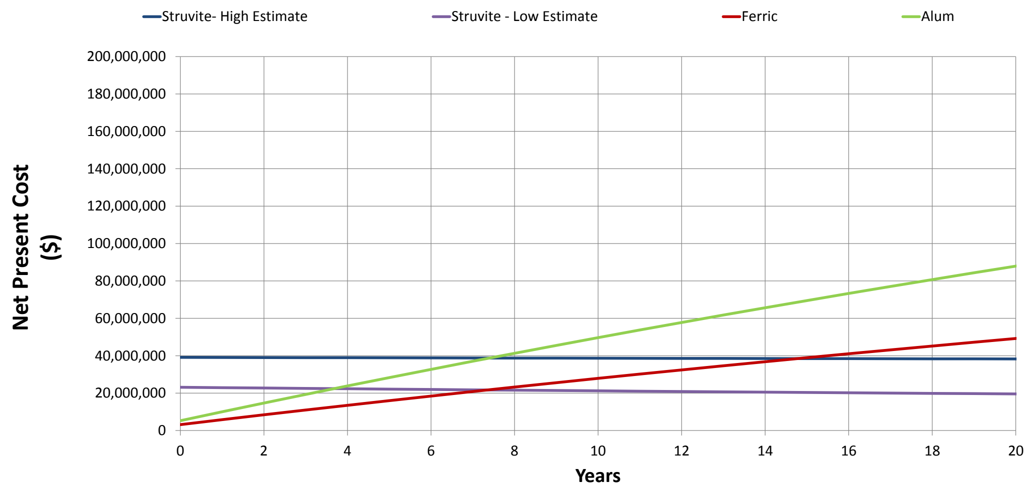

Figure 4-7. Summary of Payback Period for Plant 16 – Scenario 2.

Table 4-12. Plant 16 Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% Al2(SO4)3•14H2O
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% FeCl3
Unit cost for ferric chloride	$ 400	per dry ton
MgCl2 stock concentration	30	% MgCl2
Unit cost for MgCl2	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime (Ca(OH2) stock concentration	10	% Ca(OH)2
Unit cost for lime Ca(OH)2	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 200	per dry ton

4.5 Plant 17 Case Study

Plant designation	Plant 17
Location	Ohio, USA
Current nutrient limits (mg/L)	None
Emerging nutrient limits (mg/L)	TN – Not available TP – Not available
Configuration	Conventional activated sludge
Solids management configuration	Primary sludge and sludge from two other facilities are gravity thickened and combined with DAF thickened WAS, prior to belt filter dewatering and incineration
Biosolids disposal method	Incineration followed by ash landfill
Mainstream design flow (MGD)	55 MGD (annual average basis)
Mainstream current average flow (MGD)	27.7
Minimum operating temperature (°C; °F)	11°C
Effluent nutrient concentrations	Not applicable
Sidestream flow (MGD)	0.11 (filtrate) 0.86 (GTO) 0.407 (DAF underflow)
Sidestream nitrogen concentration (mg/L)	101 (NH3 filtrate) 12.9 (NH3 GTO) 1.8 (NH3 DAF underflow)
Sidestream phosphorus concentration (mg/L)	101 (TP filtrate); 63 (Ortho-P filtrate) 11 (TP GTO); 5 (Ortho-P GTO) 5 (TP DAF underflow); 3 (Ortho-P DAF underflow)

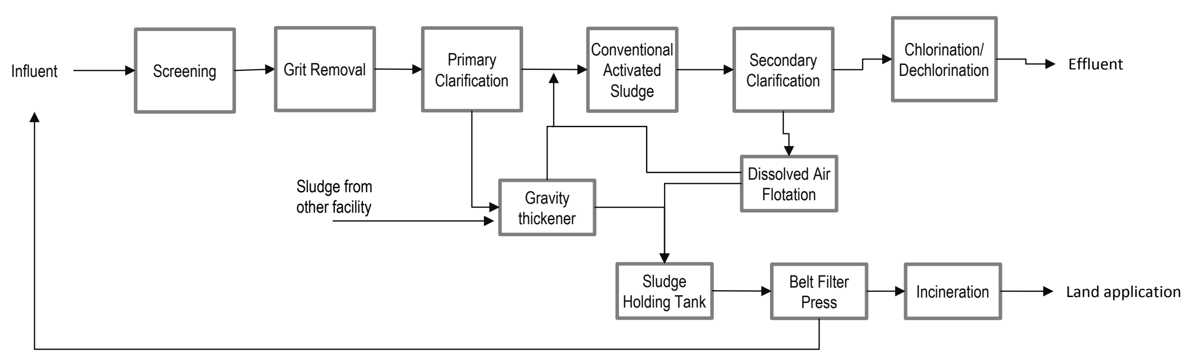

Figure 4-8. Plant 17 Process Flow Diagram.

Liquid treatment at Plant 17 consists of screening, grit removal, primary clarification, conventional activated sludge, secondary clarification, and disinfection by chlorination. Solids treatment at this facility consists of gravity thickening of primary sludge and sludge from other WRRFs, DAF thickening of Plant 17 WAS, belt filter press dewatering, and incineration. Since this facility does not perform anaerobic stabilization, nuisance struvite formation has not been observed.

4.5.1 Evaluation of Sidestream Nutrient Control

A conceptual level evaluation, using TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery. Recovery of phosphorus from incinerator ash was not considered at this point since the capital and operating requirements for this technology are not well established at present. Future efforts should consider this option.

For this evaluation, two scenarios were considered:

- Scenario 1: Assumes that current operation would continue and that the struvite recovery facility would treat the filtrate stream only.
- Scenario 2: Assumes that the facility has implemented anaerobic digestion and that recovery would be attempted on the dewatering centrate.

4.5.1.1 Scenario 1

In this analysis, the following were assumed for the evaluation:

- Anaerobic stabilization is not practiced.
- Recovery is performed on the belt filter press filtrate only.
- New buildings and reactors are required to accomplish nutrient recovery.
- All costs for chemicals and nutrient market value were derived from defaults within the TERRY – Phosphorus resource (Table 4-15).

Results from this phase of analyses are summarized in Table 4-13 and indicate that even without anaerobic digestion, implementing nutrient recovery from the belt filter press flow can remove up to 9% of the total P load to the facility. If the low estimate capital option for struvite recovery is considered, the net present cost is lower than the conventional options which include ferric or alum addition. In contrast, the high estimate capital option would not be economically viable compared with the conventional alternatives. This result is important as it clearly indicates that a more detailed site-specific study would be needed to ascertain the true costs associated with implementing struvite recovery under current conditions.

Table 4-13. Summary of Costs and Struvite Recovery Potential for Plant 17 – Scenario 1.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$4,270,000	$ (5,650,000)	324	$18,000
Struvite Recovery from Sidestream Flow – Low Estimate	$820,000	$ (1,610,000)	324	$18,000
Ferric Addition to Sidestream Flow	$370,000	$ (1,630,000)		
Alum Addition to Sidestream Flow	$370,000	$ (2,070,000)		

4.5.1.2 Scenario 2

In this analysis, it was assumed:

- ♦ Anaerobic stabilization is implemented (costs not included in evaluation).
- ♦ New buildings and reactors are required to accomplish nutrient recovery.
- ♦ All costs for chemicals and nutrient market value were derived from defaults within the TERRY – Phosphorus resource (Table 4-15).

Results from this phase of analyses are summarized in Table 4-14 and are used to illustrate the scenario in which P recovery would be the most favorable. Under this scenario, if the facility transitions to anaerobic digestion, the amount of struvite that could be recovered increases significantly. Consequently, implementing struvite recovery under this scenario can be a favorable alternative relative to sidestream metal salt addition. The potential payback period would range from three to nine years in this scenario (Figure 4-9). It should be noted that this payback does not include costs associated with implementing anaerobic digestion.

Table 4-14. Summary of Costs and Struvite Recovery Potential for Plant 17 – Scenario 2.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$12,150,000	$ (7,480,000)	7,495	$411,000
Struvite Recovery from Sidestream Flow – Low Estimate	$7,730,000	$ (2,300,000)	7,495	$411,000
Ferric Addition to Sidestream Flow	$380,000	$ (19,280,000)		
Alum Addition to Sidestream Flow	$380,000	$ (29,550,000)		

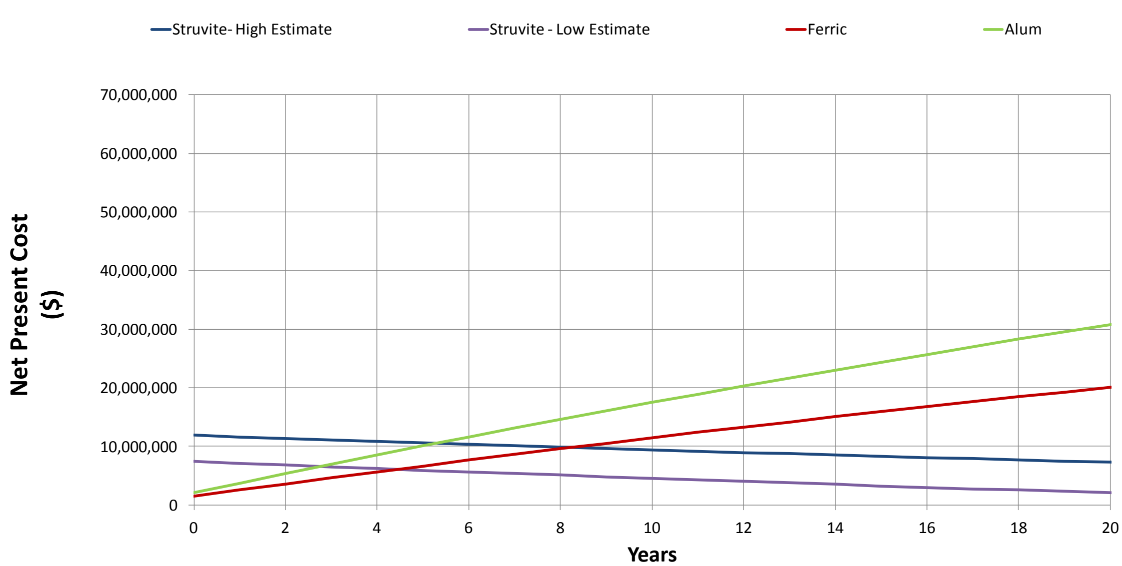

Figure 4-9. Summary of Payback Period for Plant 17 – Scenario 2.

Table 4-15. Plant 17 Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% Al2(SO4)3•14H2O
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% FeCl3
Unit cost for ferric chloride	$ 400	per dry ton
MgCl2 stock concentration	30	% MgCl2
Unit cost for MgCl2	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime (Ca(OH2) stock concentration	10	% Ca(OH)2
Unit cost for lime Ca(OH)2	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 300	per dry ton

4.6 Plant 18 Case Study

Plant designation	Plant 18
Location	Ohio, USA
Current nutrient limits (mg/L)	TN – N/A NH_3-N – 1.0 mg/L monthly average (June-Oct) 2.5 mg/L monthly average (May) 3.7 mg/L monthly average (Nov – April) TP – No limit currently. P-Index is being implemented in Ohio for land application of biosolids. These are nutrient limits at 68 MGD annual average flow conditions.
Process configuration	Activated sludge aerobic treatment for organic removal and nitrification.
Solids management configuration	Primary sludge is thickened in gravity thickeners and processed through anaerobic digestion. Waste activated sludge (WAS) is thickened with thickening centrifuges. A portion of thickened WAS is blended with primary sludge and sent to Anaerobic digestion. Remaining WAS is dewatered and reused through composting or off-site digestion. Digested biosolids are either dewatered and reused through a deep row hybrid poplar program (reuse for tree growth and landscape mulch) or thickened and reused through liquid land application.
Biosolids disposal method	Liquid land application (class B), deep row hybrid poplar program (reuse for tree growth and landscape mulch, class B), off-site digestion (unclassified), and composting (unclassified).
Mainstream design flow (MGD)	68 (average) 150 (peak)
Mainstream current operation flow (MGD) (2011 - 2013)	75
Maximum operating temperature (°C; °F)	n/a
Minimum operating temperature (°C; °F)	n/a
Effluent nutrient concentrations (2011 - 2013)	n/a
Sidestream flow (MGD) (2011 - 2013)	Dewatering centrate (digested): ~ 0.85 MGD
Sidestream nitrogen load (lb/day)	7,800 lb/d
Sidestream phosphorus load (lb/day)	470 lb/d

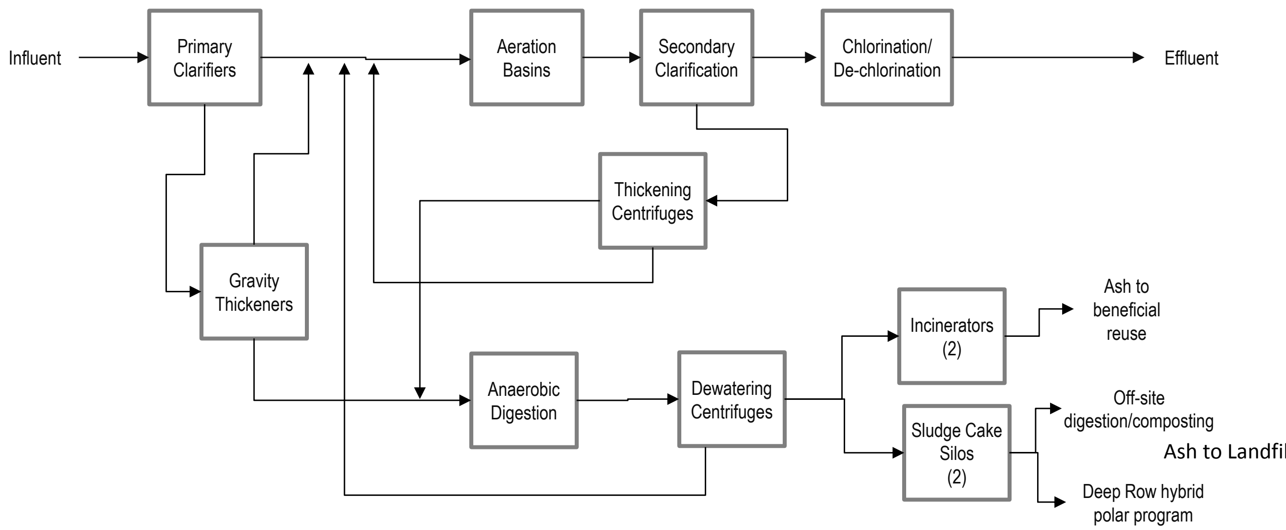

Figure 4-10. Plant 18 Process Flow Diagram.

Plant 18 is a 68 MGD facility that utilizes conventional activated sludge to remove organics, total suspended solids (TSS), and influent nitrogen. The facility is required to meet effluent ammonia concentration limits of 1 to 3.7 mg/L depending on the time of year. Solids handling at this facility consists of gravity thickening of primary sludge and centrifuge thickening of WAS, anaerobic digestion, and centrifuge dewatering. The facility has instituted reuse of all biosolids produced through several avenues:

- Liquid biosolids land application (Class B).
- Deep row hybrid poplar program (Class B).
- Composting (Unclassified).
- Off-site digestion (Unclassified).

Biosolids that are reused through liquid biosolids land application and the deep row hybrid poplar program are processed through anaerobic digestion and thickening or dewatering. Biosolids reused through composting or off-site digestion are processed directly through dewatering.

The highest source of phosphorus returned to the activated sludge process is centrate from dewatering centrifuges from processing digested sludge. Nutrient recovery is being evaluated at Plant 18 to prevent struvite formation, reduce TP content of land applied liquid biosolids to balance the phosphorus to nitrogen ratio for land application users, reduce sludge produced, reduce the effluent phosphorus to proactively prepare for future effluent phosphorus limits, and increase environmental sustainability.

4.6.1 Evaluation of Sidestream Nutrient Control

Plant 18 does not currently have TN or TP removal beyond nutrients contained in sludge that are removed through the biosolids handling process. A conceptual level evaluation, using TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery. For this evaluation, the following were assumed:

- Current operation would continue.
- Anaerobic stabilization would continue to be practiced.
- The facility would proactively pursue P removal from sidestreams through chemical addition or nutrient recovery.
- New buildings and reactors would be required to accomplish nutrient recovery.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-17).

Results from this high level evaluation are summarized in Table 4-16. They indicate that the net present cost for struvite recovery is greater than the net present value (NPV) for ferric chloride addition but lower than the NPV for alum addition. Payback analyses indicate that a payback period of 10-15 years could be observed if struvite recovery was compared to the alum sidestream treatment option (Figure 4-11). Cumulatively, these results indicate that a more detailed site-specific evaluation is warranted for Plant 18 since it appears that the struvite recovery option can be economically viable. These more detailed studies should seek to refine unit costs associated with chemicals, sludge disposal options, struvite resale value etc. as well as examine scenarios where biological phosphorus removal is used for removing phosphorus in the mainstream process.

Table 4-16. Summary of Costs and Struvite Recovery Potential for Plant 18.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$4,350,000	$(10,050,000)	1,958	$108,000
Struvite Recovery from Sidestream Flow – Low Estimate	$3,400,000	$(8,930,000)	1,958	$108,000
Ferric Addition to Sidestream Flow	$580,000	$(8,240,000)		
Alum Addition to Sidestream Flow	$580,000	$(11,190,000)		

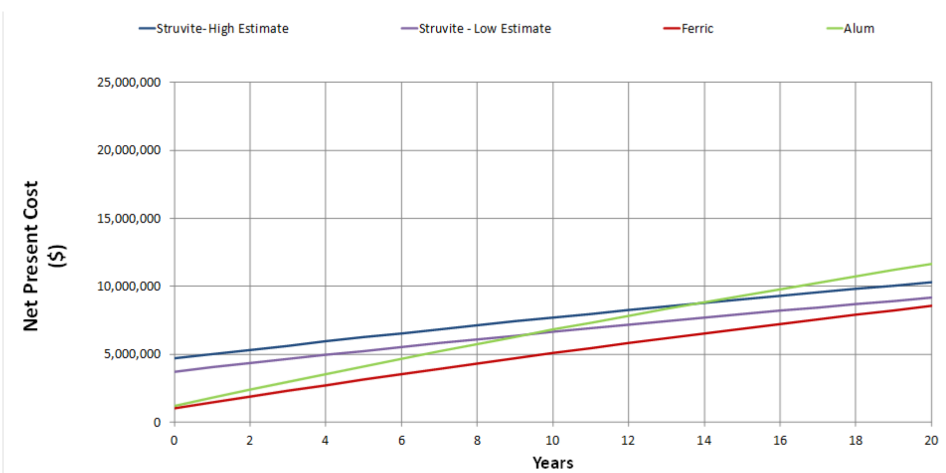

Figure 4-11. Summary of Payback Period for Plant 18.

Table 4-17. Plant 18 Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% $Al_2(SO_4)_3•14H_2O$
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% $FeCl_3$
Unit cost for ferric chloride	$ 400	per dry ton
MgCl2 stock concentration	30	% $MgCl_2$
Unit cost for MgCl2	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime (Ca(OH2) stock concentration	10	% $Ca(OH)_2$
Unit cost for lime Ca(OH)2	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 300	per dry ton

4.7 Plant 19 Case Study

Plant designation	Plant 19
Location	Ohio, USA
Current nutrient limits (mg/L)	TN – N/A NH_3-N – 1.0 mg/L monthly average (June-Oct) 2.0 mg/L monthly average (May) 3.4 mg/L monthly average (Nov – April) TP – No limit currently. P-Index is being implemented in Ohio for land application of biosolids. These are nutrient limits at 114 MGD annual average flow conditions.
Process configuration	Activated sludge aerobic treatment for organic removal and nitrification.
Solids management configuration	Primary sludge (PS) is thickened in gravity thickeners and stabilized through anaerobic digestion. Waste activated sludge (WAS) is thickened with thickening centrifuges and sent to anaerobic digesters or directly to dewatering centrifuges. Digested or undigested solids are either reused through off-site digestion, composting, or a deep row hybrid poplar program or disposed of through incineration. Ash produced through the incineration process is sent to ash trailers then to beneficial reuse.
Biosolids disposal method	Incineration, Deep row hybrid poplar program (reuse for tree growth and landscape mulch, class B), off-site digestion (unclassified), and composting (unclassified).
Mainstream design flow (MGD)	114 (average) 330 (peak)
Mainstream current operation flow (MGD) (2011 - 2013)	106.5 MGD
Maximum operating temperature (°C; °F)	n/a
Minimum operating temperature (°C; °F)	n/a
Effluent nutrient concentrations (2011 - 2013)	n/a
Sidestream flow (MGD) (2011 - 2013)	Dewatering centrate (digested): 1.07 MGD
Sidestream nitrogen load (lb/day)	3,600 lb/d
Sidestream phosphorus load (lb/day)	630 lb/d

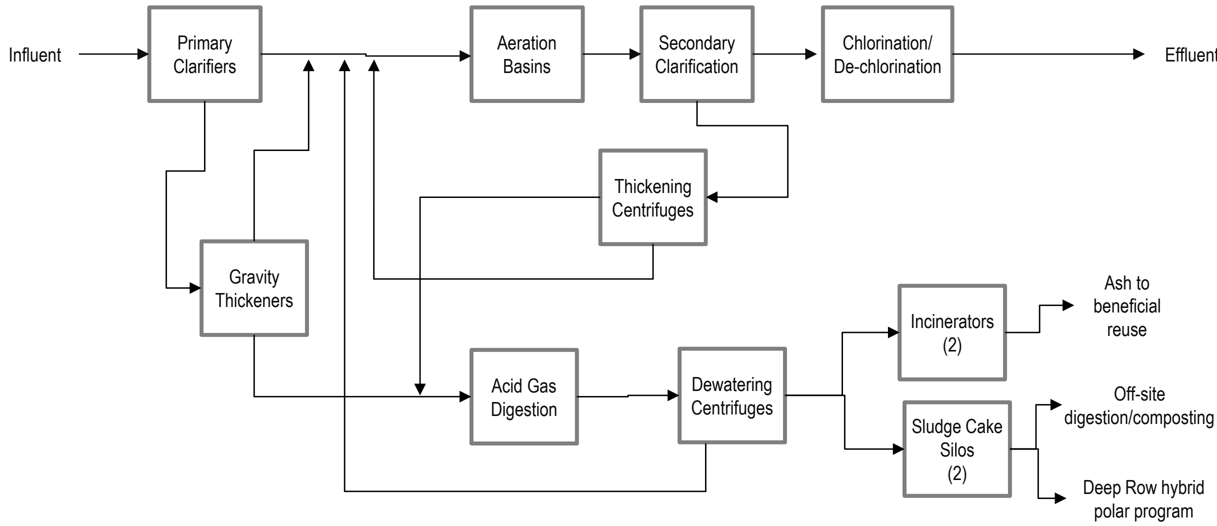

Figure 4-12. Plant 19 Process Flow Diagram.

Plant 19 is a 114 MGD facility that utilizes conventional activated sludge to remove organics, total suspended solids (TSS), and influent nitrogen. The facility is required to meet effluent ammonia concentration limits of 1-3.4 mg/L depending on the time of year. Solids handling at this facility consists of gravity thickening of primary sludge and centrifuge thickening of WAS, anaerobic digestion, and centrifuge dewatering. Biosolids are either reused through one of three different avenues or disposed of through incineration. Reuse options include:

- Deep row hybrid poplar program (Class B).
- Composting (Unclassified).
- Off-site digestion (Unclassified).

Biosolids that are reused through the deep row hybrid poplar program are processed through anaerobic digestion and dewatering. Biosolids reused through composting or offsite digestion or incinerated are processed directly through dewatering. Nutrient recovery is being evaluated at Plant 19 to prevent struvite formation, reduce sludge produced, increase environmental sustainability, and reduce the effluent phosphorus to proactively prepare for future effluent phosphorus limits.

4.7.1 Evaluation of Sidestream Nutrient Control

Plant 19 does not currently implement TN or TP removal beyond nutrient removal through the biosolids handling process. A conceptual level evaluation, using TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery.

For this evaluation, it was assumed that current operation would continue and that the struvite recovery facility would treat the dewatering centrate streams from digested biosolids. Additional assumptions are listed below:

- Current operation would continue.
- Anaerobic stabilization would continue to be practiced.

- ♦ The facility would proactively pursue P removal from sidestreams through chemical addition or nutrient recovery.
- ♦ New buildings and reactors would be required to accomplish nutrient recovery.
- ♦ All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-19).

Results from this high level evaluation are summarized in Table 4-18. They indicate that the net present cost for struvite recovery options are the lowest when compared with ferric or alum addition. Payback analyses indicate that a payback period of eight years could be observed if struvite recovery was compared to the alum sidestream treatment option (Figure 4-13), while a payback of approximately 16 years would be observed if compared with ferric chloride addition. Cumulatively, these results give a good indication that struvite recovery option can be economically viable at Plant 19; however, a more detailed evaluation is warranted to ensure that the unit costs associated with chemicals, sludge disposal options, struvite resale value etc., are refined. Additionally, these detailed evaluations can consider the potential benefits that might be achieved if biological phosphorus removal were used for removing phosphorus in the mainstream process in the future.

Table 4-18. Summary of Costs and Struvite Recovery Potential for Plant 19.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$5,230,000	$(11,860,000)	3,065	$168,000
Struvite Recovery from Sidestream Flow – Low Estimate	$5,150,000	$(11,760,000)	3,065	$168,000
Ferric Addition to Sidestream Flow	$640,000	$(12,210,000)		
Alum Addition to Sidestream Flow	$640,000	$(16,860,000)		

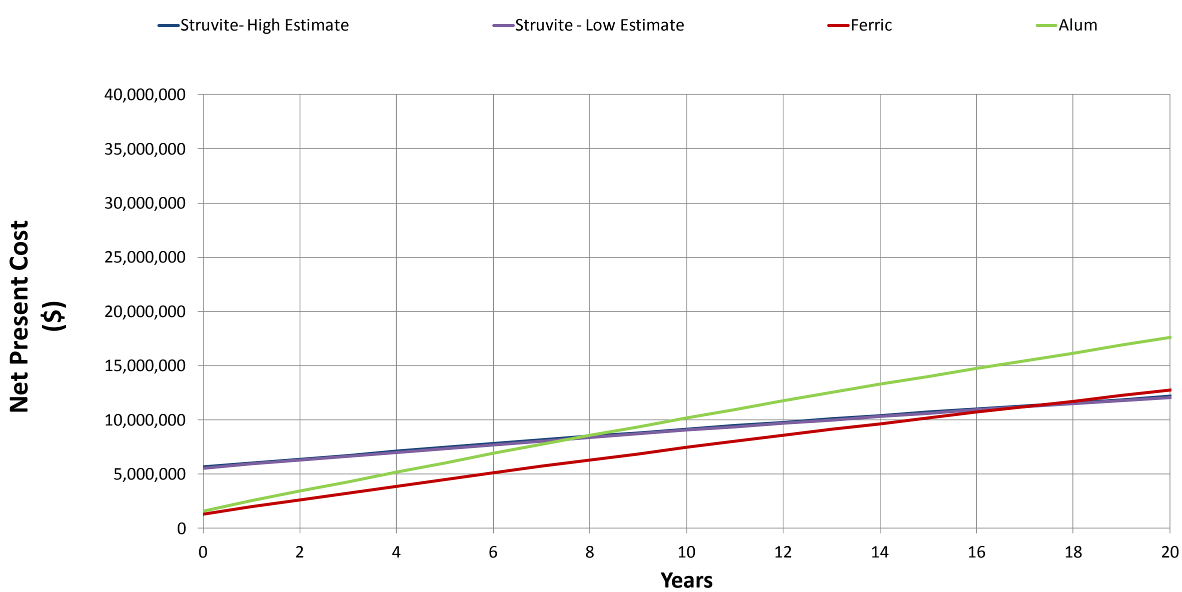

Figure 4-13. Summary of Payback Period for Plant 19.

Table 4-19. Plant 19 Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% Al2(SO4)3•14H2O
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% FeCl3
Unit cost for ferric chloride	$ 400	per dry ton
MgCl2 stock concentration	30	% MgCl2
Unit cost for MgCl2	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime (Ca(OH2) stock concentration	10	% Ca(OH)2
Unit cost for lime Ca(OH)2	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 300	per dry ton

4.8 Plant 20 Case Study

Plant designation	Plant 20
Location	Colorado, USA
Current nutrient limits (mg/L)	Total Ammonia (begin 1/1/2015) – 2 to 4.6 mg-N/L (30-day avg), 6.2 to 12.7 mg-N/L (Daily Maximum) Nitrite plus Nitrate – 8.68 mg-N/L (weekly average)
Emerging nutrient limits (mg/L)	TN – 2 mg-N/L (>2025) TP – 1.0 mg-P/L (2018) TP - 0.1 mg-P/L (2022)
BNR configuration	North Complex - Modified Ludzack-Ettinger with Sidestream Nutrient Removal Basins South Complex – A2O with Sidestream Nutrient Removal Basins (High Purity Oxygen Decommissioned in 2014)
Solids management configuration	Thin-sludge primary clarifier pumping coupled with gravity thickeners for primary sludge and DAF thickening for WAS. Comingled sludges are stabilized in a two-phase anaerobic digester complex
Biosolids disposal method	Centrifuge dewatering and Land Application
Mainstream design flow (MGD)	220 MGD
Influent nutrient loads	TP – 6,700 lb/d TKN – 48,000 lb/d
Mainstream current operation flow (MGD)	130 MGD (2013)
Maximum operating temperature (°C; °F)	23
Minimum operating temperature (°C; °F)	14
Effluent nutrient concentrations (5-year average)	North Outfall South Outfall Ammonia (mg-N/L) 2.1 21.4 TIN (mg-N/L) 11.1 23.9 TP n/a n/a
Sidestream flow (MGD)	1.0
Sidestream nitrogen load (lb/day; % of total N load)	10,000 lb/day; 20%
Sidestream phosphorus load (lb/day; % of total P load)	n/a

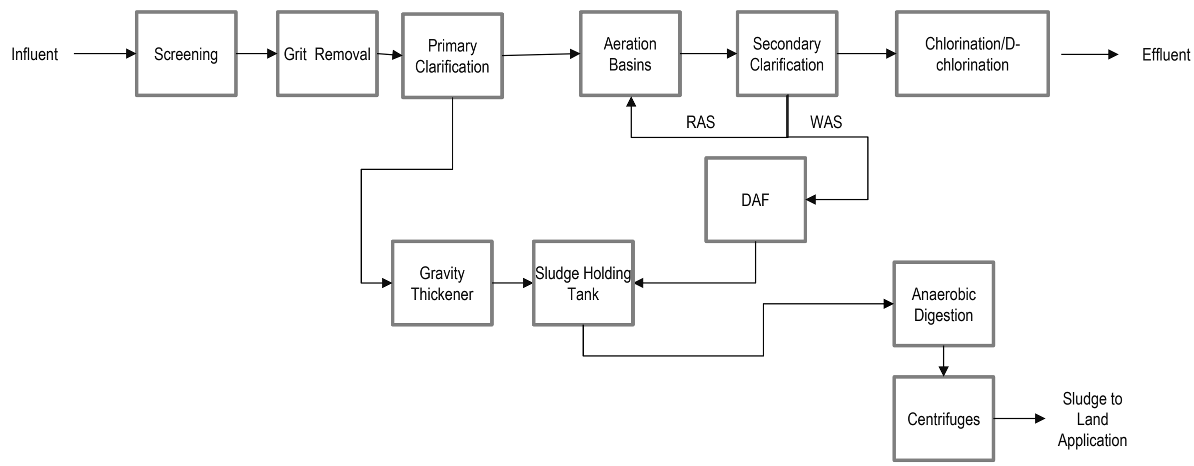

Figure 4-14. Plant 20 Process Flow Diagram.

Plant 20 is comprised of two complexes (north and south) for liquid stream treatment with centralized solids handling and stabilization facilities located between the two complexes. Started in 2014, the south complex was converted from high purity oxygen to the A2O process with sidestream nutrient removal basins. In 2015, the north complex will be modified to include sidestream anaerobic basins for enhanced biological phosphorus removal.

Treatment consists of screening, grit removal, primary clarification, biological nitrogen and phosphorus removal, and disinfection by chlorination. The solids thickening processes consist of thin-sludge pumping from the primary clarifiers to gravity thickeners and DAF thickening of WAS. The co-mingled solid are fed to two-stage anaerobic digesters. The stabilized biosolids are dewatered via centrifuges and the biosolids are transported off-site for land application.

Plant 20 experiences significant nuisance struvite formation throughout the solids process and especially so when one or more the complexes are operated for EBPR. Land application of the biosolids at irrigated sites are likely to be impacted by Colorado's phosphorus index (COPI). For several reasons, irrigated sites are preferred for land application versus dry land sites. Table 4-20 lists the key drivers behind consideration of nutrient recovery.

Table 4-20. Summary of Drivers Associated with Extractive Nutrient Recovery for Plant 19.

Driver	Causes	Implemented Solutions
Nuisance struvite formation	• Anaerobic digestion of primary sludge and WAS	• Piloted struvite recovery • Evaluate post-aeration after anaerobic digestion
More stringent effluent TP limits	• Discharge to P impaired watershed	• Bio-P with struvite sequestration and recovery
Sludge dewaterability	• Experience thus far associates Bio-P with higher polymer costs and lower cake solids concentrations	• Evaluate technology options for improving feed sludge dewaterability
Soil P index may limit biosolids land application rate and subsequently reduce the nitrogen value to the farmer	• Discharge to P impaired watershed	• Evaluate struvite recovery • Evaluate seasonal ammonia recovery from centrate to supplement nitrogen value of land applied biosolids on P-constrained sites

4.8.1 Evaluation of Sidestream Nutrient Control

Plant 18 piloted nutrient recovery via struvite crystallization. Results from this pilot indicated that struvite recovery could remove between 72 and 91% of the ortho-P present in the sidestream. A detailed cost evaluation of this technology was not performed during the pilot, therefore a conceptual level evaluation, using TERRY – Phosphorus, was performed for this facility to estimate the potential costs and paybacks that would be associated with implementing struvite recovery.

For this evaluation, two scenarios were considered. Scenario 1 assumes that current operation would continue and that the struvite recovery facility would treat the sidestream flow only. Scenario 2 assumes that the facility implements enhanced WAS release technology and that the struvite recovery facility would treat the combined WAS release flow and centrate.

4.8.1.1 Scenario 1

In this analysis, the following were assumed:

- The facility would proactively pursue P removal from sidestreams through chemical addition or nutrient recovery.
- New buildings and reactors would be required to accomplish nutrient recovery.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-23).

Results from this phase of analyses are summarized in Table 4-21 and indicate that struvite recovery would be highly favorable at this facility. The potential payback period versus conventional metal salt addition is predicted to range from five to 13 years in this scenario (Figure 4-15).

Table 4-21. Summary of Costs and Struvite Recovery Potential for Plant 19 – Scenario 1.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$26,600,000	$(22,580,000)	16,638	$911,000
Struvite Recovery from Sidestream Flow – Low Estimate	$19,020,000	$(13,690,000)	16,638	$911,000
Ferric Addition to Sidestream Flow	$490,000	$(32,380,000)	–	–
Alum Addition to Sidestream Flow	$490,000	$(57,500,000)	–	–

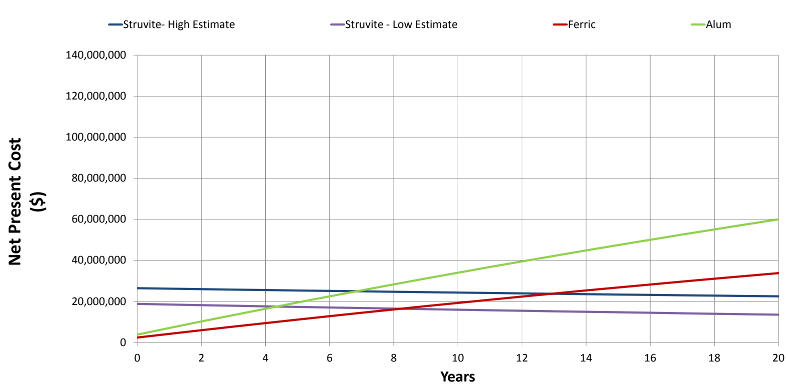

Figure 4-15. Summary of Payback Period for Plant 19 – Scenario 1.

4.8.1.2 Scenario 2

For Scenario 2, it was assumed:

- Enhanced WAS phosphorus release would be practiced.
- Anaerobic stabilization would be continued.
- New buildings and reactors would be required to accomplish nutrient recovery.
- All costs for chemicals were derived from defaults within the TERRY – Phosphorus resource (Table 4-23).

Results from this phase of analyses confirmed findings from the Scenario 1 analyses. Struvite recovery at this facility would become more favorable if WAS release was implemented as this option increases the amount of phosphorus available for recovery. Net present worth and payback results are summarized in Table 4-22 and Figure 4-16.

Table 4-22. Summary of Costs and Struvite Recovery Potential for Plant 19 – Scenario 2.

Option	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow – High Estimate	$44,470,000	$(34,910,000)	27,946	$1,531,000
Struvite Recovery from Sidestream Flow – Low Estimate	$ 25,150,000	$(12,220,000)	27,946	$1,531,000
Ferric Addition to Sidestream Flow	$490,000	$(52,540,000)	–	–
Alum Addition to Sidestream Flow	$490,000	$(95,730,000)	–	–

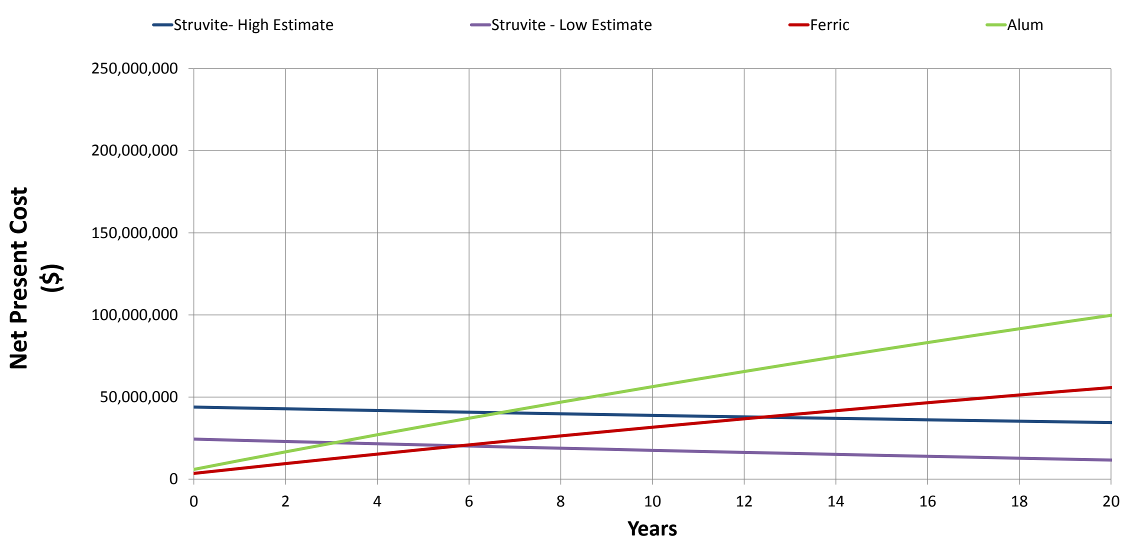

Figure 4-16. Summary of Payback Period for Plant 19 – Scenario 2.

Table 4-23. Plant 19 Summary of Costs Utilized for Deriving Conceptual Level Estimate.

Alum stock concentration	48	% $Al_2(SO_4)_3 \cdot 14H_2O$
Unit cost for alum	$ 400	per dry ton
Ferric chloride stock concentration	38	% $FeCl_3$
Unit cost for ferric chloride	$ 400	per dry ton
$MgCl_2$ stock concentration	30	% $MgCl_2$
Unit cost for $MgCl_2$	$ 600	per dry ton
NaOH stock concentration	25	% NaOH
Unit cost for caustic (NaOH)	$ 500	per dry ton
Lime ($Ca(OH)_2$) stock concentration	10	% $Ca(OH)_2$
Unit cost for lime $Ca(OH)_2$	$ 100	per dry ton
Unit cost for supplemental carbon	$ 0.18	per lb COD
Specify unit cost of anhydrous ammonia	$ 1,128.00	per dry ton
Specify unit cost of recovered struvite	$ 300	per dry ton

CHAPTER 5.0

CONCLUSIONS

5.1 Strategies to Navigate Barriers Limiting Implementation of Nutrient Recovery

Struvite crystallization and recovery is the most mature extractive nutrient recovery technology as it has been employed at over 20 facilities throughout the world (see Resource Recovery Technology Matrix – Nutrients available at www.werf.org). Therefore, it provides valuable key lessons for helping accelerate the implementation of extractive nutrient recovery options.

A review of existing full-scale struvite harvesting installations has shown that adoption of extractive nutrient recovery technologies is typically favorable when the payback periods are less than 10 years and when implementation of the recovery technology provides multiple benefits to the WRRFs. These benefits can include:

- Mitigating the impact of the sidestream nutrient content on the mainstream nutrient removal process and providing a factor of safety for mainstream EBPR.
- Minimizing nuisance struvite formation and re-gaining infrastructure capacity.
- Reducing chemical and energy costs.
- Reducing chemical sludge production (if metal salt addition is practiced).
- Manipulating the nutrient (phosphorus and nitrogen) content of biosolids.
- Improving sludge dewaterability.

Quantifying these and other site-specific benefits (cost and non-cost) can help make the economic case for implementing nutrient recovery technologies. Within this context, a summary of strategies employed by existing full-scale WRRFs to navigate the barriers limiting implementing nutrient recovery is provided in Table 5-1. This information has been translated into a framework that can be used to aid the decision making process (Figure 5-1).

Table 5-1. List of Considerations Associated with Adopting Extractive Nutrient Recovery.

Barrier	Considerations	Resolution
Technical	• Technologies are unknown entities. • Insufficient time and staff to review available technologies and decide on path forward.	• Utilize existing state of science technology review summaries, e.g., WERF NTRY1R12 Resource Recovery Technology Matrix - Nutrients, to review technology fundamentals and find references to existing installations. • Contact utilities that have experience with technology (see technology matrix for contact information). • Engage in WERF LIFT-TEP program on nutrient recovery to acquire further knowledge and experience with technology.
	• Insufficient data to evaluate technology performance i.e., % removal, struvite production. • Lack of manufacture's independent systematic performance information.	• Review case study guidance documents and TERRY – Phosphorus user manual to determine data needs. • Perform detailed sampling in collaboration with consulting engineer.
	• Insufficient experience in operating extractive nutrient recovery technology. • Lack of access to intellectual property created in trials with technology manufactures.	• Contact utilities that have experience with technology and schedule site visit (see technology matrix for contact information). • Engage in WERF LIFT-TEP program on nutrient recovery to acquire further knowledge and experience with technology. • If funds are available, pilot the technologies that are under consideration.
	• Unknown maintenance requirements and long-term operational viability.	• Contact utilities that have experience with technology and schedule site visit (see technology matrix for contact information). • Engage in WERF LIFT-TEP program on nutrient recovery to acquire further knowledge and experience with technology. • Provide flexibility in design to bypass and/or upgrade facility with improved technology.
Economic	• Insufficient and/or competing needs for funds. • Costs (cash and in-kind) associated with running technology trials at utilities.	• Utilize TERRY – Phosphorus to perform a preliminary evaluation to determine whether extractive nutrient recovery process can provide benefit to facility. • Perform detailed engineering evaluation in conjunction with consulting engineer. a. Consider additional benefits of implementing extractive nutrient recovery e.g., reduction in operating costs, reduction in energy costs,

Barrier	Considerations	Resolution
		mitigation of nuisance struvite formation, reduction of biosolids mass, benefits to land application rates. • Examine business models and delivery mechanisms utilized by technology providers to minimize capital and operating cost requirements. • Explore regionalization of service and importation of solids to increase scale of operation while charging tipping fees for imported solids.
	• Unknowns regarding cost of implementation, operating costs, etc.	• Review case study guidance documents to obtain point of reference for existing installations. • Contact utilities that have experience with technology (see technology matrix for contact information). • Utilize TERRY – Phosphorus to calculate order of magnitude estimates associated with capital and operating costs.
	• Uncertainty with respect to future demand for fertilizer product.	• Utilize existing state of science technology review summaries and market analyses, e.g., WERF NTRY1R12 Resource Recovery Technology Matrix, to determine regional demand for different fertilizer products. • Examine business models utilized by technology providers to guarantee operating costs/reimbursement costs for struvite production.
	Competition for product if many utilities adopt the technology.	• Examine business models utilized by technology providers to guarantee operating costs/reimbursement costs for struvite production. • Explore alternative routes for product entry into the fertilizer market. • Explore regionalization of service and importation of solids to increase scale of operation while charging tipping fees for imported solids.
Regulatory	Lack of regulatory drivers i.e., no effluent nutrient limits.	• Consider and quantify other benefits of technology e.g., reduction in operating costs, reduction in energy costs, mitigation of nuisance struvite formation, reduction of biosolids mass, benefits to land application rates
	Lack of public acceptance due to increases in utility bills and concerns with the safety of the final product.	• Engage the public to demonstrate benefits to the environment and impact on costs. • Increase public awareness through press releases, public hearings, tours.

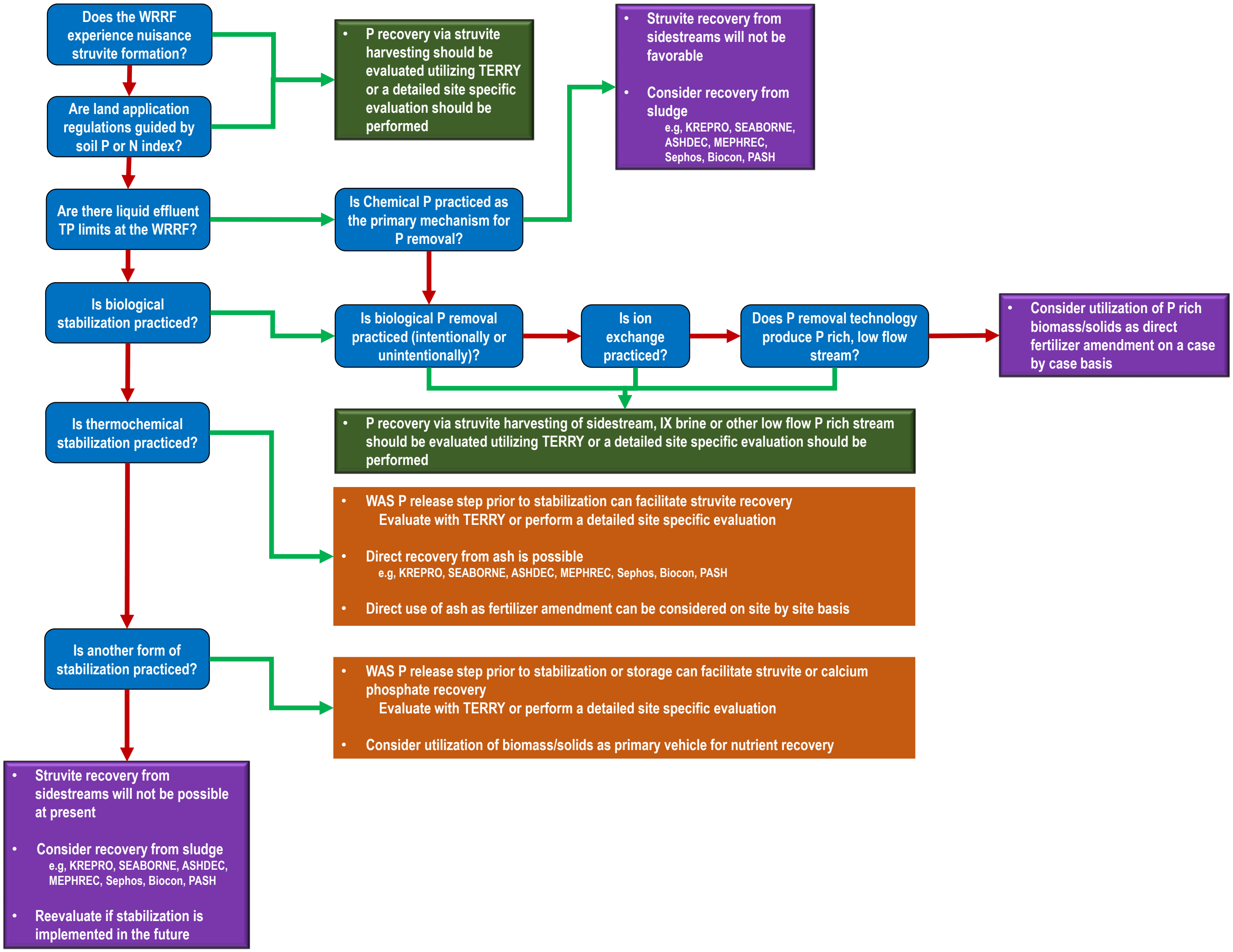

Figure 5-1. Decision Tree for Considering Extractive Nutrient Recovery.

5.2 Leveraging Benefits for Adopting Extractive Nutrient Recovery

Fundamentally, evaluating nutrient recovery must be a site-specific evaluation in order to properly quantify the aforementioned benefits; however, there are a few key elements that can be distilled within a consistent methodology:

- Capital cost estimates should take into account new building requirements as well as additional tankage that can be used for equalization and/or enhanced WAS release. Costs associated with odor control should also be factored into the evaluation.
- Operating cost evaluations should take into account all chemicals required including pH adjustment, magnesium, ammonia, and other acids (e.g., muriatic acid, citric acid, CO_2). A similar approach should be employed for the conventional treatment approach (assumed to be metal salt addition). As the regional cost of metals salts (e.g., ferric and alum) vary significantly, payback analyses must take this factor into account.
- Benefits analyses should quantify reductions in supplemental carbon requirements, reduction in aeration requirements, and reduction in biosolids production for nutrient recovery versus conventional alternative.
- If benefits are anticipated with respect to nuisance struvite formation, attempts should be made to quantify existing mitigation costs so that all options can be compared with a current action alternative. This includes a comparison of costs with the conventional treatment approach (assumed to be metal salt addition), whereby region specific costs of metals salts (e.g., ferric and alum) are taken into account.
- Where possible, calculations should also be undertaken to determine the benefits to N and P content of the biosolids and determine whether these changes have a favorable or non-favorable impact on land application requirements. If nitrogen containing precipitates are not predominant, the primary benefits to biosolids nutrient content will be related to the reduced phosphorus in the cake. It is also essential to note that these evaluations do not differentiate between plant available and non-available nutrients. Therefore, care must be taken to determine whether a benefit to plant available nitrogen and phosphorus in the biosolids cake can truly be attributed to the struvite harvesting process.

This approach can be rationalized by the underlying need for utilities to minimize capital and operating costs, particularly when considering new technologies. Individually, these benefits may not be sufficiently compelling to warrant adoption of recovery technology; however, when considered in tandem with each other, the economic and operating benefits may become sufficiently attractive to allow for implementation.

5.3 Next Steps for the Industry

Future research should focus on verifying the benefits noted for struvite recovery facilities. This should include whole plant sampling events coupled with benchmarking of nutrient levels and dewaterability characteristics pre- and post-implementation of recovery technologies.

Further research is also needed to understand whether recovery of other products like potassium struvite or hydroxyapatite can also be favorable at WRRFs. This work is needed to help the industry develop a diversified product catalogue. Diversification in this manner will provide WRRFs with the flexibility to select the chemical nutrient product with the highest potential value in a specific region. A critical element of this work will be developing data characterizing nutrient release and plant uptake to allow for direct comparisons with more conventionally produced fertilizers.

Lastly, it is necessary for the industry to track the true O&M requirements of the nutrient recovery technologies. At the time of this report, the first full-scale facility in North America was in operation for only five years. As these facilities continue to come online, it is necessary to independently assess the true cost of operating these facilities and determine whether the proposed benefits align with the initial claims.

APPENDIX A

REQUEST FOR INFORMATION FOR WERF PROPOSAL NO. NTRY1R12 NUTRIENT RECOVERY IN THE GLOBAL WATER INDUSTRY TECHNOLOGY PROVIDERS

HAZEN AND SAWYER. P.C
AND
CH2M

Confidentiality

Information included in this Request for Information (RFI) will be used to prepare reports as required by the Water Environment Research Foundation per RFP NTRY1R12 which addresses resource recovery in the global water industry. All attempts will be made to maintain the confidentiality of the information provided in response to this RFI. No proprietary information will be shared outside of the project team (Hazen and Sawyer, CH2M, and WERF). Additionally, all organizations participating in this study have the option of requesting anonymity in all publications.

Introduction and Purpose of the RFI

With this RFI, we request information regarding your organization and your products/services as related to WERF Project No NTRY1R12, which examines the barriers and challenges associated with implementing resource recovery in water and wastewater industries. The same information will be gathered from different organizations and will be used to develop a report that documents barriers and incentives for embracing nutrient recovery technologies during wastewater treatment. Physical references will also be included in technology fact sheets that will be part of the Water Environment Research Foundation report.

Organization Name
Clean Water Services
OSTARA
Multiform Harvest
Procorp
DHV Crystalactor
3XR
Paques
Battelle Memorial Institution
NuReSys bvba

Scope

Information is requested regarding process principles, prior experiences during technology implementation, and research and development efforts as applicable.

RFI Procedure

The overarching objective of this study is to gather and disseminate information on the current state of development of nutrient recovery including drivers and barriers to its adoption. This RFI has been carefully prepared to meet this objective. The project team (Hazen and Sawyer, P.C. and CH2M) recognizes that it may not be possible for technology providers to reveal information that may jeopardize their competitive advantage. Unless stated otherwise by the technology provider, the responses to this RFI will be evaluated and included in the final report, which will be available to WERF subscribers and the public at large.

Responses

Send the completed form and required attachments by email to Ron Latimer rlatimer@hazenandsawyer.com no later than **September, 7, 2012**.

Contacts

Contact persons listed here are available for assistance if needed.

Ron Latimer
Senior Associate
Hazen and Sawyer, P.C
(678) 244-6705
rlatimer@hazenandsawyer.com

Samuel Jeyanayagam
Vice President/Senior Principal Technologist
CH2M
(703) 376-5268
Samuel.Jeyanayagam@ch2m.com

Wendell Khunjar
Director of Applied Wastewater Research
Hazen and Sawyer, P.C
(703) 267-2759
wkhunjar@hazenandsawyer.com

Requested Information

We request information that describes:

- Process principles where applicable,
- Technological (including technical performance) details to the extent possible,
- Prior experiences in the implementation of technology where applicable,
- Operational and management costs associated with technology implementation
- Research and Development efforts to the extent possible.

This information will be used to perform an assessment of the economic, environmental and social benefits to using nutrient recovery strategies for treatment.

Specific data needs are provided below:

Technology Name:

- Provide the official name
- Provide aliases for this technology

Overview of Technology

- Provide a description of principles behind this technology
    - What is the primary recovered product from this technology?
    - Are there secondary products that can be recovered? If so, please provide the identity and chemical composition of these products.
- Provide a process flow diagram (PFD) of this technology. In scenarios where the PFD discloses proprietary information, please provide redacted PFDs.
- Provide process flow diagrams showing how this technology can/has been incorporated into existing treatment facilities.
- Provide details regarding the application of this technology within municipal wastewater treatment facilities, i.e., can/has this technology been applied for recovering resources from:
    - Mainstream flows.
    - Sidestream flows (e.g., supernatant recovered after dewatering of anaerobically digested sludge, supernatant from gravity thickened waste activated sludge).
    - Biological Sludge.
    - Chemical Sludge.
    - Incinerator Ash.
- Provide details regarding the application of this technology outside of the municipal wastewater treatment industry,
    - Industry.
    - Type of waste treated (e.g., food waste, agricultural wastes, etc.).
    - Products recovered.
- Provide details regarding the target and typical recovery efficiencies of this technology
    - % N recovery.
    - % P recovery.

Process Requirements

1) Provide detailed description of input requirements, e.g.:
   a. Minimum and maximum nitrogen and/or phosphorus concentration.
   b. Temperature.
   c. pH.
   d. Minimum and maximum flow rates per treatment module.
   e. Pre-treatment requirements (e.g., filtration, heating requirements).
   f. Other limiting conditions.
2) Provide a detailed description of additional chemical inputs needed
   a. Provide a list of all inputs and indicate whether continuous or on an as needed basis.
   b. Provide information regarding minimum quality requirements for each input.
   c. Provide information regarding quantities needed per lb of product recovered.
   d. Provide a list of alternative chemical inputs that can be used in lieu of the primary sources.
   e. Provide a costs associated with acquiring these chemicals.
   f. Provide contact information for sources of these chemicals.
3) Provide a detailed estimate of the mechanical equipment needed to implement this technology.
4) Provide a detailed estimate of the labor needs associated with operating this technology.
5) Provide an overview of the operational experiences associated with implementing these technologies including lessons learned.
6) Provide information describing energy requirements for the entire process.
7) Provide details regarding expected downtime (hrs or days) per year.

Recoverable Product(s)

1) Provide details regarding the primary and/or secondary products that are recovered with this technology
   a. Name.
   b. Chemical formula of product.
2) Provide details regarding the quality of product recovered (Provide chemical analysis, if possible)
   a. %N and/or %P
   b. Moisture content.
   c. Impurities
      i) Provide details regarding microbiological contaminants incorporated during wastewater processing.
      ii) Provide details regarding inorganic impurities such as heavy metals (e.g., cadmium, and organic micropollutants)
   d. Grain size.
   e. Special storage/handling requirements.
3) Provide details regarding the projected end-market use of these products.
   a. Provide market/economic assessment data associated with each product.
   b. Provide an estimate of future trends in product demand and market stability.
   c. Provide details on alternative markets for this product that can be employed in the event that the primary demand declines or disappears,
   d. Provide details on the estimated size of the primary market (e.g., tons per year),

        i) Could there be competition among wastewater treatment plants if widespread implementation of this technology occurs?
    e. Provide details on the minimum quantity of product that is needed to ensure that there is a viable supply in the marketplace.
    f. Provide details on how competitive wastewater agencies can participate in these markets.

Costs

1) Provide details regarding capital cost per treatment module associated with this technology.
2) Provide details regarding operation and maintenance costs associated with this technology
    a. How frequently would major parts or equipment need to be replaced or significantly refurbished, and which parts/equipment are these? Provide estimated replacement costs.
3) Minimum and maximum throughputs where technology would be cost-effective.
4) Provide details contrasting real payback vs. the projected payback for projects that have been implemented.

Scale of Testing

1) Provide data regarding testing of this technology at:
    a. Lab-scale (provide this data for embryonic technologies that have not been tested at pilot/full-scale).
    b. Pilot-scale.
    c. Full-scale.
    d. Minimum and maximum treatment module size available for full-scale implementation.

    Please include facilities that are currently testing, have tested or have installed this technology.
2) For each facility, please provide
    a. Location where tested/implemented.
    b. Year of testing/implementation.
    c. Size of plant flow being treated (MGD).
    d. Quantity of sidestream flow being treated (GPD).
    e. Characteristics of sidestream or mainstream flow being treated (TKN, TP, COD, etc.).
    f. Amount of product recovered (lbs/day).
    g. Contact information for each test site.

Procurement and Marketing Support

1) Provide details regarding the different procurement options that are available to clients e.g., Conventional Design Bid Build, Design Build, Design Build Operate, Design Build Own and Operate, Design-Build-Own-Operate-Finance, or some variation thereof.).
2) Provide details on end product marketing options that would be provided to the agency if the technology is implemented.

Challenges/Barriers to Implementation

1) Provide a list of challenges and barriers that are faced when selling this technology to wastewater agencies
    a. What conditions would need to be in place for a wider acceptance of your technology?
    b. Are these challenges region specific?
    c. How have you overcome these challenges?

2) Provide a list of criteria for the successful implementation of your technology at wastewater treatment plants.
3) What types of wastewater treatment plants would benefit most from your technology (e.g., nutrient removal permit requirements, long MCRT activated sludge, etc.).
4) What types of wastewater treatment plants would benefit least from your technology?
5) If this technology is not embraced by the water and wastewater industry, do you have contingency plans for approaching alternate industries?
   a. Provide a list of alternate industries in which this technology can/has been implemented.
   b. Provide a list of challenges and barriers that are faced when selling this technology in this alternate industry.
   c. Are these challenges region specific?
   d. How have you overcome these challenges?

APPENDIX B

REQUEST FOR INFORMATION FOR WERF PROPOSAL NO. NTRY1R12 NUTRIENT RECOVERY IN THE GLOBAL WATER INDUSTRY – UTILITIES

HAZEN AND SAWYER, P.C
AND
CH2M

Confidentiality

Information included in this Request for Information (RFI) will be used to prepare reports as required by the Water Environment Research Foundation per RFP NTRY1R12 which addresses resource recovery in the global water industry. All attempts will be made to maintain the confidentiality of the information provided in response to this RFI. No proprietary information will be shared outside of the project team (Hazen and Sawyer, CH2M, and WERF). Additionally, all organizations participating in this study have the option of requesting anonymity in all publications.

Introduction and Purpose of the RFI

With this RFI, we request information relevant to this WERF Project (# NTRY1R12). Specifically, the information gathered from our utility partners will be used to document barriers and incentives for embracing nutrient recovery technologies during wastewater treatment.

RFI Procedure

The overarching objective of this WERF study is to gather and disseminate information on the current state of development of nutrient recovery including drivers and barriers to its adoption. This RFI has been carefully prepared to meet this objective. The project team (Hazen and Sawyer, P.C. and CH2M) recognizes that some of the utilities receiving this RFI may have entered into a confidentiality agreement with one or more nutrient recovery technology providers, which may limit the information they are able to reveal, Unless stated otherwise by the utility, the responses to this RFI will be evaluated and included in the final report, which will be available to WERF subscribers and the public at large.

Responses

Send the completed form and required attachments by email to Ron Latimer rlatimer@hazenandsawyer.com no later than **September, 30, 2012**.

Contacts

Contact persons listed here are available for assistance if needed.

Ron Latimer
Senior Associate
Hazen and Sawyer, P.C
(678) 244-6705
rlatimer@hazenandsawyer.com

Samuel Jeyanayagam
Vice President/Senior Principal Technologist
CH2M
(703) 376-5268
Samuel.Jeyanayagam@ch2m.com

Wendell Khunjar
Director of Applied Wastewater Research
Hazen and Sawyer, P.C
(703) 267-2759
wkhunjar@hazenandsawyer.com

Requested Information

In general, this RFI solicits information specific to each utility. The type of information that is needed will depend on the utility's current status with respect to nutrient recovery. We expect your utility to belong to one of the following four categories.

1) **Identify the category your utility belongs to:**
   - ☐ **Category 1**: Have not initiated a study or on-site testing of nutrient recovery technologies. Please proceed to #2 below.
   - ☐ **Category 2**: Completed evaluation but have not implemented nutrient recovery. Please proceed to #3 below.
   - ☐ **Category 3**: In the process of implementing nutrient recovery. Please proceed to #4 below.
   - ☐ **Category 4**: Have an operating nutrient recovery system. Please proceed to #5 below.

2) **Requested Information from Category 1 Utilities (Have not evaluated nutrient recovery)**
   Note: Please respond to the queries as completely as possible. Use additional sheets if necessary.

a. Is the utility planning on initiating an evaluation of nutrient recovery in the next 12 months?
   - ☐ Yes. Pease indicate the planned effort and the anticipated start and completion dates.
   - ☐ No.

b. List the reasons (drivers) for the interest in nutrient recovery.

c. List the reasons (barriers) why the utility has not installed a nutrient recovery facility as yet.

d. Provide a copy (electronic preferred) of the master/facility plan or other sources that provide plant specific information such as:
   - i. Name of plant
   - ii. Capacity (average and peak)
   - iii. Liquid and solids treatment train
   - iv. Permit limits
   - v. Biosolids disposal method
   - vi. Historic plant data including return stream characteristics (5 years)
   - vii. Annual operating cost breakdown (3 years) – power, labor, chemicals, biosolids disposal, etc.

e. Does the plant have struvite and/or vivianite scaling issues?
   - ☐ Yes. Indicate location(s) of scaling. Describe how struvite scaling is currently managed? Provide estimate of annual labor requirements and cost of managing it.
   - ☐ No.

f. Any other reports or sources of information relevant to nutrient recovery?
   - ☐ Yes. Please provide copies of the reports.
   - ☐ No.

g. Please provide additional thoughts or comments regarding drivers and barriers to implementing nutrient recovery at municipal wastewater treatment plants.

3) **Requested Information from Category 2 Utilities (Completed evaluation but have not implemented nutrient recovery)**

Note: Please respond to the queries as completely as possible. Use additional sheets if necessary.

a. List the reasons (drivers) for evaluating nutrient recovery.
b. What work has been completed with respect to nutrient recovery?
   - ☐ Paper evaluation
   - ☐ Pilot study
   - ☐ Additional sampling (not associated with pilot study)
   - ☐ Preliminary design
   - ☐ Detailed design
   - ☐ Other, please describe
c. Provide the following for the completed work noted above:
   i. Brief scope description
   ii. Completion date
   iii. Listing of recommended improvements and estimated cost
   iv. The total fee for the completed work
v. Provide a copy (electronic preferred) of the final report.
d. Is the utility planning on moving forward with implementation of the recommended improvements?
   - ☐ Yes. Describe the next steps and provide anticipated schedule.
   - ☐ No. List the reasons (barriers) for not moving forward.
   - ☐ Delayed. List the reasons for delaying implementation. Provide the anticipated date of implementation, if known.
e. Provide a copy (electronic preferred) of the master/facility plan or other sources that provide plant specific information such as:
   i. Name of plant
   ii. Capacity (average and peak)
   iii. Liquid and solids treatment train
   iv. Permit limits
   v. Biosolids disposal method
   vi. Historic plant data including return stream characteristics (5 years)
   vii. Annual operating cost breakdown (3 years) – power, labor, chemicals, biosolids disposal, etc.
f. Does the plant have struvite and/or vivianite scaling issues?
   ☐ Yes. Indicate location(s) of scaling. Describe how struvite scaling currently managed? Provide estimate of annual labor requirements and cost of managing it.
   ☐ No.
g. Any other reports or sources of information relevant to nutrient recovery?
   ☐ Yes. Please provide copies of the reports.
   ☐ No.
h. Please provide additional thoughts or comments regarding drivers and barriers to implementing nutrient recovery at municipal wastewater treatment plants.

4) **Requested Information from Category 3 Utilities (In the process of implementing nutrient recovery)**

Note: Please respond to the queries as completely as possible. Use additional sheets if necessary.

a. List the reasons (drivers) for deciding to implement nutrient recovery.
b. What work was completed prior to making the decision to adopt nutrient recovery
    - Paper evaluation
    - Pilot testing
    - Additional sampling (not associated with pilot study)
    - Site visits
    - Pre-design report
    - Life cycle analysis
    - Pay-back period determination
    - Other, please describe
c. Provide the following for each of the completed work noted above:
    i. Brief scope description
    ii. Completion date
    iii. The total fee for the completed work
    iv. A copy (electronic preferred) of the final report.
d. Names of technology providers from whom proposals were solicited during the evaluation phase
e. Provide the following if on-site pilot testing was completed:
    i. Technologies tested?
    ii. Location of testing (centrate/filtrate, waste sludge)
    iii. Duration of testing
    iv. Operational schedule (hours/day; days/week.)
    v. Who operated the pilot units?
    vi. Was there opportunity for hands-on learning?
    vii. Cost of pilot testing?
    viii. Provide a copy of the pilot study report
f. Provide the following for the nutrient recovery system that is being/going to be installed.
    - Design criteria including nutrient flow and loading to the system
    - Size and number of all components necessary for a fully functional system including, but not limited to:
        - Struvite reactors
        - Chemical feed systems
        - Dewatering and drying equipment
        - All pumps
        - Chemical and storage
    - Process flow diagram
    - Facility layout showing all components and overall footprint requirements
    - Estimate of product generated (lbs/d) under average conditions.
    - Power, chemical, and man-hour requirements under average conditions

- Is the utility planning on increasing the staffing level to operate the nutrient recovery system?
- What are the anticipated plant-wide impacts of including nutrient recovery?

g. What is the project delivery method?
   - ☐ Conventional Design Bid Build
   - ☐ Design Build (DB)
   - ☐ Design Build Operate (DBO)
   - ☐ Design Build Operate Transfer (DBOT)
   - ☐ Other. Please specify

h. List the reasons for adopting this delivery method?

i. If DB/DBO/DBOT or a variation is being used, briefly describe the terms and conditions.

j. What is the capital cost associated with implementing this option?

k. Who is responsible for marketing the final product?

l. What is the anticipated annual revenue from product sale?

m. What is the anticipated payback period?

n. Please provide copies (prefer electronic version) of the following:
   - Equipment supply and product marketing contracts, if possible
   - All published papers on the project

o. Provide a copy (electronic preferred) of completed master/facility plan or other sources that provide plant specific information such as:
   i. Name of plant
   ii. Capacity (average and peak)
   iii. Liquid and solids treatment train
   iv. Permit limits
   v. Biosolids disposal method
   vi. Historic plant data including return stream characteristics (5 years)
   vii. Annual operating cost breakdown (3 years) – power, labor, chemicals, biosolids disposal, etc.

p. Does the plant have struvite and/or vivianite scaling issues?
   - ☐ Yes. Indicate location(s) of scaling. Describe how struvite scaling is currently managed. Provide estimate of annual labor requirements and cost of managing it.
   - ☐ No.

q. Please provide additional thoughts or comments regarding drivers and barriers to implementing nutrient recovery at municipal wastewater treatment plants.

Requested Information from Category 4 Utilities (Have an operating nutrient recovery system)

Note: Please respond to the queries as completely as possible. Use additional sheets if necessary.

a. List the reasons (drivers) for implementing nutrient recovery.
b. What work was completed prior to making the decision to adopt nutrient recovery
   - ☐ Paper evaluation
   - ☐ Pilot testing
   - ☐ Additional sampling (not associated with pilot study)
   - ☐ Site visits
   - ☐ Pre-design report
   - ☐ Life cycle analysis
   - ☐ Pay-back period determination
   - ☐ Other, please describe
c. Provide the following for each of the completed work noted above:
   i. Brief scope description
   ii. Completion date
   iii. The total fee for the completed work
   iv. A copy (electronic preferred) of the final report.
d. Names of technology providers from whom proposals were solicited during the evaluation
e. Provide the following if on-site pilot testing was completed:
   i. Technologies tested?
   ii. Location of testing (centrate/filtrate, waste sludge)
   iii. Duration of testing
   iv. Operational schedule (hours/day; days/week)
   v. Who operated the pilot units?
   vi. Was there opportunity for hands-on learning?
   vii. Cost of pilot testing?
   viii. Provide a copy of the pilot study report
f. Provide the following for the nutrient recovery system that is in use.
   - Design criteria including flow and loading to the system
   - Size and number of all components of the fully functional system including, but not limited to:
     - Struvite reactors
     - Chemical feed systems
     - Dewatering and drying equipment
     - All pumps
     - Chemical and product storage
   - Process flow diagram
   - Facility layout showing all components and overall footprint requirements
   - Operating data including mass balance, if available
   - Product generated (lbs/d) under average conditions.
   - Power, chemical, and man-hour requirements under average conditions

- Did the utility increase the staffing level to operate the nutrient recovery system?
- What is the initial operator training needs in terms of number of operator-days
- What are the plant-wide impacts of including nutrient recovery at your plant?

g. What was the project delivery method?
   - ☐ Conventional Design Bid Build
   - ☐ Design Build (DB)
   - ☐ Design Build Operate (DBO)
   - ☐ Design Build Operate Transfer (DBOT)
   - ☐ Other. Please specify

h. What were the reasons for adopting this delivery method?

i. If DB/DBO/DBOT or a variation was being used, briefly describe the terms and conditions.

j. What is the capital cost associated with implementing this option?

k. Who is responsible for marketing the final product?

l. What is the annual revenue from product sale?

m. What is the payback period?

n. Please provide copies (prefer electronic version) of the following:
   - Equipment supply and product marketing contracts, if possible
   - All published papers on the project

o. Provide a copy (electronic preferred) of completed master/facility plan or other sources that provide plant specific information such as:
   i. Name of plant
   ii. Capacity (average and peak)
   iii. Liquid and solids treatment train
   iv. Permit limits
   v. Biosolids disposal method
   vi. Historic plant data including return stream characteristics (5 years)
   vii. Annual operating cost breakdown (3 years) – power, labor, chemicals, biosolids disposal, etc.

p. Does the plant have struvite and/or vivianite scaling issues?
   - ☐ Yes. Indicate location(s) of scaling. Describe how struvite scaling is currently managed. Provide estimate of annual labor requirements and cost of managing it.
   - ☐ No.

q. Please provide additional thoughts or comments regarding drivers and barriers to implementing nutrient recovery at municipal wastewater treatment plants.

REFERENCES

Willis, J., L. Stone, K. Durden, C. Hemenway, and R. Greenwood (2012). Barriers to Biogas Use for Renewable Energy. WERF.

WERF Subscribers

WASTEWATER UTILITY

Alabama
Montgomery Water Works & Sanitary Sewer Board

Alaska
Anchorage Water & Wastewater Utility

Arizona
Avondale, City of
Peoria, City of
Phoenix Water Services Department
Pima County Wastewater Reclamation Department
Tempe, City of

Arkansas
Little Rock Wastewater

California
Central Contra Costa Sanitary District
Corona, City of
Crestline Sanitation District
Delta Diablo
Dublin San Ramon Services District
East Bay Dischargers Authority
East Bay Municipal Utility District
Encino, City of
Fairfield-Suisun Sewer District
Fresno Department of Public Utilities
Irvine Ranch Water District
Las Gallinas Valley Sanitary District
Las Virgenes Municipal Water District
Livermore, City of
Los Angeles, City of
Montecito Sanitation District
Napa Sanitation District
Novato Sanitary District
Orange County Sanitation District
Sacramento Regional County Sanitation District
San Diego, City of
San Francisco Public Utilities, City and County of
San Jose, City of
Sanitation Districts of Los Angeles County
Santa Barbara, City of
Santa Cruz, City of
Santa Rosa, City of
Silicon Valley Clean Water
South Orange County Wastewater Authority
Stege Sanitary District
Sunnyvale, City of
Thousand Oaks, City of

Colorado
Aurora, City of
Boulder, City of
Centennial Water & Sanitation District
Greeley, City of
Littleton/Englewood Wastewater Treatment Plant
Metro Wastewater Reclamation District
Platte Canyon Water & Sanitation District

Connecticut
Greater New Haven WPCA

District of Columbia
DC Water

Florida
Hillsborough County Public Utilities
Hollywood, City of
JEA
Miami-Dade County
Orange County Utilities Department
Orlando, City of
Palm Beach County
Pinellas County Utilities
Reedy Creek Improvement District
St. Petersburg, City of
Tallahassee, City of
Toho Water Authority

Georgia
Atlanta Department of Watershed Management
Augusta, City of
Clayton County Water Authority
Cobb County Water System
Columbus Water Works
Gwinnett County Department of Water Resources
Macon Water Authority
Savannah, City of

Hawaii
Honolulu, City & County of

Idaho
Boise, City of

Illinois
Greater Peoria Sanitary District
Metropolitan Water Reclamation District of Greater Chicago
Sanitary District of Decatur

Indiana
Jeffersonville, City of

Iowa
Ames, City of
Cedar Rapids Water Pollution Control Facilities
Des Moines, City of

Kansas
Johnson County Wastewater
Lawrence, City of
Olathe, City of

Kentucky
Louisville and Jefferson County Metropolitan Sewer District

Louisiana
Sewerage & Water Board of New Orleans

Maine
Bangor, City of
Portland Water District

Maryland
Anne Arundel County
Calvert County Water, Sewerage Division
Howard County Bureau of Utilities
Washington Suburban Sanitary Commission

Massachusetts
Boston Water & Sewer Commission
Upper Blackstone Water Pollution Abatement District

Michigan
Ann Arbor, City of
Gogebic-Iron Wastewater Authority
Holland Board of Public Works
Saginaw, City of
Wayne County Department of Public Services
Wyoming, City of

Minnesota
Metropolitan Council Environmental Services
Rochester, City of
Western Lake Superior Sanitary District

Missouri
Independence, City of
Kansas City Missouri Water Services Department
Metropolitan St. Louis Sewer District

Nebraska
Lincoln Wastewater & Solid Waste System

Nevada
Henderson, City of

New Jersey
Bergen County Utilities Authority

New York
New York City Department of Environmental Protection

North Carolina
Cape Fear Public Utilities Authority
Charlotte-Mecklenburg Utilities
Durham, City of
Metropolitan Sewerage District of Buncombe County
Old North State Water Company Inc.
Orange Water & Sewer Authority
Raleigh, City of

Ohio
Avon Lake Municipal Utilities
Columbus, City of
Dayton, City of
Metropolitan Sewer District of Greater Cincinnati
Northeast Ohio Regional Sewer District
Summit County

Oklahoma
Oklahoma City Water & Wastewater Utility Department
Tulsa, City of

Oregon
Bend, City of
Clean Water Services
Gresham, City of
Lake Oswego, City of
Oak Lodge Sanitary District
Portland, City of
Water Environment Services

Pennsylvania
Philadelphia, City of, Water Department
University Area Joint Authority

South Carolina
Beaufort - Jasper Water & Sewer Authority
Charleston Water System
Greenwood Metropolitan District
Mount Pleasant Waterworks
Spartanburg Water
Sullivan's Island, Town of

Tennessee
Cleveland Utilities
Murfreesboro Water & Sewer Department
Nashville Metro Water Services

Texas
Austin, City of
Dallas Water Utilities
Denton, City of
El Paso Water Utilities
Fort Worth, City of
Houston, City of
Kilgore, City of
San Antonio Water System
Trinity River Authority

WERF Subscribers

Utah
Salt Lake City Department of Public Utilities

Virginia
Alexandria Renew Enterprises
Arlington County
Fairfax County
Fauquier County
Hampton Roads Sanitation District
Hanover County
Hopewell Regional Wastewater Treatment Facility
Loudoun Water
Lynchburg Regional Wastewater Treatment Plant
Prince William County Service Authority
Richmond, City of
Rivanna Water & Sewer Authority
Upper Occoquan Service Authority

Washington
Everett, City of
King County Department of Natural Resources & Parks
Puyallup, City of
Seattle Public Utilities
Sunnyside, Port of

Wisconsin
New Water
Kenosha Water Utility
Madison Metropolitan Sewerage District
Milwaukee Metropolitan Sewerage District
Racine Water & Wastewater Utility
Sheboygan, City of
Stevens Point, City of
Wausau Water Works

Australia
Cairns Regional Council
Coliban Water
Goulburn Valley Water
Queensland Urban Utilities
Yarra Valley Water
Wannon Water
Water Services Association of Australia

Canada
Calgary, City of
EPCOR
Lethbridge, City of
Metro Vancouver
Toronto, City of
Winnipeg, City of

Denmark
VandCenter Syd

STORMWATER UTILITY

California
San Francisco Public Utilities, City & County of
Santa Rosa, City of
Sunnyvale, City of

Colorado
Aurora, City of

Florida
Orlando, City of

Iowa
Cedar Rapids Water Pollution Control Facilities
Des Moines, City of

Kentucky
Sanitation District No. 1

Pennsylvania
Philadelphia, City of, Water Department

Tennessee
Chattanooga Stormwater Management

Washington
Bellevue Utilities Department
Seattle Public Utilities

Wisconsin
Stevens Point, City of

STATE AGENCY

Connecticut Department of Energy and Environmental Protection
Harris County Flood Control District
Urban Drainage & Flood Control District, CO

CORPORATE

AECOM
Alan Plummer Associates Inc.
American Cleaning Institute
American Structurepoint, Inc.
Aqua-Aerobic Systems Inc.
ARCADIS
BCR Environmental
Black & Veatch Corporation
Brown and Caldwell
Burns & McDonnell
Carollo Engineers, P.C.
CDM Smith
CH2M
Clear Cove Systems, Inc.
D&B/Guarino Engineers LLC
Effluential Synergies LC
EMA Inc.
Environmental Operating Solutions Inc.
Evoqua Water Technologies
Gannett Fleming Inc.
GeoSyntec Consultants
GHD Inc.
Global Water Advisors Inc.
Greeley & Hansen LLC
Hazen & Sawyer P.C.
HDR Inc.
Holmes & McGrath Inc.
Jacobs Engineering Group Inc.
KCI Technologies Inc.
Kelly & Weaver P.C.
Kennedy/Jenks Consultants
KORE Infrastructure, LLC
Larry Walker Associates
LimnoTech
McKim & Creed
MWH
NTL Alaska Inc.
OptiRTC, Inc.
PICA Corporation
Pure Technologies Ltd.
RainGrid, Inc.
Ramboll Environ
Ross Strategic
Stone Environmental Inc.
Stratus Consulting Inc./ Abt Associates
Suez-Environnement
Synagro Technologies Inc.
Tata & Howard Inc.
Tetra Tech Inc.
The Cadmus Group Inc.
The Low Impact Development Center Inc.
Wright Water Engineers Inc.
Zoeller Pump Company

Austria
Sanipor Ltd.

Canada
Associated Engineering

Norway
Aquateam COWI AS

INDUSTRY

American Water
Bill & Melinda Gates Foundation
Chevron Energy Technology Company
DuPont
Eastman Chemical Company
Eli Lilly & Company
InSinkErator
Johnson & Johnson
Procter & Gamble Company
United Water Services LLC
Veolia Water North America
Water Services Association of Australia

List as of 10/8/15

WERF Board of Directors

WERF Research Council

WERF
Water Environment Research Foundation

WERF Product Order Form

As a benefit of joining the Water Environment Research Foundation, subscribers are entitled to receive one complimentary copy of all final reports and other products. Additional copies are available at cost (usually $10). To order your complimentary copy of a report, please write "free" in the unit price column. WERF keeps track of all orders. If the charge differs from what is shown here, we will call to confirm the total before processing.

Name Title

Organization

Address

City State Zip Code Country

Phone Fax Email

Stock #	Product	Quantity	Unit Price	Total
			Postage & Handling	
			VA Residents Add 5% Sales Tax	
			Canadian Residents Add 7% GST	
			TOTAL	

Method of Payment:

(All orders must be prepaid.)

❑ Check or Money Order Enclosed

❑ Visa ❑ Mastercard ❑ American Express

Account No. Exp. Date

Signature

Shipping & Handling:

Amount of Order	United States	Canada & Mexico	All Others
Up to but not more than:	Add:	Add:	Add:
$20.00	$7.50*	$9.50	50% of amount
30.00	8.00	9.50	40% of amount
40.00	8.50	9.50	
50.00	9.00	18.00	
60.00	10.00	18.00	
80.00	11.00	18.00	
100.00	13.00	24.00	
150.00	15.00	35.00	
200.00	18.00	40.00	
More than $200.00	Add 20% of order	Add 20% of order	

* minimum amount for all orders

Make checks payable to the Water Environment Research Foundation.

To Order (Subscribers Only):

Log on to www. werf.org and click on "Publications."

Phone: 571-384-2100
Fax : 703-299-0742

WERF
Attn: Subscriber Services
635 Slaters Lane
Alexandria, VA 22314-1177

To Order (Non-Subscribers):

Non-subscribers may order WERF publications either through WERF or IWAP (www.iwapublishing.com). Visit WERF's website at www.werf.org for details.

WERF

Water Environment Research Foundation
635 Slaters Lane, Suite G-110 ▪ Alexandria, VA 22314-1177
Phone: 571-384-2100 ▪ Fax: 703-299-0742 ▪ Email: werf@werf.org
www.werf.org
WERF Stock No. NTRY1R12b

Co-published by

IWA Publishing
Alliance House, 12 Caxton Street
London SW1H 0QS
United Kingdom
Phone: +44 (0)20 7654 5500
Fax: +44 (0)20 7654 5555
Email: publications@iwap.co.uk
Web: www.iwapublishing.com
IWAP ISBN: 978-1-78040-792-0

December 2015