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Manitoba Conservation and Climate
Environmental Stewardship Division
Environmental Compliance and Enforcement
1007 Century Street
Winnipeg, MB R3H 0W4

Attention: Shannon Kohler, Director

RE: NEWPCC INTERIM PHOSPHOROUS REMOVAL DETAIL REVIEW AND BENCHSCALE TESTING REPORT

The City of Winnipeg Water and Waste Department is submitting the attached report for your review. To assist in your review, the City and AECOM are available in January 2021 to go through the report with you and your staff.

The City plans to share the findings of the attached report to Winnipeg City Council for review and budget request in Q1 2021. If approved the City will submit a Notice-of-Alteration request to Manitoba Conservation and Climate and proceed to detailed design and construction. For this reason, the City is requesting that the report remain confidential. The Executive Summary will be publically posted on the City's Water and Waste website after Council consideration.

The findings of the report will be shared with members of the North End Sewage Treatment Plant (NEWPCC) Project Advisory Committee (PAC) in January 2021.

Should you have any questions on this report, please contact me at 204-986-4904 or by email at mpaetkau@winnipeg.ca.

Sincerely,

[redacted]

Michelle Paetkau, M.Sc., P. Eng.
Acting Branch Head of Wastewater Planning and Project Delivery

Attachment: NEWPCC Interim Phosphorous Removal Detail Review and Benchscale Testing Report

MP/dr

c: Siobhan Burland Ross, M. Eng., P. Eng., Manitoba Conservation and Climate (email)
Yvonne Hawryliuk, MSc, Manitoba Conservation and Climate (email)
M.L. Geer, CPA, CA, Water and Waste Department (email)

G.K. Patton, P. Eng., Water and Waste Department (email)
R. Grosselle, Water and Waste Department (email)
C. Carroll, Water and Waste Department (email)
C. Javra, Water and Waste Department (email)
D. Griffin, Water and Waste Department (email)

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City of Winnipeg

NEWPCC Interim Phosphorus Removal Detail Review and Benchscale Testing

Final Report

Prepared by:

AECOM
99 Commerce Drive
Winnipeg, MB, Canada R3P 0Y7
www.aecom.com

204 477 5381 tel
204 284 2040 fax

Prepared for:

City of Winnipeg
110-1199 Pacific Avenue
Winnipeg, MB R3E 3S8

Date: December, 2020

Project #: 60624189

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1	December 11, 2020	Mona Lashkarizadeh	Draft
2	December 17, 2020	K. Sears	Final

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AECOM
99 Commerce Drive 204 477 5381 tel
Winnipeg, MB, Canada R3P 0Y7 204 284 2040 fax
www.aecom.com

Michelle Paetkau, P.Eng.
Senior Planning Engineer
City of Winnipeg
110-1199 Pacific Avenue
Winnipeg, MB R3E 3S8

December 17, 2020

Project #
60624189

Dear Ms. Paetkau:

Subject: NEWPCC Interim Phosphorus Removal Detail Review and Benchscale Testing Final Report

AECOM is pleased to submit our final summary report for the NEWPCC Interim Phosphorus Removal Detail Review and Benchscale Testing Project (RFP 1179-2019). The report provides a summary of the analysis and evaluation for the three scenarios listed in the RFP and follow-up benchscale work conducted at the University of Manitoba. As well, the report includes a discussion of the risks and benefits associated with interim phosphorus removal and a Class 4 cost estimate of the recommended option.

We look forward to meeting with you to discuss this report and any comments that you may have.

Sincerely,
AECOM Canada Ltd.

[redacted]

Keith Sears, Ph.D., P.Eng.
Project Manager
Keith.Sears@aecom.com

KS:ag
Encl.

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AECOM: 2015-04-13

Authors

Report Prepared By: [redacted]

Matt Kowalski, Ph.D., EIT
Water/Wastewater Engineer-in-Training

[redacted]

Mona Lashkarizadeh, M.Sc., P.Eng.
Water/Wastewater Engineer

Report Reviewed By: [redacted]

Keith Sears, Ph.D., P.Eng.
Project Manager

[redacted]

Executive Summary

Scope

In 2019 AECOM conducted a preliminary review of eight options to temporarily reduce the phosphorus discharge from the North End Water Pollution Control Centre (NEWPCC) (Temporary Phosphorus Removal at NEWPCC, AECOM 2019). The report provided a short list of alternatives that should be evaluated in further detail.

In January 2020 the City retained AECOM (RFP No. 1179 2019) to conduct a detailed study to evaluate the three options as follows:

1. Scenario 1 – Dose additional ferric chloride to the anaerobic digesters.
2. Scenario 2 – Dose additional ferric chloride to the anaerobic digesters + primary clarifiers.
3. Scenario 3 – Dose additional ferric chloride to the anaerobic digesters + HPO reactors.

The scope of this study is to conduct detailed wastewater computer simulations using the BioWin™ software, and then confirm certain key model parameters with benchscale testing. The intent of benchscale work is to also identify any biological toxicity issues that the computer model is not able to predict. The overall goal of the project is to have confidence in the computer modelling work, and to be able to select an option as the basis for a conceptual design and cost estimate.

Background: Existing Infrastructure and Nutrient Removal Upgrades

The City of Winnipeg successfully upgraded the West End Water Pollution Control Centre (WEWPCC) to biological nutrient removal in 2008, and is currently upgrading the South End Water Pollution Control Centre (SEWPCC) to biological nutrient removal. At the NEWPCC, the City has recently completed the Enhanced Preliminary Design to upgrade to biological nutrient removal. Currently a new Headworks Facility Design/Build package is in the bid phase and expected to close in January 2021. This package will include a new raw wastewater pumping station, fine screening, grit removal, and standby power. These elements are all intended to improve the reliability and resilience of the NEWPCC and will improve the preliminary treatment for the subsequent new nutrient removal and biosolids upgrades.

With regards to regulations, the City of Winnipeg currently operates the NEWPCC under Environment Act Licence No. 2684 RRR dated June 2009 that outlines the terms and conditions for the operation of the NEWPCC.

Within the Environmental Act Licence there are nutrient limits both on the effluent to the Red River and on the sidestream treatment process that treats centrate from the anaerobic digesters. The City has successfully been meeting these sidestream limits since the sidestream treatment process was constructed in 2006.

The current liquid treatment process in NEWPCC consists of raw sewage pumping, screening, grit removal, primary clarification, secondary treatment (high purity oxygen or HPO) reactors, secondary clarifiers, and disinfection using ultraviolet (UV) irradiation.

Sludge generated at the WEWPCC and the SEWPCC is trucked to the NEWPCC, and then treated in the anaerobic digesters. When a treatment facility removes phosphorus, the phosphorus is simply transferred from the liquid phase to the sludge. Therefore, once the SEWPCC nutrient removal upgrade comes on-line the phosphorus load stored in the sludge trucked to the NEWPCC will more than double. During the anaerobic treatment process, this additional phosphorus will release and needs to be immobilized to prevent it from returning into the NEWPCC mainstream process.

Wastewater Modelling (BioWin) and Benchscale Testing

A model for the current treatment process at the NEWPCC was developed and calibrated using the plant's historical data. The modelling work confirmed that the capacity of the anaerobic digesters becomes the limiting factor in implementing interim phosphorus removal at the NEWPCC.

Scenario 1 is the only option that does not impact the overall capacity of the digesters. This option is capable of reducing the overall phosphorus load to the Red River from the NEWPCC by about 8 percent per year. However, more importantly Scenario 1 addresses the more than 150 tonnes/yr of phosphorus that will be trucked from the SEWPCC to the NEWPCC digesters and will eliminate significant maintenance issues (i.e., nuisance struvite formation).

Scenario 2 and Scenario 3 both have an impact on digestion capacity. It is estimated that both scenarios could be used at the NEWPCC for about 9 months of the year and would be capable of reducing the overall phosphorus load to the Red River from the NEWPCC by about 23 percent per year. The overall goal would be to reduce effluent total phosphorus concentration without negatively impacting other treatment processes at the NEWPCC. This assumes that during periods of high wastewater loads, or when a digester is taken out of service, then ferric chloride dosing to the primary clarifiers or HPO reactors would need to be turned off.

Benchscale tests conducted at the University of Manitoba between September and October, 2020 generally confirmed the key parameters used in the BioWin model. Two parameters in the benchscale work that differed from the model was the ratio of ferric chloride to phosphorus removal and chemical sludge production in Scenarios 2 and 3. The University work indicated that Scenarios 1 and 2 required less ferric chloride, while Scenario 3 needed more ferric chloride to remove a given amount of phosphorus. The benchscale work also indicated higher sludge production values than the modelling work. The study did not indicate any adverse toxic effects of increased ferric dosing on the anaerobic digestion process or HPO reactors. While, the parameters that differed in the benchscale study may have an impact on overall removal efficiencies, they will not impact the capital costs presented in this report. Overall, based on the results of the University work, it was concluded that the BioWin model for average conditions was sufficiently accurate to use as the basis for a conceptual design and cost estimate. Due to Covid-19 and the University of Manitoba shutdown, maximum month conditions were not tested in March 2020. It is anticipated that the maximum month testing will be completed in March 2021 to verify the impacts of higher wastewater loads.

Preliminary Cost Estimates

AECOM prepared a Class 4 AACE level cost estimate for the expansion of the ferric chloride storage and pumping system at the NEWPCC (**Table ES 1**). This includes a new chemical building for additional ferric chloride and sodium hydroxide storage, new piping, dosing pumps, and ancillary items. This level of cost estimate is defined by the AACE as projects that are at the feasibility level stage, and should be considered as having a range of accuracy within -30% to +50%.

An optional cost of $2,000,000 has been included in the cost estimate for the delivery of ferric chloride railcars to the NEWPCC, which has been identified as a particular risk to the project. The existing chemical unloading system at the NEWPCC can accommodate one railcar at a time. Based on the reliability of chemical delivery from Canadian National and Canadian Pacific railways, an allowance to upgrade the City's unloading system to a two-railcar system has been provided as an optional item.

Table ES1: Preliminary Cost Estimate for Chemical System Expansion at NEWPCC

Description	Estimated Total Capital Cost
Capital Cost	$ 4,830,000
Engineering (15%)	$ 725,000
Sub-total	**$ 5,555,000**
Contingencies (50%)	$ 2,780,000
Total	**$ 8,400,000**
Additional Railcar receiving Bay (Optional)*	**$ 2,000,000**

The current railcar receiving station is designed to receive and unload one railcar at a time. A second bay can be added to the receiving station to allow for receiving two railcars.

Implementing Scenario 1, 2 or 3 will approximately triple the amount of ferric chloride needed at the NEWPCC. It will also require that an additional chemical (sodium hydroxide) be used to maintain a neutral pH in the digesters. These additional chemicals will increase the overall Operation and Maintenance (O&M) costs up to $2,200,000/yr.

Recommendation

It is recommended that the conceptual design be based on providing the ability to dose ferric chloride to the digesters, the primary clarifiers, and the HPO reactors. This provides Operations staff with the flexibility to operate Scenario 1, Scenario 2, and/or Scenario 3. As there are some differences between the modelling and benchscale work, it is expected that full scale testing will more accurately verify removal efficiencies and impacts on digesters capacity.

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Appendices

Appendix A. Mass Balance
Appendix B. JAAO Environmental Engineering Report

1. Introduction

1.1 Current Process and Ferric Chloride Addition at NEWPCC

According to Environment Act Licence 2684 RRR and the Notice of Alternation response received on December 5, 2019, as of January 1, 2020, the North End Water Pollution Control Centre (NEWPCC) is required to meet the final effluent quality listed in **Table 1** for all flows less than 705 ML/d. In response to the January 1, 2020, compliance date, the City of Winnipeg (the City) indicated that prior to implementing interim phosphorus removal, further testing is required to assess potential risks to other treatment processes and the safety of the operations staff. The objective of this study was to evaluate potential options for implementing interim phosphorus removal at the NEWPCC prior to construction of the NEWPCC Biological Nutrient Removal (BNR) Upgrade Project.

Table 1: New NEWPCC Effluent Limits

Parameter	Limit	Unit	Occurrence
BOD	25	mg/L	98th percentile
TSS	25	mg/L	98th percentile
E. Coli	200	Most Probable Number (MPN)/100 ml	Monthly geometric mean
TP	1	mg/L	30-day rolling average
TN	15	mg/L	30-day rolling average
Ammonia	Variable	Kg N/d	Daily

The current liquid treatment process in the NEWPCC consists of raw sewage pumping, screening, grit removal, primary clarification, secondary treatment (high purity oxygen or HPO) reactors, secondary clarifiers, and disinfection using ultraviolet (UV) irradiation.

The primary and secondary sludge generated in the liquid stream are co-thickened in the primary clarifiers. The co-thickened sludge from the NEWPCC and the hauled sludge from the West End Water Pollution Control Centre (WEWPCC) and the South End Water Pollution Control Centre (SEWPCC) are stabilized through anaerobic digestion and dewatering.

The centrate from the centrifuges (dewatering process) is further treated in the sidestream sequencing batch reactors (SBRs) for ammonium removal prior to being recycled to the mainstream.

Following the completion and commissioning of the SEWPCC BNR Upgrade the total phosphorus concentration in the SEWPCC's effluent discharged to the Red River will be less than 1 mg/L. Most of the phosphorus removed from the wastewater will be retained in the sludge and transported to the NEWPCC for treatment which will increase the phosphorus load at the NEWPCC.

The NEWPCC sidestream treatment SBR effluent is regulated under Environment Act Licence No. 2684 RRR.

The limits set for the SBR effluent are 119 kg/d of total phosphorus (TP) and 838 kg/d of total nitrogen (TN), both based on a 30-day rolling average. The phosphorus stored in sludge; however, is released during anaerobic digestion; therefore, ferric chloride is dosed to recapture the phosphorus in order to meet the SBR effluent limit.

Currently ferric chloride is dosed at two points around the anaerobic digesters. Ferric chloride is added to the primary sludge line before the digesters and after the digesters (prior to the dewatering) to control hydrogen sulfide concentration, struvite formation and to remove phosphorus. The current total dose of ferric chloride is on average approximately 600 kg Fe/d. With the upcoming SEWPPC BNR upgrade, it is expected that the phosphorus load will increase which will necessitate a higher ferric chloride dose to the anaerobic digesters.

2. Operational Limits

AECOM reviewed the background documents and met with the City's operation staff to identity the plant's operational limits based on the previous studies and staff experience. Of the operational limits evaluated, two were identified as the most important and were to be considered during the evaluation of each scenario.

2.1 Anaerobic Digesters

There is a total of six anaerobic digesters at the NEWPCC. Four of the digesters (Digesters 9, 10, 11 and 12) were constructed between 1963 and 1965. The two newer digesters (Digesters 3 & 14) were constructed in 1986. All six digesters are 33.5 m in diameter. Digesters 9, 10, 11 and 12 have a flat bottom with an operating depth of 7.05 m. The digestion volume provided by the four older digesters is 6,200 m^3 each.

According to Veolia's Technical Memorandum #1, "Operational Impact of SEWPCC Upgrade/ Expansion Project on Anaerobic Digesters" Digesters 13 and 14 have a conical bottom with an operating level of 7.05 m to account for observed permanent foam blankets in the digesters. Therefore, the volume provided by the straight wall portion is 6,200 m^3 and the cone part of the digesters provide an approximate volume of 585 m^3. The total volume provided by each of the two newer digesters is 6,785 m^3. It is assumed that all 6 digesters will be in service in the year 2023 and the combined total digestion volume available will be 38,370 m^3.

Solids loading rate and solids retention time are important design parameters for anaerobic digesters. The volatile solids (VS) loading rate is used to ensure stable performance of the anerobic digestion process and to prevent upset conditions that may lead to failure of the digestion process. A previous study by Veolia (Technical Memorandum #1, "Operational Impact of SEWPCC Upgrade/ Expansion Project on Anaerobic Digesters", 2015) indicated the average allowable volatile solids load was 86,333 kg VS/d assuming all 6 digesters in service. The maximum allowable load was in turn estimated at 122,784 kg VS/d. Assuming a VSS/TSS ratio of 0.71 the allowable average and maximum total solids (TS) loading rates are 121,596 kg TS/d and 172,935 kg TS/d, respectively.

Solids retention time is used to assure that sufficient time is available for solids digestion. Following a previous study by Veolia (Technical Memorandum 2/3 – Operational Impact of SEWPCC Upgrade/Expansion Project on Anaerobic Digesters, 2016) the minimum recommended solids retention time in the digesters is 15 days at 35^oC. If the SRT decreases below 15 days, the anaerobic digestion process efficiency can be negatively affected. Using the SRT criteria, the maximum sludge volume that can be fed to the digesters is 2,558 m^3/d.

2.1.1 Primary Clarifiers

Following discussions with the City, the primary sludge concentration at NEWPCC's primary clarifiers is 3.5%. Increasing the thickness of the primary sludge beyond this point impacts the operation of the HPO reactors. Hence, 3.5% primary sludge thickness was used for all models.

3. BioWin Modelling

3.1 Purpose and Scope of the Modelling Work

A model for the current treatment process at the NEWPCC was developed in BioWin 6.0 modelling software and was calibrated using the plant's historical data. The goal of the modelling work was to assess the impact of chemical phosphorus removal on the operation of the anaerobic digesters and other mainstream processes, and to assess the impact on the plant's overall mass balance through the liquid and solid stream processes in the year 2023. The modelling work focused on three different scenarios in which ferric chloride would be dosed to anaerobic digesters, primary clarifiers and/or high-purity oxygen reactors.

3.2 Interim Phosphorus Removal Options

3.2.1 Increased Sidestream Chemical Phosphorus Removal – Scenario 1

Increased sidestream chemical phosphorus removal was modelled with ferric chloride dosed into the two points simulating the current operational strategy at the NEWPCC (**Figure 1**). Annual average and max month flows and loads were modelled. The additional ferric chloride dose was added to the anaerobic digesters in order to achieve soluble phosphorus concentration in the centrate below 20 mg PO_4-P/L and to reduce nuisance non-ferric precipitation below 600 kg/d.

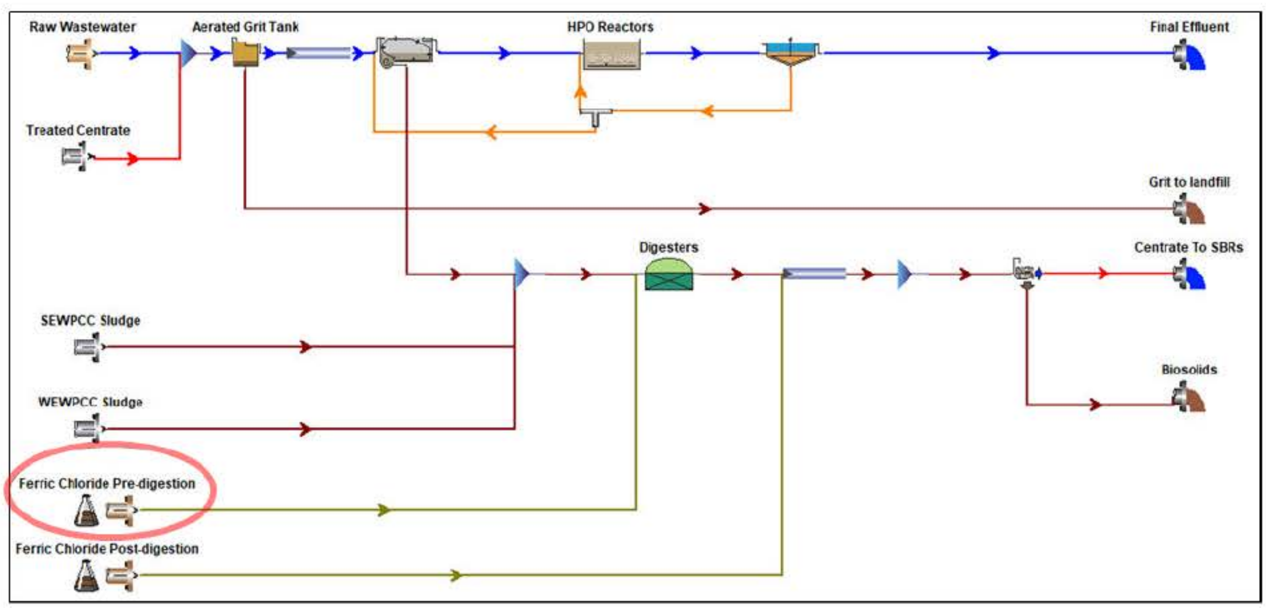

Figure 1: NEWPPC Process Flow Diagram for Scenario 1
(Ferric chloride dosed before and after anaerobic digesters)

3.2.2 Chemically Enhanced Primary Treatment – Scenario 2

Chemically enhanced primary treatment (CEPT) was modelled with an increased dose of ferric chloride added to the anaerobic digesters (Scenario 1) plus an additional dose to the mixing channel downstream of the grit removal tanks and before the Primary Clarifiers (**Figure 2**). The goal was to determine the effect of chemical phosphorus removal on downstream processes. Annual average and max month flows and loads were modelled. The ferric chloride dose to the anaerobic digesters and primary clarifiers was adjusted in order to achieve soluble phosphorus concentration in the centrate below 20 mg PO_4-P/L, reduce nuisance non-ferric precipitation below 600 kg/d and reduce total phosphorus concentration in the final effluent.

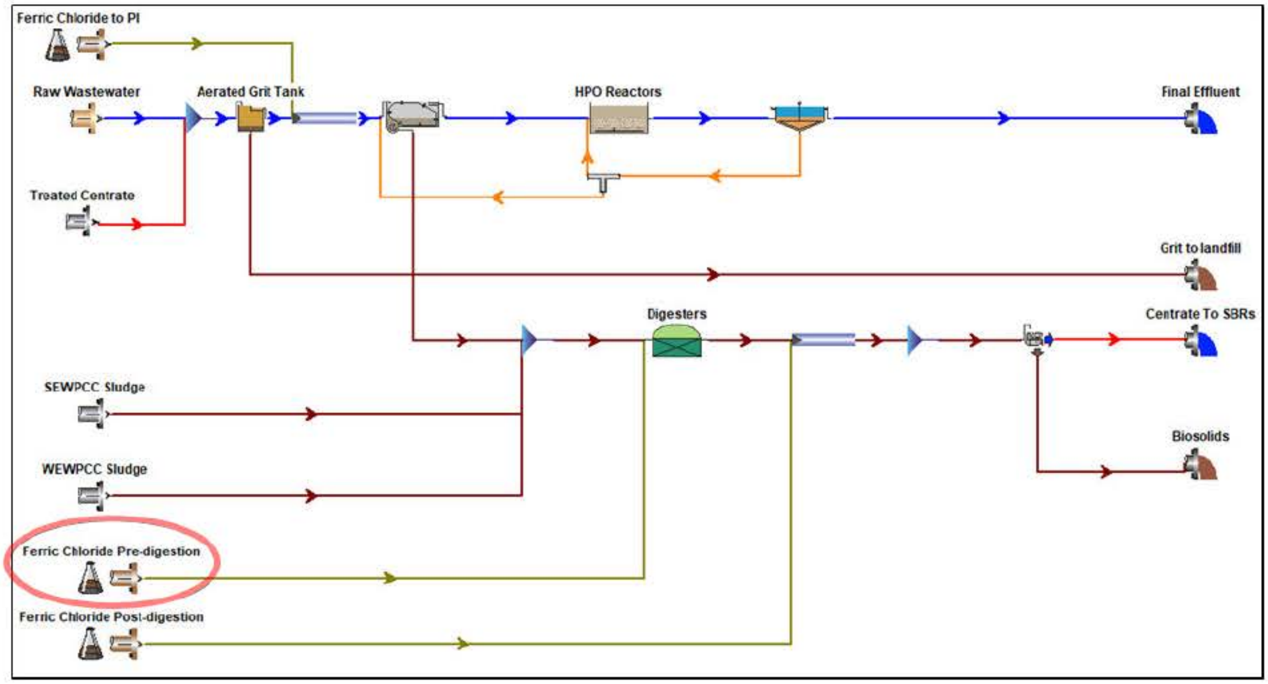

Figure 2: NEWPPC Process Flow Diagram for Scenario 2
(Ferric chloride dosed to the primary influent channels as well as before and after the anaerobic digesters)

3.2.3 Chemical Phosphorus Removal in HPO Reactors – Scenario 3

Chemical phosphorus removal in Scenario 3 was modelled with an increased dose of ferric chloride added to anaerobic digesters (Scenario 1) plus an additional dose to the HPO reactors (**Figure 3**). The goal was to determine the effect of chemical phosphorus removal on downstream processes. Annual average and max month flows and loads were modelled. The ferric chloride dose to the anaerobic digesters and HPO reactors were adjusted in order to achieve soluble phosphorus concentrations in the centrate below 20 mg PO_4-P/L, reduce nuisance non-ferric precipitation below 600 kg/d, and reduce total phosphorus concentrations in the final effluent.

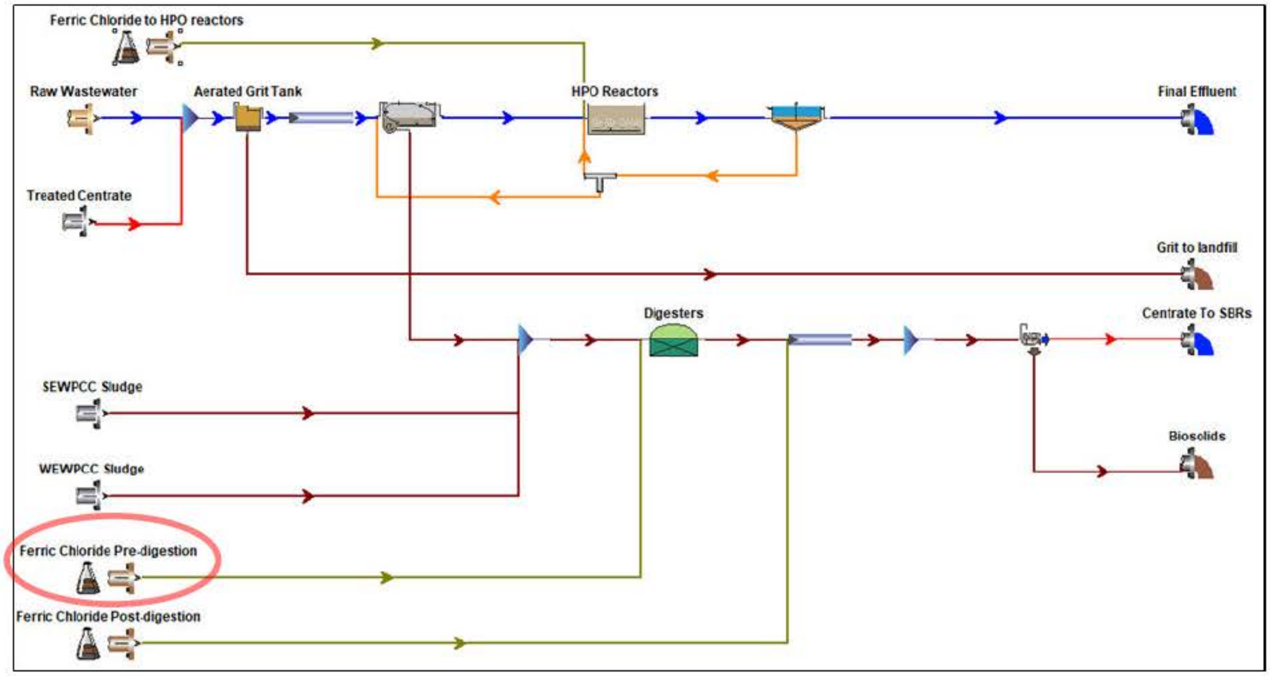

Figure 3: NEWPPC Process Flow Diagram for Scenario 3
(Ferric chloride dosed to the HPO bioreactors as well as before and after the anaerobic digesters)

3.3 Max Month and Max Week Conditions

Based on the seasonal influent loading variations between NEWPCC, SEWPCC and WEWPCC, it is possible that a maximum month or maximum week influent load condition could happen simultaneously at each of the three treatment plants. This in turn would result in increased solids loading to the NEWPCC digesters. Under such conditions the anaerobic digesters would be operating below the target SRT. **Figure 4** shows a comparison between digester SRT under different conditions and scenarios. Under average conditions the SRT is around 16-18 days. However, under max month conditions it drops to 11 days. Under these conditions the SRT is below the recommended minimum value of 15 days. Under max week conditions it decreases to 8 days. As described earlier this is below the recommended operating SRT of 15 days. The SRT of the digesters is primarily governed by the flow of primary sludge from the clarifiers.

While the City currently experiences short term SRT drops below 15 days, they mitigate these events by buffering sludge volumes in the primary clarifiers to limit the sludge flow to the digesters. They also increase the digester temperature to 37°C to offset the lower SRT over the short term. While these strategies are helpful in maintaining short term digester performance, it is a balancing act between preserving sidestream and mainstream performance. It is important for the City to maintain the sludge buffering capability in their primary clarifiers to maintain digester performance. Since Scenario 2 and Scenario 3 reduce the buffering capacity, they are not recommended during maximum month conditions.

It is also worth mentioning that SEWPCC sludge is trucked to the NEWPCC at a concentration of approximately 3.5%. After the SEWPCC upgrade is complete, the City will have the ability to thicken sludge above 3.5% with the newly installed rotary drum thickeners (RTD). This will decrease the volume of sludge trucked from the NEWPCC and could improve the digester operation at NEWPCC. Since the SEWPCC is still under construction, the performance of the RDTs cannot yet be confirmed.

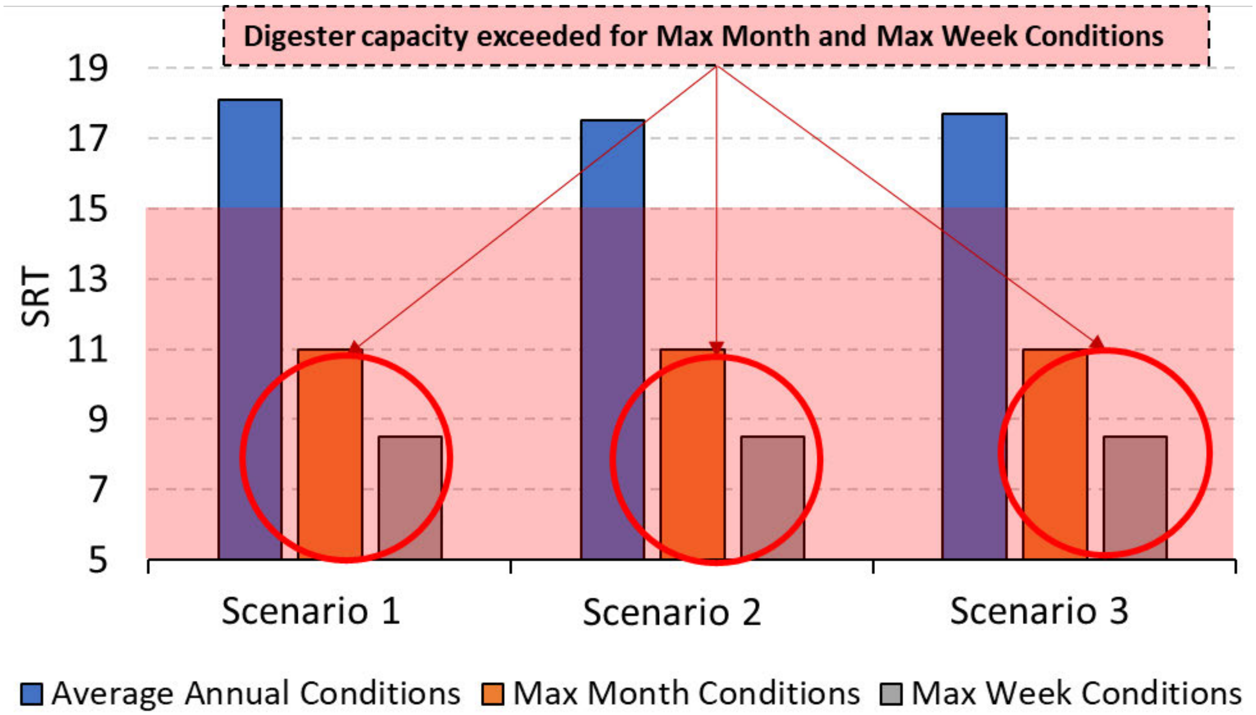

Figure 4: Anaerobic Digester SRT under Different Conditions and Scenarios

3.4 Overview of Modelling Results for Scenario 1

During the development of the models several sensitivity analyses were run in order to investigate the relationships between various process parameters and ferric chloride dosages. The sensitivity analyses were used to identify operational risks and establish practical limits for chemical phosphorus removal.

3.4.1 Effect of Ferric Chloride Dose on Anaerobic Digesters

The models were run with different ferric chloride doses to asses the impact on several operational parameters including primary sludge production, non-ferric precipitation, centrate and final effluent phosphorus concentrations during annual average conditions.

In Scenario 1 ferric chloride is dosed to the anaerobic digesters. **Figure 5** shows the relationship between the ferric chloride dose and anaerobic digesters SRT when primary sludge concentration is controlled at 3.5%.

Figure 5 shows that the SRT is approximately 18 days and ferric chloride does not have a significant impact on the SRT in the digesters. This is because the volume of ferric chloride solution is insignificant compared to the flow of sludge.

Figure 5 also shows the relationship between the ferric chloride dose and the final effluent TP concentration. Without increasing the ferric chloride dose, the phosphorus concentration in the final effluent discharged to the Red River would be approximately 3.5 mg/L. The model shows that the final effluent TP concentration can be reduced to as low as 3.1 mg/L by dosing approximately 1600 kg Fe/d to the digesters.

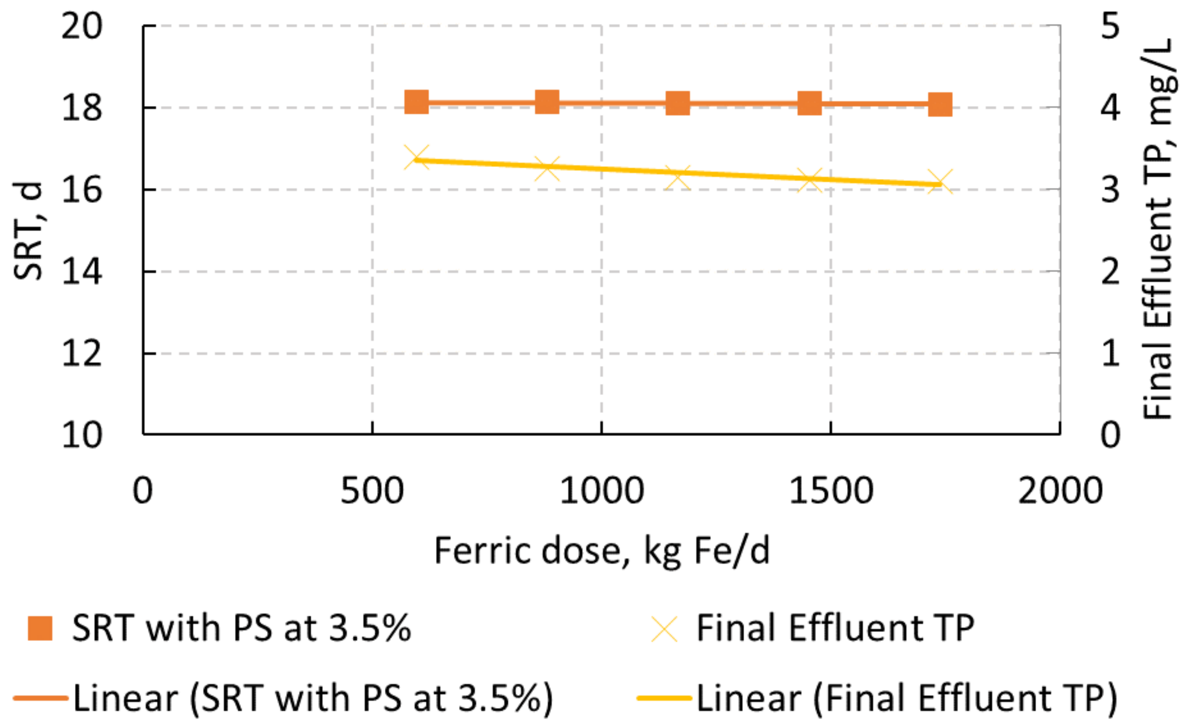

Figure 5: Scenario 1 – Annual Average Model – Effect of Ferric Chloride Dose on Anaerobic Digesters SRT and Final Effluent Phosphorus Concentration

3.4.2 Effect of Ferric Chloride on Nuisance Precipitation

In Scenario 1, additional ferric chloride is dosed to the anaerobic digesters to keep the soluble phosphorus concentration in the centrate as close as possible to the current values. During anaerobic digestion the phosphorus stored in the biomass is released and can react with ammonium, calcium and magnesium to form various precipitates including struvite, hydroxy-apatite, brushite and vivianite. These precipitates are known to cause scaling in the tanks and pipes which results in pipe clogging and more frequent maintenance and cleaning requirements. Dosing ferric chloride to the anaerobic digesters also serves to reduce the formation of these precipitates since iron oxide has a higher affinity for ortho-phosphate than the aforementioned elements.

The model was run with various ferric chloride doses to assess the impact of dose on the amount of precipitation and soluble phosphorus concentration in the centrate.

The relationship between ferric dose and formation of the nuisance non-ferric precipitates is shown in **Figure 6**. The reduction in the formation of these precipitates is linearly proportional to the ferric dose.

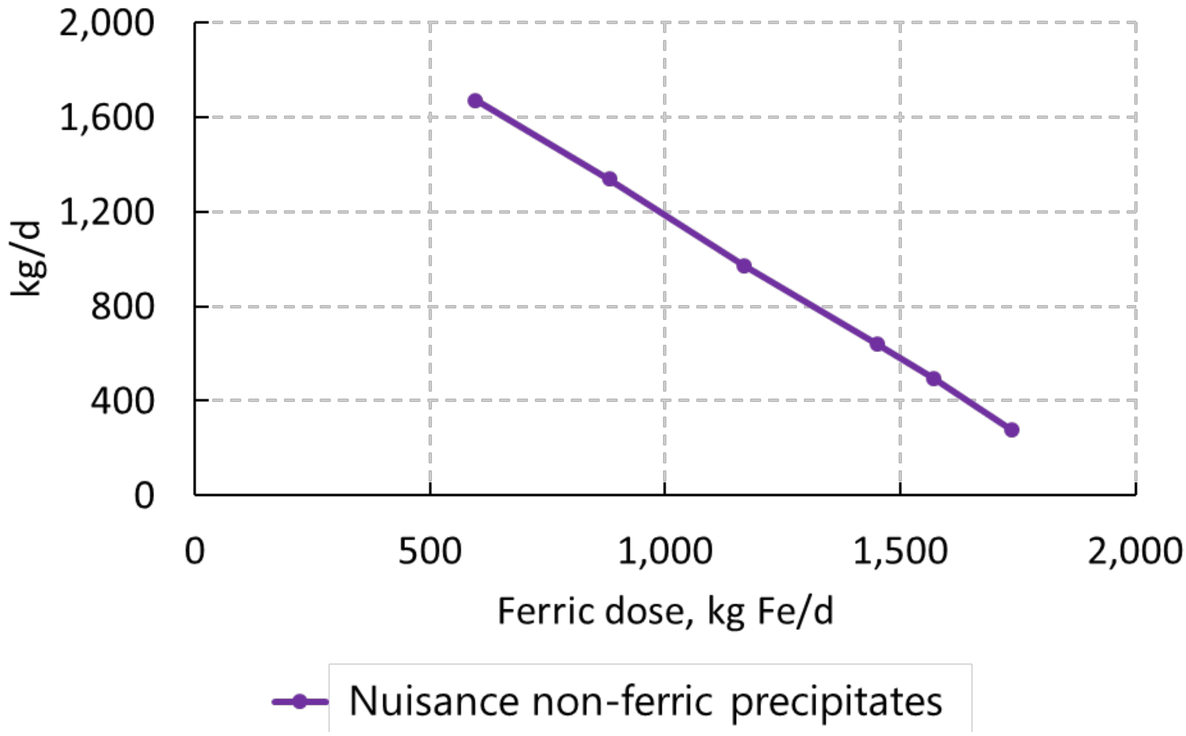

Figure 6: Scenario 1 – Annual Average Model – Effect of Ferric Chloride Dose on Precipitate Formation

Additionally, the precipitation potential between different scenarios was compared in **Figure 7**. Based on historical data, currently approximately 600 kg/d of precipitates could be formed in the solids stream processes. In comparison, if the current dose was kept the same, in 2023 that amount would potentially increase to as much as 1700 kg/d due to the extra phosphorus load from the SEWPCC. The model predicted that in order to limit the amount of precipitation to the current levels, approximately 1600 kg Fe/d should be dosed to the anaerobic digesters which is an increase of 1000 kg Fe/d from the current dose. These estimates are, however, based on the typical concentrations of magnesium and calcium in municipal wastewater, which may vary.

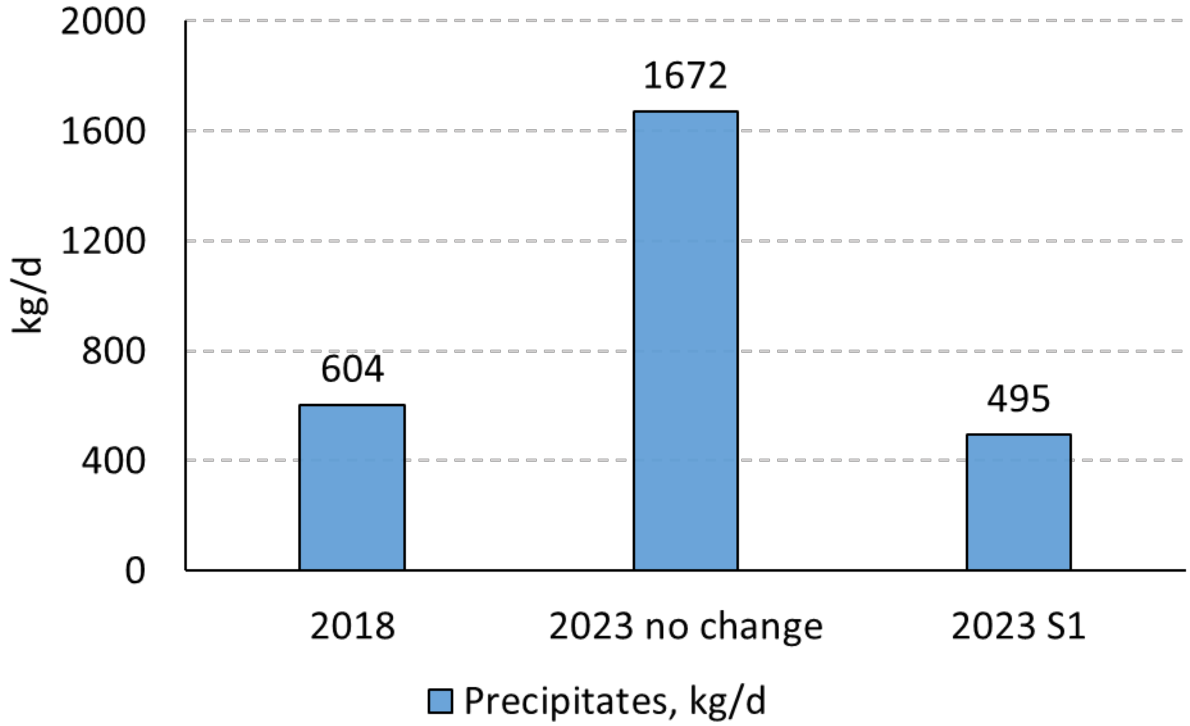

Figure 7: Scenario 1 – Annual Average Model – The Non-Ferric Precipitation Potential between Different Scenarios

3.5 Overview of Modelling Results for Scenario 2

Implementation of Scenario 1 reduces ortho-phosphate in the centrate and also controls nuisance non-ferric precipitation. Further phosphorus removal can be achieved by dosing additional ferric chloride to the mainstream. This approach is represented in Scenario 2 and Scenario 3. However, the level of phosphorus removal is limited by the amount of sludge produced due to its effects on the operation of primary clarifiers and/or the effect of ferric chloride on the HPO reactors and secondary clarifiers. Based on discussions with the City, and their operational experience with accommodating additional sludge in the primary clarifiers and digesters, AECOM modelled Scenario 2 such that the final effluent concentration was reduced to 2.5 mg/L. This was thought to limit the risk to other processes within plant.

The modelling results presented in Section 3.4 indicate that approximately 1600 kg Fe/d can be dosed to the anaerobic digesters, with the dose of ferric chloride added to the primary clarifiers determining the phosphorus concentration in the final effluent. **Figure 8** shows the effect of varying ferric chloride dose to the primary clarifiers on centrate ortho-phosphate concentration and nuisance precipitation. With a ferric dose of 1600 kg Fe/d to the digesters (**Figure 8**) and no additional ferric dose to the primary clarifiers, the amount of nuisance precipitation would be approximately 500 kg/d which is slightly less than the current levels. With an additional 750 kg Fe/d dosed to the primary clarifiers, nuisance precipitation further decreases to 200 kg/d and the concentration of ortho-phosphate in centrate would be approximately 10 mg/L. With the same dose, the final effluent TP concentration would be reduced from 3.1 mg/L to approximately 2.5 mg/L.

HPO reactors accumulate carbon dioxide in the headspace which results in a relatively low pH (approximately 6.5) in the mixed liquor. Adding higher dose of ferric chloride to the mainstream will consume alkalinity in the wastewater and may decrease the pH in the HPO reactors. Low pH can impact the biological processes in the reactors. The modelling results were further verified with benchscale testing to account for the impact of ferric chloride dosing on pH and toxicity. Benchscale testing results are presented in Section 4.

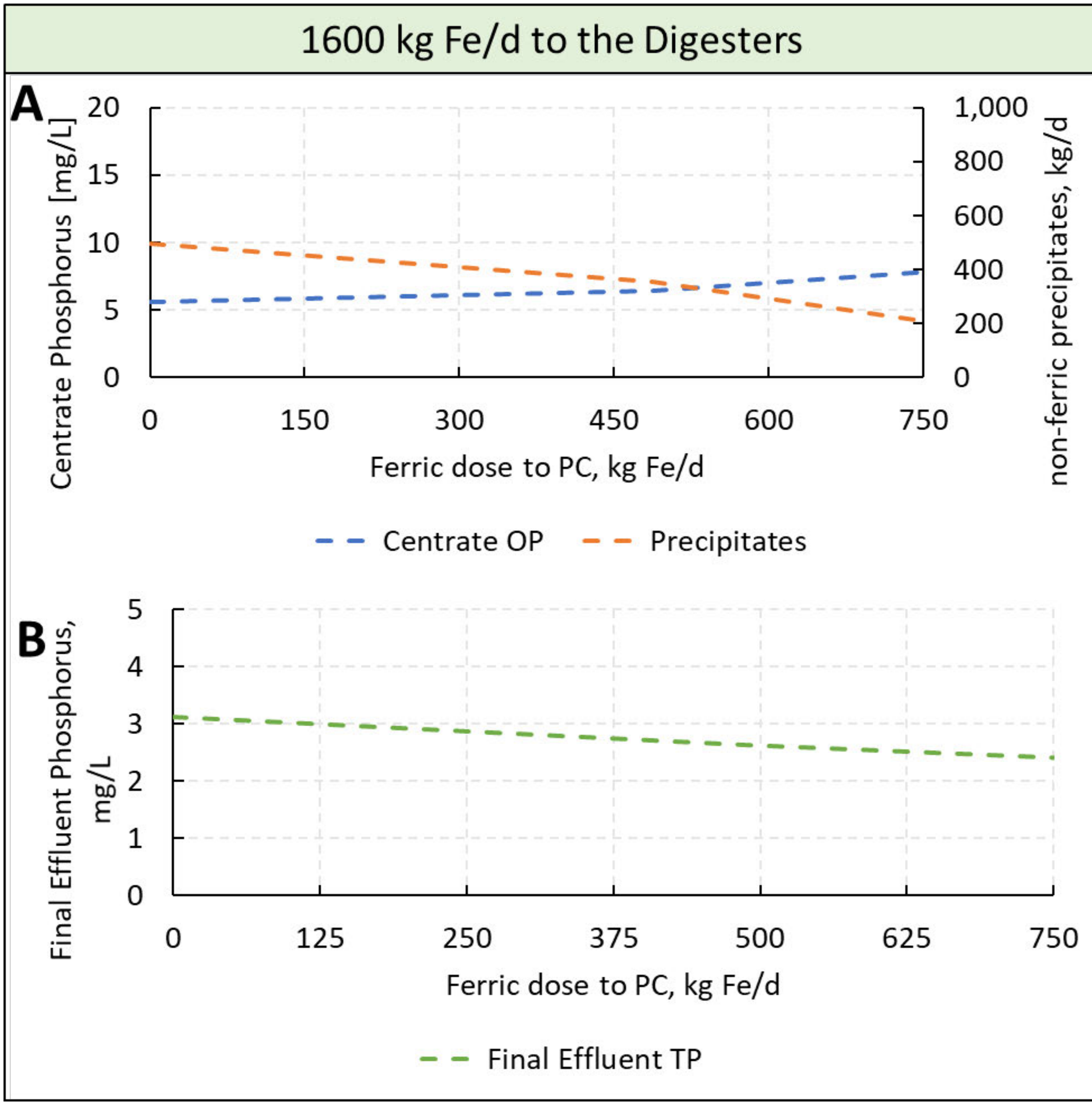

Figure 8: Scenario 2 – Annual Average Model – Effect of Ferric Dose to Primary Clarifiers on Centrate Ortho-Phosphate Concentration, Nuisance Precipitation (A) and Final Effluent Phosphorus Concentration (B)

In Scenario 2, ferric chloride dosing to the primary clarifiers increases primary sludge production. **Figure 9A** shows the relationship between primary sludge production and ferric dose. The sludge production increased from around 52,000 kg/d to almost 55,000 kg/d with a ferric chloride dose of 750 kg Fe/d to the primary clarifiers. This is an increase of approximately 6% in solids load to the anaerobic digesters.

Figure 9B shows the relationship between the ferric chloride dose and the anaerobic digester SRT. At a primary sludge concentration of 3.5% and no ferric chloride dose to the primary clarifiers, the anaerobic digester SRT was approximately 18 days. The SRT, however, decreases with increased ferric dose due to the higher flow of primary sludge. With a ferric chloride dose of 750 kg Fe/d to the primary clarifiers, the SRT decreased to approximately 17.5 days.

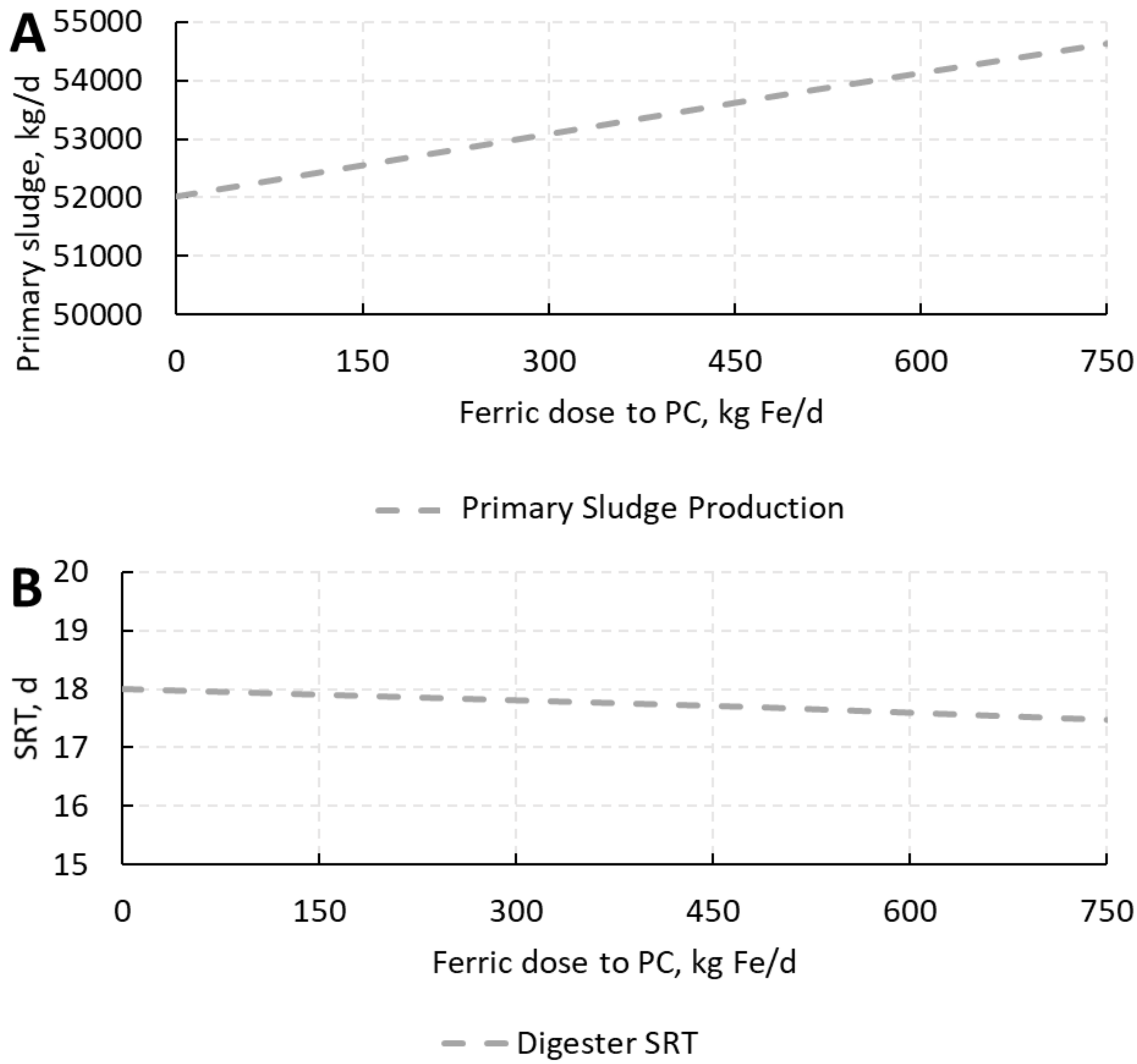

Figure 9: Scenario 2 – Annual Average Model – Effect of Ferric Dose to Primary Clarifiers on Primary Sludge Production (A) and Anaerobic Diesters' SRT (B)

3.6 Overview of Modelling Results for Scenario 3

In Scenarios 3, the additional ferric chloride is dosed directly to the HPO reactors. **Figure 10A** shows the effect of different ferric chloride doses to the HPO reactors on centrate ortho-phosphate concentration and nuisance precipitation in the anaerobic digesters. With a ferric chloride dose of 1600 kg Fe/d to the digesters and no additional ferric chloride dose to the HPO reactors, the amount of nuisance precipitation would be approximately 500 kg/d. The concentration of ortho-phosphates would be approximately 5 mg/L. As with Scenario 2, and the operational experience at the NEWPCC, AECOM modelled the impacts of dosing ferric chloride to the HPO reactors, such that the final effluent TP concentration was less than 2.5 mg/L. This was thought to limit the impacts of clarifier sludge loading rates and maintain sludge production to within acceptable levels. Modeling results indicated that additional ferric chloride dose of 300 kg Fe/d to the HPO reactors could reduce the final effluent TP concentration from 3.1 mg/L to approximately 2.5 mg/L without negatively impacting other treatment processes at the NEWPCC.

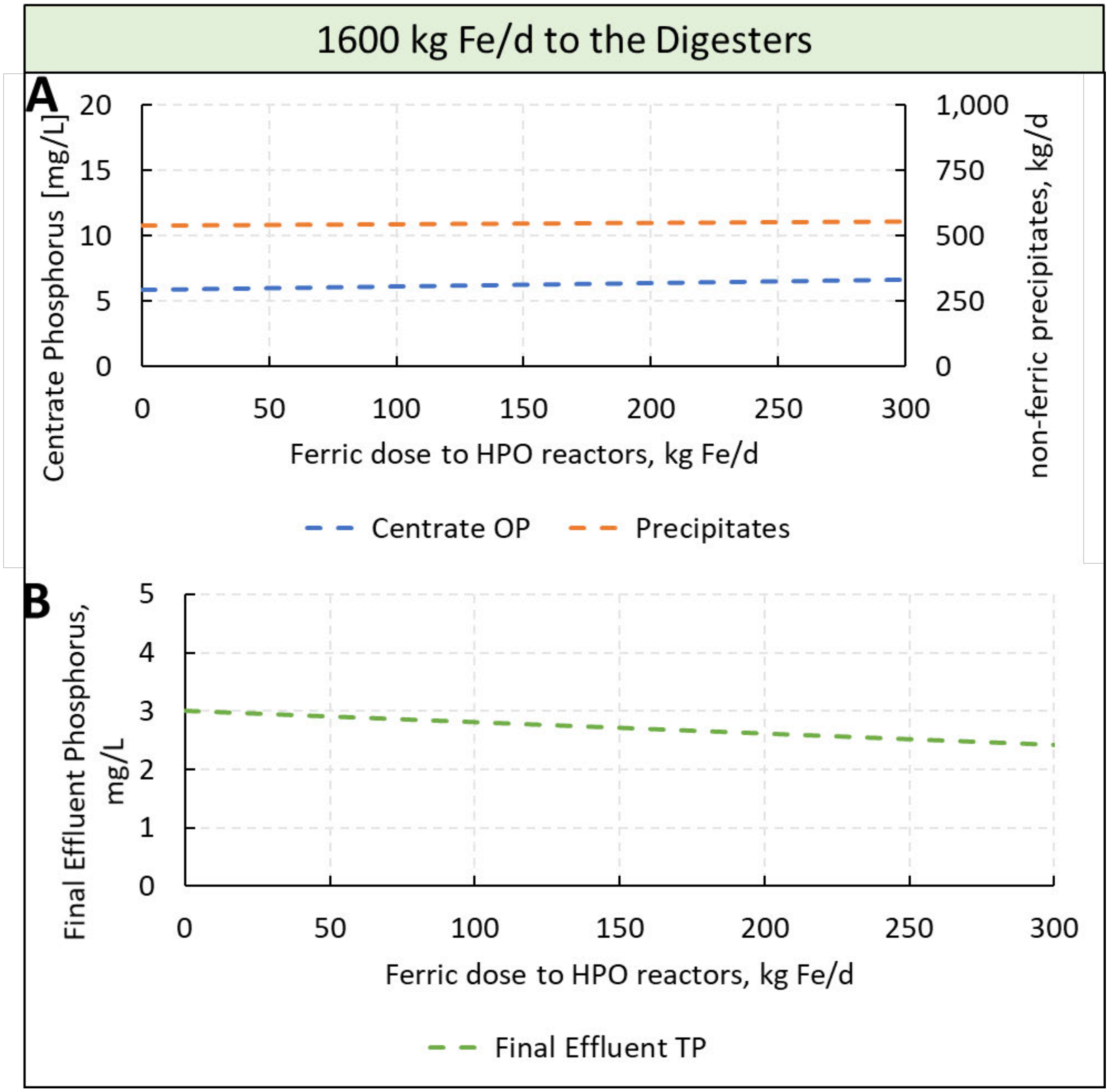

Figure 10: Scenario 3 – Annual Average Model – Effect of Ferric Dose to the HPO Reactors on Centrate Ortho-Phosphate Concentration, Nuisance Precipitation (A) and Final Effluent Phosphorus Concentration (B)

In this scenario, ferric precipitates in the HPO reactors and is removed with waste activated sludge (WAS). Since WAS is co-thickened in the primary clarifiers this also affects primary sludge production. **Figure 11A** shows primary sludge production vs ferric dose in Scenario 3. The sludge production increased from around 52,000 kg/d to almost 53,000 kg/d at a ferric dose of 300 kg Fe/d.

Figure 11B shows the relationship between ferric chloride dose and anaerobic digesters SRT when primary sludge concentration was controlled at 3.5%. Scenario 3 had a less significant impact on the digester SRT compared to Scenario 2.

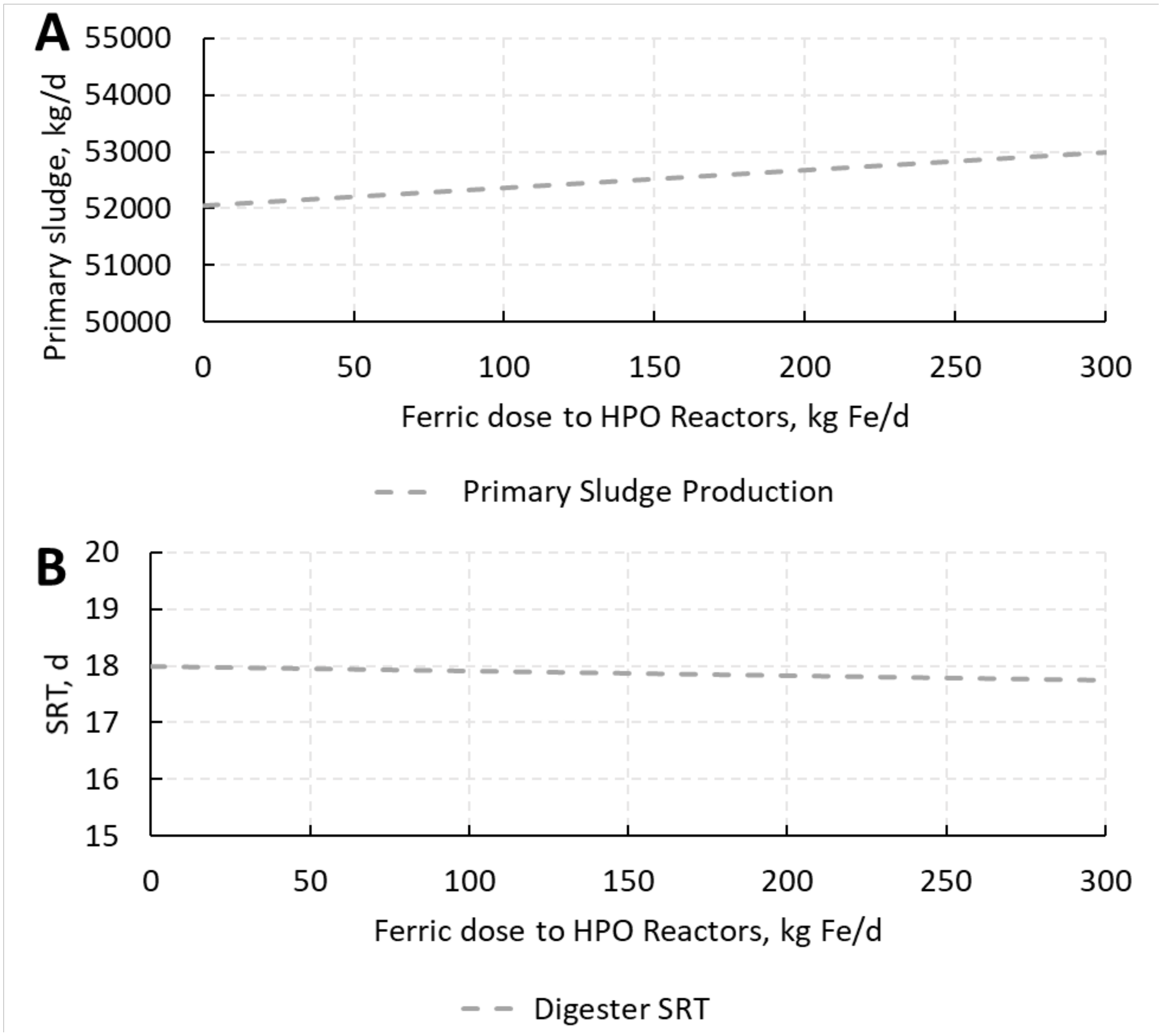

Figure 11: Scenario 3 – Annual Average Model – Effect of Ferric Dose to Primary Clarifiers on Primary Sludge Production (A) and Anaerobic Diester SRT (B)

3.7 Comparison

Both Scenarios 2 and 3 have the potential to reduce the overall phosphorus load to the Red River from the NEWPCC.

Figure 12[1] shows the reduction in the phosphorus load discharged to the Red River from both NEWPCC and SEWPCC. The total phosphorus load discharged to the Red River from the NEWPCC for Scenario 1 is approximately 8% lower and for Scenarios 2 or 3 approximately 23% lower than the "no change" scenario. It was assumed that Scenario 1 can be implemented on a year-round basis, while Scenarios 2 and 3 can be implemented for 9 months of the year.

[1] *The graph is based on the annual average loads and removals to estimate the effluent TP loads. It was assumed that the sidestream removal will be all-year round. For S2 and S3, it was assumed that they will be used during 9 months in a year and removal during the 3 months would be the same as S1.*

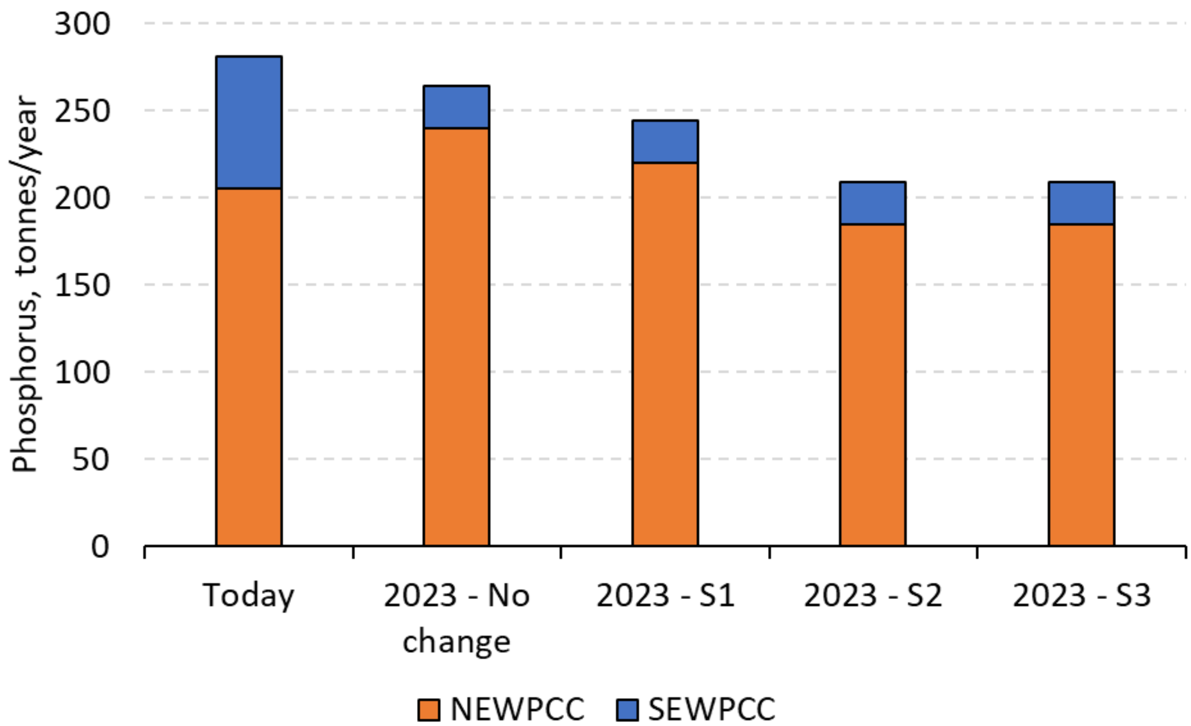

Figure 12: Comparison of Phosphorus Load to Red River

4. Benchscale Testing

4.1 Purpose and Scope of the Benchscale Testing

A series of benchscale phosphorus removal tests were conducted at the University of Manitoba's Environmental Engineering Laboratory. Three different interim phosphorus removal scenarios were tested for average conditions and the impact of each on various parameters including alkalinity consumption (pH), sludge production, and anaerobic digestion was investigated. Tests were developed to replicate steady state conditions expected at NEWPCC. A more detailed explanation of the procedures can be found in **Appendix B**.

Scenario 1 simulated side stream phosphorus removal where soluble phosphorus is precipitated in two steps; during and after anaerobic digestion. Scenario 2 simulated CEPT where soluble phosphorus is precipitated during the primary clarification process. Finally, Scenario 3 simulated phosphorus removal in HPO reactors where soluble phosphorus is removed during the biological carbon removal process. Results obtained during benchscale testing were used to better estimate the required coagulant doses necessary to achieve desired levels of phosphorus removal.

4.2 Scenario 1: Side-Stream Chemical Phosphorus Removal

In this option, ferric chloride was dosed to a blend of NEWPCC and WEWPCC sludges prior to digestion and subsequently after bio-methanation potential (BMP) tests to achieve less than 20 mg PO_4-P/L in the centrate. The primary objective of this scenario was to maintain the current effluent soluble phosphorus concentration with the projected increased phosphorus load from SEWPCC.

Benchscale tests investigated the required ferric chloride doses and the impact of the ferric chloride doses on alkalinity and pH, and its overall effects on digestion.

4.2.1 Results

Samples from NEWPCC and WEWPCC were collected and analyzed, **Table 2** summarizes the raw sample characteristics.

Table 2: Scenario 1 Raw Sample Characteristics

Parameter	Unit	NEWPCC Primary Sludge	NEWPCC Digested Sludge	WEWPCC Sludge
pH		5.79	7.08	5.04
Alkalinity	mg $CaCO_3$/L	840	2,680	420
Total Solids (TS)	mg/L	26,832	13,274	32,458
Volatile Solids (VS)	mg/L	21,990	8,550	27,844
Ortho-P	mg/L	77.1	97.2	483.0

NEWPCC primary sludge and WEWPCC holding tank sludge were combined at a ratio of 7:3 to replicate conditions once SEWPCC BNR upgrades are complete. The mixed sludge characteristics are summarized in **Table 3**.

Table 3: NEWPCC Primary Sludge and WEWPCC Holding Tank Sludge Mixture Characteristics

Parameter	Unit	NEWPCC PS + WEWPCC Sludge
pH		5.57
Alkalinity	mg $CaCO_3$/L	1,020
TS	mg/L	28,526
VS	mg/L	23,526
Ortho-P	mg/L	207.9

4.2.1.1 Ferric Chloride Dose Upstream of Anaerobic Digestion

Jar testing was completed on the sludge mixture for four different ferric chloride doses. The four ferric chloride doses prior to digestion were 0, 135, 250, and 500 mg Fe/L of sludge; the control dose, the current dose for hydrogen sulfide control, half the BioWin predicted dose, and the BioWin predicted dose, respectively. A total of four sets of jar tests were completed with the following conditions: no pH adjustment, a duplicate of no pH adjustment, pH adjusted to 6 during jar tests, and pH adjusted to 7 during jar tests.

The results indicate that ferric chloride addition at higher doses (above 135 mg Fe/L) caused a drop in pH, which also affected ortho-phosphate removal (**Figure 13**).

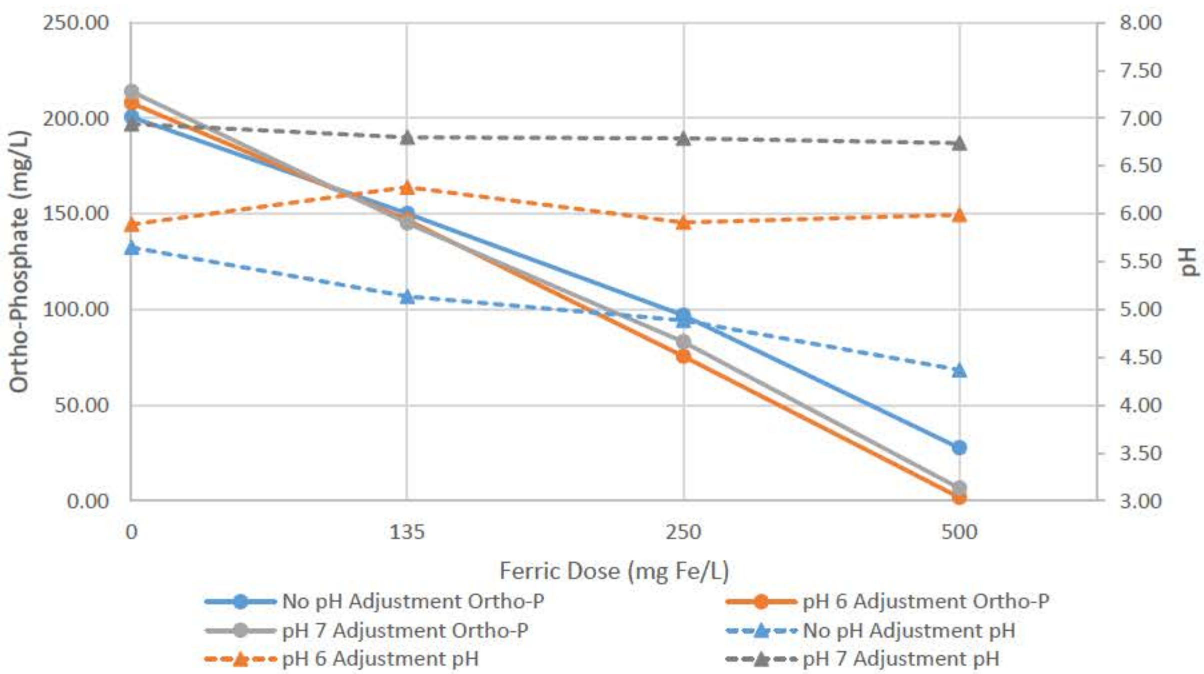

Figure 13: Soluble Ortho-Phosphate and pH for Scenario 1 Jar Tests

4.2.1.1.1 Impacts on Anaerobic Digestion

After 20 minutes of reaction time, 35.7 mL of the sludge from the jar test was added to 464.3 mL of NEWPCC digested sludge to replicate the current digester volumetric loading rate of 0.07 $m^3/m^3/d$ based on historical data for the

NEWPCC. The 500 mL bottles were placed in a water bath of 36 ℃ and mixed with magnetic mixers for 15 days to simulate the conditions in a mesophilic anaerobic digester with an SRT of 15 days.

Cumulative biogas production and biogas composition were monitored during the BMP test to assess the impact of ferric chloride addition on digestion during the BMP tests, as shown in **Figure 14**, **Figure 15**, and **Figure 16**. Biogas was sampled and analyzed for gas composition 5 times throughout the 15 days. Based on the results presented in **Figures 14** through **16**, the quantity of gas production was slightly higher at the neutral pH of 7.

Figure 17, **Figure 18** and **Figure 19** show the biogas composition throughout the BMP tests. The average methane content for each sample was between 60% to 70%, which is a typical biogas composition in anaerobic digesters.

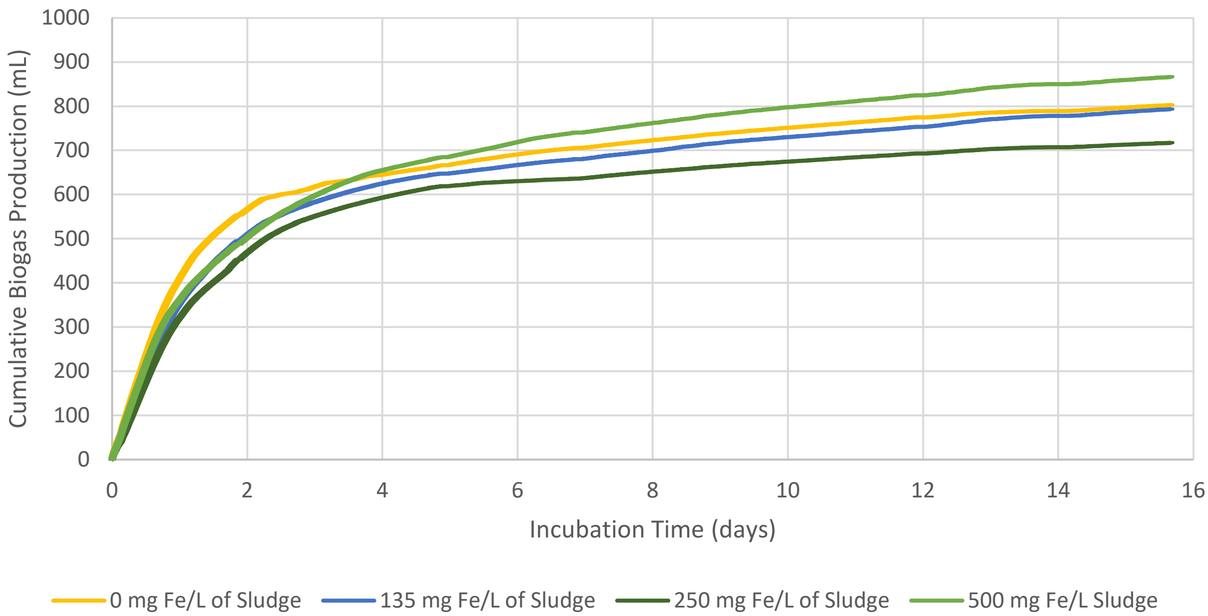

Figure 14: Scenario 1 Cumulative Biogas Production – No pH Adjustment

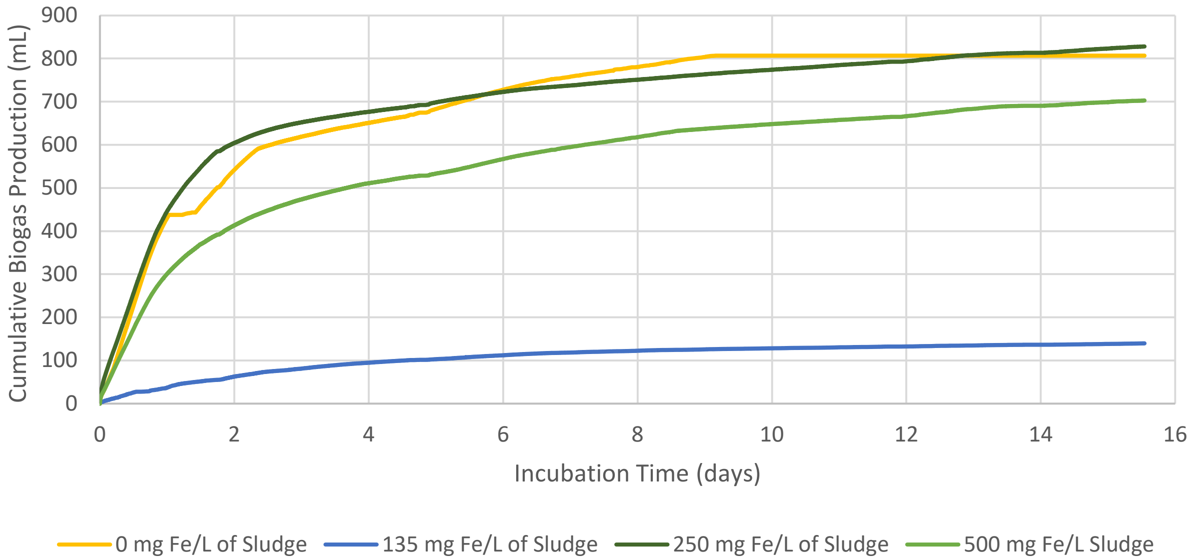

Figure 15: Scenario 1 Cumulative Biogas Production – pH 6 Adjustment. (*Error in automatic biogas production recording for 135 mg Fe/L of sludge and should be disregarded)

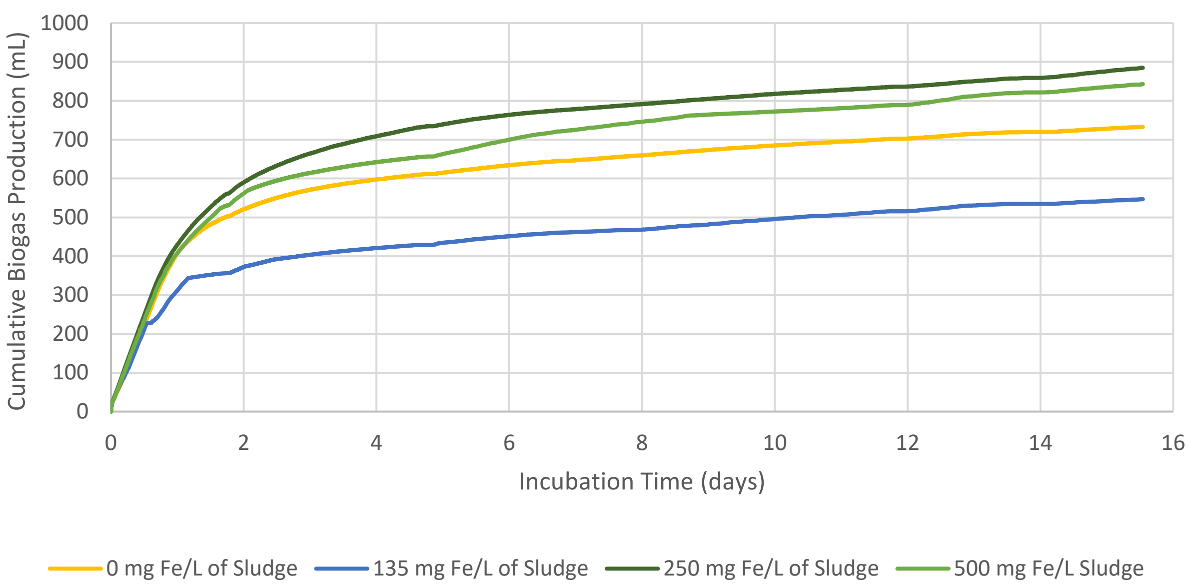

Figure 16: Scenario 1 Cumulative Biogas Production – pH 7 Adjustment (*Error in automatic biogas production recording for 135 mg Fe/L of sludge and should be disregarded)

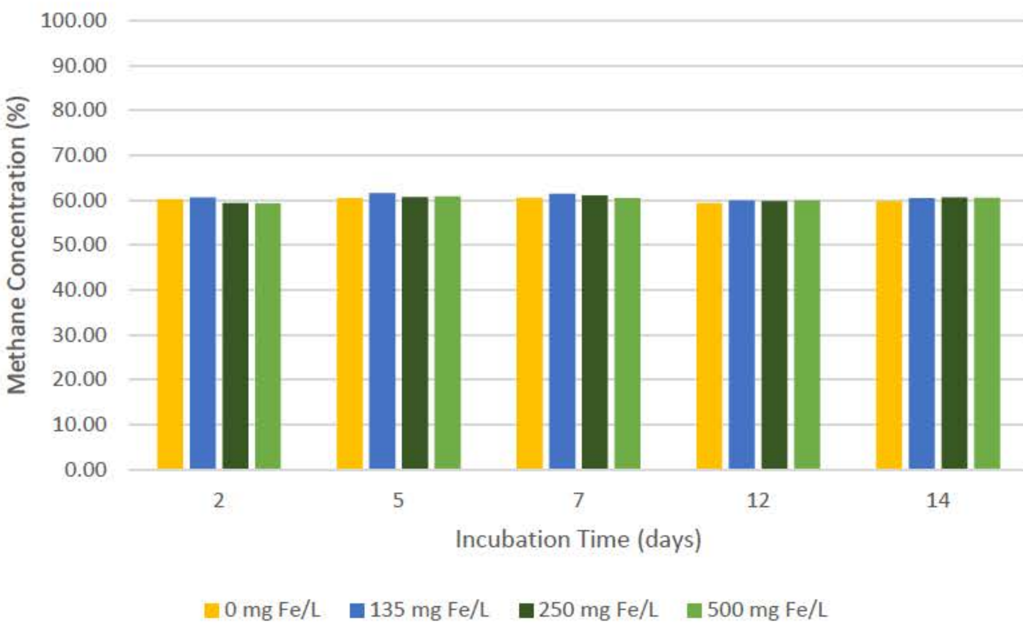

Figure 17: Scenario 1 Biogas Composition – No pH Adjustment

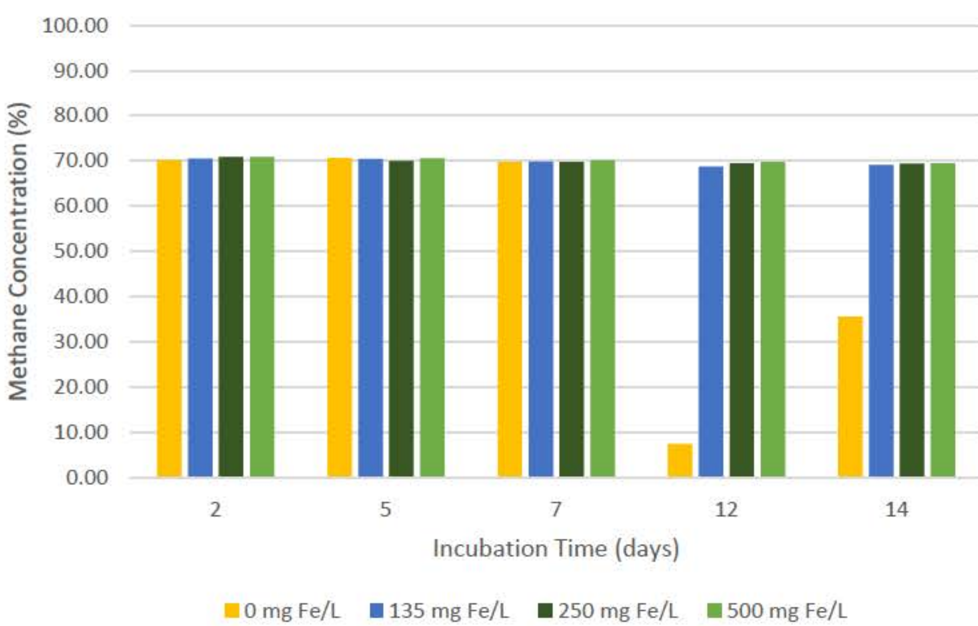

Figure 18: Scenario 1 Biogas Composition – pH 6 Adjustment

Gas composition on day 12 and day 14 for the 0 mg Fe/L dose was excluded when calculating average methane concertation due to the bottle seal being compromised after day 9 of the BMP test.

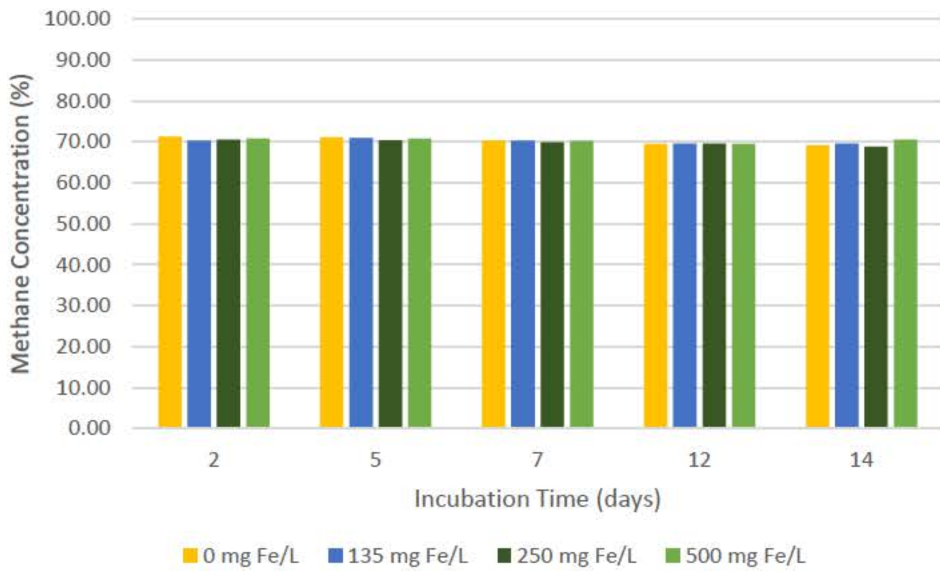

Figure 19: Scenario 1 Biogas Composition – pH 7 Adjustment

Total solids and volatile solids destruction after the 15-day BMP test were found to be between 7 and 17% and 17 and 25%, respectively, as shown in **Figure 20**.

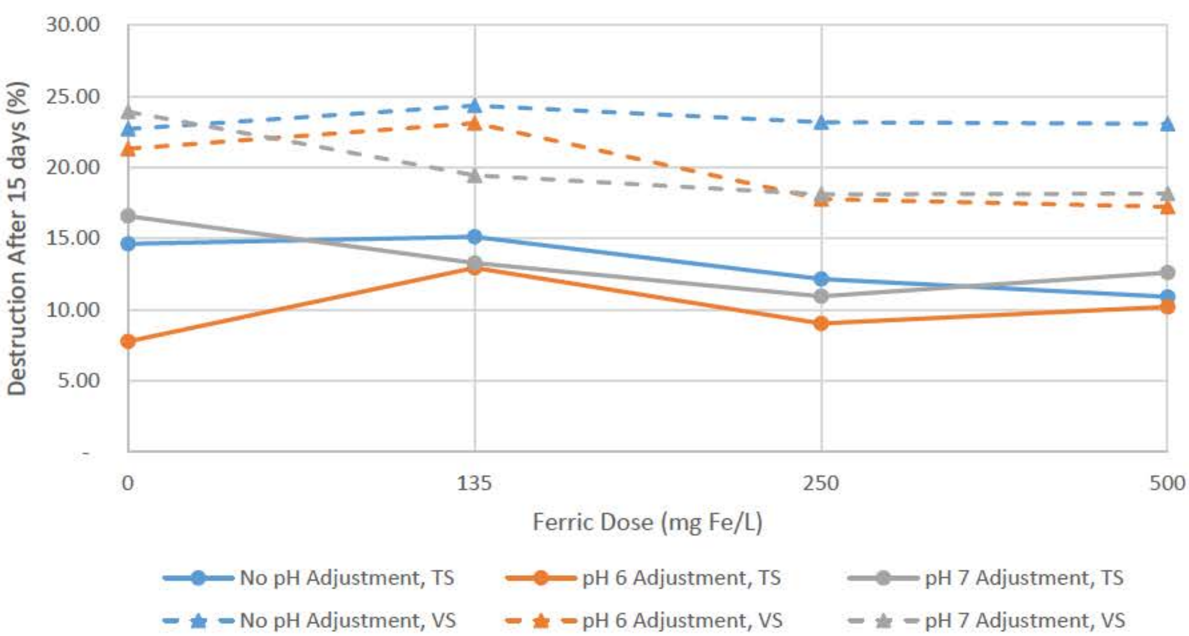

Figure 20: Scenario 1 Total Solids and Volatile Solids Destruction

Soluble ortho-phosphate in the digested samples was found to be between 75 and 90 mg/L, with pH ranging from 7.2 and 7.4, as shown in **Figure 21**.

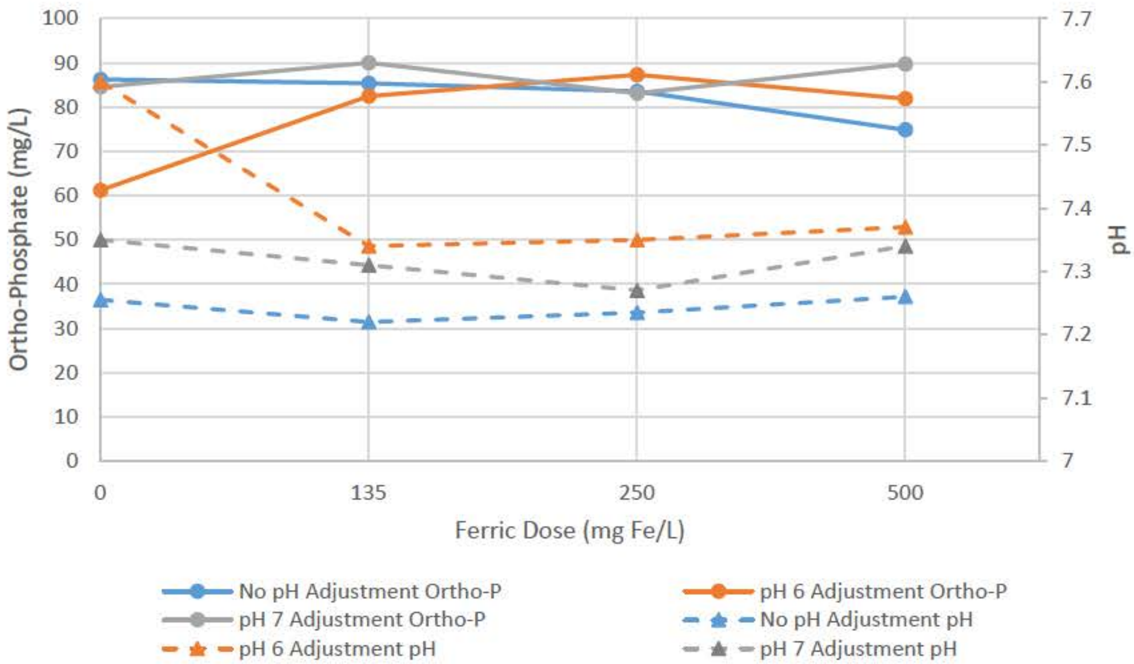

Figure 21: Soluble Ortho-Phosphate and pH for Scenario 1 Post Digestion

4.2.1.2 Ferric Chloride Dose Downstream of Anaerobic Digestion

As the objective for Scenario 1 dosing was to reach a soluble ortho-phosphate concentration of around 20 mg/L in the centrate, a second ferric chloride dose after digestion was necessary. A dose of 200 mg Fe/L of digested sludge was added to all samples. **Figure 22** shows the soluble ortho-phosphate and pH of the samples after the second ferric chloride dose.

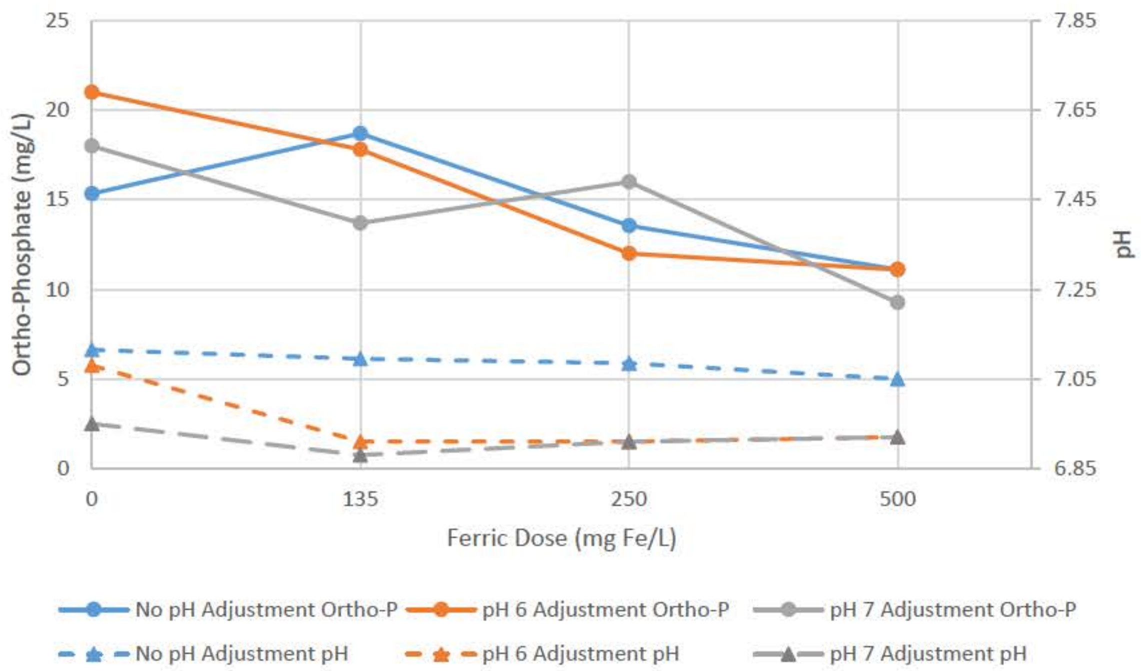

Figure 22: Soluble Ortho-Phosphate and pH for Scenario 1 After Second Ferric Chloride Dose

4.2.1.3 Impacts on Sludge Dewaterability

Duplicate capillary suction time (CST) tests were completed on all samples after digestion and again after the second ferric dose to determine the effect of ferric chloride addition on sludge dewaterability. **Figure 23** outlines the average CST for each sample. The results indicated that the pre-digestion ferric chloride dose did not have considerable impacts on dewaterability, while the post digestion dose improved sludge dewaterability.

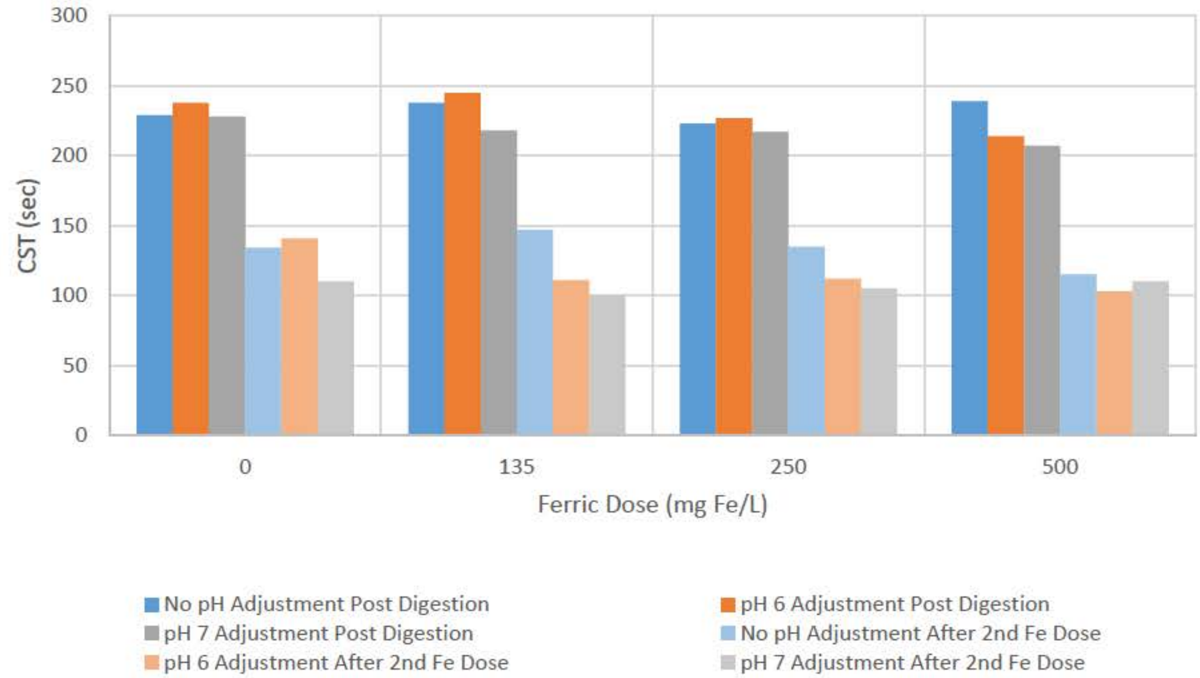

Figure 23: Scenario 1 Capillary Suction Time

4.3 Scenario 2: Chemically Enhanced Primary Treatment

In the jar tests for Scenario 2, ferric chloride was dosed to Primary Influent (PI) samples to achieve soluble phosphorus concentration of approximately 2.2 mg PO_4-P/L in the supernatant after coagulation. Based on the modelling, if the primary effluent ortho-phosphate was reduced to 2.2 mg/L (corresponding primary effluent total phosphorus of 5.1 mg/L), then biological uptake in the HPO reactors would be sufficient to achieve a final effluent total phosphorus concentration of 2.5 mg TP/L.

4.3.1 Results

Samples from NEWPCC and WEWPCC were collected and analyzed on November 2, 2020. **Table 4** summarizes the raw sample characteristics.

Table 4: Scenario 2 Raw Sample Characteristics

Parameter	Unit	NEWPCC Primary Influent	NEWPCC Digested Sludge	WEWPCC Sludge
pH		7.12	7.34	5.32
Alkalinity	mg $CaCO_3$/L	280	2680	660
TS	mg/L	1,032	13,954	38,086
VS	mg/L	528	8,890	32,972
Ortho-P	mg/L	4.64	63.2	496

Two phases of jar tests were completed for Scenario 2. Phase 1 jar tests were completed on primary influent (PI) to determine the mixing regime and ferric chloride dose to be used for Phase 2 jar tests and BMP tests. For Phase 1 results, refer to the JAAO Environmental Engineering Report provided in **Appendix B**. The six ferric chloride doses tested in Phase 1 were 0, 5, 10, 15, 20 and 30 mg Fe/L of PI. The three mixing regimes tested were as follows:

- 1 minute rapid (100 rpm) followed by 7.5 minutes of slow mixing (40 rpm),
- 2 minutes rapid, 15 minutes slow, and
- 5 minutes rapid, 30 minutes slow.

Based on the results from Phase 1 jar tests, it was determined that a dose of 8 mg Fe/L is sufficient to reduce the primary effluent ortho-phosphate concentration to less than 2.2 mg/L for Scenario 2. This is lower than the Biowin predicted dose of 14 mg Fe/L. For the purpose of the Phase 2 jar tests a range of 0-18 mg Fe/L was used to capture the full range of doses that could be expected.

Jar testing was completed on primary influent for four different ferric chloride doses based on the Phase 1 jar tests and BioWin modeling. The four ferric doses used for testing were 0, 8, 14, and 18 mg Fe/L of primary influent. After 30 minutes of settling, the volume of settled sludge was recorded and sampled for further testing and analysis. Supernatant was sampled immediately following the 30 minutes of settling for further analysis, with results shown in **Table 5**.

Table 5: Scenario 2 Supernatant Characteristics

Parameter	Unit	0 mg Fe/L	8 mg Fe/L	14 mg Fe/L	18 mg Fe/L
pH		7.12	6.96	6.85	6.79
Alkalinity	mg $CaCO_3$/L	290	270	220	220
Ortho-P	mg/L	4.82	2.14	0.76	0.15

The ferric chloride dose of 8 mg Fe/L of primary influent and 14 mg Fe/L of primary influent had ortho-phosphate concentrations of 2.14 mg/L and 0.76 mg/L, respectively, as shown in **Figure 24**.

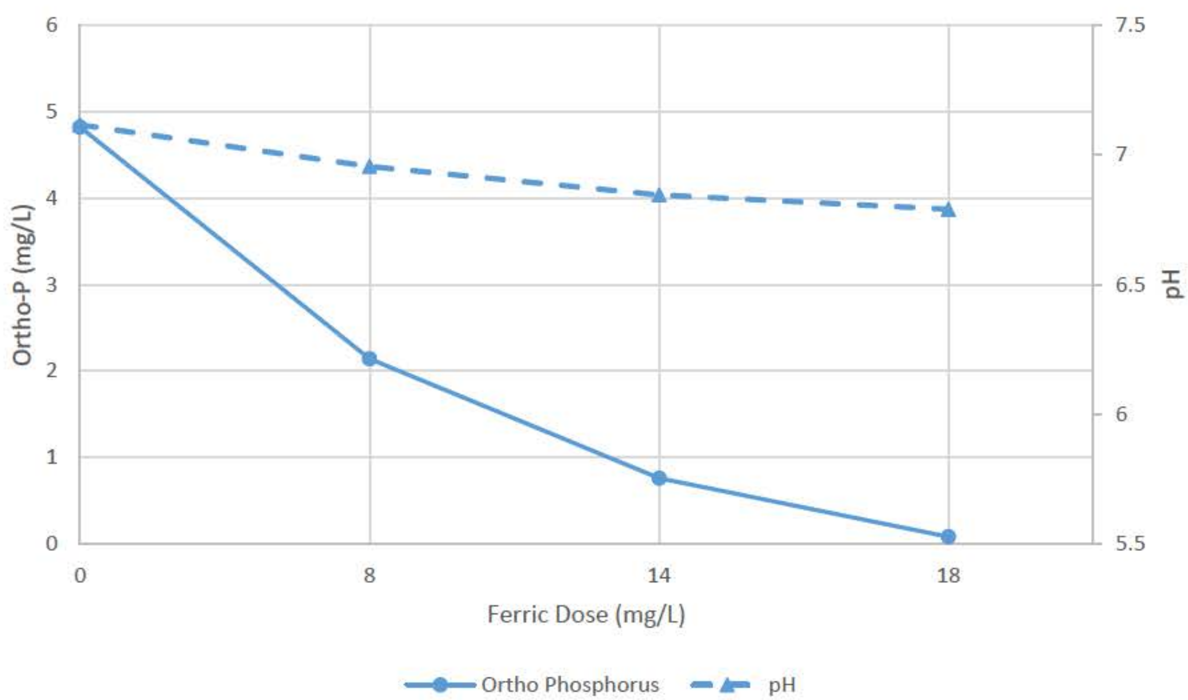

Figure 24: Soluble Ortho-Phosphate for Scenario 2 Phase 2 Jar Tests

4.3.1.1 Sludge Production

The volume of settled sludge increased as well as the total sludge produced as the ferric dose increased, as shown in **Figure 25**.

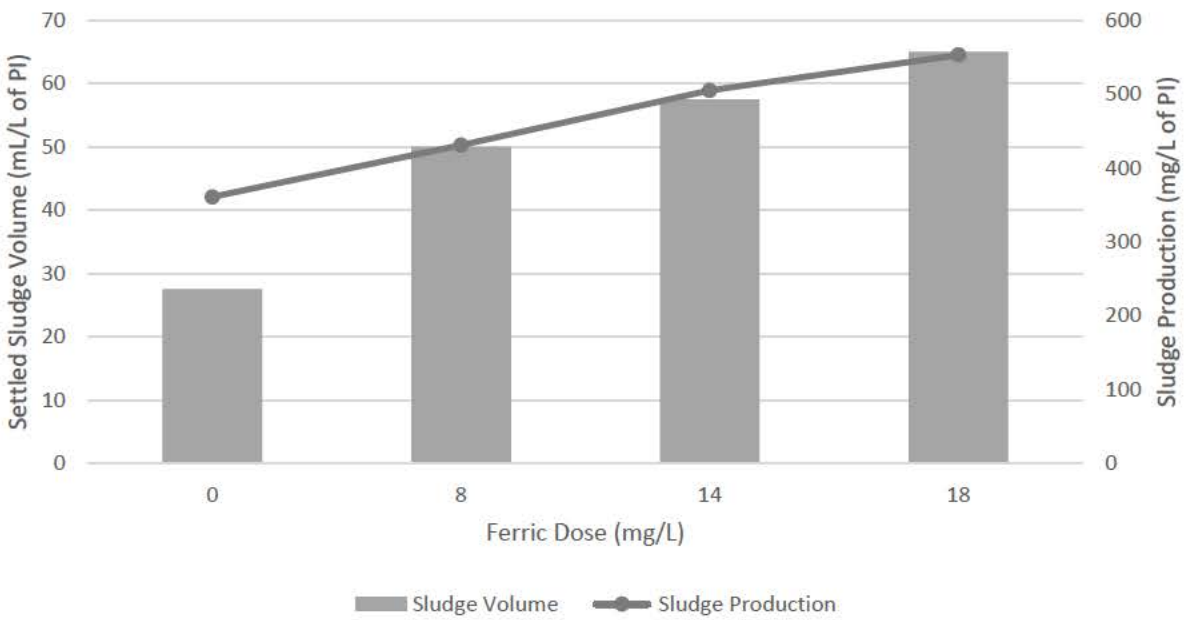

Figure 25: Scenario 2 Phase 2 Sludge Production

4.3.1.2 Impacts on Oxygen Uptake Rate

Specific oxygen uptake rate (SOUR) tests were completed on supernatant samples from all jar tests. Mixed liquor from all 3 NEWPCC trains were collected and combined in equal parts. Two litres of the mixed liquor were settled for 30 minutes and then 800 mL of the settled biomass was collected for the oxygen uptake rate (OUR) test. The biomass was aerated prior to the OUR test to ensure biomass was not in a state of starvation. 20 mL of biomass was combined with 380 mL of supernatant from each jar test and further aerated until reaching a dissolved oxygen (DO) level of 8 mg/L. The biomass and supernatant mixture were then transferred to a 350 mL BOD bottle and a DO probe was inserted to record the drop in DO every 30 seconds until the DO reached 1 mg/L. DO versus time was plotted and a trendline was plotted on the linear portion. The absolute value of the trendline slope is the sample's OUR in mg O2/L/h. OUR is then divided by the volatile solids of the biomass used in the test to determine the SOUR in mg O2/g VS/h. As shown in **Figure 26**, the SOUR decreases as the ferric dose increases.

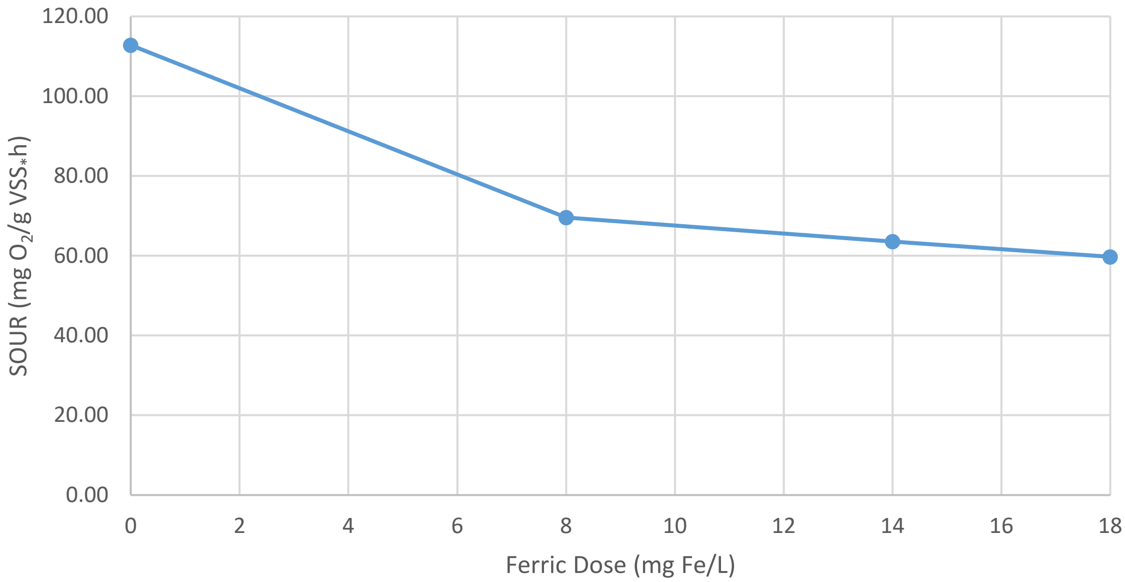

Figure 26: Scenario 2 SOUR

4.3.1.3 Impacts on Anaerobic Digestion

Seven parts of the sludge produced from each jar test were then mixed with three parts of WEWPCC sludge sampled from the holding tank. The mixed sludge was then added to digester inoculum at a volumetric loading rate of 0.07 $m^3/m^3/d$ and a 15-day BMP was started to record biogas production. **Figure 27** shows the gas production for the two sets (duplicate) of ferric doses over the 15 days. Each bottle contains 500 mL of sludge, made up of 25.0 mL of sludge from the jar test, 10.7 mL of WE sludge, and 464.3 mL of digester inoculum.

Cumulative biogas production during the BMP test is shown in **Figure 27**. Biogas was sampled and analyzed for gas composition 5 times throughout the 15 days. **Figure 28** shows the biogas composition throughout the BMP tests. Comparing the biogas volume and methane content of the control dose (0 mg Fe/L) with those of the highest dose (18 mg Fe/L) does not indicate any impacts on anaerobic digestion.

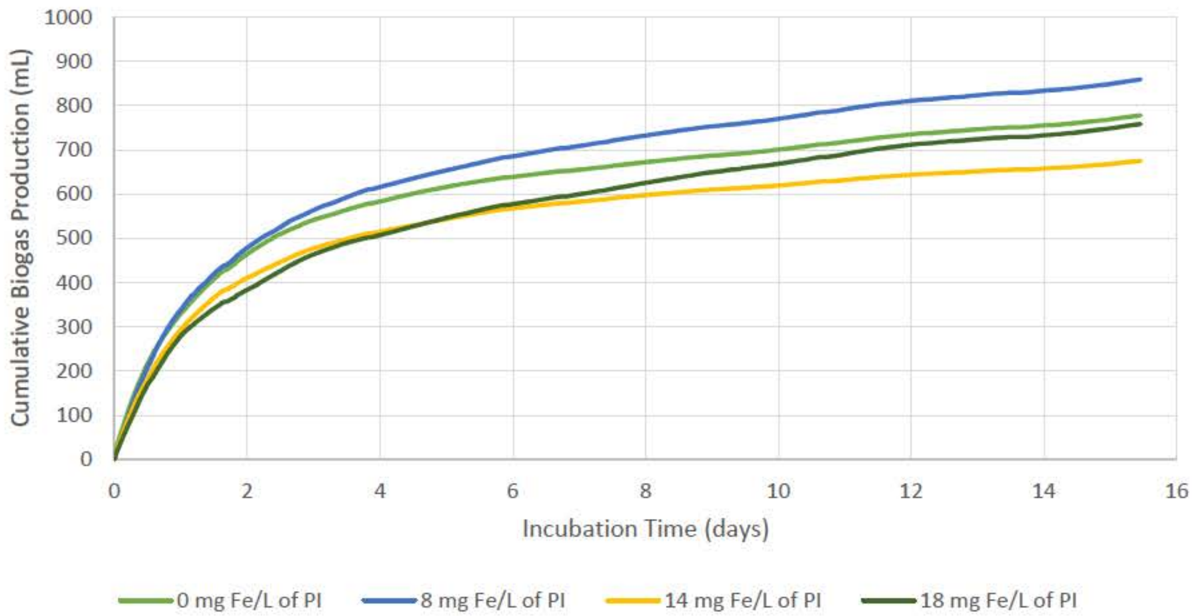

Figure 27: Scenario 2 Cumulative Biogas Production

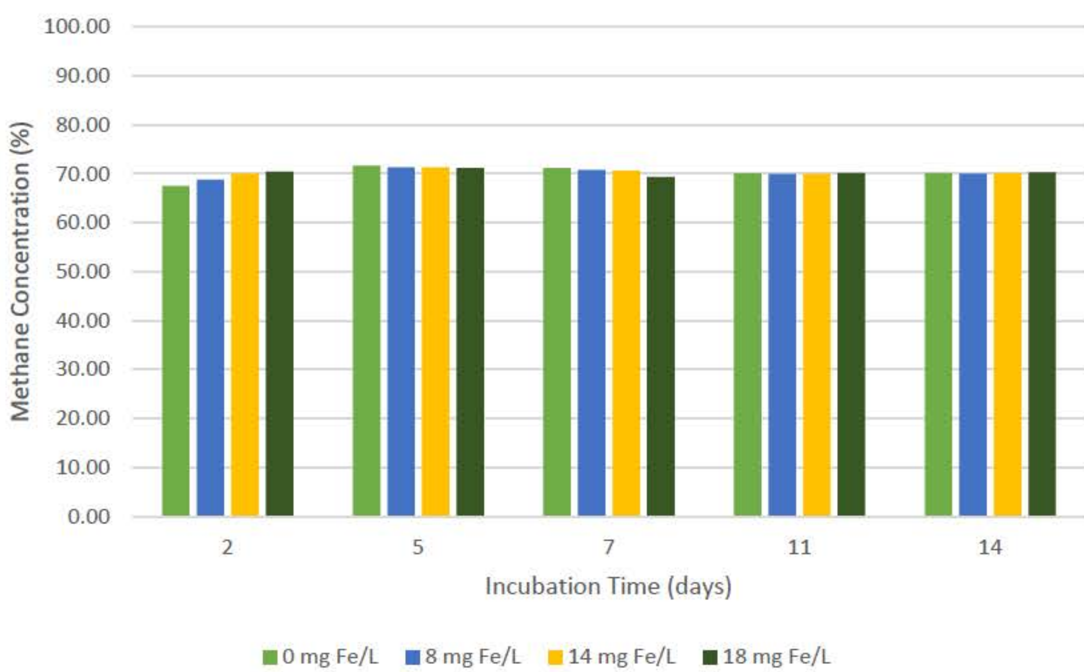

Figure 28: Scenario 2 Biogas Composition

Total solids and volatile solids destruction after the 15-day BMP test were found to be between 12-15% and 21-24%, respectively, as shown in **Figure 29**.

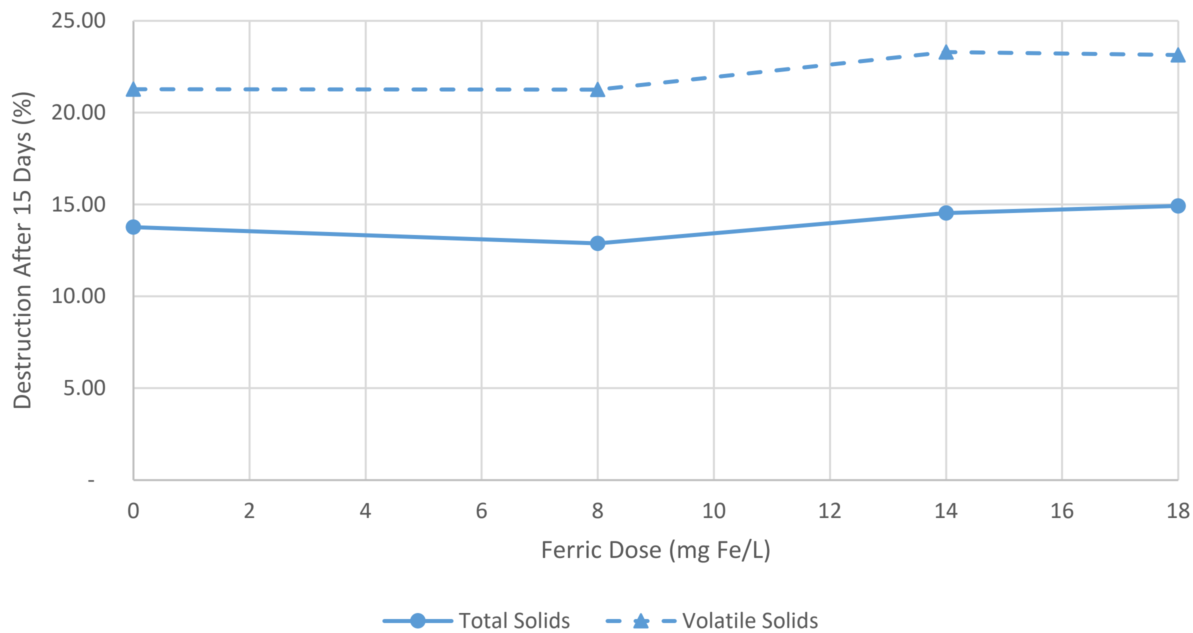

Figure 29: Scenario 2 Total Solids and Volatile Solids Destruction

Soluble ortho-phosphate in the digested samples was found to be between 79 and 84 mg/L indicating, all with a pH around 7.25, as shown in **Figure 30**.

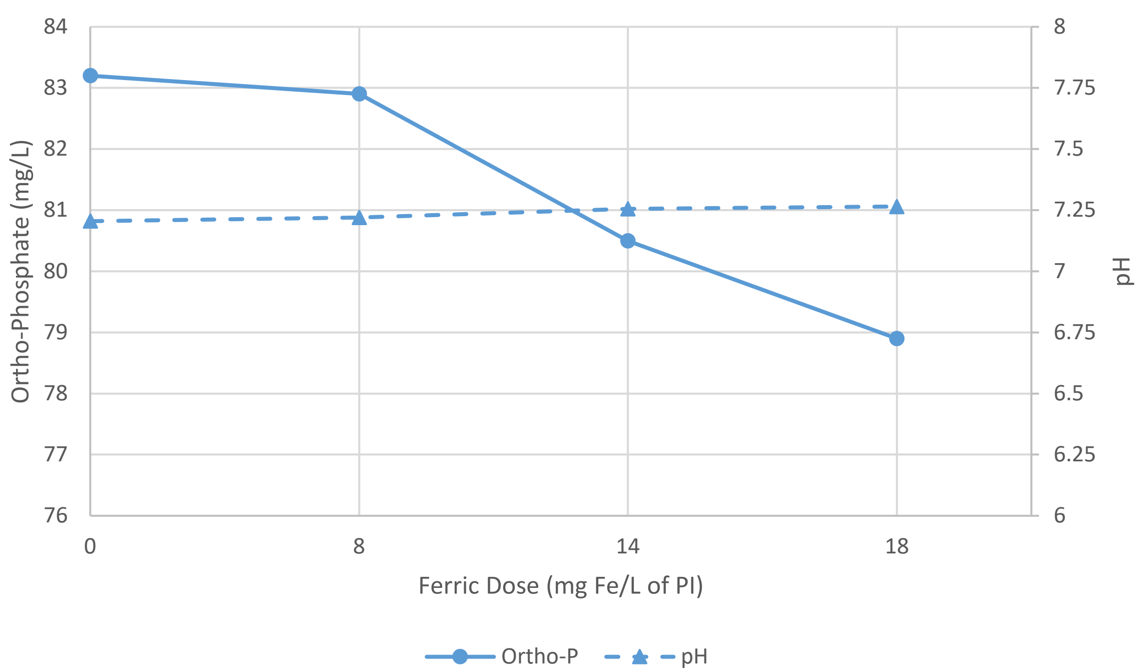

Figure 30: Soluble Ortho-Phosphate and pH for Scenario 2 Post Digestion

4.3.1.4 Impacts on Sludge Dewaterability

Duplicate CST tests were completed on all samples after digestion to determine the effect on dewaterability. **Table 6** outlines the average CST for each sample. According to the CST test results, adding ferric chloride to primary influent did not affect sludge dewaterability.

Table 6: Scenario 2 Capillary Suction Times After Digestion

Ferric Dose Before Digestion	Unit	CST
0 mg Fe/L	sec	218
8 mg Fe/L	sec	222
14 mg Fe/L	sec	263
18 mg Fe/L	sec	272

4.4 Scenario 3: Chemical Phosphorus Removal in HPO Reactors

In Scenario 3, ferric chloride was dosed to the mixed liquor (ML) from HPO reactors to achieve soluble phosphorus concentration of approximately 2 mg PO_4-P/L in the supernatant after coagulation. Having an ortho-phosphate concentration of 2 mg/L in the final effluent would result in a total phosphorus concentration of approximately 2.5 mg/L.

4.4.1 Results

Mixed liquor from the NEWPCC was collected from each of the three HPO trains and combined in equal parts for testing. **Table 7** summarizes the raw sample characteristics.

Table 7: Scenario 3 Phase 2 Raw Sample Characteristics

Parameter	Unit	NEWPCC Mixed Liquor	NEWPCC Primary Sludge	NEWPCC Digested Sludge	WEWPCC Sludge
pH		6.55	6.07	7.37	5.32
Alkalinity	mg CaCO3/L	220	1180	2680	620
TS	mg/L	3,006	29,044	12,720	35,166
VS	mg/L	2,202	22,880	8,112	29,992
Ortho-P	mg/L	5.47	84.3	69.4	555

Two phases of jar tests were completed for Scenario 3, as were completed for Scenario 2. Phase 1 jar tests were completed on mixed liquor to determine the mixing regime and ferric chloride dose to be used for phase 2 jar tests and BMP test, for Phase 1 results refer to JAAO Environmental Engineering Report provided in **Appendix B**.

The four ferric chloride doses tested in Phase 1 were 0, 10, 20 and 30 mg Fe/L of mixed liquor. The three mixing regimes tested were 7.5 minutes of slow (40 rpm), 15 minutes slow, and 30 minutes slow mixing.

Based on the Scenario 3 Phase 1 jar tests, it was determined that a dose of 15 mg Fe/L be used for the Scenario 3 Phase 2 testing to achieve a soluble ortho-phosphate of approximately 2 mg/L in the final effluent. Additional tests using a 20 mg Fe/L dose to achieve a soluble ortho-phosphate of 0.8 mg/L in the final effluent, the control dose of 0 mg Fe/L, and the BioWin predicted dose of 10 mg Fe/L were conducted. All Phase 2 jar tests were completed with 7.5 minutes of slow mixing (40 rpm). After 30 minutes of settling, the volume of settled sludge was recorded and sampled for further testing. Supernatant was sampled immediately following the 30 minutes of settling for further testing, with results outlined in **Table 8**.

Table 8: Scenario 3 Supernatant Characteristics

Parameter	Unit	0 mg Fe/L	10 mg Fe/L	15 mg Fe/L	20 mg Fe/L
pH		6.7	6.59	6.54	6.47
Alkalinity	mg CaCO3/L	220	210	200	190
Ortho-P	mg/L	5.47	2.67	1.53	0.679

Soluble ortho-phosphate concentration in the supernatant was as expected based on the Phase 1 testing. The ferric chloride dose of 10 mg Fe/L of ML and 20 mg Fe/L of ML had ortho-phosphate concentrations of 2.66 mg/L and 0.68 mg/L, respectively, as shown in **Figure 31**.

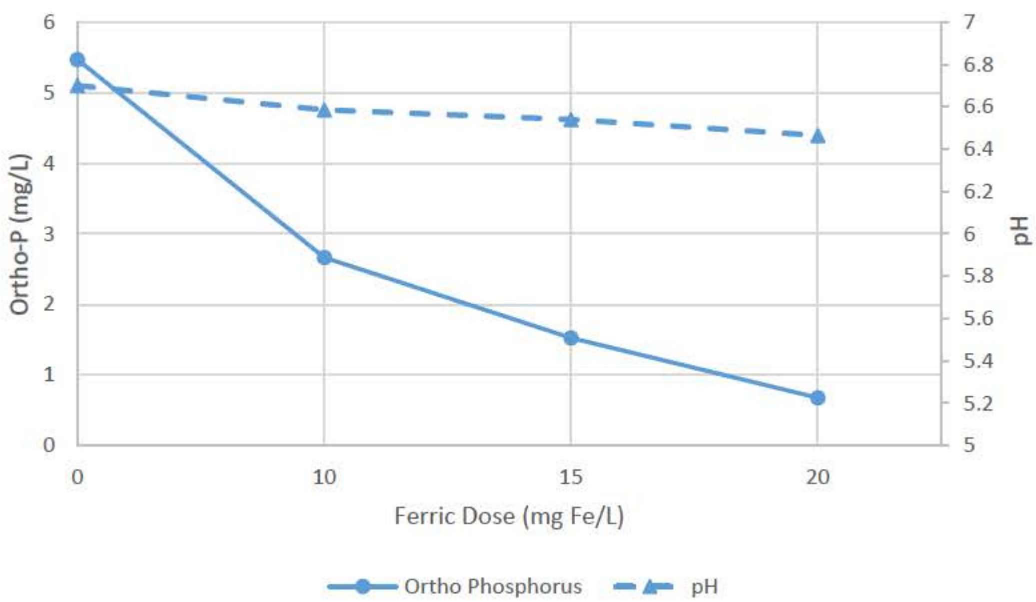

Figure 31: Soluble Ortho-Phosphate for Scenario 3 Phase 2 Jar Tests

4.4.1.1 Sludge Production

The volume of settled sludge increased as well as the total sludge produced per liter of mixed liquor as the ferric chloride dose increased, as shown in **Figure 32**.

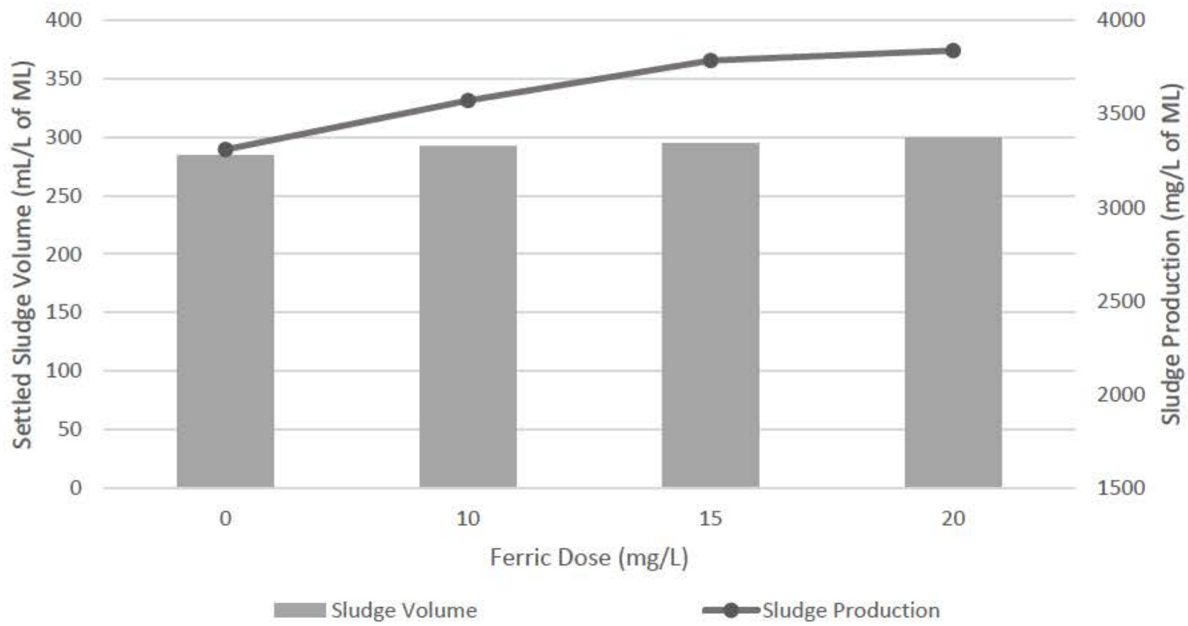

Figure 32: Scenario 3 Phase 2 Sludge Production

4.4.1.2 Impacts on UV Disinfection

Ultraviolet transmittance (UVT) was measured on all supernatant samples to determine if UV treatment would be inhibited. As the ferric chloride dose to the mixed liquor increased, UVT increased, as shown in **Figure 33**.

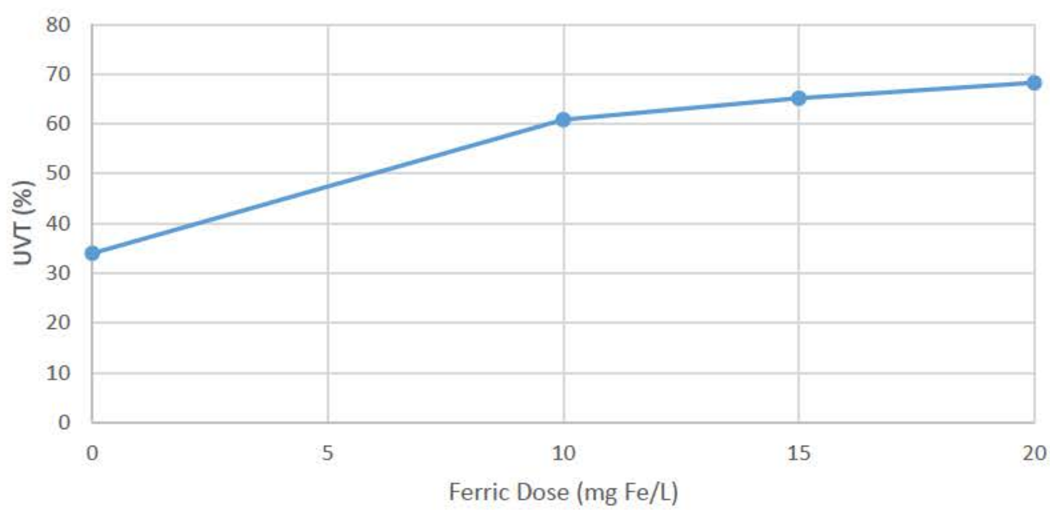

Figure 33: UVT for Scenario 3 Supernatant

4.4.1.3 Impacts on Anaerobic Digestion

Sludge produced in the jar tests was then mixed with primary sludge at a ratio of 45:55. Seven parts of the mixed sludge were then mixed with three parts of WEWPCC sludge sampled from the holding tank. The mixed sludge was then added to digester inoculum at a volumetric loading rate of 0.07 $m^3/m^3/d$ and a 15-day BMP was started to record biogas production. Each bottle contained 500 mL of sludge, made up of 11.4 mL sludge from the jar test, 13.6 mL primary sludge, 10.7 mL WEWPCC sludge, and 464.3 mL digester inoculum.

Cumulative biogas production during the BMP test is shown in **Figure 34**. Biogas was sampled and analyzed for gas composition 4 times throughout the 15 days. **Figure 35** shows the biogas composition throughout the BMP tests. Methane concentrations were considered in the normal range at 60% and production was similar for the various ferric chloride doses.

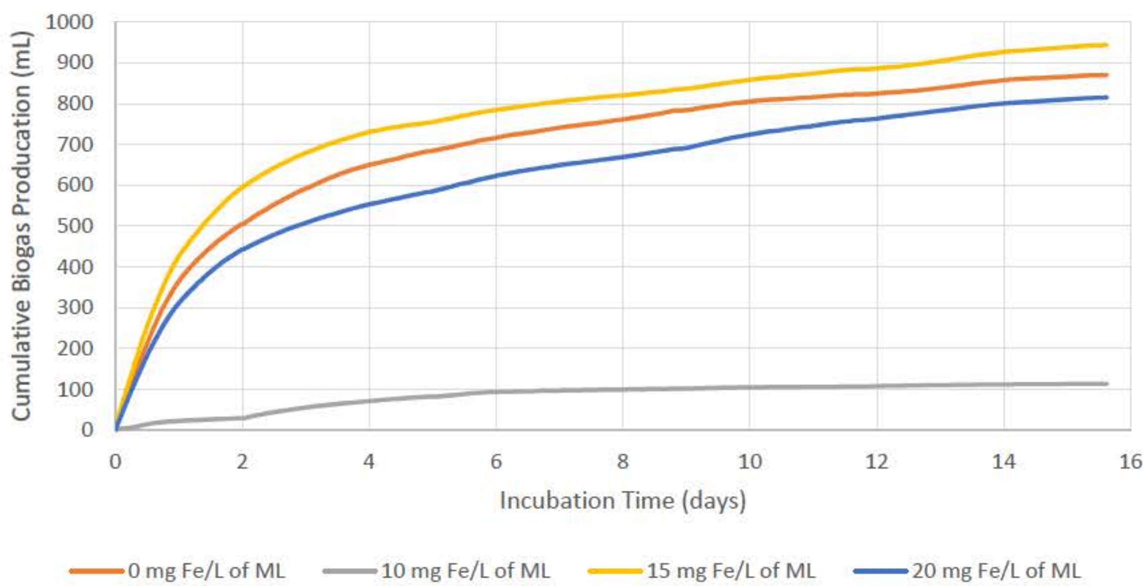

Figure 34: Scenario 3 Cumulative Biogas Production (*Error in automatic biogas production recording for 10 mg Fe/L of ML and should be disregarded)

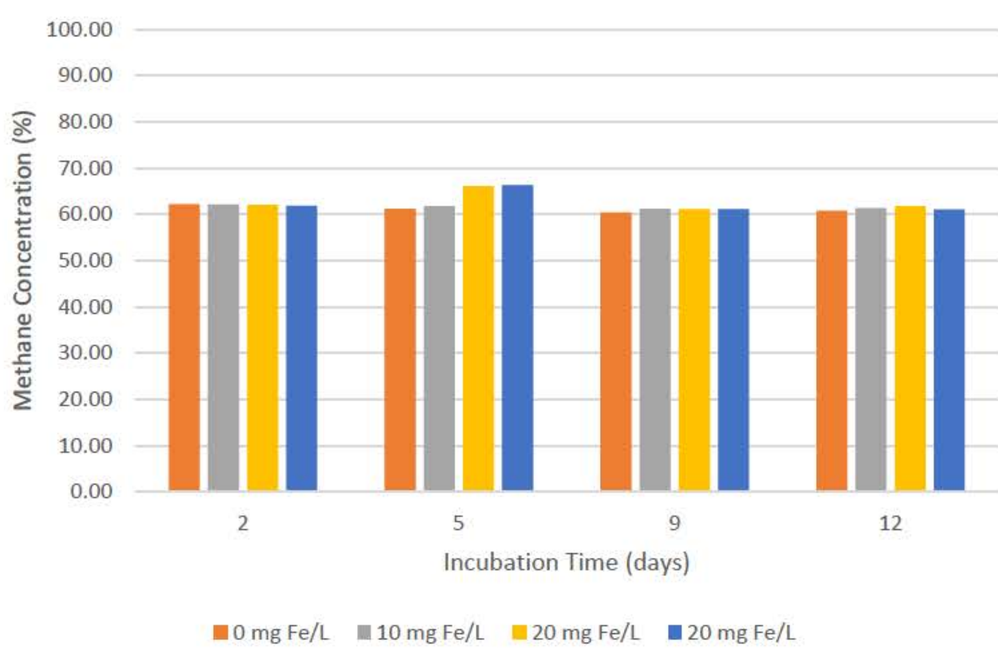

Figure 35: Scenario 3 Biogas Composition

Total solids and volatile solids destruction after the 15-day BMP test were found to be between 12-13% and 19-21%, respectively, as shown in **Figure 36**.

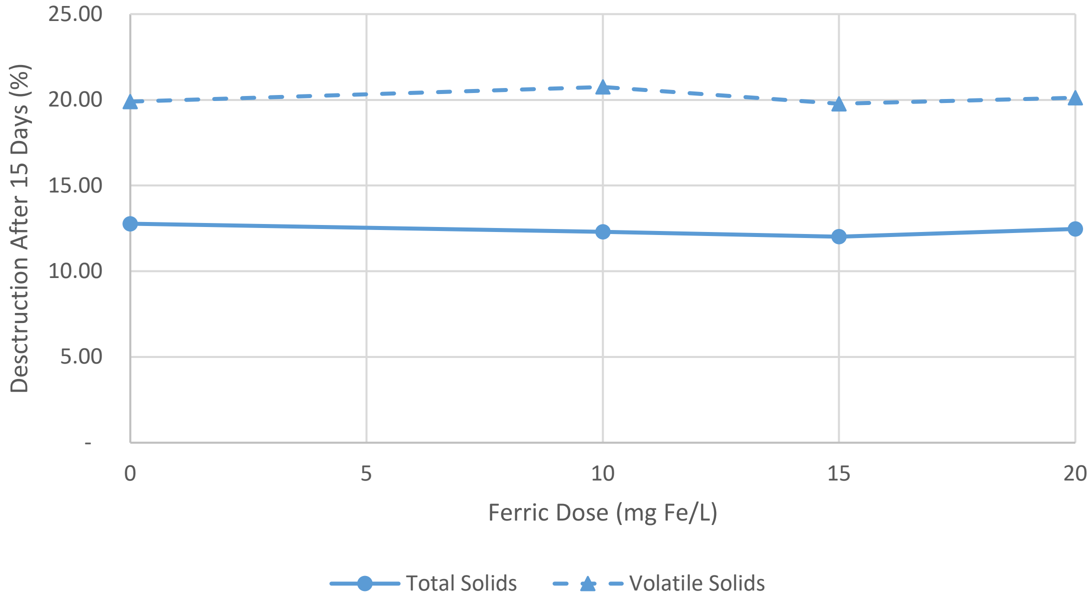

Figure 36: Scenario 3 Total Solids and Volatile Solids Destruction

Soluble ortho-phosphate in the digested samples was found to be between 86 and 94 mg/L, all with a pH around 7.1, as shown in **Figure 37**.

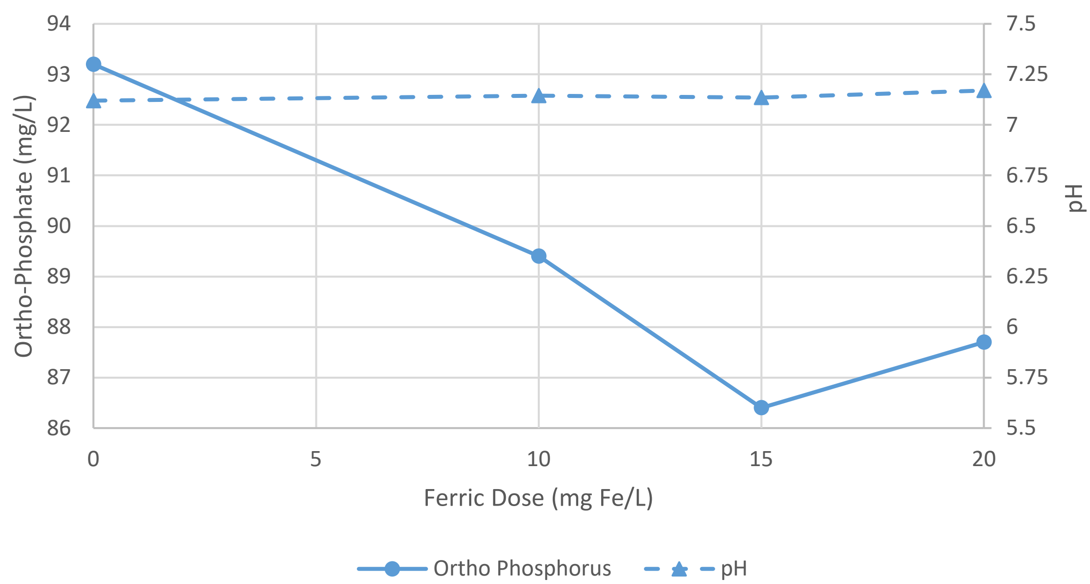

Figure 37: Soluble Ortho-Phosphate and pH for Scenario 3 Post Digestion

4.4.1.4 Impacts on Sludge Dewaterability

Duplicate CST tests were completed on the sludge after digestion to determine the effect of ferric chloride dose on sludge dewaterability. **Table 9** outlines the average CST for each sample. According to the CST test results, adding ferric chloride to the mixed liquor from HPO reactors did not affect sludge dewaterability.

Table 9: Scenario 3 Capillary Suction Times After Digestion

Ferric Dose Before Digestion	Unit	CST
0 mg Fe/L	sec	214
8 mg Fe/L	sec	230
14 mg Fe/L	sec	224
18 mg Fe/L	sec	221

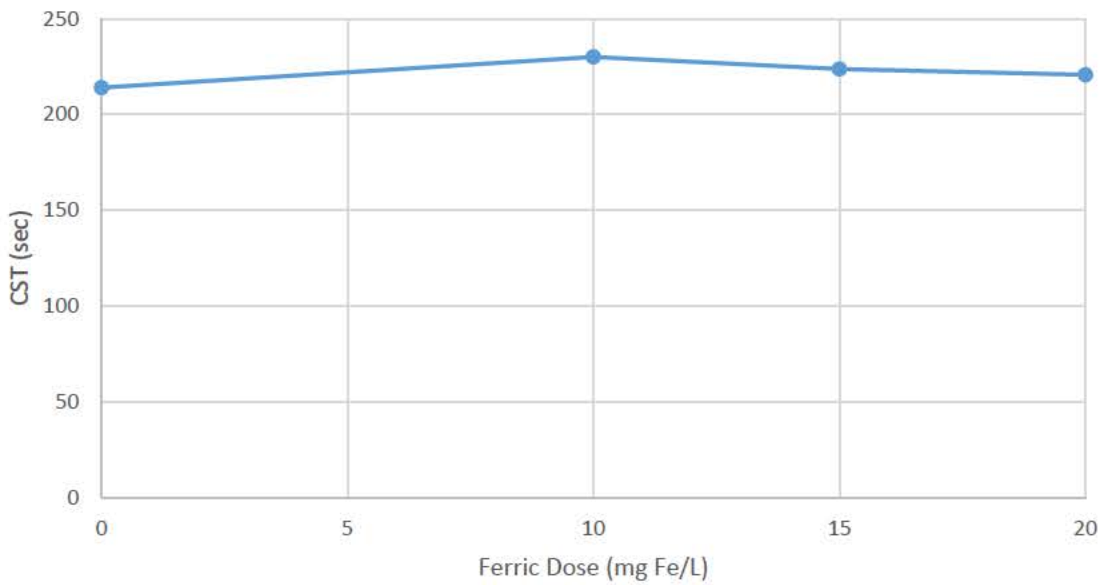

Figure 38: Scenario 3 Capillary Suction Time

5. Analysis and Evaluation Summary

5.1 Summary of BioWin Modelling Findings

The modelling results presented in the previous Sections are summarized below:

1. After SEWPCC BNR commissioning, the phosphorus load to NEWPCC will increase. This will in turn cause an increase in the concentration of phosphorus in the digested sludge, centrate and final effluent. Higher phosphorus concentration in the digested sludge increases the nuisance non-ferric precipitation potential in the solids stream processes. Based on these observations, additional ferric chloride dosing to the anaerobic digesters (evaluated under Scenario 1) will be required to control nuisance precipitation and lower the phosphorus concentration in the centrate.
2. According to the modelling results, the capacity of the digesters limits the amount of phosphorus removal from the mainstream at NEWPCC.
3. Modelling revealed that under maximum month and maximum week conditions, the digester SRT will fall below the target of 15 days. For this reason, it is not recommended to operate interim phosphorus removal for Scenario 2 or 3 under these conditions.
4. Scenarios 2 and 3 are feasible under average conditions, with the amount of interim phosphorus removal dependant on digester performance.
5. Due to the increased ferric chloride dose to the anaerobic digesters, additional alkalinity to the digesters for pH adjustment is required. Without pH adjustment, the Biowin model predicts pH dropping to 6.7 in the digesters which will impact the performance of the methanogenic bacteria.

5.2 Summary of Benchscale Testing Findings

1. Benchscale testing was delayed as the University of Manitoba was closed from March to September 2020 due to COVID-19. After the University reopened in September 2020, work resumed and benchscale testing was completed on samples representing the average conditions at the NEWPCC. Since the time period for collecting maximum month samples was missed (due to University closure), the benchscale testing will be conducted in March/April 2021 to assess the impact of interim phosphorus removal during maximum month conditions. Also, due to limited time and the high quantity of jar test samples only BMP tests were conducted to evaluate the impacts of ferric chloride addition on anaerobic digestion. When maximum month conditions are tested in 2021, a more accurate benchscale digester should be run with continuous feed based on the selected ferric chloride doses.
2. In Scenario 1, it was possible to achieve a soluble ortho-phosphate concentration of 20 mg P/L or less in the supernatant by dosing ferric chloride before and after digestion. Dosing a higher amount of ferric chloride prior to digestion did not show a negative effect on biogas and methane production during anaerobic digestion. The pH of the digested sludge was not affected, but further investigation for a continuous feed would need to be conducted to ensure the drop in feed pH does not negatively affect the digester performance over time. Methane content in biogas produced by sludge that was adjusted to pH 6 and 7 prior to digestion was approximately 10% higher than methane generated from the sludge where pH was not adjusted. Total and volatile solids destruction during the digestion process were not found to be affected by the higher ferric chloride dose or the pH adjustment. The latter indicated that the digestion was not affected. Capillary suction time tests conducted on the digested sludge showed no impact of the higher ferric dose or of pH adjustment prior to digestion. The CST was significantly decreased after the second ferric chloride dose post-digestion.
3. In Scenario 2, the results from Phase 1 and Phase 2 jar tests indicate a ferric dose between 8 and 14 mg Fe/L is sufficient to lower the final effluent total phosphorus concentration less than 2.5 mg/L, with pH dropping only slightly below 7.0. Sludge production (mg/L of primary influent) was shown to increase 20% and 40%

from the control dose for ferric doses of 8 and 14 mg Fe/L, respectively. Dosing ferric chloride to the primary influent did not show a negative effect on biogas and methane production during digestion. Total and volatile destruction during the digestion process was also not found to be affected by dosing ferric chloride to the primary clarifiers. Capillary suction time tests conducted on the digested sludge were not shown to be affected by the ferric chloride dosing to primary influent. Specific oxygen uptake rate on the primary effluent/supernatant decreased as the ferric chloride dose increased.

4. In Scenario 3, the results from Phase 1 and Phase 2 jar tests indicate a ferric dose between 10 and 15 mg Fe/L is sufficient to lower the final effluent total phosphorus concentration less than 2.5 mg/L, with pH dropping only slightly below 6.7 for both ferric chloride doses. It was found that UVT of the final effluent increased as the ferric chloride dose increased, indicating UV treatment effectiveness would increase when dosing ferric chloride to the HPO reactors. Sludge production (mg/L of mixed liquor) was shown to increase 8% and 15% from the control dose for ferric chloride doses of 10 and 15 mg Fe/L, respectively. Dosing ferric chloride to the HPO reactors did not show a negative effect on biogas and methane production during digestion. Total solids and volatile solids destruction during the digestion process were not found to be affected by dosing ferric chloride to the HPO reactors. Capillary suction time tests on the digested sludge were not shown to be affected by the ferric chloride dosing to HPO.

5.3 BioWin Modeling and Benchscale Testing Comparison

5.3.1 Ferric Chloride Demand

The total amount of ferric chloride required to achieve the desired ortho-phosphate concentration depends on the initial ortho-phosphate concentration in the wastewater. Since the initial ortho-phosphate concentration in the BioWin model and samples used for benchscale testing are different, the mass ratio of the ferric chloride added to ortho-phosphate removed are compared to provide a standardized method for analysis.

Scenario 1

The BioWin modeling and benchscale testing results for ferric to ortho-phosphate ratio (Fe:P) for each of the dosing points for Scenario 1 are compared in **Table 10.** Since BioWin did not predict a pH drop, only one ratio (neutral pH) is provided. However, jar testing was completed under different conditions and the ratio for each of these conditions is provided in **Table 10**.

Table 10: Scenario 1Fe to Ortho-Phosphate Ratio

Source	mg Fe /mg Ortho-P (1st Dosing Point)			mg Fe /mg Ortho-P (2nd Dosing Point)		
BioWIn Modeling	2.6			4.6		
Benchscale testing	No pH Adj	pH 6	pH7	No pH Adj	pH 6	pH7
	2.7	2.4	2.4	3.3	2.8	2.5

Scenario 2

The BioWin modeling and benchscale testing results for Fe:P ratio for Scenario 2 are compared in **Table 11.**

Table 11: Scenario 2 Fe/Ortho-Phosphate Ratio

Source	mg Fe /mg Ortho-P
BioWIn Modeling	5
Benchscale testing	3.45

Scenario 3

The BioWin modeling and benchscale testing results for Fe:P ratio for Scenario 3 are compared in **Table 12.**

Table 12: Scenario 3 Fe/Ortho-Phosphate Ratio

Source	mg Fe /mg Ortho-P
BioWIn Modeling	2.7
Benchscale testing	3.8

Overall, the difference in the ratios and the impact on total coagulant consumption is summarized in **Table 13**.

Table 13 Average Daily Ferric Consumption Modelled versus Benchscale

Description	BioWin (kg Fe/d)	Benchscale (kg Fe/d)
Scenario 1	1570	1530
Scenario 2	750	520
Scenario 3	300	420

5.3.2 Sludge Production

Scenario 1

In Scenario 1, ferric chloride is added to the sludge stream, which does not have considerable impacts sludge volume and on digesters SRT.

Scenario 2

The impact of dosing ferric chloride to primary clarifiers on primary sludge production is compared in **Table 14**.

The settling time in primary clarifiers is approximately six times higher than the settling time allowed during the benchscale testing (3 hrs vs 30 min). The amount of settled sludge increases with longer settling times. The impact of settling time becomes more important when coagulant is not added. Therefore, the increase in sludge production based on the benchscale testing results may not be a true representation of the real conditions at the NEWPCC.

Table 14: Scenario 2 Sludge Production

Source	% increase in Sludge Production
BioWIn Modeling	10%
Benchscale testing	20%

•Increase in sludge production is based on an Ortho-phosphate concentration of 2.2 mg/L in primary effluent

Scenario 3

The impact of dosing ferric chloride to HPO reactors on waste activated sludge production is compared in **Table 15.**

Due to the shorter settling time in benchscale testing, the same as Scenario 2, the increase in sludge production based on the benchscale testing results may not be a true representation of the real conditions at the NEWPCC.

Table 15: Scenario 3 Sludge Production

Source	% increase in Sludge Production
BioWIn Modeling	6%
Benchscale testing	15%

•Increase in sludge production is based on an Ortho-phosphate concentration of 2 mg/L in final effluent

5.3.3 General Conclusions Biowin Modelling and Benchscale Testing

For Scenario 1 and 2, the benchscale work indicated a slightly lower Fe:P removal ratio as compared to the modelling work. However, in contrast for Scenario 3, the benchscale work found that the Fe:P ratio was slightly higher than the modelling work (**Table 13**). With regard to preparing a conceptual design, the chemical system will be sized with the flexibility to accommodate a full range of chemical flows.

The sludge production values observed in the benchscale study were higher than those predicted by modelling. For Scenario 2 benchscale predicted 20% versus a modelling result of 10%. Similarly, for Scenario 3 benchscale predicted 15% versus a modelling result of 6%. This difference would have an impact on digester performance, which in turn would lead to less chemical being dosed to the mainstream, and an overall decrease in phosphorus removal. Due to the small volumes of sludge produced in the lab scale work, there are likely some inherent errors due to weight scale and measurement accuracy resolutions. During full scale implementation, a more accurate understanding of sludge production can be made. However, it is worth noting that the results of the benchscale study do present a level of risk to meeting projected interim phosphorus removal objectives.

5.4 Evaluation of the Scenarios

The impacts of each scenario were assessed based on technical, operational, and environmental criteria. A general impact of capital and operational costs was also indicated. A summary of the evaluation of alternatives and a combination of all scenarios is presented below.

5.4.1 Scenario 1

Scenario 1 (Increased Sidestream Chemical Removal) This option can be used to maintain the SBR effluent TP limits within the regulatory limit and maintain the NEWPCC secondary effluent at concentrations slightly lower than 2019/2020 concentrations. The amount of metal salt needed will more than double from the current requirement, which will trigger the need for digester pH control. Jar testing has confirmed the amount of chemical needed for pH control. The current chemical storage system will need to be upgraded to accommodate the increased chemical usage. The mass balance for this Scenario is provided in **Appendix A**.

Table 16: Process Evaluation for Scenario 1

Scenario 1	Increased Sidestream Chemical Phosphorus Removal
STANDARD:	**Maintain Centrate TP below 20 mg/L** **Maintain Nuisance Precipitation below 600 kg/d**
TECHNICAL CRITERIA	
1. Reliability:	The City has been dosing ferric chloride to the digesters/dewatering since 2006. This alternative is simply an adjustment to the chemical dosing rate to remove more phosphorus, offsetting the increased phosphorus load coming from the SEWPCC. It is considered a reliable method of sidestream phosphorus removal. One of the critical factors will be delivery of chemicals.
2. Robustness:	Equipment such as the chemical metering pumps used at the NEWPCC and chemical storage are considered robust.
3. Flexibility:	Operations staff can change chemical dose based on required effluent quality. This alternative is capable of reducing the overall discharge load to the Red River by up to eight percent.
4. Impact on Other Parts of the Plant:	The addition of chemicals to the digestion/dewatering process does not decrease digester capacity.
5. Space Requirements:	The current chemical storage and dosing system will need to be upgraded to accommodate the increased chemical usage.

6. Compatibility with Future BNR:	The future BNR upgrade will incorporate a struvite recovery system. However, sidestream chemical back-up for sulphide control will be maintained. Therefore, this system can be incorporated into the future build-out.
7. Constructability:	This alternative requires construction of a new chemical storage building and installation of additional chemical piping for ferric chloride and sodium hydroxide dosing, which should not interfere with the operation of the other processes at the NEWPCC.
OPERATIONAL CRITERIA	
1. Ease of Operation:	Positive displacement chemical dosing pumps are already used at the NEWPCC to feed ferric chloride to the digestion/dewatering process. The addition of similar dosing pumps for the additional ferric chloride and sodium hydroxide system should not have significant impacts on the operation and would require regular attention and monitoring by staff.
2. Ease of Maintenance:	Maintenance would be relatively straightforward and typical of equipment maintenance requirements.
3. Operator Safety:	The larger volume of ferric and additional chemical required for pH adjustment increases the risks associated with chemicals handling and storage. Additional training for sodium hydroxide handling and continued training for ferric chloride handling should be given to minimize the risk of an incident and to properly deal with an incident should one occur.
Environmental and Aesthetic Criteria	
1. Traffic:	There would be additional deliveries for ferric chloride and sodium hydroxide and an increase in the traffic for biosolids disposal.
2. Noise:	There will be no increase in noise.
3. Visual:	A new chemical storage building is likely to be built on the south east of the plant beside the existing railcar receiving station.
4. Odours:	There would be no noticeable difference in odour from the current levels.

5.4.2 Scenario 2

Scenario 2 (Chemically Enhanced Primary Treatment) This option can be used to maintain the SBR effluent TP load within the regulatory limit and can be used to temporarily reduce phosphorus from the mainstream. The amount of metal salt needed will increase by about 48% as compared to Scenario 1. The current chemical storage system will need to be upgraded to accommodate the increased chemical usage in sidestream and a new storage and dosing system for mainstream will need to be constructed. The mass balance for this Scenario is provided in **Appendix A**.

Table 17: Process Evaluation for Scenario 2

Scenario 2	**Chemically Enhanced Primary Treatment + Increased Sidestream Chemical Phosphorus Removal**
STANDARD:	**Reduce Final Effluent TP below 2.5 mg/L** **Maintain Centrate TP below 20 mg/L** **Maintain Nuisance Precipitation below 600 kg/d**
TECHNICAL CRITERIA	
1. Reliability:	The reliability of the process is largely dependent on providing adequate dose and dispersion of the metal salts upstream of the primary clarifiers. Since the primary purpose of CEPT is phosphorus trimming and not BOD/TSS removal, precise control is not required. One of the critical factors will be delivery of chemicals.
2. Robustness:	This alternative requires relatively accurate dosing of chemicals upstream of the primary clarifiers. Equipment such as chemical metering pumps and chemical storage are considered relatively robust.

3. Flexibility:	Since operations staff will have the ability to change the chemical dose based on desired effluent quality, this process is considered flexible.
4. Impact on Other Parts of the Plant:	The addition of chemicals for CEPT will increase the overall sludge quantities in the primary clarifiers, and could potentially have an impact on the sludge collection system. This will impact digester capacity but is not expected to exceed their capacity during average conditions. This alternative cannot be used when a digester is taken out of service or during maximum month conditions. Overall, capacity reduction in the digesters is approximately 3 percent.
5. Space Requirements:	New chemical storage and dosing system will need to be build to accommodate the increased chemical usage.
6. Compatibility with Future BNR:	The future BNR upgrade will likely have a back-up chemical phosphorus removal system, so this alternative could be incorporated into the future build-out.
7. Constructability:	This alternative requires construction of new chemical storage building and installation of additional chemical piping for ferric chloride and sodium hydroxide dosing, which should not interfere with the operation of the other processes at the NEWPCC.
OPERATIONAL CRITERIA	
1. Ease of Operation:	For Scenario 2, the positive displacement chemical dosing pumps used for Scenario 1 will pump ferric chloride to the day tank that will likely be installed at the headworks area. From the day tank, ferric chloride can flow by gravity (tank height needs to be adjusted to allow gravity flow) to the primary influent channel located downstream of the grit removal. The additional piping, flowmeter and automated vales for controlling ferric chloride dose to CEPT will require regular attention and monitoring by the City staff.
2. Ease of Maintenance:	Maintenance would be relatively straightforward and typical of equipment maintenance requirements.
3. Operator Safety:	Although plant staff already use ferric chloride, considerable increase in ferric demand and an additional chemical for pH adjustment increases the risks associated with chemical unloading, storage and dosing. Continued training should be given to minimize the risk of an incident and to properly deal with an incident should one occur.
Environmental and Aesthetic Criteria	
1. Traffic:	There would be additional deliveries for ferric chloride and sodium hydroxide and an increase in the traffic for biosolids disposal.
2. Noise:	There will be no increase in noise.
3. Visual:	A new chemical storage building is likely to be built on the south east of the plant beside the existing railcar receiving station.
4. Odours:	If ferric chloride is used, it is expected that odours would be reduced. If an alternative metal salt is used, there would be no noticeable difference in odour.

5.4.3 Scenario 3

Scenario 3 (Chemical Phosphorus Removal in HPO Reactors) This option will maintain the SBR effluent TP load within the regulatory limit and can be used to temporarily reduce phosphorus from the mainstream. The amount of metal salt needed will increase by more than 20% compared to Scenario 1. The current chemical storage system will need to be upgraded to accommodate the increased chemical usage in sidestream and a new storage and dosing system for mainstream will need to be constructed. The mass balance for this Scenario is provided in **Appendix A**.

Table 18: Process Evaluation for Scenario 3

Scenario 3	**Chemical Phosphorus Removal in HPO Reactors + Increased Sidestream Chemical Phosphorus Removal**
STANDARD:	**Reduce Final Effluent TP below 2.5 mg/L** **Maintain Centrate TP below 20 mg/L** **Maintain Nuisance Precipitation below 600 kg/d**
TECHNICAL CRITERIA	
1. Reliability:	The addition of metal salts (ferric chloride) to mixed liquor is a well established and reliable technology for phosphorus removal. The primary disadvantage is the increase in mixed liquor concentration and the ability of the secondary clarifiers to accommodate the increased solids loading rate.
2. Robustness:	This alternative is considered robust and does not require any unusual equipment for operation.
3. Flexibility:	Since operations staff will have the ability to change chemical dosage based on desired effluent quality this process is considered flexible. If used in conjunction with CEPT, this alternative is considered flexible.
4. Impact on Other Parts of the Plant:	The addition of chemicals to the HPO reactors will increase the overall sludge quantities generated at the NEWPCC. This will impact digester capacity but is not expected to exceed their capacity during average conditions. This alternative cannot be used when a digester is taken out of service or during maximum month conditions. Overall, capacity reduction in digester is approximately 3 percent.
5. Space Requirements:	New chemical storage and dosing system will need to be built to accommodate the increased chemical usage.
6. Compatibility with Future BNR:	The future BNR upgrade will incorporate a chemical back-up system and therefore, it is envisioned that this alternative could be incorporated into the future build-out.
7. Constructability:	This alternative requires construction of new chemical storage building and installation of additional chemical piping for ferric chloride and sodium hydroxide dosing, which should not interfere with the operation of the other processes at the NEWPCC.
OPERATIONAL CRITERIA	
1. Ease of Operation:	For Scenario 3, the positive displacement chemical dosing pumps used for Scenario 1 will pump ferric chloride to the day tank that will likely be installed at the headworks area. From the day tank, ferric chloride can flow by gravity (tank height needs to be adjusted to allow gravity flow) to the primary effluent channel feeding the HPO reactors. The additional piping, flowmeter and automated vales for controlling ferric chloride dose to HPOs will require regular attention and monitoring by the City staff.
2. Ease of Maintenance:	Maintenance would be relatively straightforward and typical of equipment maintenance requirements.
3. Operator Safety:	Considerable increase in ferric chloride demand and an additional chemical for pH adjustment increases the risks associated with chemical unloading, storage and dosing. Continued training should be given to minimize the risk of an incident and to properly deal with an incident should one occur.
Environmental and Aesthetic Criteria	
1. Traffic:	There would be additional deliveries for ferric chloride and sodium hydroxide and an increase in the traffic for biosolids disposal.
2. Noise:	There will be no significant increase in noise.
3. Visual:	A new chemical storage building is likely to be built on the south east of the plant beside the existing railcar receiving station.
4. Odours:	There would be no noticeable difference in odour from the current levels.

6. Risks and Benefits

A Risk Management Plan was developed at the early stage of the project and was updated as the project progressed to capture the potential risks and benefits as they were identified.

Some of the key risks and benefits associated with interim phosphorus removal implementation at the NEWPCC are summarized below.

6.1 Benefits

6.1.1 Reduce Phosphorus Load to Red River

Interim phosphorus removal at the NEWPCC will decrease the total annual phosphorus load to the Red River. Implementing Scenario 1 could reduce the overall phosphorus load from the NEWPCC to the Red River by about 8% annually. Trimming more phosphorus from the mainstream using Scenario 2 or 3 could reduce the overall annual phosphorus load to the Red River from the NEWPCC by about 23%.

6.1.2 Minimize struvite Precipitation

Additional ortho-phosphate from SEWPCC sludge after the BNR upgrade will increase the chance of struvite precipitation in solids handling equipment and piping at the NEWPCC. Scenario 1 will immobilize the additional ortho-phosphate from SEWPCC, which minimizes nuisance struvite precipitation.

6.2 Risks

6.2.1 Digesters Cleaning

Typically, the anaerobic digesters at the NEWPCC are cleaned on an alternating schedule every other year, with odd numbered digesters cleaned one year and even numbered digesters cleaned the next year. Taking a single digester out of service has a reduces the SRT in the system. **Figure 39** compares the digester SRT with 6 and 5 digesters in service between different Scenarios. Under average conditions, with only 5 digesters in service the SRT decreases to approximately 15 days in Scenario 1 and 14.5 days in Scenarios 2 and 3. The digesters are therefore near capacity when one digester is taken out of service. Therefore, it is recommended that mainstream ferric chloride dosing (Scenario 2 or Scenario 3) during these periods digester cleaning should be avoided.

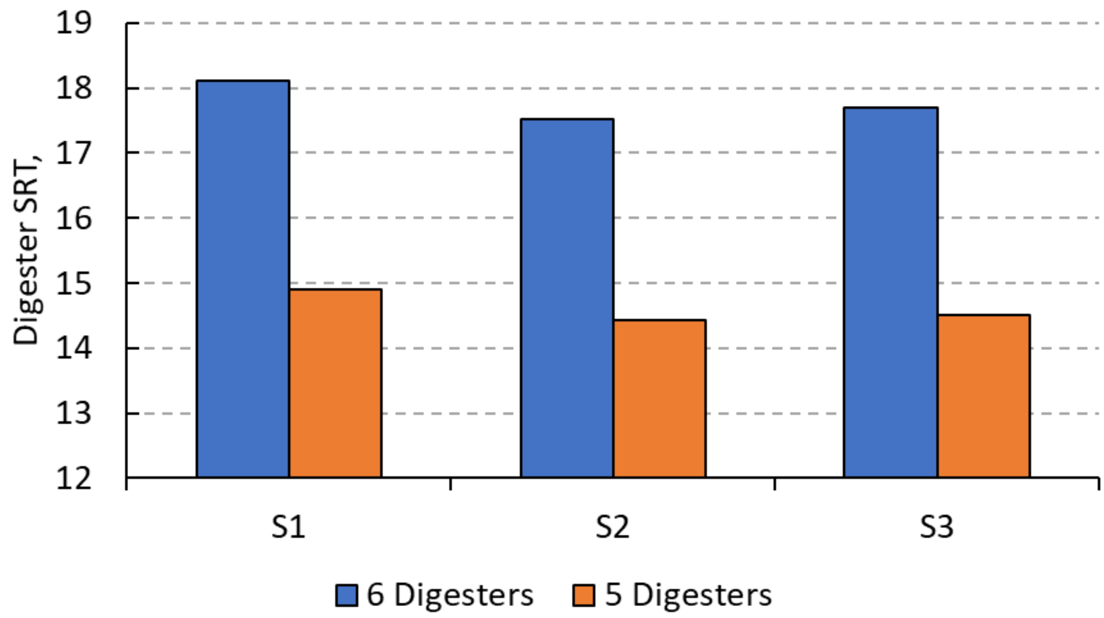

Figure 39: Comparing Digesters SRT with 5 and 6 Digesters in Service

6.2.2 Grit Build-Up

Grit is an inert material which is heavier than sludge and settles to the bottom of digesters and accumulates in the poorly mixed or unmixed areas. As grit accumulates, it reduces the active volume in a digester leading to shorter SRTs. In this study, no allowance has been made for grit build-up in the digesters. Allowing for grit accumulation in the digesters further reduces the capacity of the digesters and limits the ability for interim phosphorus removal.

6.2.3 Sludge Production

The benchscale study showed a higher value for sludge production for Scenarios 2 and 3 compared to the modelling work. It is understood that due to the scale of the jar tests, small errors in measurements can cause a considerable difference in the final results. However, the higher predicted amount of sludge production estimated in the benchscale study should be taken into consideration as a potential risk for full scale application. The ferric chloride doses predicted by BioWin for Scenarios 2 and 3 are applicable if the sludge production stays within the range predicted by the model. If full scale application shows higher sludge production than those predicted by modelling, ferric chloride doses for Scenarios 2 and 3 will need to be adjusted accordingly.

6.2.4 SEWPCC Sludge

The SEWPCC phosphorus load is an estimate only and the actual phosphorus load cannot be determined until the BNR upgrade is complete.

The sludge flow and concentration from the proposed high-rate clarification process (Actiflo) at SEWPCC can affect the digesters at NEWPCC. Since the SEWPCC upgrade is not complete, this impact cannot be verified.

6.2.5 Future Development

The potential future residential and industrial developments were not considered in this study. Allowing for future development reduces the available capacity for interim phosphorus removal.

6.2.6 Ferric Chloride Delivery

Ferric chloride can be delivered to the site either by railcars or tanker trucks. Since tanker truck capacity is less than railcar (approximately one-third), and the final cost of the product is much higher when delivered by truck, it is recommended to continue with railcar delivery.

Currently ferric chloride is delivered to the NEWPCC by railcars every 15 to 22 days. With the current ferric chloride demand and delivery frequency, the operation staff experience issues with frequent delivery delays. For interim phosphorus removal, the delivery frequency will increase from once every 22 days to once per week. Any delays to delivery could impact interim phosphorus removal.

The current railcar receiving station at the NEWPCC is designed to accommodate one railcar at a time. Since ferric chloride freezes at approximately -26°C, the railcars cannot be stored outside for an extended period during the winter. In order to receive two railcars simultaneously major upgrades are required at the railcar receiving station.

6.2.7 Traffic Management

Increasing ferric chloride delivery frequency and adding an additional chemical (sodium hydroxide) which will be delivered by trucks, will cause higher traffic in the area. With the current and the potential future construction activities occurring around the site, traffic management may become an issue and requires further consideration.

6.2.8 Safety

With the substantial increase in ferric chloride demand and the requirement for pH adjustment, the operations staff will need to handle larger volumes of ferric chloride and a new type of chemical for pH adjustment. Also, with the additional ferric chloride dosing points added to the mainstream (Scenario 2 and 3), there will be more chemical pipes running throughout the plant from the ferric chloride storage area (South) to the headworks and bioreactors area (North), **Figure 42**.

These will increase the chemical contact risks associated with chemical storage and handling which requires further training and monitoring.

7. Review of Alternative Chemicals

The City was contacted by several vendors offering alternatives to ferric chloride for phosphorus removal chemicals. In response, AECOM prepared and distributed a questionnaire to all interested vendors. A total of six vendors were contacted, and only two responded to the questionnaire. The two vendors who responded to the questionnaire were Bishop Water Technologies and RichTerra. Their technology and previous experience were further reviewed by the project team and are summarized below.

7.1 RE300

Bishop Water Technologies (BWT) offers a coagulant called RE300 which includes rare earth elements. RE300 is a novel coagulant made with rare earth minerals, lanthanum and cerium. Like ferric chloride the phosphorus removal process is based on chemical precipitation. The chemical has been trialed in a few small wastewater treatment plants but there is no large full-scale application yet. An advantage of this product compared to ferric chloride is its lower molar ratio to phosphorus of 1:1. The supplier also stated that this ratio does not change with changing phosphorus concentration. The vendor claims that RE300 is a non-toxic chemical and can be dosed anywhere in the process train including anaerobic digesters, however, it does not remove hydrogen sulfide which is a disadvantage. RE300 is not yet approved in Manitoba, whereas ferric chloride is accepted and widely used in several water and wastewater treatment plants in the Province. The molecular weight of RE300 is almost two times that of ferric chloride. This indicates that even though the molar ratio of RE300 to phosphorus is 1:1, this does not necessarily translate to a reduction of chemicals. It depends on the relative ferric molar ratios that are required. In the case of the NEWPCC side stream application where Fe to P ratio is relatively low (approximately 1.3) it would actually require less ferric chloride than RE300. On the other hand, in mainstream the required Fe:P ratio is higher (approximately 3) and it would require around 2 times more ferric chloride than RE300 (**Figure 40**).

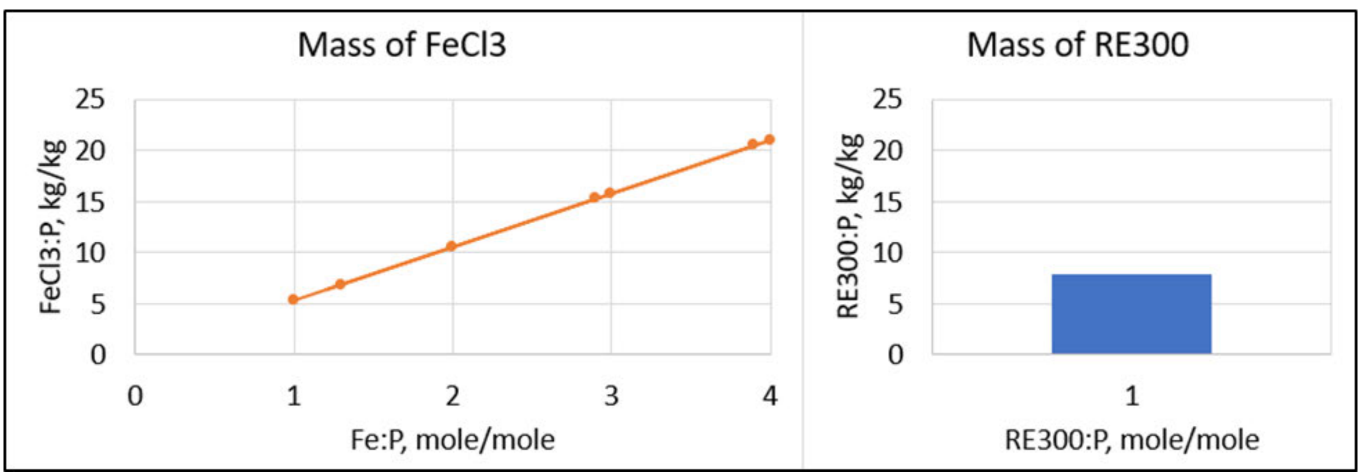

Figure 40: Comparison of Mass of Ferric Chloride and RE300 Required to Precipitate Phosphorus at NEWPCC Based on the Required Chemical:P Molar Ratios

The cost of RE300 is higher than ferric chloride. Based on preliminary review, RE300 would be cost-effective only if the required Fe:P ratio were greater than approximately 4.5 (**Figure 41**). The preliminary modelling results, however, show that the required Fe:P ratio is lower than 4.5. RE300 is therefore not recommended as an alternative chemical due to its higher cost compared to ferric chloride and no previous full-scale applications in wastewater treatment plants of comparable size to NEWPCC. According to AECOMs conversation with the supplier, they are willing to test the chemical on samples from NEWPCC in their facility. They did not recommended testing of their chemical at the

NEWPCC. Based on this, AECOM cannot recommend the use of this chemical until jar testing can be independently conducted at the NEWPCC.

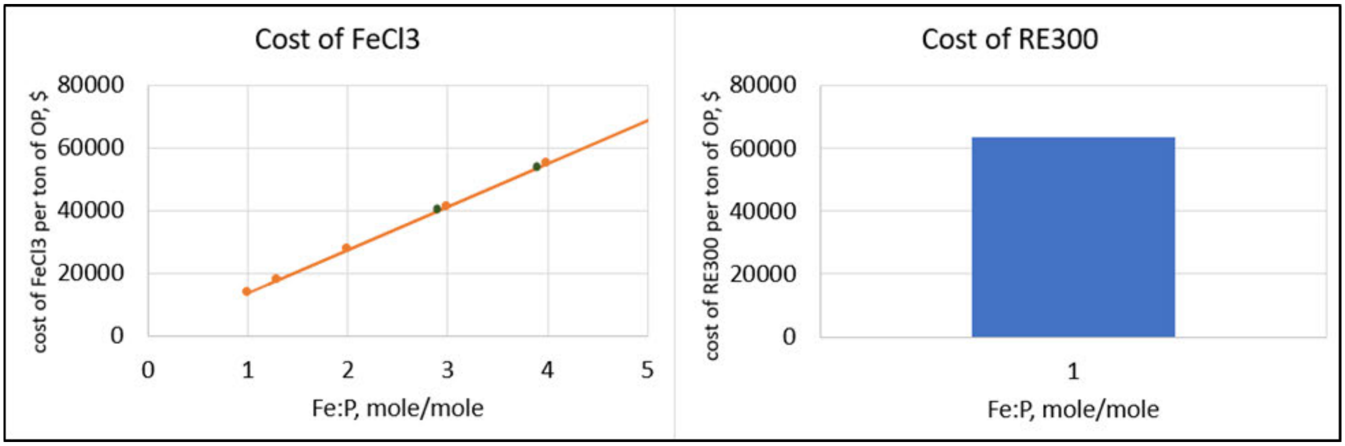

Figure 41: Comparison of Cost of Ferric Chloride and RE300 to Remove Phosphorus at NEWPCC Based on the Required Chemical:P Molar Ratios

7.2 RichTerra

RichTerra offers a biological agent consisting of a group of bacteria and enzymes which can eliminate phosphorus from wastewater. According to the supplier's response to the questionnaire and online research, there have been no full-scale applications. The product is in the form of a liquid suspension which can be dosed to the headworks of the plant. The vendor claims that it is non-toxic and does not impact downstream processes. The vendor claims that the phosphorus is removed biologically but the exact biochemical process has not been explained and very limited information is available about this product. Normally, phosphorus that is removed biologically from the mainstream is in turn re-released during the digestion process when sludge is stabilized, so it is unclear as to whether this type of biological agent will be effective. The cost of this product is higher than ferric chloride.

The product cannot bet recommended due to lack of information provided by the vendor, and without any full-scale applications in service.

7.3 Alum

Using alum as a coagulant has been previously reviewed by AECOM as part of NEWPCC Centrate Treatment Design.

Based on ferric and alum dosing trials it has been determined that ferric chloride improved the dewaterability of digested biosolids more than alum. The review found that alum is also not recognized as a valuable sludge conditioning agent and is rarely used for this purpose while ferric chloride is used more often in similar applications. Additionally, ferric chloride produced a dryer sludge cake and provided reductions in polymer dosages.

Ferric chloride in contrast to alum was found to be effective in struvite control as well as reduction of sulfide concentration in biogas. Ferric chloride reacts with hydrogen sulfide (H_2S) present in the sludge and will strip the methane gas generated in the digesters from H_2S and make the gas less corrosive to use as an energy source.

7.4 General Conclusion

Since ferric chloride is currently dosed to the anaerobic digesters and the logistics for chemical delivery are already in place, it is not recommended to change the coagulant for interim phosphorus removal.

If an alternative chemical is used for phosphorus removal, ferric chloride still needs to be dosed to the anaerobic digesters for hydrogen sulfide control which introduces another chemical which requires storage and handling. As well, further testing would be required to define the impact of using two metal salts on biosolids composition and land application.

8. Cost Estimates

8.1 Proposed Upgrade

Currently the ferric chloride storage system at the NEWPCC consist of two 80 m^3 tanks and ferric chloride is delivered by railcar, approximately every 22 days. Implementing interim phosphorus removal at the NEWPCC will require additional ferric chloride storage tanks and weekly railcar deliveries to meet the ferric chloride demand. Also, a sodium hydroxide storage tank and dosing system will be required to maintain a neutral pH in the digesters. The new chemical storage and dosing system at the NEWPCC will include:

- A new chemical storage building for additional ferric chloride and sodium hydroxide storage and dosing.
- Two chemical dosing skids and ancillary equipment.
- New chemical piping, fittings and valves from the dosing skids to the dosing points. It is assumed that all the existing ferric chloride piping will be replaced.
- A day tank and eyewash station at the headworks area for Scenario 2 and 3.

Proposed pipe route drawing and a 3D model for the new chemical storage building are provided in **Figure 42** and **Figure 43**, respectively.

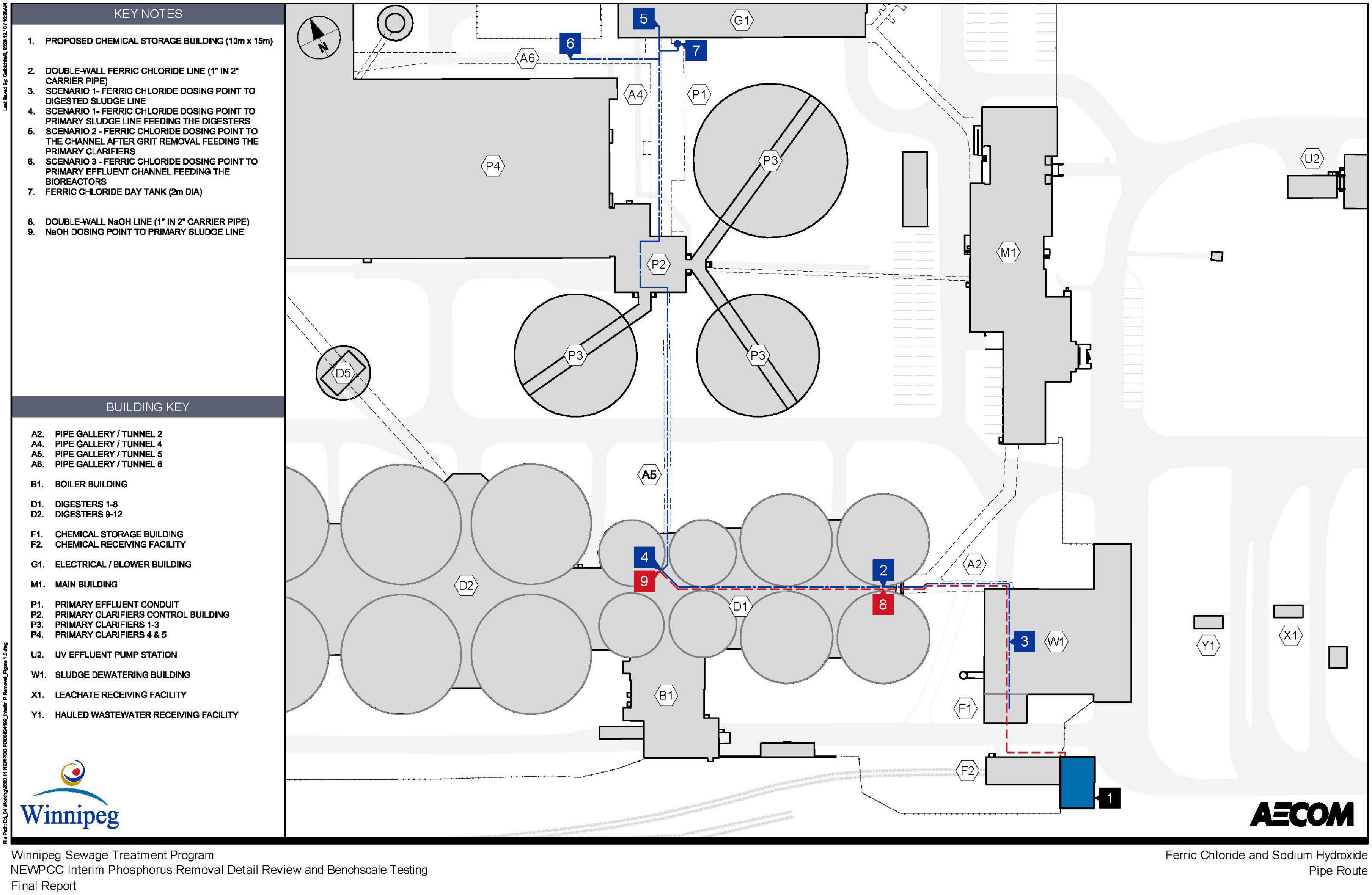

Figure 42: Proposed Pipe Route

Figure 43: 3D Model for the Proposed New Chemical Storage Building

8.2 Cost Estimates

The capital cost estimate is based on Class 4 AACE International Recommended Practices and is considered to be accurate within +50%/-30%. These are to be considered Rough Order of Magnitude (ROM) estimates suitable for making business decisions.

The following sections describe the methodology and assumptions that have been used to derive the capital cost estimate.

8.3 Methodology for Developing the Capital Cost Estimate

Cost estimates can be derived from stochastic or deterministic factors. Stochastic cost estimates are derived by applying standard factors to process equipment or other parametric variables, such as the floor area of a building. The deterministic approach uses quantity take-offs for generating the cost estimate. The cost estimate for the new chemical storage and dosing system upgrades used a combination of stochastic and deterministic methods, as indicated in this Section.

The cost estimate consists of the following major components:

- **Process equipment supply and installation (deterministic and some stochastic):** These costs are derived from vendor quotes (both specifically solicited for this project and archival), previous projects, accounting records from similar construction projects where available, and experience.
- **Building (stochastic and professional judgment):** The capital costs for the new building is based on estimating the required footprint of the building.
- **Instrumentation and control (stochastic):** Instrumentation and controls were based on percentage of the overall estimate.
- **Engineering (deterministic and stochastic):** Standard allowance, which includes Preliminary and Detailed Design and Contract Administration costs. This cost include engineering services such as preliminary design document and tender ready documents preparation, contract administration, and inspection.

8.3.1 Contingency

The capital cost estimate includes a contingency for elements of costs, within the defined scope of work covered by the estimate that cannot be explicitly foreseen or described based on the level of project definition. This contingency is an allowance to cover undefined items resulting from limitations in the level of project definition.

The contingency will likely be required to complete the project and as such is an integral part of the capital cost estimate. The contingency is not intended to cover items such as changes to the scope of the project.

8.4 Opinion of Probable Cost

8.4.1 Capital Cost

At the conceptual design level there are still a number of unknown factors affecting the design and the cost estimate. The effect of these factors cannot be quantified at this time, and therefore the Opinion of Probable Cost is based on our current understanding of the project, available data and the assumptions detailed in this report.

An optional cost of $2,000,000 has been included in the cost estimate. This cost is meant to identify the particular risk to the project of the delivery of ferric chloride railcars to the NEWPCC. The existing chemical unloading system at the NEWPCC can accommodate one railcar at a time. However, based on the reliability of chemical delivery from

Canadian National and Canadian Pacific railways, an allowance to upgrade the City's unloading system to a two-railcar system has been provided as an optional item.

The summary of the capital cost estimate for the upgrade is presented in **Table 19**.

Table 19: Opinion of Probable Capital Costs for Interim Phosphorus Removal at NEWPCC

Description	Estimated Total Capital Cost
Capital Cost*	$ 4,830,000
Engineering (15%)	$ 725,000
Sub-total	**$ 5,555,000**
Contingencies (50%)*	$ 2,780,000
Total**	**$ 8,400,000**
Additional Railcar receiving Bay (Optional)*	**$ 2,000,000**

* Rounded up to nearest $10,000
** Rounded up to nearest $100,000

It is worth mentioning that most of the capital cost is associated with the new chemical storage facility which is required for implementing Scenario 1. The capital cost premium to implement Scenario 2 and Scenario 3 is approximately 6% of the total capital cost presented in **Table 19**.

8.4.2 O&M Cost

The operation and maintenance (O&M) costs were estimated based on the chemical and labour costs associated with ferric chloride and sodium hydroxide supply, delivery, and unloading.

According to our conversation with the operations staff at the NEWPCC, at minimum it takes about one day for one person to unload a railcar and approximately half a day for two persons to unload a truck. With the increased ferric chloride delivery frequency and sodium hydroxide delivery, approximately 52 additional person days per year would be required for chemical handling.

A summary of the O&M costs is shown in **Table 20.**

Table 20: O&M Costs for Interim Phosphorus Removal at NEWPCC

Description	Yearly O&M Cost*
Interim Phosphorus Removal	$ 2,200,000

**The numbers are rounded to nearest $100,000.*

The O&M costs are expected to increase by approximately 2% to 3% per year due to inflation.

9. Next Steps

Due to Covid-19 and the University of Manitoba laboratory shutdown, maximum month conditions were not tested in March 2020. Although it is not recommended to operate Scenario 2 or Scenario 3 during maximum month conditions, it is recommended that the maximum month testing be completed in March 2021 to verify the impacts of high wastewater loads. The impact of grit during events such as spring melt can have significant impacts on wastewater characteristics, which when combined with cold water temperatures can affect chemical dosing and sludge production values. It is also recommended a benchscale flow through anaerobic reactor be operated during this period to capture useful information on digester toxicity.

During the preparation of this report another alternative to Scenario 1 was identified that could reduce overall capital costs. This alternative would include dosing ferric chloride to the sludge holding tanks at the SEWPCC and WEWPCC before hauling the sludge to the NEWPCC. Since chemical storage and dosing systems are already available at the WEWPCC and will be installed at the SEWPCC as part of the BNR upgrade, no additional infrastructure would be required. This alternative can immobilize the additional ortho-phosphate load from the WEWPCC and SEWPCC and can reduce the non-ferric precipitation in the sludge handling equipment and piping at the NEWPCC. The feasibility of this option can be evaluated during early 2021.

The design phase can progress concurrently with the additional work listed above. A conceptual schedule is shown in **Figure 44**.

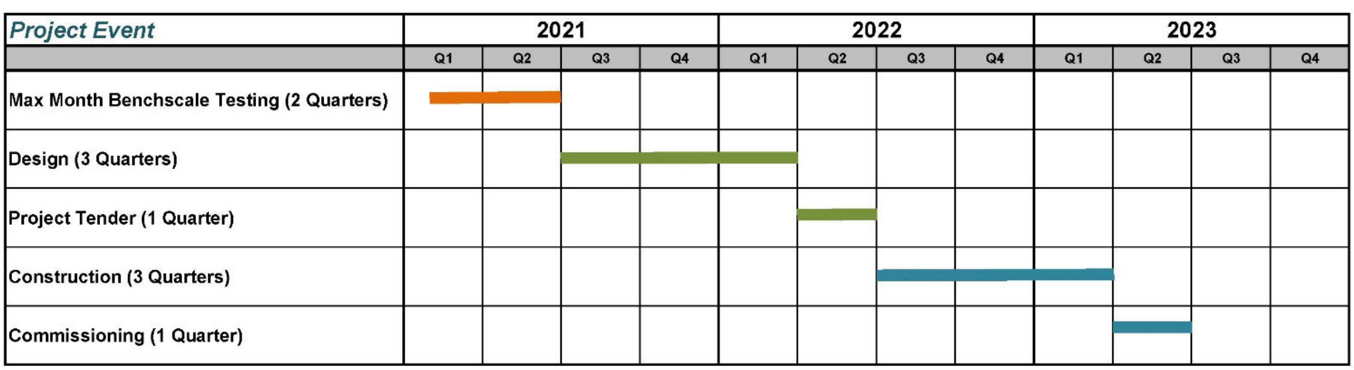

Figure 44: Conceptual Schedule for Interim Phosphorus Removal at NEWPCC

10. Recommendations

BioWin modelling has shown that Scenario 1 can be used to remove the additional phosphorus load in the NEWPCC digesters resulting from the SEWPCC BNR upgrade. As well, under average flow and load conditions, Scenarios 2 and 3 could be used to reduce phosphorus from the mainstream. The amount of phosphorus removed in the mainstream can be adjusted by the ferric chloride dose to the primary clarifiers or HPO reactors. If Scenario 2 or Scenario 3 are implemented for 9 months of the year, the overall phosphorus load to the Red River from the NEWPCC could be reduced by about 23 percent per year.

Jar testing confirmed the feasibility of phosphorus removal in Scenario 1 as well as in Scenarios 2 and 3 during average conditions. The results from jar testing confirmed key parameters such as the ratio of ferric chloride to phosphorus removal predicted by BioWin for each Scenario. For Scenarios 1 and 2, benchscale results showed a lower ratio than the BioWin prediction. However, for Scenario 3, benchscale work showed a slightly higher ratio. Sludge production values were also observed to be higher in benchscale versus the modelling work, which could limit the amount of ferric chloride dosed into the mainstream. The benchscale testing showed that there should not be any adverse toxic effects of increased ferric dosing on the anaerobic digestion process or HPO reactors. When maximum month conditions are tested in March 2021 it is recommended that a benchscale digester be run with continuous feed based on the selected ferric dosage. Increased ferric dosing to the primary sludge caused pH reduction. It is recommended that any interim phosphorus removal upgrade include a sodium hydroxide system to neutralize the pH in the digesters.

Based on the review of alternative chemicals for phosphorus removal as well as the results from jar tests it is recommended to proceed with ferric chloride for the preliminary and detailed design.

For the capital and O&M costs estimates, it was assumed that a new chemical storage facility will be built for additional ferric chloride and sodium hydroxide storage and the frequency of railcar delivery will increase to approximately once per week. This will increase the overall O&M costs to $2,200,000/yr.

The design would include, two new ferric chloride storage tanks, one new sodium hydroxide storage tank, a chemical building, two chemical metering systems, a ferric chloride day tank at the headworks area, and new chemical piping to the HPO bioreactors, primary clarifiers, and digesters.

Additionally, it was recognized that dosing ferric chloride into the sludge holding tanks at the WEWPCC and SEWPCC is also a feasible alternative to Scenario 1 that may result in reduced capital costs. Although not part of the scope of this work, this alterative would involve using existing chemical dosing infrastructure at the WEWPCC and SEWPCC to dose ferric chloride into the sludge prior to arriving at NEWPCC. While the overall operational costs would be the same as Scenario 1, the ferric chloride storage requirements at NEWPCC would be reduced.

Appendix A

Mass Balance

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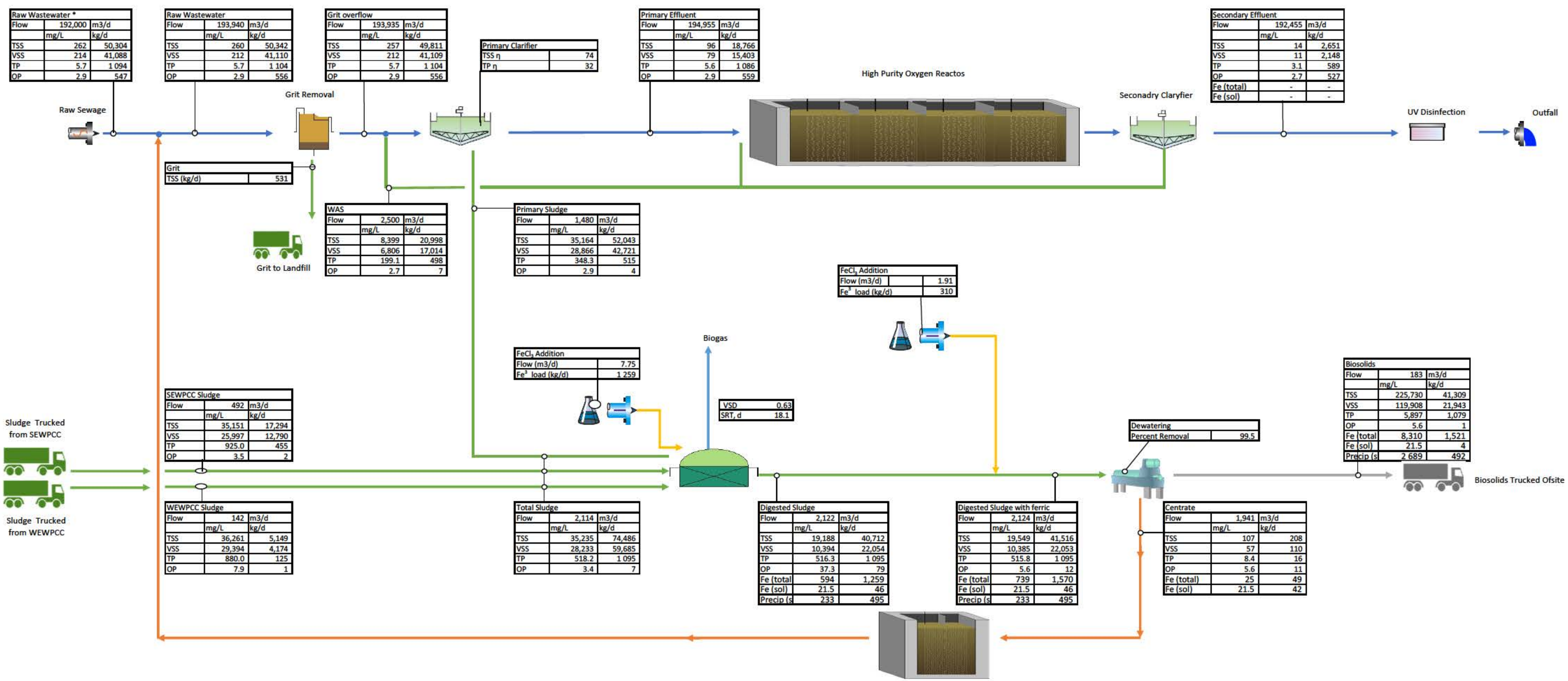
Scenario 1

NEWPCC Mass Balance in Biowin 6.0
2023 Scenario 1

ANNUAL AVERAGE CONDITIONS



Raw Wastewater *		
Flow	192,000	m3/d
	mg/L	kg/d
TSS	262	50,304
VSS	214	41,088
TP	5.7	1 094
OP	2.9	547

Raw Wastewater		
Flow	193,940	m3/d
	mg/L	kg/d
TSS	260	50,342
VSS	212	41,110
TP	5.7	1 104
OP	2.9	556

Grit	
TSS (kg/d)	531

Grit overflow		
Flow	193,935	m3/d
	mg/L	kg/d
TSS	257	49,811
VSS	212	41,109
TP	5.7	1 104
OP	2.9	556

Primary Clarifier	
TSS η	74
TP η	32

Primary Effluent		
Flow	194,955	m3/d
	mg/L	kg/d
TSS	96	18,766
VSS	79	15,403
TP	5.6	1 086
OP	2.9	559

Secondary Effluent		
Flow	192,455	m3/d
	mg/L	kg/d
TSS	14	2,651
VSS	11	2,148
TP	3.1	589
OP	2.7	527
Fe (total)	-	-
Fe (sol)	-	-

WAS		
Flow	2,500	m3/d
	mg/L	kg/d
TSS	8,399	20,998
VSS	6,806	17,014
TP	199.1	498
OP	2.7	7

Primary Sludge		
Flow	1,480	m3/d
	mg/L	kg/d
TSS	35,164	52,043
VSS	28,866	42,721
TP	348.3	515
OP	2.9	4

$FeCl_3$ Addition	
Flow (m3/d)	1.91
Fe^3 load (kg/d)	310

$FeCl_3$ Addition	
Flow (m3/d)	7.75
Fe^3 load (kg/d)	1 259

VSD	0.63
SRT, d	18.1

SEWPCC Sludge		
Flow	492	m3/d
	mg/L	kg/d
TSS	35,151	17,294
VSS	25,997	12,790
TP	925.0	455
OP	3.5	2

WEWPCC Sludge		
Flow	142	m3/d
	mg/L	kg/d
TSS	36,261	5,149
VSS	29,394	4,174
TP	880.0	125
OP	7.9	1

Total Sludge		
Flow	2,114	m3/d
	mg/L	kg/d
TSS	35,235	74,486
VSS	28,233	59,685
TP	518.2	1 095
OP	3.4	7

Digested Sludge		
Flow	2,122	m3/d
	mg/L	kg/d
TSS	19,188	40,712
VSS	10,394	22,054
TP	516.3	1 095
OP	37.3	79
Fe (total	594	1,259
Fe (sol)	21.5	46
Precip (s	233	495

Digested Sludge with ferric		
Flow	2,124	m3/d
	mg/L	kg/d
TSS	19,549	41,516
VSS	10,385	22,053
TP	515.8	1 095
OP	5.6	12
Fe (total	739	1,570
Fe (sol)	21.5	46
Precip (s	233	495

Dewatering	
Percent Removal	99.5

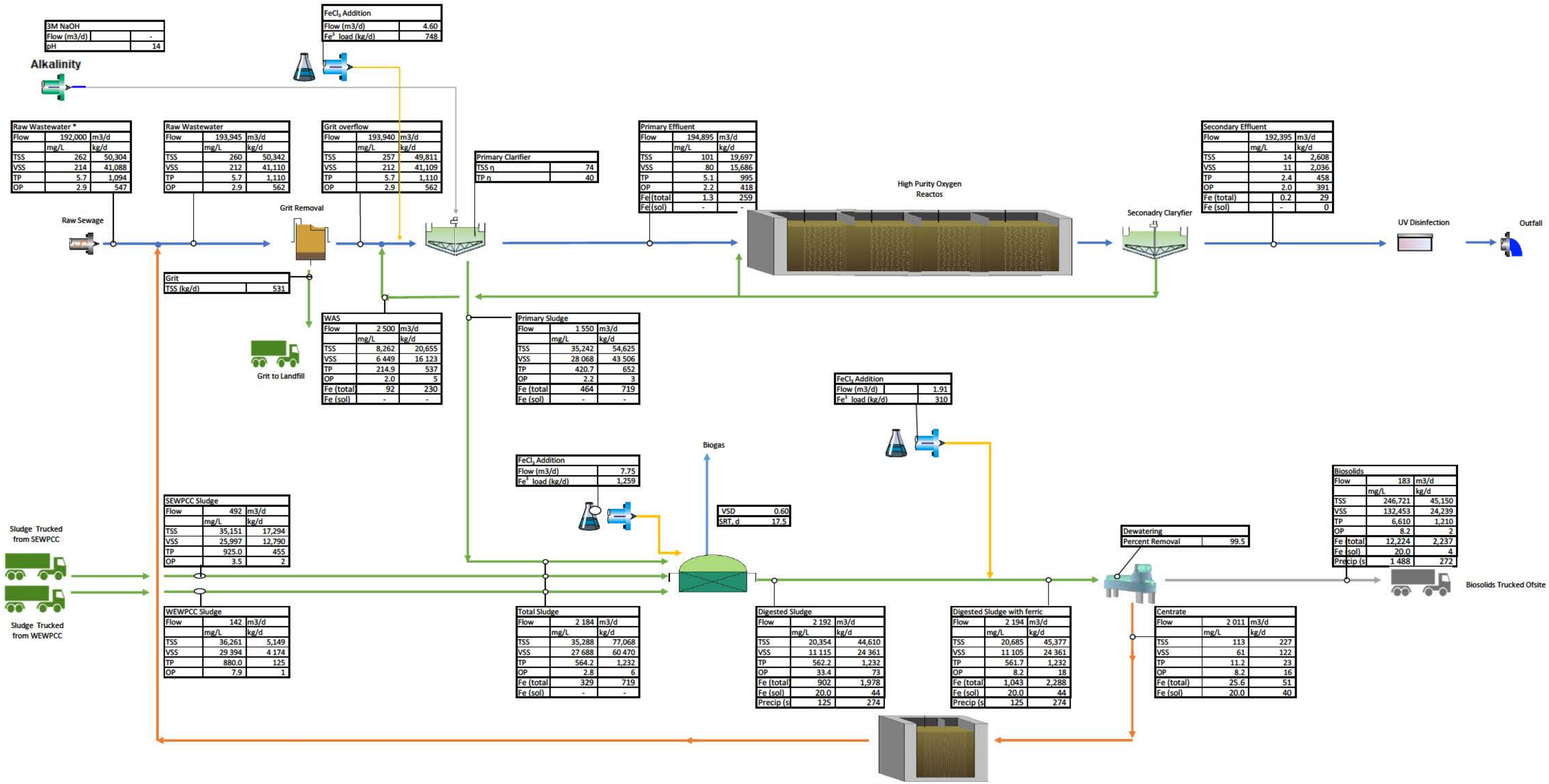
Centrate		
Flow	1,941	m3/d
	mg/L	kg/d
TSS	107	208
VSS	57	110
TP	8.4	16
OP	5.6	11
Fe (total)	25	49
Fe (sol)	21.5	42

Biosolids		
Flow	183	m3/d
	mg/L	kg/d
TSS	225,730	41,309
VSS	119,908	21,943
TP	5,897	1,079
OP	5.6	1
Fe (total	8,310	1,521
Fe (sol)	21.5	4
Precip (s	2 689	492

Scenario 2

NEWPCC Mass Balance in Biowin 6.0
2023 Scenario 2

ANNUAL AVERAGE CONDITIONS



3M NaOH	
Flow (m3/d)	-
pH	14

$FeCl_3$ Addition	
Flow (m3/d)	4.60
Fe^3 load (kg/d)	748

Raw Wastewater *		
Flow	192,000	m3/d
	mg/L	kg/d
TSS	262	50,304
VSS	214	41,088
TP	5.7	1,094
OP	2.9	547

Raw Wastewater		
Flow	193,945	m3/d
	mg/L	kg/d
TSS	260	50,342
VSS	212	41,110
TP	5.7	1,110
OP	2.9	562

Grit overflow		
Flow	193,940	m3/d
	mg/L	kg/d
TSS	257	49,811
VSS	212	41,109
TP	5.7	1,110
OP	2.9	562

Primary Clarifier	
TSS η	74
TP η	40

Primary Effluent		
Flow	194,895	m3/d
	mg/L	kg/d
TSS	101	19,697
VSS	80	15,686
TP	5.1	995
OP	2.2	418
Fe (total	1.3	259
Fe (sol)	-	-

Secondary Effluent		
Flow	192,395	m3/d
	mg/L	kg/d
TSS	14	2,608
VSS	11	2,036
TP	2.4	458
OP	2.0	391
Fe (total)	0.2	29
Fe (sol)	-	0

Grit	
TSS (kg/d)	531

WAS		
Flow	2 500	m3/d
	mg/L	kg/d
TSS	8,262	20,655
VSS	6 449	16 123
TP	214.9	537
OP	2.0	5
Fe (total)	92	230
Fe (sol)	-	-

Primary Sludge		
Flow	1 550	m3/d
	mg/L	kg/d
TSS	35,242	54,625
VSS	28 068	43 506
TP	420.7	652
OP	2.2	3
Fe (total	464	719
Fe (sol)	-	-

$FeCl_3$ Addition	
Flow (m3/d)	1.91
Fe^3 load (kg/d)	310

$FeCl_3$ Addition	
Flow (m3/d)	7.75
Fe^3 load (kg/d)	1,259

VSD	0.60
SRT, d	17.5

SEWPCC Sludge		
Flow	492	m3/d
	mg/L	kg/d
TSS	35,151	17,294
VSS	25,997	12,790
TP	925.0	455
OP	3.5	2

WEWPCC Sludge		
Flow	142	m3/d
	mg/L	kg/d
TSS	36,261	5,149
VSS	29 394	4 174
TP	880.0	125
OP	7.9	1

Total Sludge		
Flow	2 184	m3/d
	mg/L	kg/d
TSS	35,288	77,068
VSS	27 688	60 470
TP	564.2	1,232
OP	2.8	6
Fe (total	329	719
Fe (sol)	-	-

Digested Sludge		
Flow	2 192	m3/d
	mg/L	kg/d
TSS	20,354	44,610
VSS	11 115	24 361
TP	562.2	1,232
OP	33.4	73
Fe (total)	902	1,978
Fe (sol)	20.0	44
Precip (s	125	274

Digested Sludge with ferric		
Flow	2 194	m3/d
	mg/L	kg/d
TSS	20,685	45,377
VSS	11 105	24 361
TP	561.7	1,232
OP	8.2	18
Fe (total)	1,043	2,288
Fe (sol)	20.0	44
Precip (s	125	274

Dewatering	
Percent Removal	99.5

Centrate		
Flow	2 011	m3/d
	mg/L	kg/d
TSS	113	227
VSS	61	122
TP	11.2	23
OP	8.2	16
Fe (total)	25.6	51
Fe (sol)	20.0	40

Biosolids		
Flow	183	m3/d
	mg/L	kg/d
TSS	246,721	45,150
VSS	132,453	24,239
TP	6,610	1,210
OP	8.2	2
Fe (total)	12,224	2,237
Fe (sol)	20.0	4
Precip (s	1 488	272

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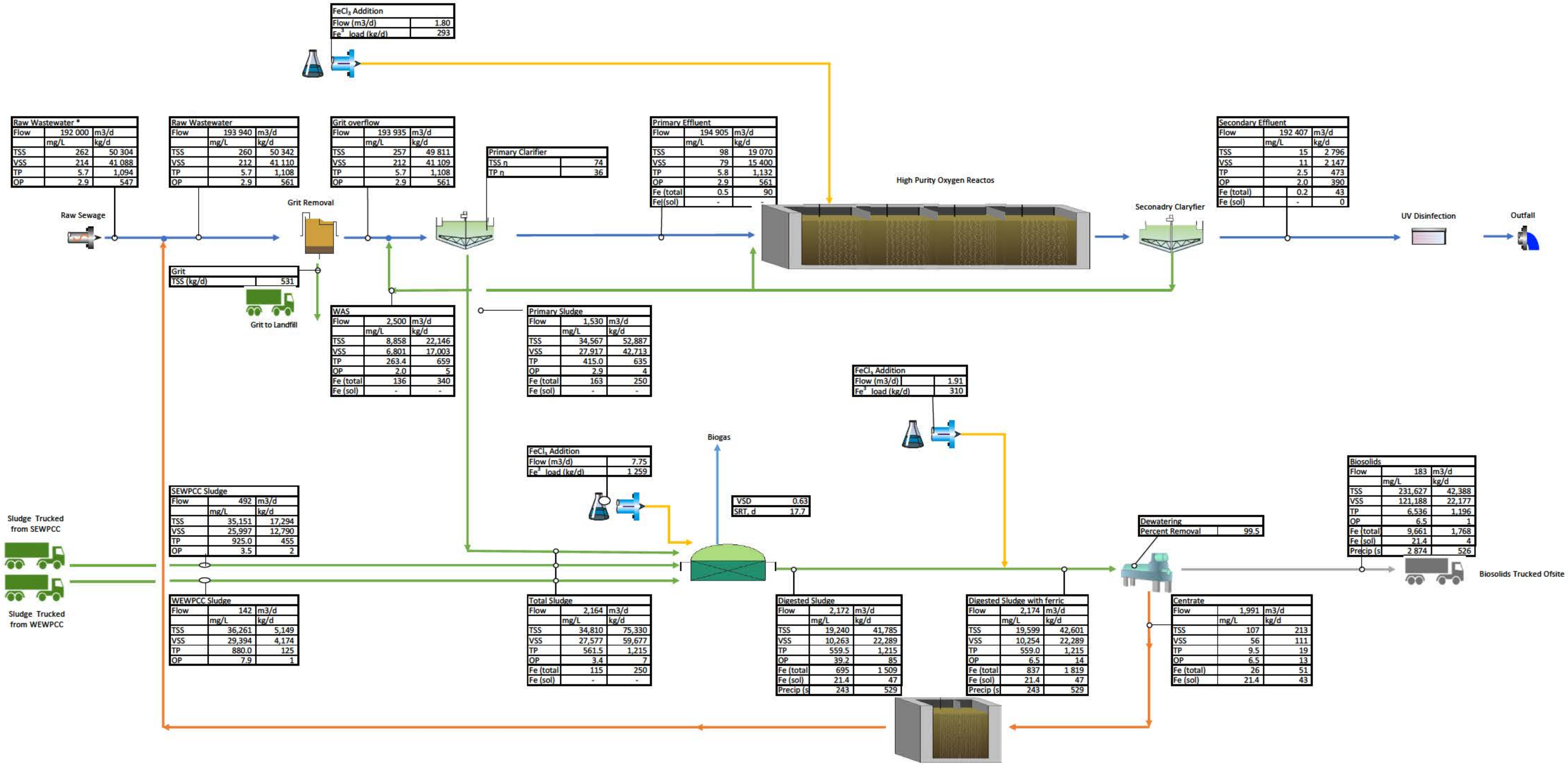
Scenario 3

NEWPCC Mass Balance in Biowin 6.0
2023 Scenario 3

ANNUAL AVERAGE CONDITIONS



FeCl3 Addition	
Flow (m3/d)	1.80
Fe3 load (kg/d)	293

Raw Wastewater *		
Flow	192 000	m3/d
	mg/L	kg/d
TSS	262	50 304
VSS	214	41 088
TP	5.7	1,094
OP	2.9	547

Raw Wastewater		
Flow	193 940	m3/d
	mg/L	kg/d
TSS	260	50 342
VSS	212	41 110
TP	5.7	1,108
OP	2.9	561

Grit overflow		
Flow	193 935	m3/d
	mg/L	kg/d
TSS	257	49 811
VSS	212	41 109
TP	5.7	1,108
OP	2.9	561

Primary Clarifier	
TSS n	74
TP n	36

Primary Effluent		
Flow	194 905	m3/d
	mg/L	kg/d
TSS	98	19 070
VSS	79	15 400
TP	5.8	1,132
OP	2.9	561
Fe (total	0.5	90
Fe (sol)	-	-

Secondary Effluent		
Flow	192 407	m3/d
	mg/L	kg/d
TSS	15	2 796
VSS	11	2 147
TP	2.5	473
OP	2.0	390
Fe (total)	0.2	43
Fe (sol)	-	0

Grit	
TSS (kg/d)	531

WAS		
Flow	2,500	m3/d
	mg/L	kg/d
TSS	8,858	22,146
VSS	6,801	17,003
TP	263.4	659
OP	2.0	5
Fe (total	136	340
Fe (sol)	-	-

Primary Sludge		
Flow	1,530	m3/d
	mg/L	kg/d
TSS	34,567	52,887
VSS	27,917	42,713
TP	415.0	635
OP	2.9	4
Fe (total	163	250
Fe (sol)	-	-

FeCl3 Addition	
Flow (m3/d)	1.91
Fe3 load (kg/d)	310

FeCl3 Addition	
Flow (m3/d)	7.75
Fe3 load (kg/d)	1 259

VSD	0.63
SRT, d	17.7

SEWPCC Sludge		
Flow	492	m3/d
	mg/L	kg/d
TSS	35,151	17,294
VSS	25,997	12,790
TP	925.0	455
OP	3.5	2

WEWPCC Sludge		
Flow	142	m3/d
	mg/L	kg/d
TSS	36,261	5,149
VSS	29,394	4,174
TP	880.0	125
OP	7.9	1

Total Sludge		
Flow	2,164	m3/d
	mg/L	kg/d
TSS	34,810	75,330
VSS	27,577	59,677
TP	561.5	1,215
OP	3.4	7
Fe (total	115	250
Fe (sol)	-	-

Digested Sludge		
Flow	2,172	m3/d
	mg/L	kg/d
TSS	19,240	41,785
VSS	10,263	22,289
TP	559.5	1,215
OP	39.2	85
Fe (total	695	1 509
Fe (sol)	21.4	47
Precip (s	243	529

Digested Sludge with ferric		
Flow	2,174	m3/d
	mg/L	kg/d
TSS	19,599	42,601
VSS	10,254	22,289
TP	559.0	1,215
OP	6.5	14
Fe (total	837	1 819
Fe (sol)	21.4	47
Precip (s	243	529

Dewatering	
Percent Removal	99.5

Centrate		
Flow	1,991	m3/d
	mg/L	kg/d
TSS	107	213
VSS	56	111
TP	9.5	19
OP	6.5	13
Fe (total)	26	51
Fe (sol)	21.4	43

Biosolids		
Flow	183	m3/d
	mg/L	kg/d
TSS	231,627	42,388
VSS	121,188	22,177
TP	6,536	1,196
OP	6.5	1
Fe (total)	9,661	1,768
Fe (sol)	21.4	4
Precip (s	2 874	526

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Appendix B

JAAO Report

Interim Phosphorus Removal at NEWPCC: Bench-scale testing of three options

Final Report to AECOM

L. Daniel, PEng, V. Wei, PhD, J. Oleszkiewicz PhD, PEng, BCEE
JAAO Environmental Engineering Ltd
636 Cloutier Drive, Winnipeg MB R3V 1T9

Winnipeg, 10.12.2020

Interim Phosphorus Removal at NEWPCC: Bench-scale testing of three options

1. Introduction

A series of bench scale phosphorus removal tests were conducted at the University of Manitoba's Environmental Engineering Laboratory. Three different phosphorus removal scenarios were tested and the impact of each of them on sludge production and anaerobic digestion were investigated. Scenario 1 simulated increased side stream chemical phosphorus removal where soluble phosphorus is precipitated in two steps: immediately before and after anaerobic digestion. Scenario 2 simulated chemically enhanced primary treatment (CEPT) where soluble phosphorus is precipitated during primary clarification process. Finally, Scenario 3 simulated phosphorus removal in high purity oxygen (HPO) reactors where soluble phosphorus is removed during the biological carbon removal process.

Results obtained during bench scale testing will help to assess the impact of each phosphorus removal scenario on the overall mass balance of the North End Water Pollution Control Center (NEWPCC) and determine the required chemical doses necessary to achieve desired levels of phosphorus removal. Dosing locations are shown in *Figure 1*.

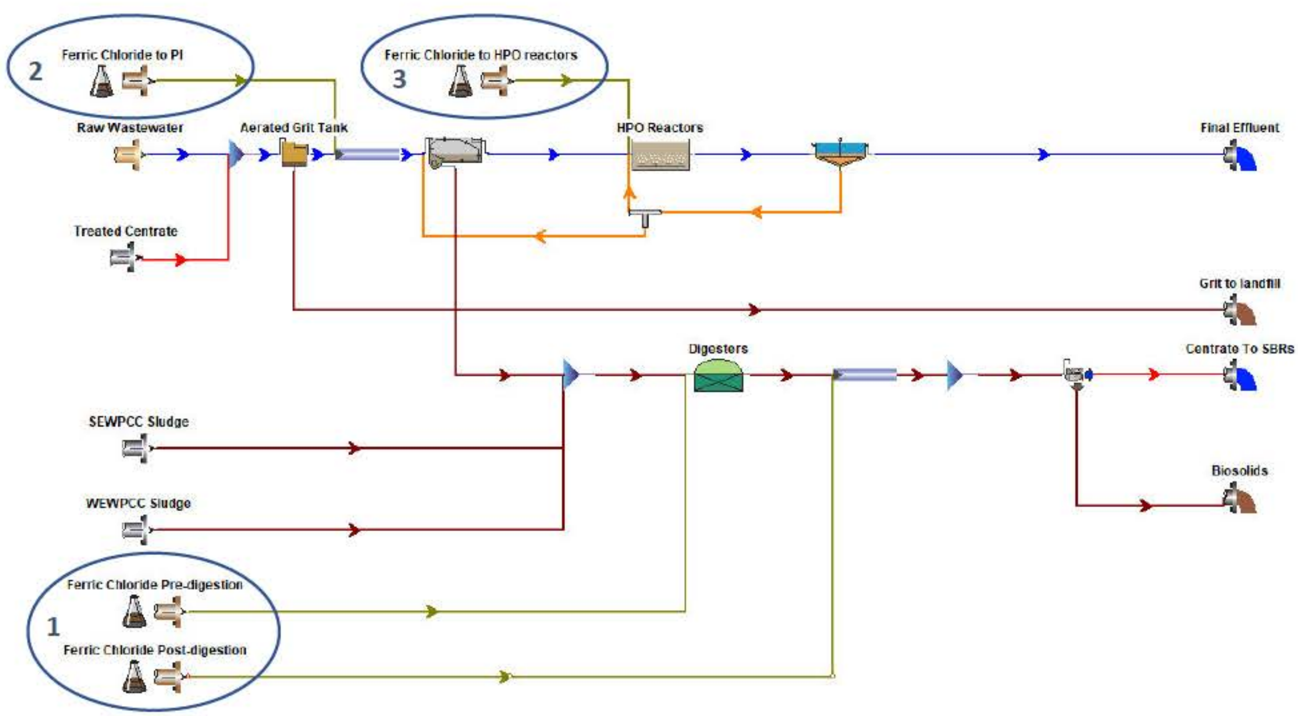

Figure 1: Ferric Dosing Locations at NEWPCC for the Three Scenarios

2. Procedures and Methods

Wastewater samples were collected with the assistance of the City of Winnipeg operations staff or by City of Winnipeg operations staff. Samples were collected in 20 L containers with minimal headspace. Samples were immediately transported to the University of Manitoba Environmental Engineering Lab for same day testing and analysis. Samples were stored in room temperature with the exception of digested sludge, which was stored in 35°C heated chamber until needed.

All pH measurements were taken with a calibrated pH probe. On-site pH measurement was conducted with a calibrated portable pH probe. Alkalinity was determined by conducting a titration of a 50 mL sample with 0.2 N H_2SO_4.

Total solids and volatile solids were measured by comparing the weight of a 30 mL to 50 mL sample before and after being dried in 103°C drying oven and again after 550°C drying oven.

Soluble ortho-phosphorus was determined by centrifuging each sample at 12,000 rpm for 8 minutes, supernatant was then diluted, if necessary, to be within the acceptable calibrated range of the Flow Injection Analyzer (FIA), filtered through a 0.45 um filter into a glass vial and then run using the FIA.

Total phosphorus was determined using the same supernatant sample used for soluble ortho phosphorus directly following centrifugation. Sample volume ranged from 1 mL to 50 mL depending on anticipated concentration. 1 mL 98% H_2SO_4 and 5 mL 65% concentrated nitric acid was added to each sample and boiled down to 1 mL. The 1 mL sample was then neutralized, diluted, and filtered using a 0.45 um filter. Samples were then analyzed using the FIA, with calibration standards that went through the same digestion steps.

Details of protocol for biomethanation potential (BMP) tests, phosphorus determination by FIA, and jar tests can be found in the appendices of Bench Scale Testing Protocol for NEWPCC Interim Phosphorus Removal Memo (AECOM, 2020).

3. Results

3.1. Scenario 1. Increased Side Stream Chemical Phosphorus Removal

Samples from NEWPCC (NE) and WEWPCC (WE) were collected and analyzed on October 14, 2020 between 8:30 and 9:30 AM for Scenario 1. Primary sludge from the NE was collected from the sample port near the primary sludge transfer pumps while the pumps were running to ensure a fresh sample. Digested sludge samples were collected following digestion, prior to the second ferric dosing point. Sludge samples from the WE were collected from the sludge holding tank, prior to being hauled to the NE.

***Table* 1** summarizes the raw sample characteristics.

Table 1: Scenario 1 Raw Sample Characteristics

Parameter	Unit	NE Primary Sludge	NE Digested Sludge	WE Sludge
pH		5.79	7.08	5.04
Alkalinity	mg $CaCO_3$/L	840	2,680	420
TS	mg/L	26,832	13,274	32,458
VS	mg/L	21,990	8,550	27,844
Ortho-P	mg/L	77.1	97.2	483.0
TP	mg/L	85.3	101.4	589.5

NE primary sludge and WE holding tank sludge were combined at a ratio of 7:3 to replicate conditions once SEWPCC upgrades are complete. The mixed sludge characteristics are summarized in ***Table 2***.

Table 2: NE Primary Sludge and WE Holding Tank Sludge Mixture Characteristics

Parameter	Unit	NE PS + WE S
pH		5.57
Alkalinity	mg $CaCO_3$/L	1,020
TS	mg/L	28,526
VS	mg/L	23,526
Ortho-P	mg/L	207.9
TP	mg/L	216.0

Jar testing was completed on mixture of NE primary sludge and WE holding tank sludge for four different ferric doses based on BioWin modeling. The four ferric doses prior to digestion were 0, 135, 250, and 500 mg Fe/L of sludge; the control dose, the current dose for hydrogen sulfide control, half the BioWin predicted dose, and the BioWin predicted dose, respectively. A reaction time of 5 minutes rapid mixing (200 rpm) and 15 minutes of slow mixing (80 rpm) was used for all doses. A total of four sets of jar tests were completed: with no pH adjustment, a duplicate of no pH adjustment, with pH adjusted to 6, and with pH adjusted to 7. On runs with pH adjustment, the pH was adjusted during the rapid mix using 5M NaOH.

The results of the four jar tests are presented in ***Figure 2.***

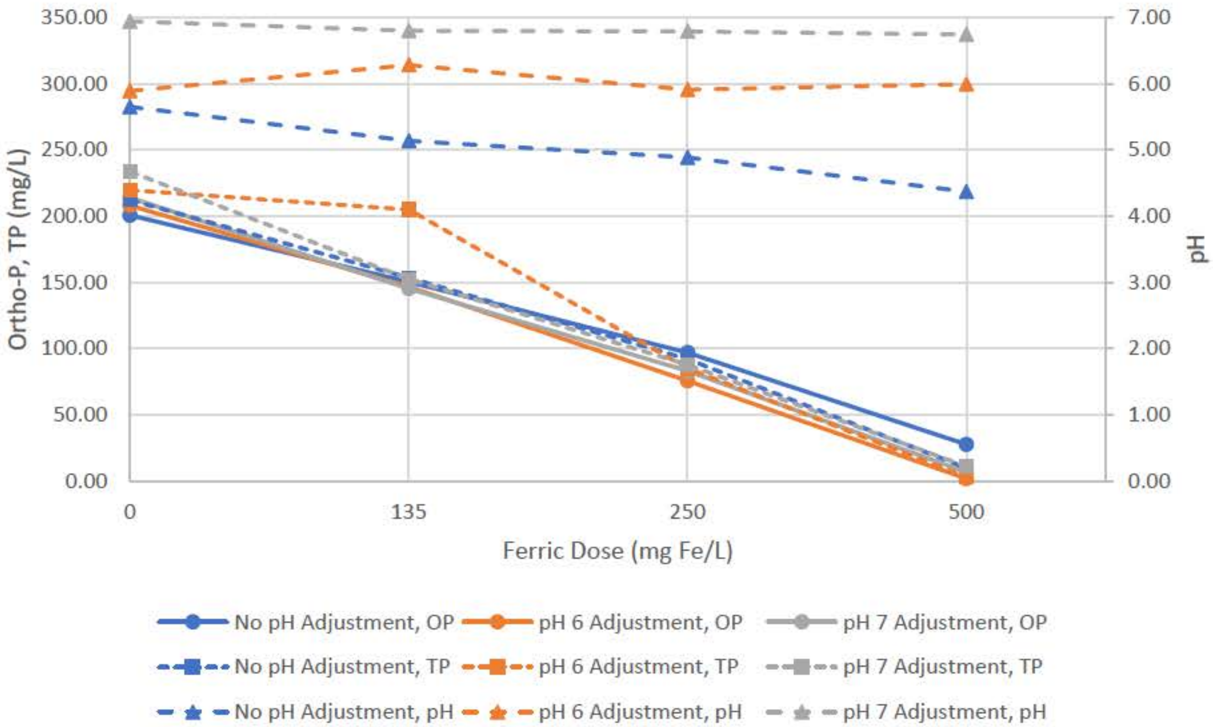

Figure 2: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 1 Jar Tests

After the 20 minutes of reaction time, 35.7 mL of the sludge from the jar test was added to 464.3 mL of NE digested sludge to replicate the current digester volumetric loading of 0.07 $m^3/m^3{*}d$ based on historical data for the NE. The 500 mL bottles were placed in a water bath of 36 degrees Celsius and mixed with magnetic mixers. Biogas produced during the 15 day test was automatically logged every minute. Cumulative biogas production during the biomethane production (BMP) test are shown in ***Figure 3***, ***Figure 4***, and ***Figure 5***. Biogas was sampled and analyzed for gas composition 5 times throughout the 15 days. ***Figure 6, Figure 7*** and ***8*** show the biogas composition throughout the BMP tests.

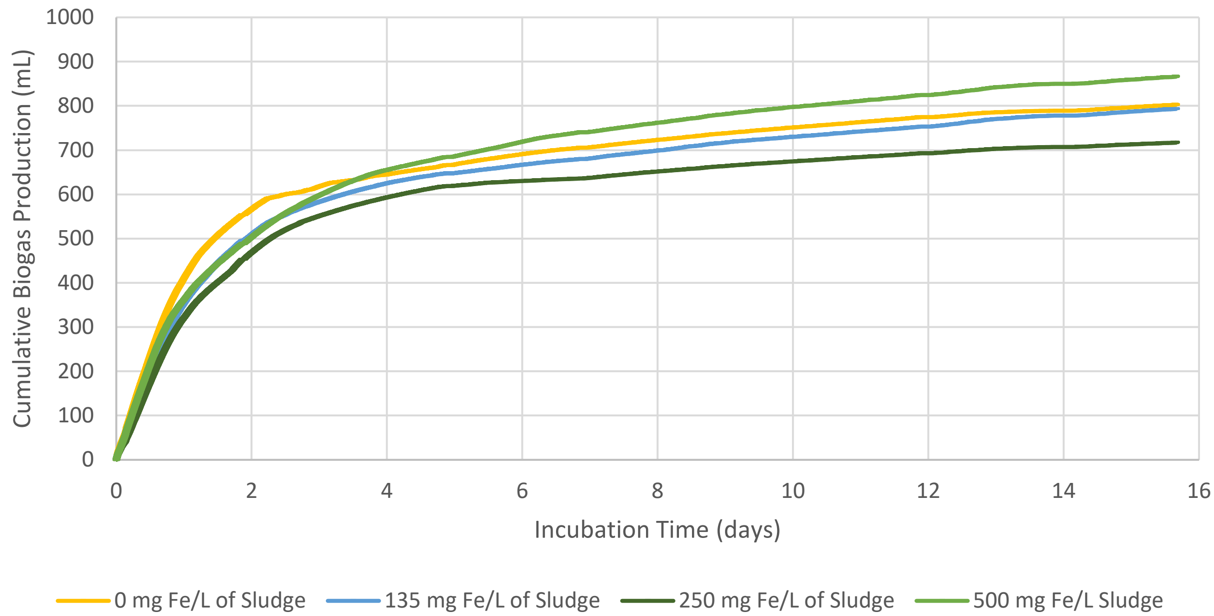

Figure 3: Scenario 1 Cumulative Biogas Production – No pH Adjustment

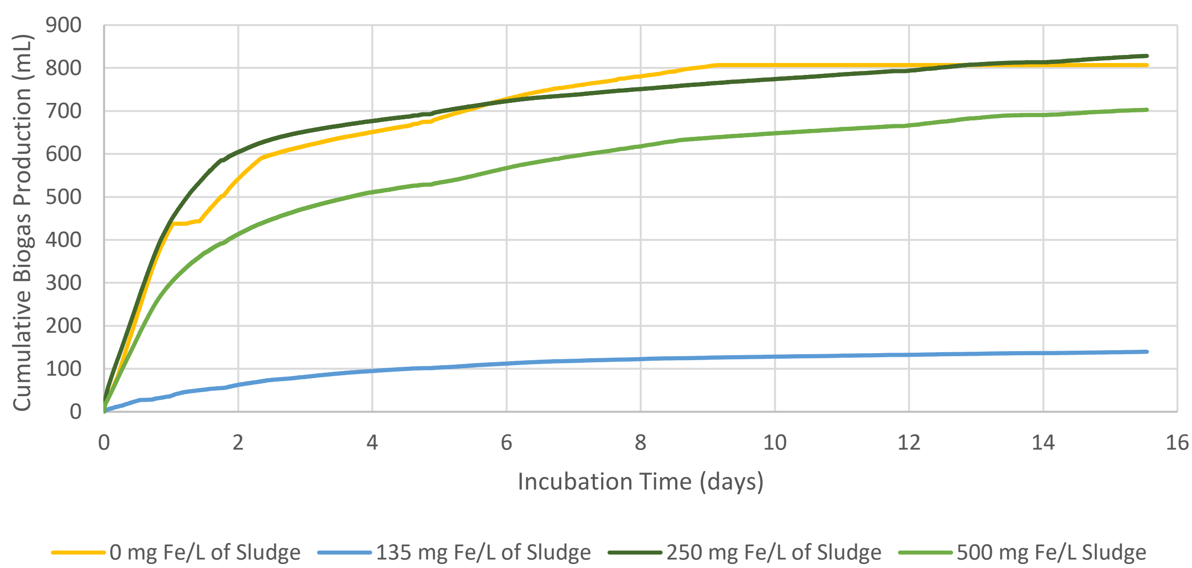

Figure 4: Scenario 1 Cumulative Biogas Production – pH 6 Adjustment. (**Error in automatic biogas production recording for 135 mg Fe/L of sludge and should be disregarded).*

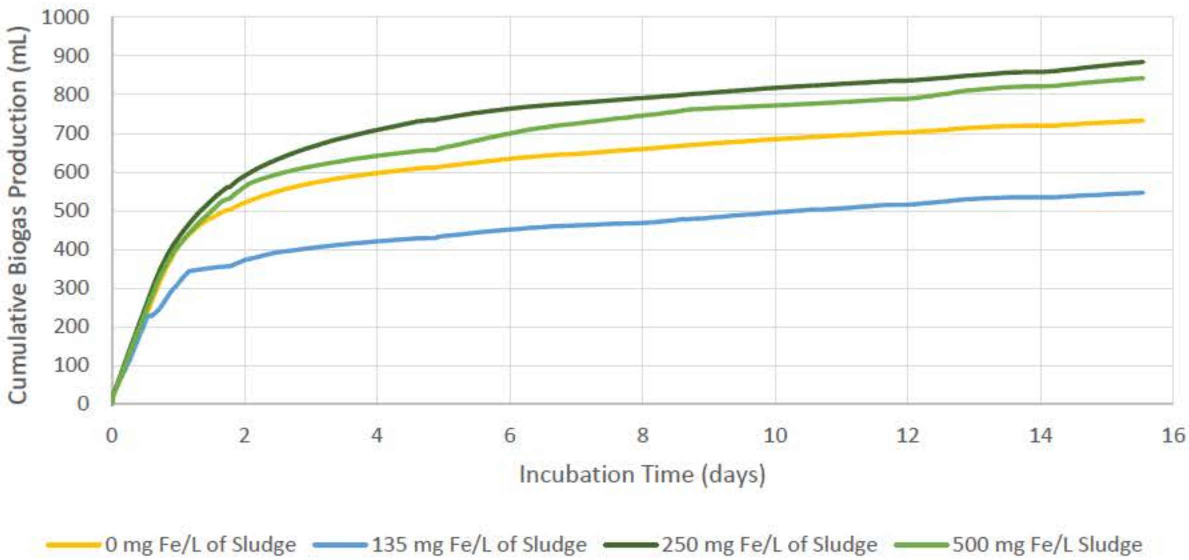

Figure 5: Scenario 1 Cumulative Biogas Production – pH 7 Adjustment *(*Error in automatic biogas production recording for 135 mg Fe/L of sludge and should be disregarded)*

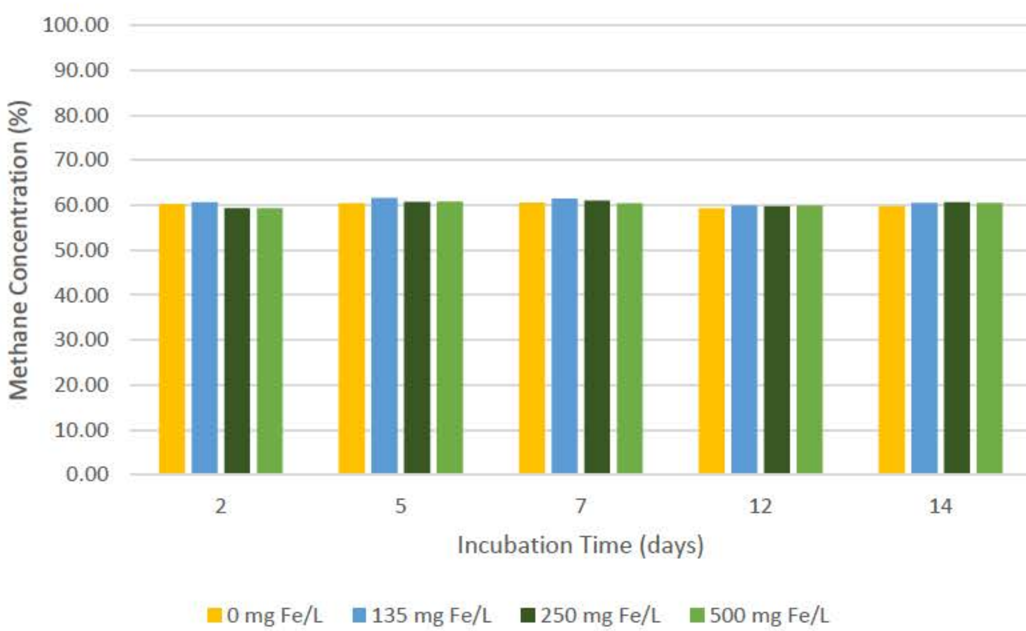

Figure 6: Scenario 1 Biogas Composition – No pH Adjustment

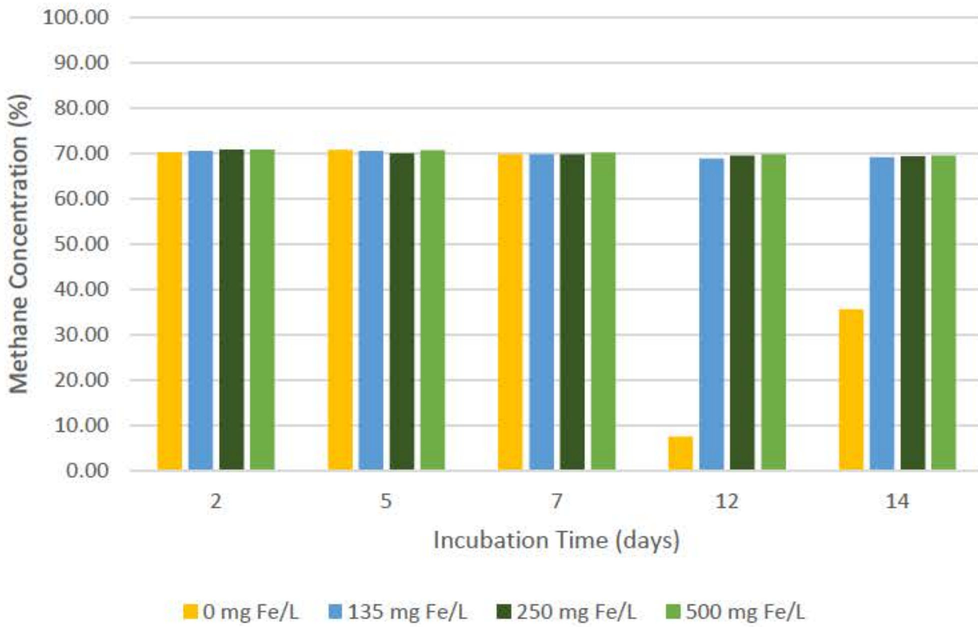

Figure 7: Scenario 1 Biogas Composition – pH 6 Adjustment

Gas composition on day 12 and 14 for the 0 mg Fe/L dose was excluded when calculating average methane concentration due to the bottle seal being compromised after day 9 of the BMP test.

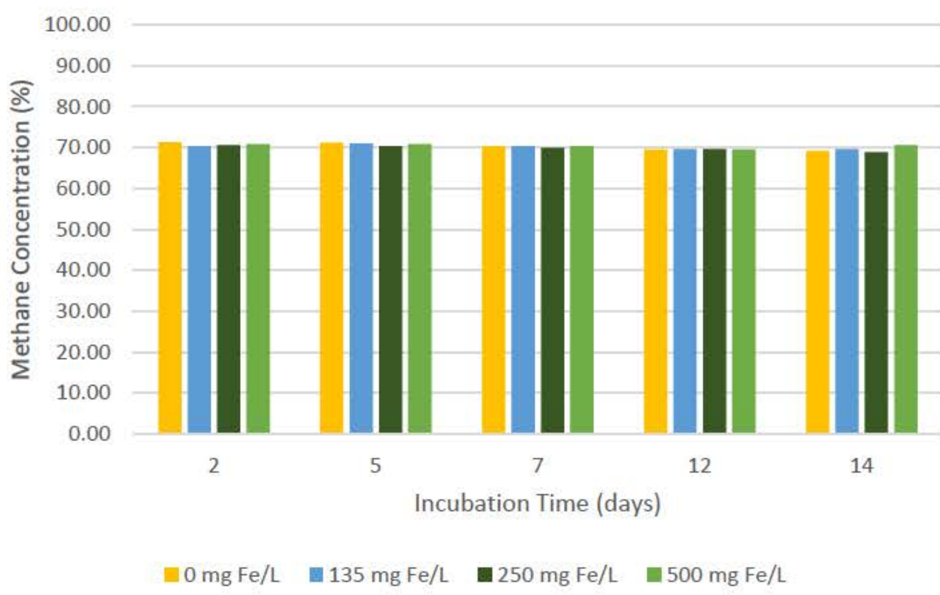

Figure 8: Scenario 1 Biogas Composition – pH 7 Adjustment

Based on the average methane content for each sample, as outlined in ***Table 3***, the methane yield for each sample over the 15-day BMP test is shown in ***Figure 9*** through ***Figure 11.***

Table 3: Scenario 1 Biogas Composition

Ferric Dose to Sludge	Unit	Methane	Other
No pH Adjustment			
0 mg Fe/L	%	60.09	39.91
135 mg Fe/L	%	60.83	39.17
250 mg Fe/L	%	60.29	39.71
500 mg Fe/L	%	60.21	39.79
Adjustment to pH 6			
0 mg Fe/L	%	70.24	29.76
135 mg Fe/L	%	69.75	30.25
250 mg Fe/L	%	69.91	30.09
500 mg Fe/L	%	70.17	29.83
Adjustment to pH 7			
0 mg Fe/L	%	70.33	29.67
135 mg Fe/L	%	70.20	29.80
250 mg Fe/L	%	69.90	30.10
500 mg Fe/L	%	70.43	29.57

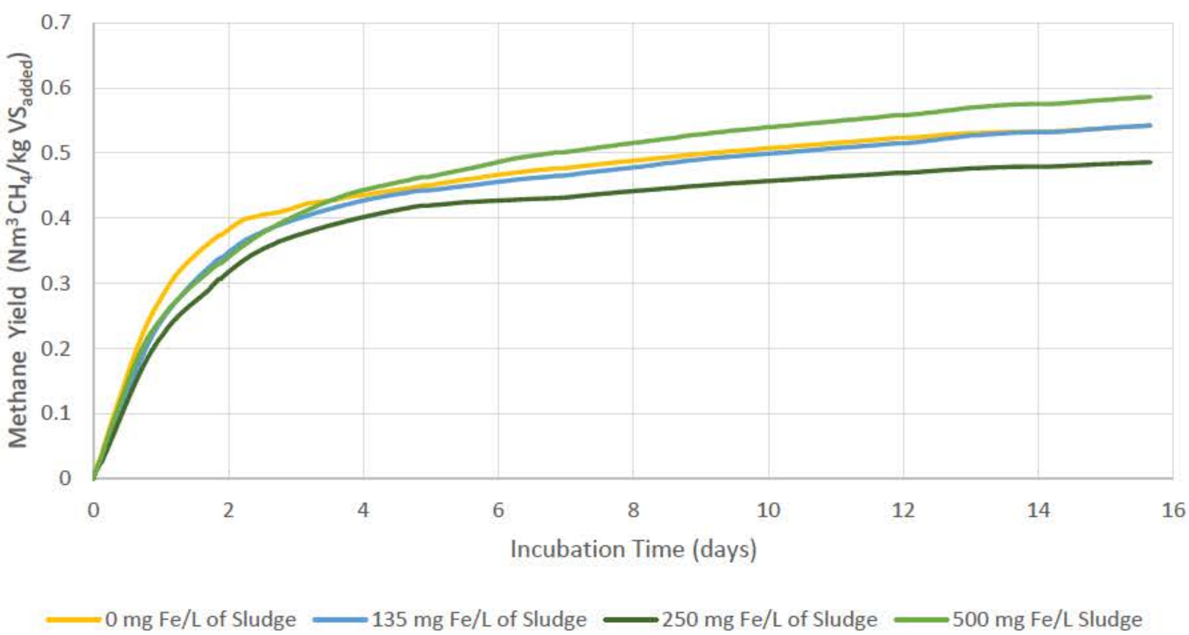

Figure 9: Scenario 1 Methane Yield – without pH Adjustment

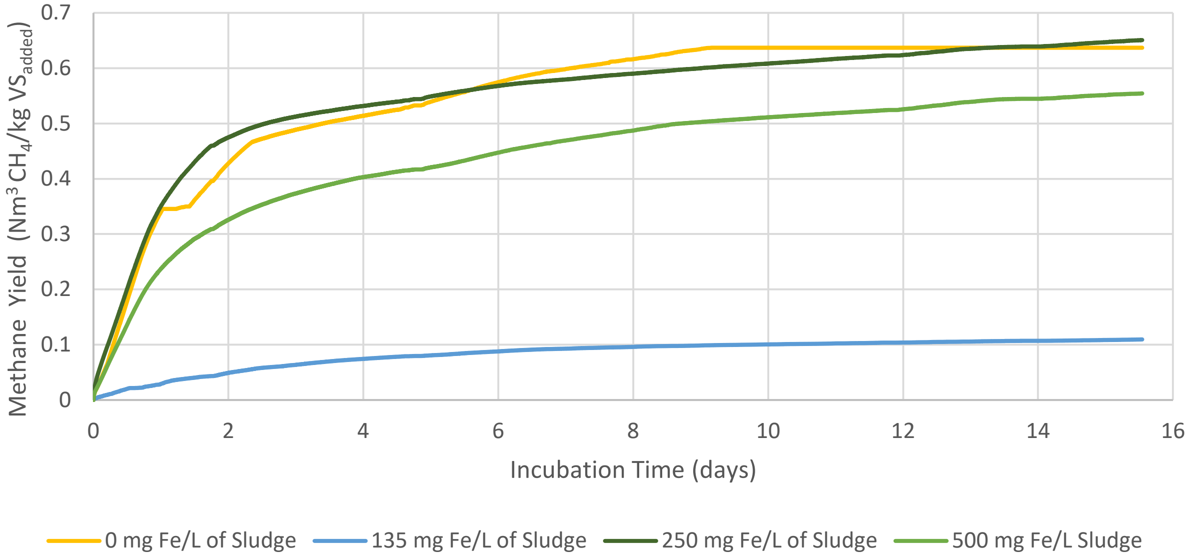

Figure 10: Scenario 1 Methane Yield – With Adjustment to pH 6 in jar test

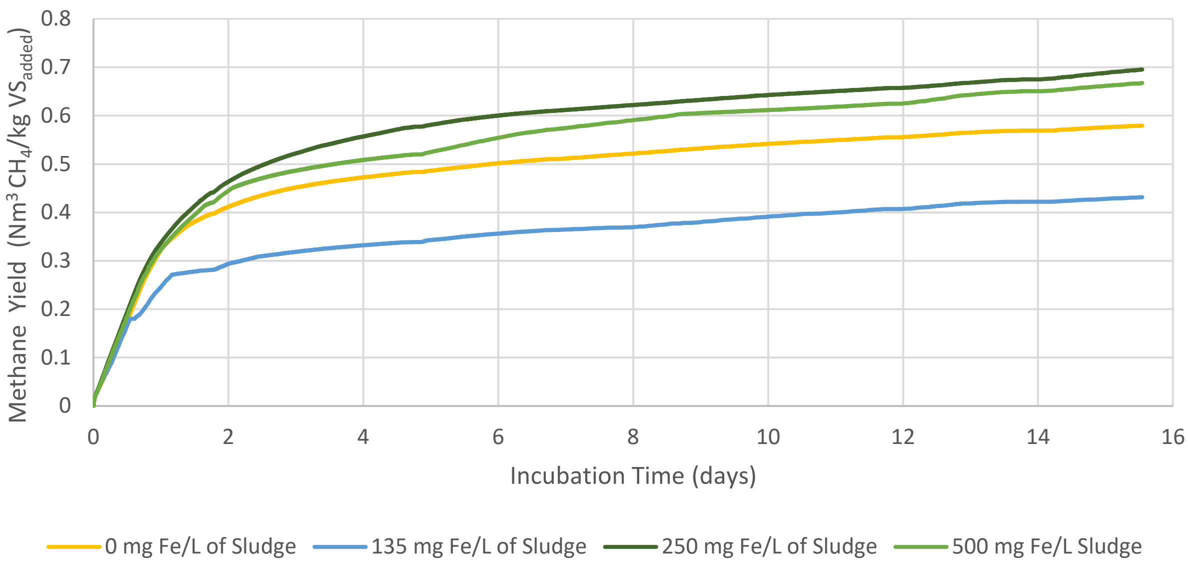

Figure 11: Scenario 1 Methane Yield – With Adjustment to pH 7 in jar test

Total solids and volatile solids destruction after the 15-day BMP test were found to be between 7 and 17% and 17 and 25%, respectively, as shown in ***Figure 12.***

Soluble ortho phosphorus in the digested samples was found to be between 80 and 90 mg/L, total phosphorus between 95 and 115 mg/L, with pH ranging from 7.2 and 7.4, as shown in ***Figure 13***.

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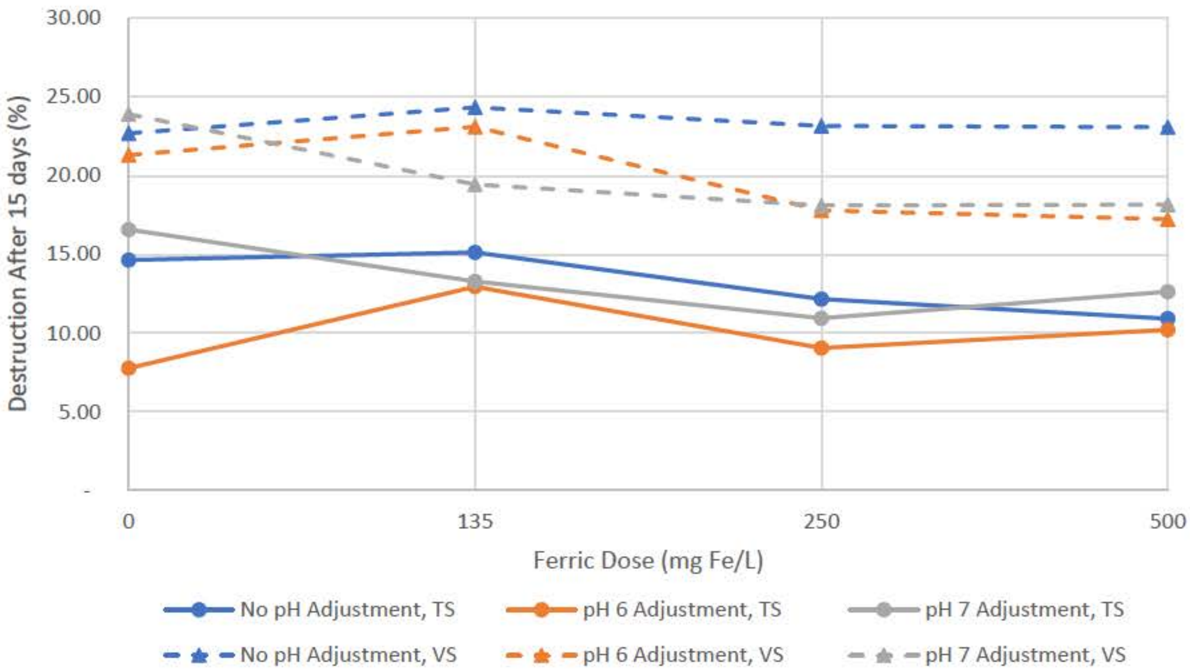

Figure 12: Scenario 1 Total Solids and Volatile Solids Destruction

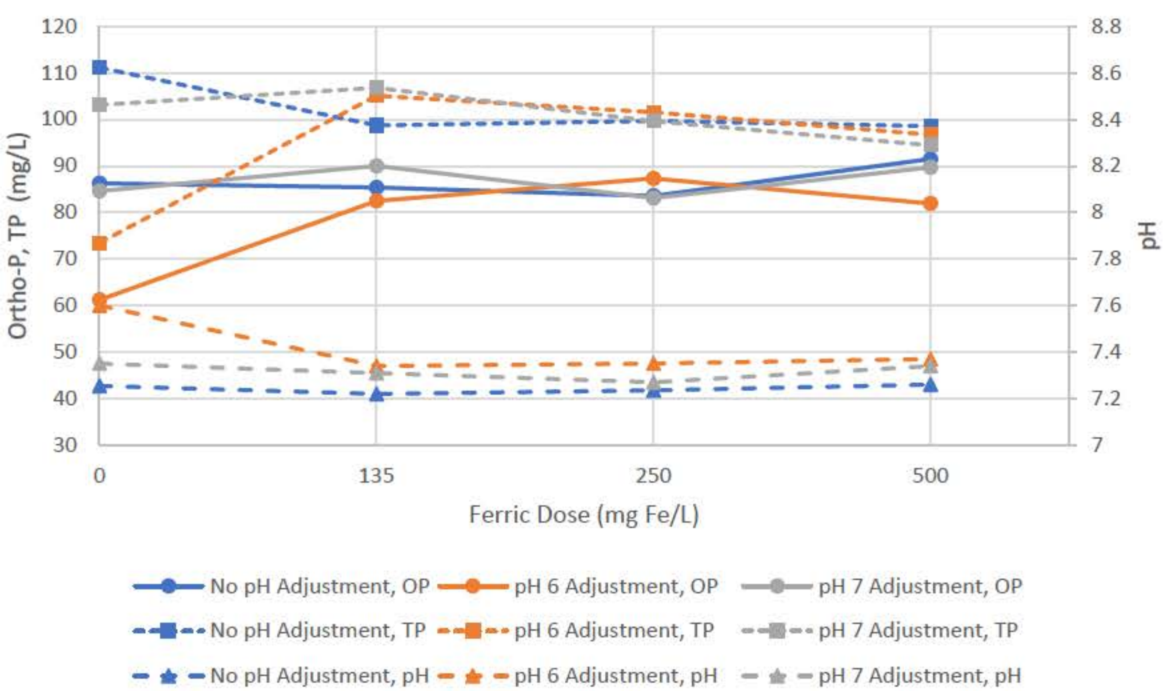

Figure 13: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 1, Post Digestion

As the objective for Scenario 1 dosing was to reach a soluble ortho phosphorus concentration of around 20 mg PO_4-P/L in the centrate, a second ferric dosing after digestion was necessary. A dose of 200 mg Fe/L of digested sludge was added to all samples. After a reaction time of 7.5 minutes, all samples were analyzed again. ***Figure 14*** shows the soluble ortho phosphorus and pH of the samples after the second ferric dose.

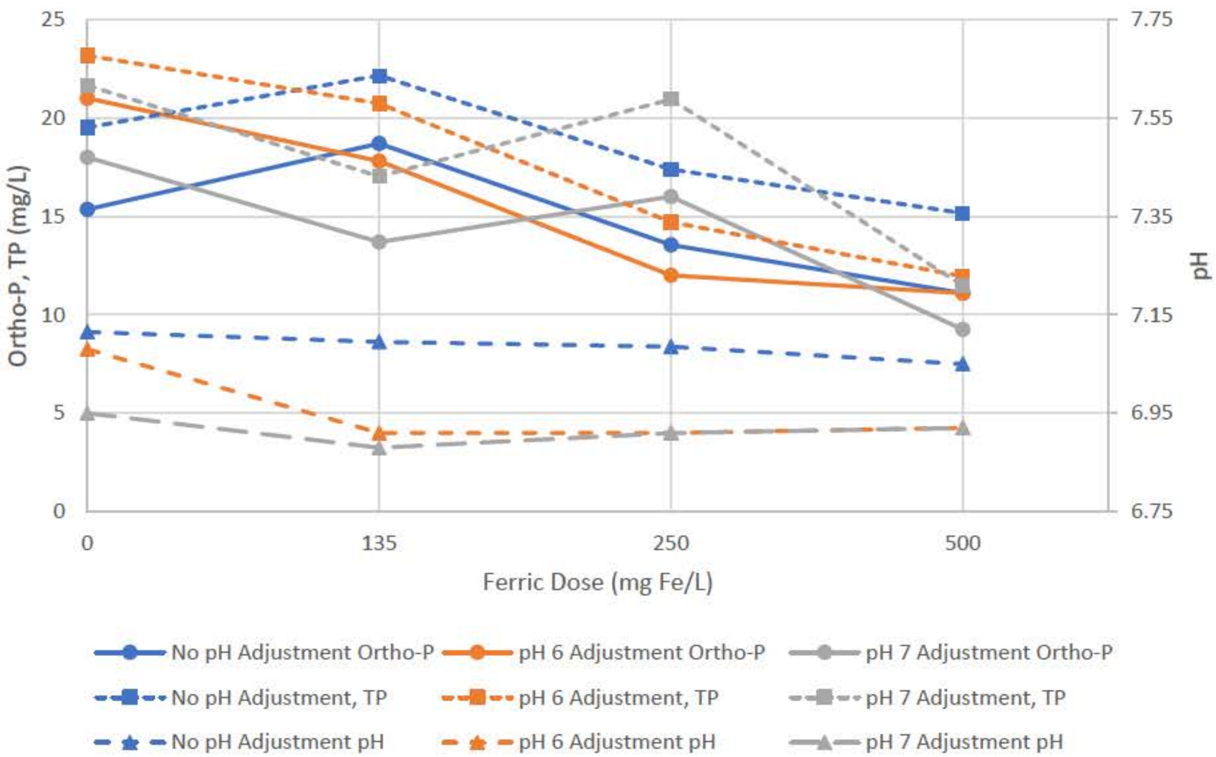

Figure 14: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 1, After Second Ferric Dose of 200 mg Fe/L.

Duplicate capillary suction time (CST) tests were completed on all samples after digestion and again after the second ferric dose to determine the affect on dewaterability. ***Table 4*** and

Table 5 outline the average CST for each sample.

Table 4: Scenario 1 Capillary Suction Times After Digestion

Ferric Dose Before Digestion	Unit	No pH Adjustment	pH 6 Adjustment	pH 7 Adjustment
0 mg Fe/L	sec	229	238	228
135 mg Fe/L	sec	238	245	218
250 mg Fe/L	sec	223	227	217
500 mg Fe/L	sec	239	214	207

Table 5: Scenario 1 Capillary Suction Times After Second Ferric Dose

Ferric Dose Before Digestion	Ferric Dose After Digestion	Unit	No pH Adjustment	pH 6 Adjustment	pH 7 Adjustment
0 mg Fe/L	200 mg Fe/L	sec	134	141	110
135 mg Fe/L	200 mg Fe/L	sec	147	111	100
250 mg Fe/L	200 mg Fe/L	sec	135	112	105
500 mg Fe/L	200 mg Fe/L	sec	115	103	110

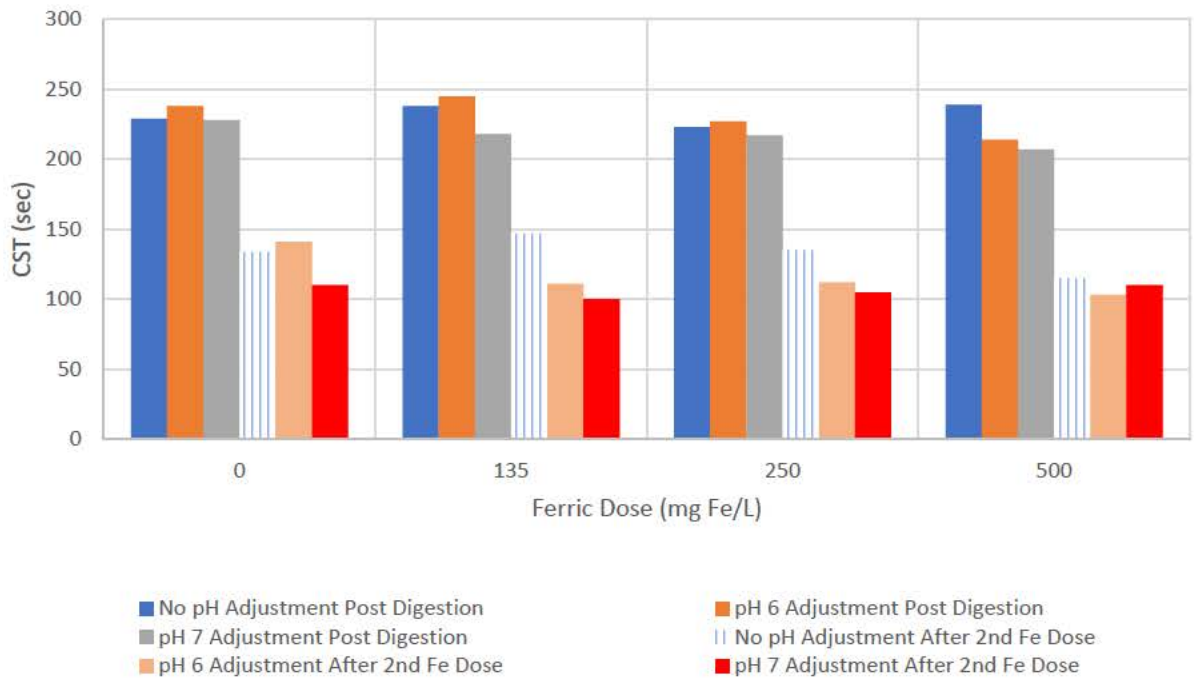

Figure 15: Scenario 1 Capillary Suction Time

3.2. Scenario 2 Chemically Enhanced Primary Treatment

3.2.1 Scenario 2 - Phase 1

Samples from NEWPCC were collected on October 21 at 9:00 AM for Scenario 2 Phase 1 jar testing. Primary influent from the NE was collected from the channel directly following grit removal. Analysis of soluble ortho phosphorus was completed on the primary influent sample, as shown in ***Table 6***.

Table 6: Scenario 2 Phase 1 Raw Sample Characteristics

Parameter	Unit	NE Primary Influent
Ortho-P	mg/L	4.42

Jar testing was completed on primary influent for six different ferric doses and three mixing regimes. The six ferric doses tested were 0, 5, 10, 15, 20 and 30 mg Fe/L of primary influent. The three mixing regimes tested were 1 minute rapid (100 rpm) followed by 7.5 minutes of slow mixing (40 rpm), 2 minutes rapid, 15 minutes slow, and 5 minutes rapid, 30 minutes slow. After 15 minutes of settling, the volume of settled sludge was recorded and sampled to determine total solids and volatile solids. Supernatant was sampled immediately following the 15 minutes of settling to test soluble ortho phosphorus. As seen below in ***Figure 16***, the mixing regime did not have a significant impact to the supernatant soluble ortho phosphorus concentration. All test for doses of 15, 20, and 30 mg Fe/L resulted in a soluble ortho phosphorus concentration less than 1 mg/L in the primary effluent. The ratio of ferric dose to ortho phosphorus removed is approximately 3.5 mg Fe/mg OP-$P_{remov.}$ for the linear portion of the graph between 5 and 15 mg Fe/L of primary influent.

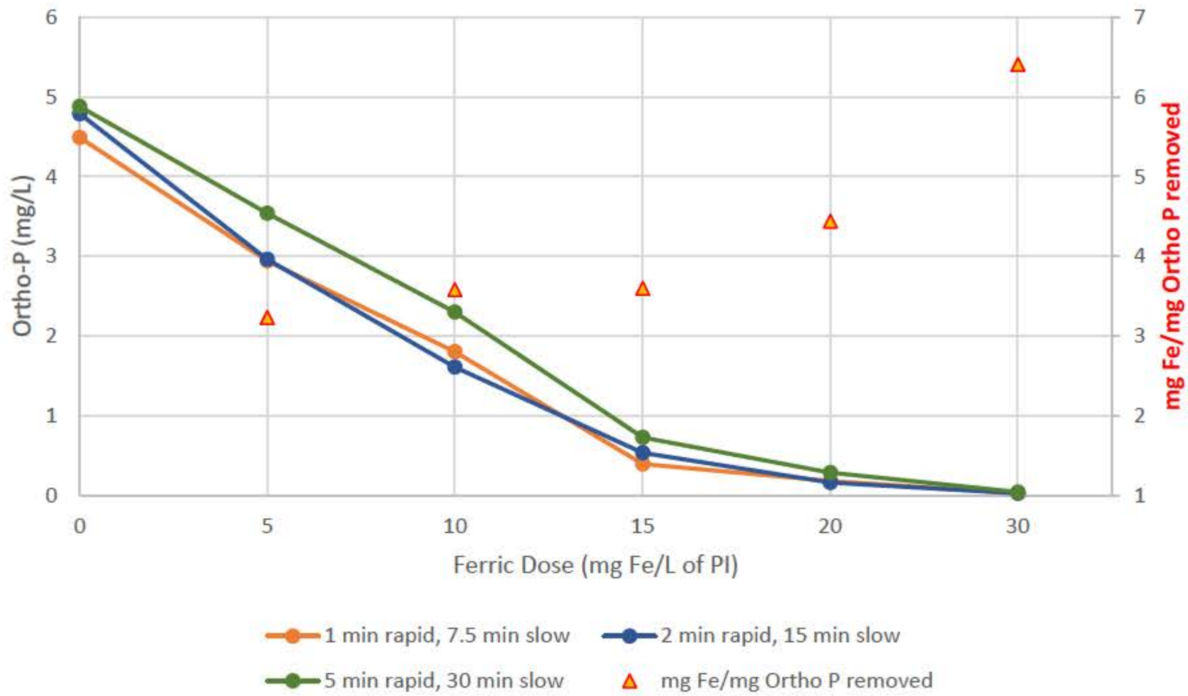

Figure 16: Soluble Ortho Phosphorus for Scenario 2 Phase 1 Jar Tests

The volume of settled sludge increased as well as the total sludge produced as the ferric dose increased, as shown in ***Figure 17***.

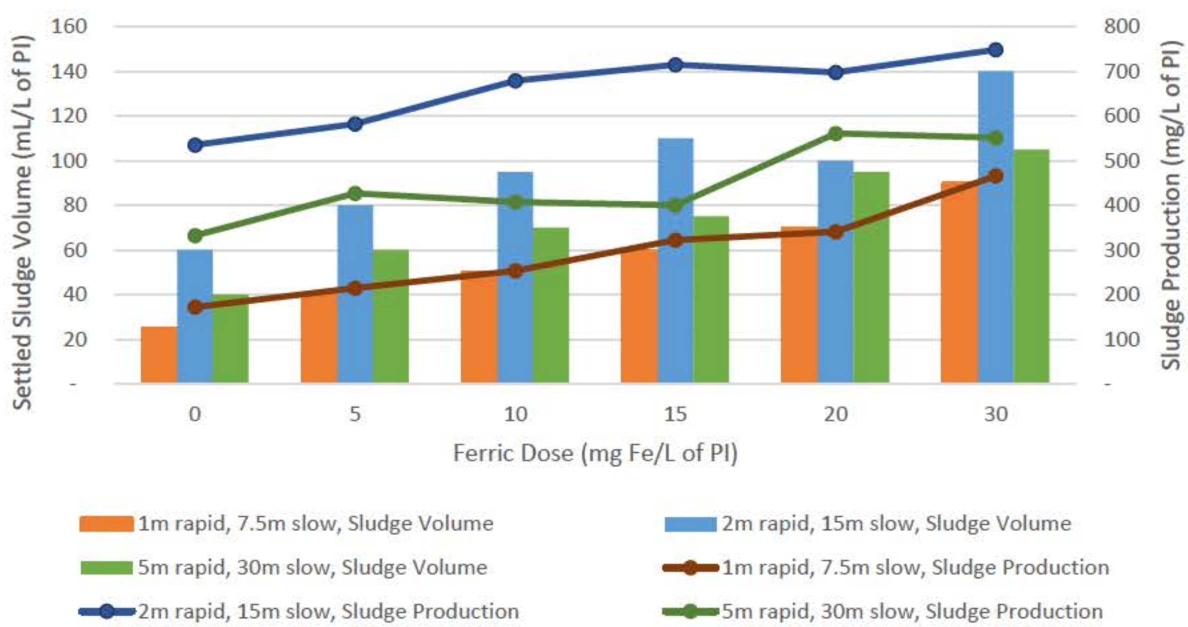

Figure 17: Settled Sludge Produced in Scenario 2 Phase 1 Jar Tests

3.1.1. Scenario 2 - Phase 2

Based on the Scenario 2 Phase 1 jar tests, it was determined that a dose of 8 mg Fe/L of primary influent would be used in Scenario 2 Phase 2 jar tests for the goal of achieving 2.2 mg P/L ortho phosphorus in the primary effluent. A dose of 14 mg Fe/L of primary influent will also be used in the Phase 2 jar test to achieve a 0.8 mg P/L ortho phosphorus in the primary effluent. The dose of 14 mg Fe/L also corresponds to the dose predicted by BioWin modeling to achieve 2.2 mg PO_4-P/L ortho phosphorus in the primary effluent. A control dose of 0 mg Fe/L and 18 mg Fe/L of primary influent was also used in Phase 2 testing.

Samples from NE and WE were collected and analyzed on November 2 between 8:30 and 10:30 AM for Scenario 2 Phase 2 testing. Primary influent from the NE was collected from the channel directly following grit removal and digested sludge samples were collected following digestion, prior to the second ferric dosing point. Sludge samples from the WE were collected from the sludge holding tank, prior to being hauled to the NE. ***Table 7*** summarizes the raw sample characteristics. Mixed liquor from all three NE trains were sampled, which were mixed in equal parts for use in the specific oxygen uptake rate (SOUR) tests.

Table 7: Scenario 2 Phase 2 Raw Sample Characteristics

Parameter	Unit	NE Primary Influent	NE Digested Sludge	WE Sludge
pH		7.12	7.34	5.32
Alkalinity	mL $CaCO_3$/L	280	2680	660
TS	mg/L	1,032	13,954	38,086
VS	mg/L	528	8,890	32,972
Ortho-P	mg/L	4.64	63.2	496
TP	mg/L	4.88	76.2	541

Jar testing was completed on primary influent for four different ferric doses based on Phase 1 testing and BioWin modeling. The four ferric doses used for Phase 2 testing were 0, 8, 14, and 18 mg Fe/L of primary influent. All Phase 2 jar tests were completed with 7.5 minutes of slow mixing (40 rpm). After 30 minutes of settling, the volume of settled sludge was recorded and sampled for further testing and analysis. Supernatant was sampled immediately following the 30 minutes of settling for further analysis, with results shown in ***Table 8***.

Table 8: Scenario 2 Phase 2 Supernatant Characteristics

Parameter	Unit	0 mg Fe/L	8 mg Fe/L	14 mg Fe/L	18 mg Fe/L
pH		7.12	6.96	6.85	6.79
Alkalinity	mL $CaCO_3$/L	290	270	220	220
Ortho-P	mg/L	4.82	2.14	0.76	0.15
TP	mg/L	4.90	2.44	1.2	0.44

Soluble ortho phosphorus concentration in the supernatant was as expected based on the Phase 1 testing. The ferric dose of 8 mg Fe/L of primary influent and 14 mg Fe/L of primary influent had ortho phosphorus concentrations of 2.14 mgPO_4-P/L and 0.76 mgPO_4-P/L, respectively, as shown in ***Figure 18***.

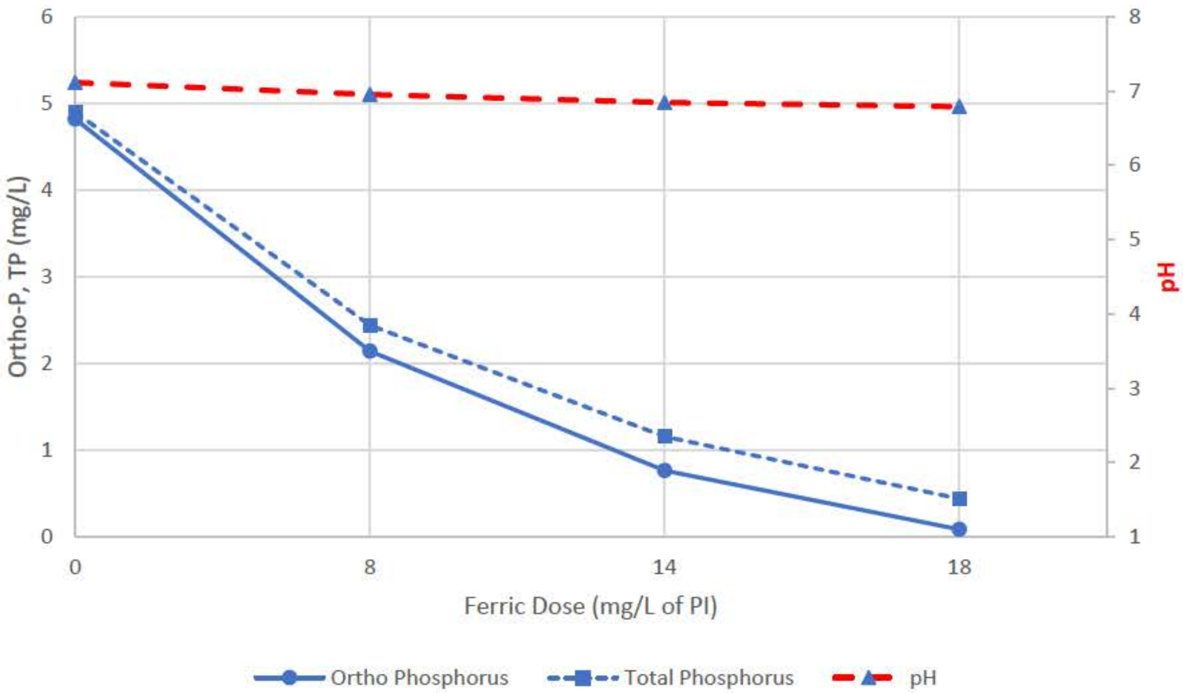

Figure 18: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 2 Phase 2 Jar Tests

The volume of settled sludge increased as well as the total sludge produced as the ferric dose increased, as shown in ***Figure 19***, similar to what was observed in Phase 1 testing.

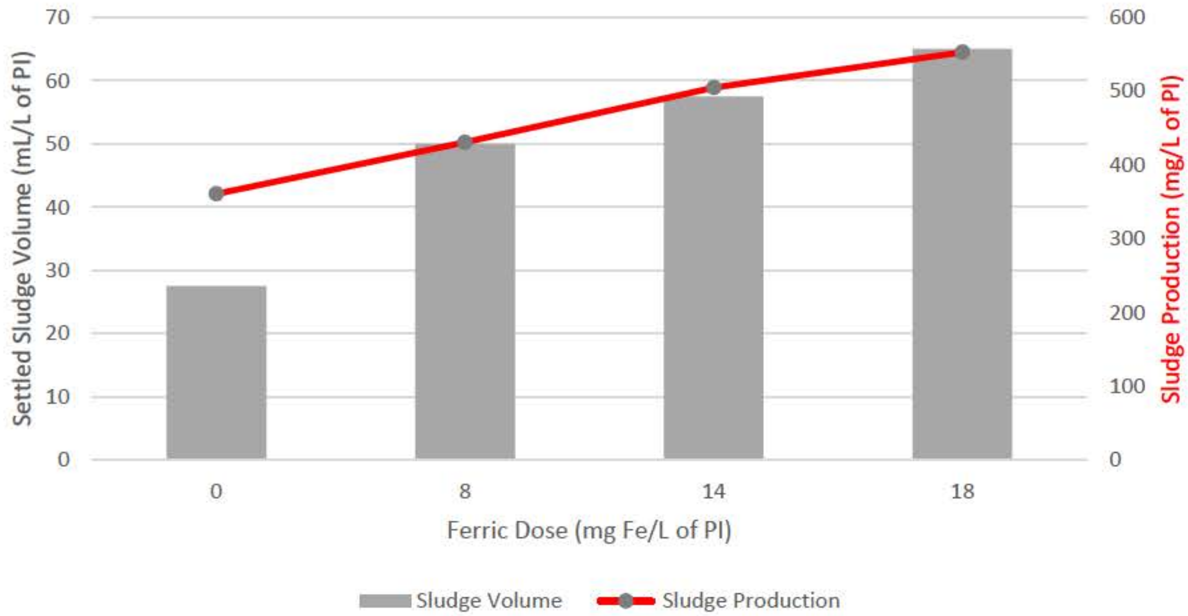

Figure 19: Scenario 2 Phase 2 Sludge Production

Seven parts of the sludge produced from each jar test was then mixed with three parts of West End Sewage Treatment Plant sludge sampled from the holding tank. The mixed sludge was then added to digester inoculum at a volumetric loading rate of 0.07 m^3/m^3*d and a 15-day BMP was started to record biogas production. *Figure 20* shows the gas production for the two sets of four ferric doses over the 15 days. Each bottle contains 500 mL of sludge, made up of 25.0 mL of sludge from the jar test, 10.7 mL of WE sludge, and 464.3 mL of digester inoculum.

Cumulative biogas production during the BMP test is shown in ***Figure 20***. Biogas was sampled and analyzed for gas composition 5 times throughout the 15 days. ***Figure 21*** shows the biogas composition throughout the BMP tests.

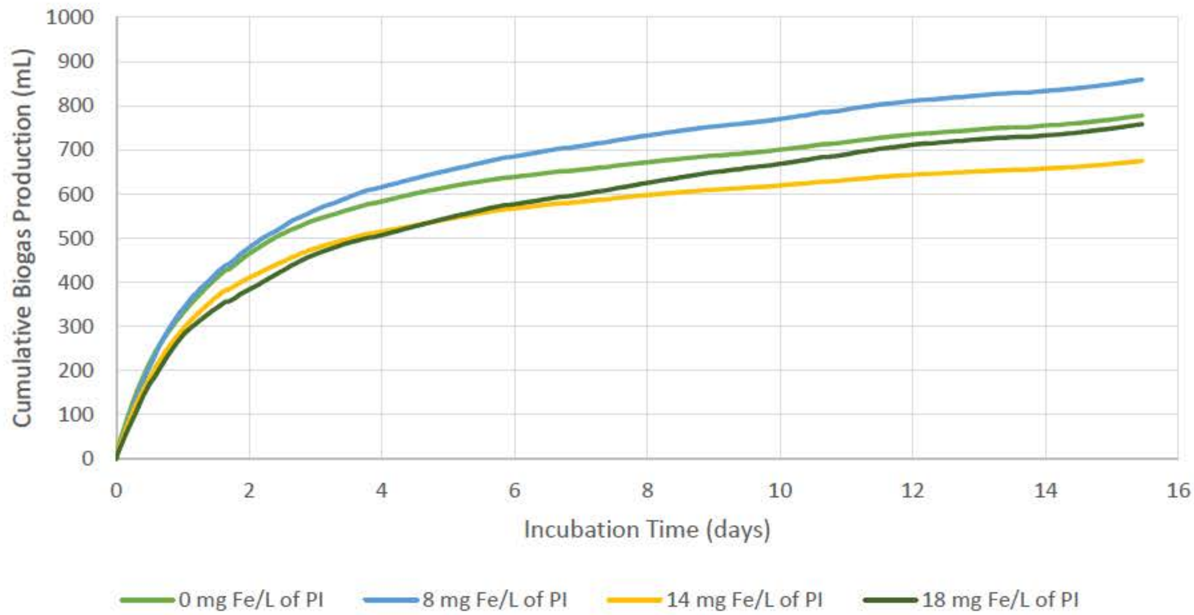

Figure 20: Scenario 2 Phase 2 Cumulative Biogas Production

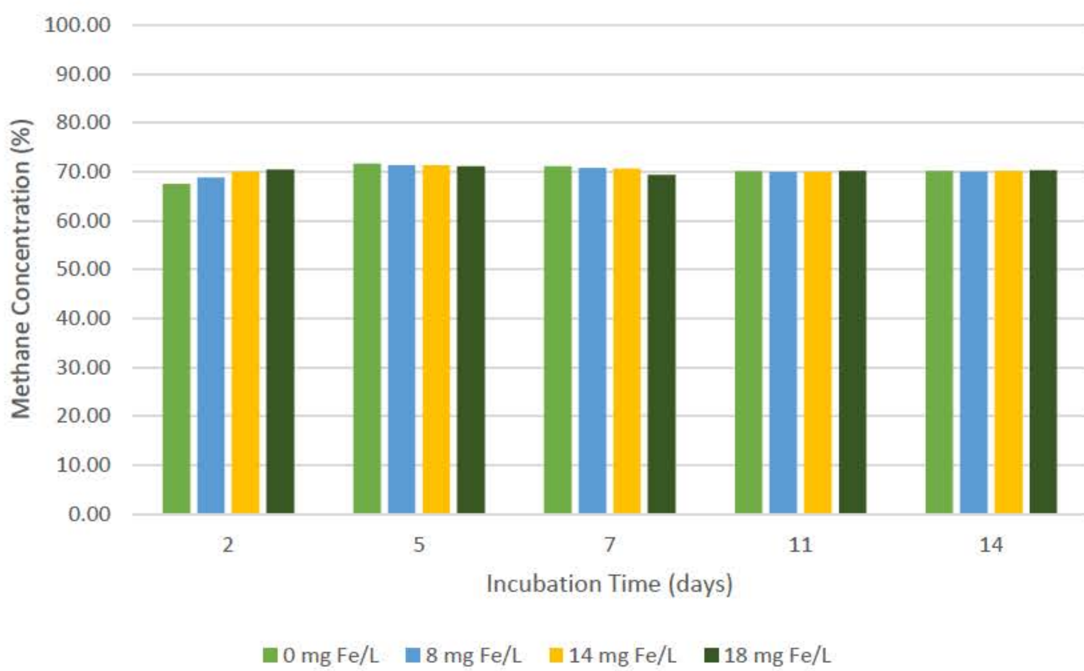

Figure 21: Scenario 2 Phase 2 Biogas Composition

Table 9: Scenario 2 Phase 2 Biogas Composition

Ferric Dose to Primary Influent	Unit	Methane	Other
0 mg Fe/L	%	70.11	29.89
8 mg Fe/L	%	70.19	29.81
14 mg Fe/L	%	70.43	29.57
18 mg Fe/L	%	70.26	29.74

Based on the average methane content for each sample, as outlined in ***Table 9***, the methane yield for each sample over the 15 day BMP test is shown in ***Figure 22.*.**

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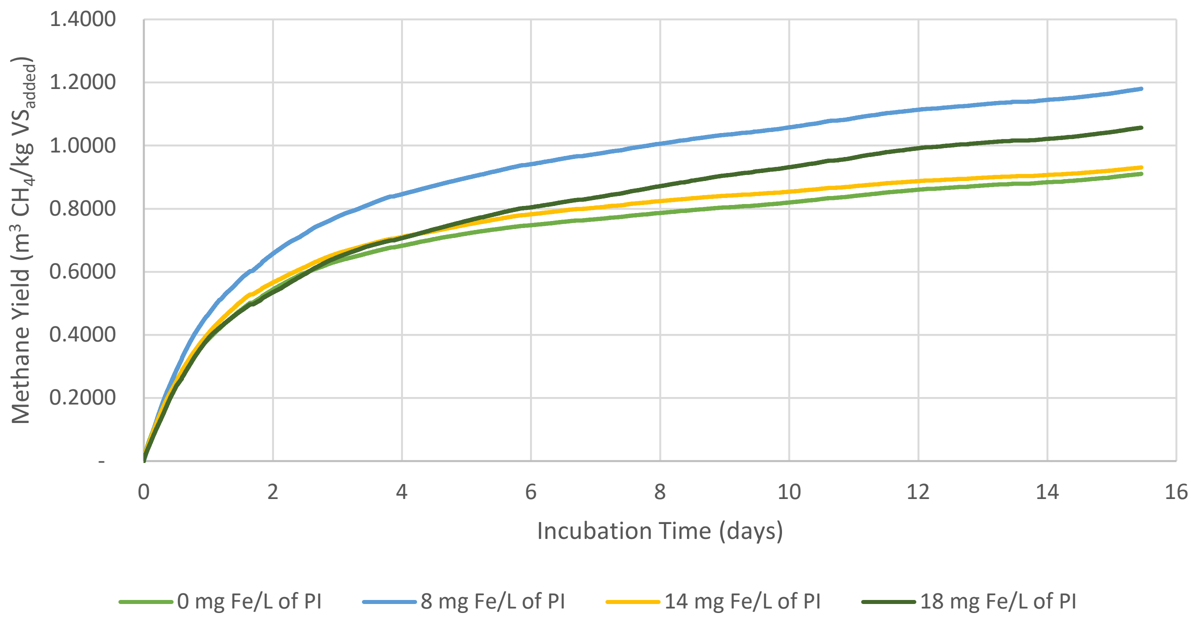

Figure 22: Scenario 2 Phase 2 Methane Yield

Total solids and volatile solids destruction after the 15-day BMP test were found to be between 12-15% and 21-24%, respectively, as shown in ***Figure 23***.

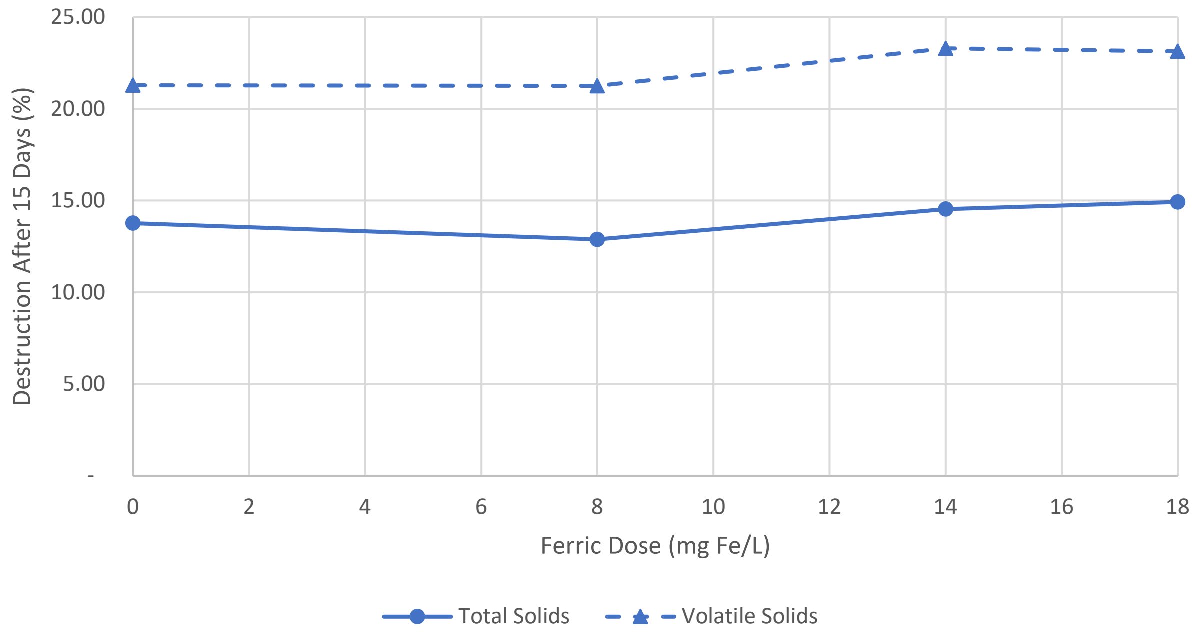

Figure 23: Scenario 2 Phase 2 Total Solids and Volatile Solids Destruction

Soluble ortho phosphorus in the digested samples was found to be between 78 and 84 mg PO_4-P/L, total phosphorus between 93 and 108 mg TP/L, all with a pH around 7.25, as shown in ***Figure 24***.

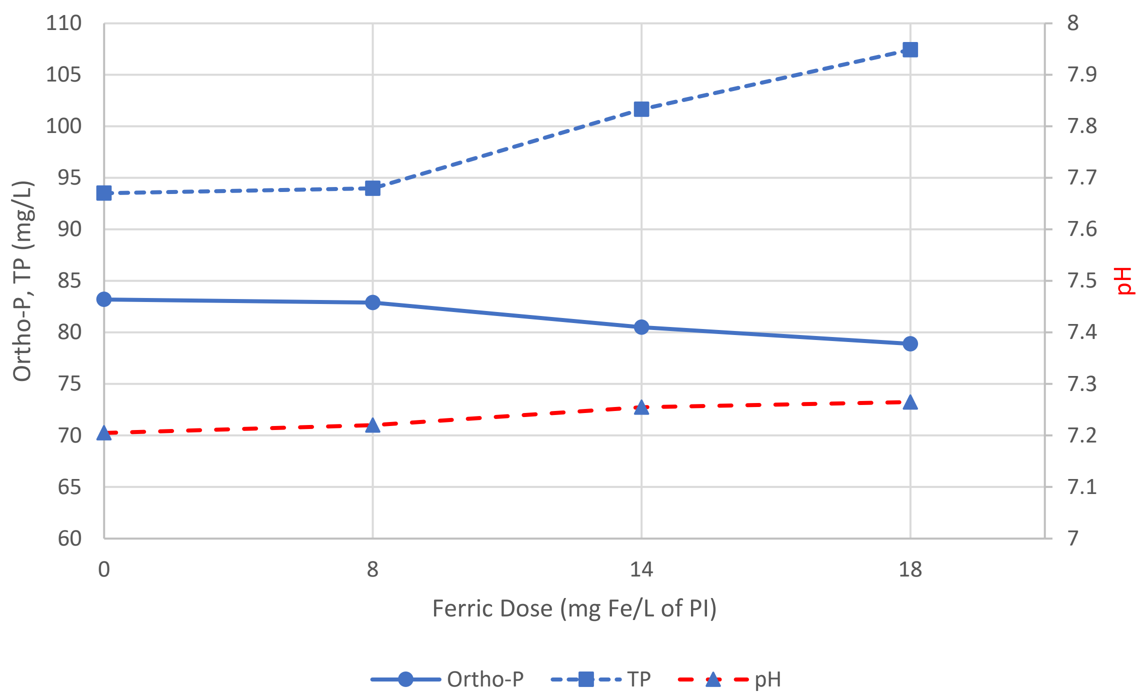

Figure 24: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 2 Phase 2 Post Digestion

Duplicate capillary suction time (CST) tests were completed on all samples after digestion to determine the effect on dewaterability. ***Table 10*** outlines the average CST for each sample.

Table 10: Scenario 2 Phase 2 Capillary Suction Times After Digestion

Ferric Dose Before Digestion	Unit	CST
0 mg Fe/L	sec	218
8 mg Fe/L	sec	222
14 mg Fe/L	sec	263
18 mg Fe/L	sec	272

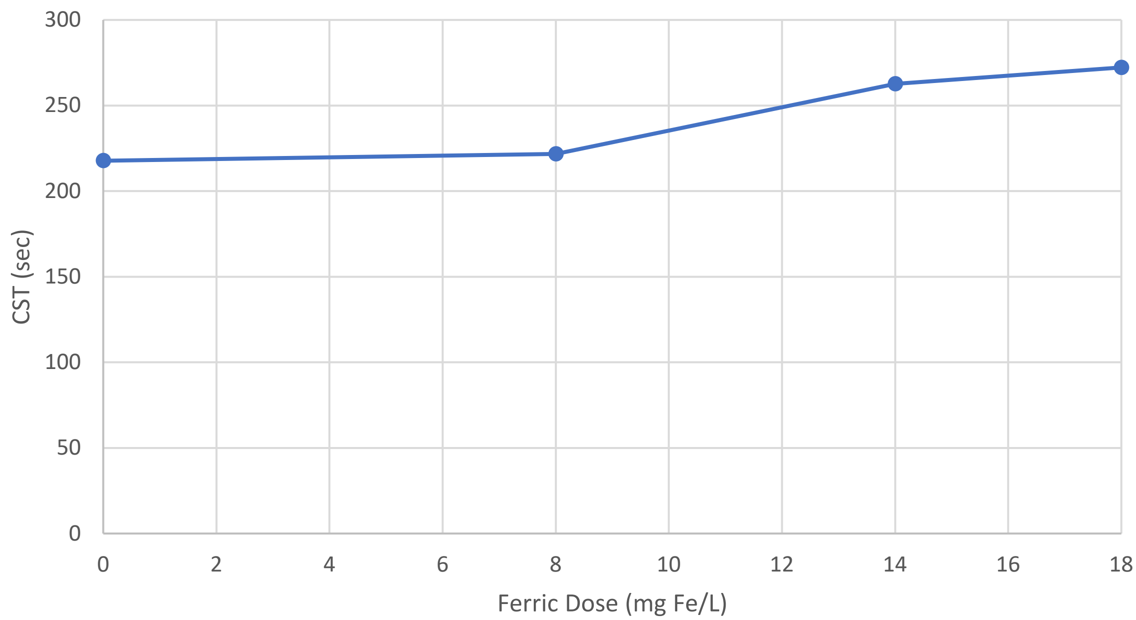

Figure 25: Scenario 2 Phase 2 Capillary Suction Time

Specific oxygen uptake rate tests were completed on supernatant samples from all jar tests. Mixed liquor from all 3 NE trains were collected and combined in equal parts. Two litres of the mixed liquor were settled for 30 minutes and then 800 mL of the settled biomass was collected for the OUR test. The biomass was aerated prior to the OUR test to ensure biomass was not in a state of starvation. 20 mL of biomass was combined with 380 mL of supernatant from each jar test and further aerated until reaching a dissolved oxygen (DO) level of 8 mg/L. The biomass and supernatant mixture were then transferred to a 350 mL BOD bottle and a DO probe was inserted to record the drop in DO every 30 seconds until the DO reached 1 mg/L. DO versus time was plotted and a trendline was plotted on the linear portion. The absolute value of the trendline slope is the samples OUR in mg O_2/L*h. OUR is then divided by the volatile solids of the biomass used in the test to determine the SOUR in mg O_2/g VS*h. As shown in ***Figure 26***, the SOUR decreases as the ferric dose increases.

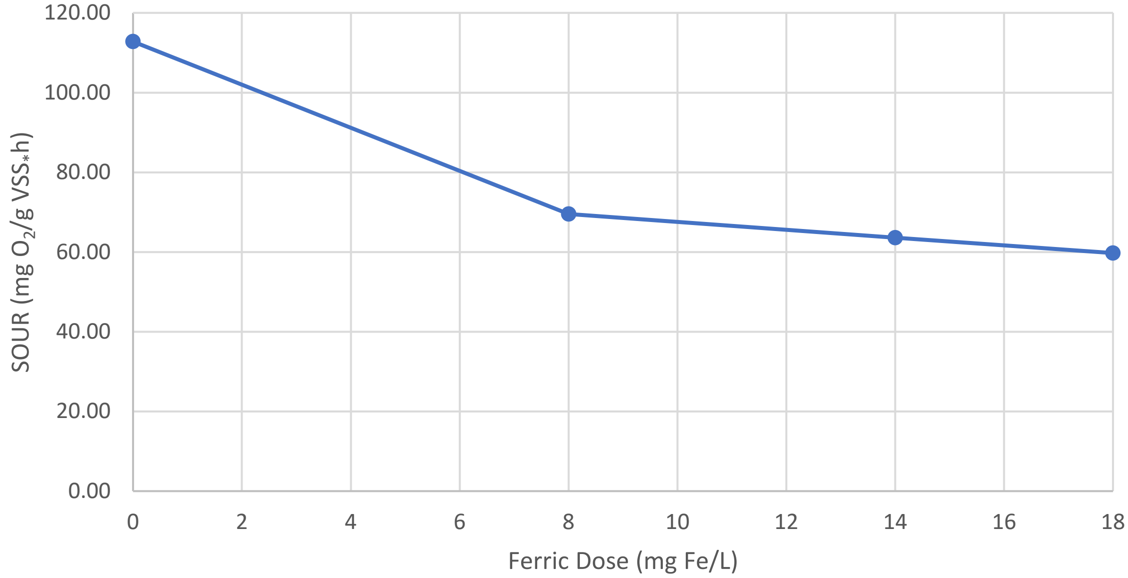

Figure 26: Scenario 2 Specific Oxygen Uptake Rate SOUR

3.2. Scenario 3

3.2.1 Scenario 3 - Phase 1

Samples from NEWPCC were collected on October 28 at 8:30 AM for Scenario 3 Phase 1 jar testing. Mixed liquor from the NE was collected from each train and combined in equal parts for testing, as shown in ***Table 11***.

Table 11: Scenario 3 Phase 1 Raw Sample Characteristics

Parameter	Unit	NE Mixed Liquor #1	NE Mixed Liquor #2	NE Mixed Liquor #3	NE Mixed Liquor Mixture
TS	mg/L	2,862	1,568	2,934	2,328
VS	mg/L	1,910	828	1,974	1,450
Ortho-P	mg/L	6.69	3.02	3.89	3.72

Jar testing was completed on mixed liquor for four different ferric doses and three mixing regimes. The four ferric doses tested were 0, 10, 20 and 30 mg Fe/L of mixed liquor. The three mixing regimes tested were 7.5 minutes of slow (40 rpm), 15 minutes slow, and 30 minutes slow mixing. After 30 minutes of settling, the volume of settled sludge was recorded and sampled to determine total solids and volatile solids. Supernatant was sampled immediately following the 30 minutes of settling to test soluble ortho phosphorus. As seen below in ***Figure 27***, the mixing regime did not have a significant impact on the supernatant soluble ortho phosphorus concentration. All tests for doses of 20 and 30 mg Fe/L resulted in a soluble ortho phosphorus concentration less than 1 mg PO_4-P/L in the secondary effluent.

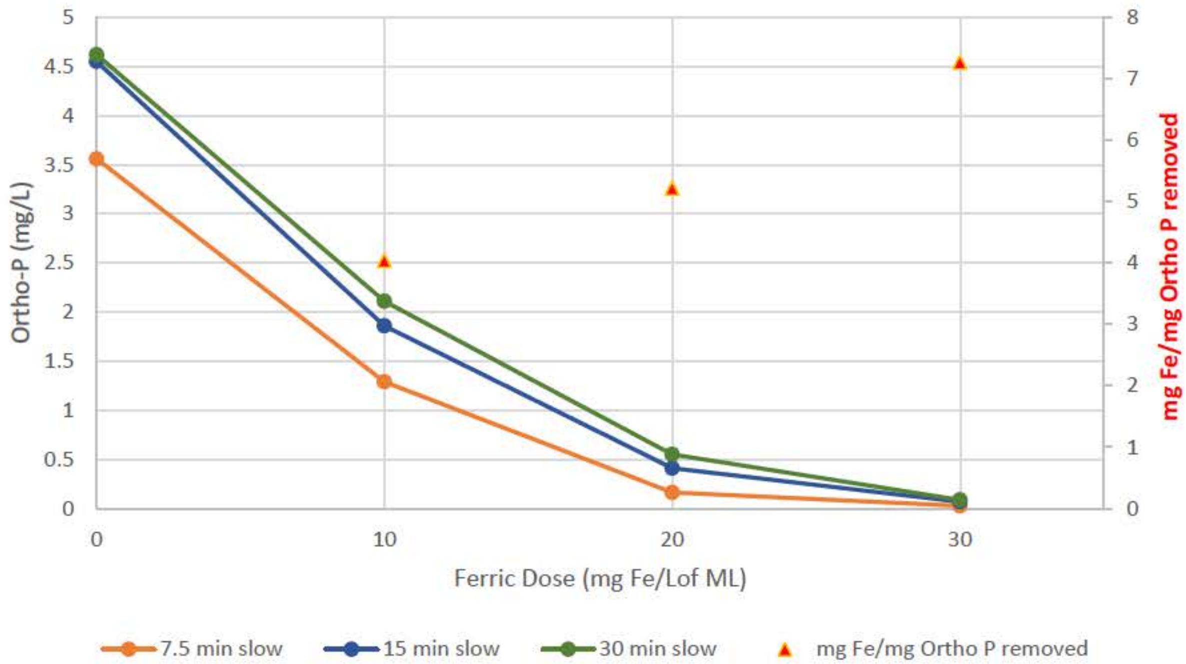

Figure 27: Soluble Ortho Phosphorus for Scenario 3 Phase 1 Jar Tests

The volume of settled sludge increased as the ferric dose increased, while the total sludge produced per litre of mixed liquor did not show a clear correlation to ferric dose, as shown in ***Figure 28***.

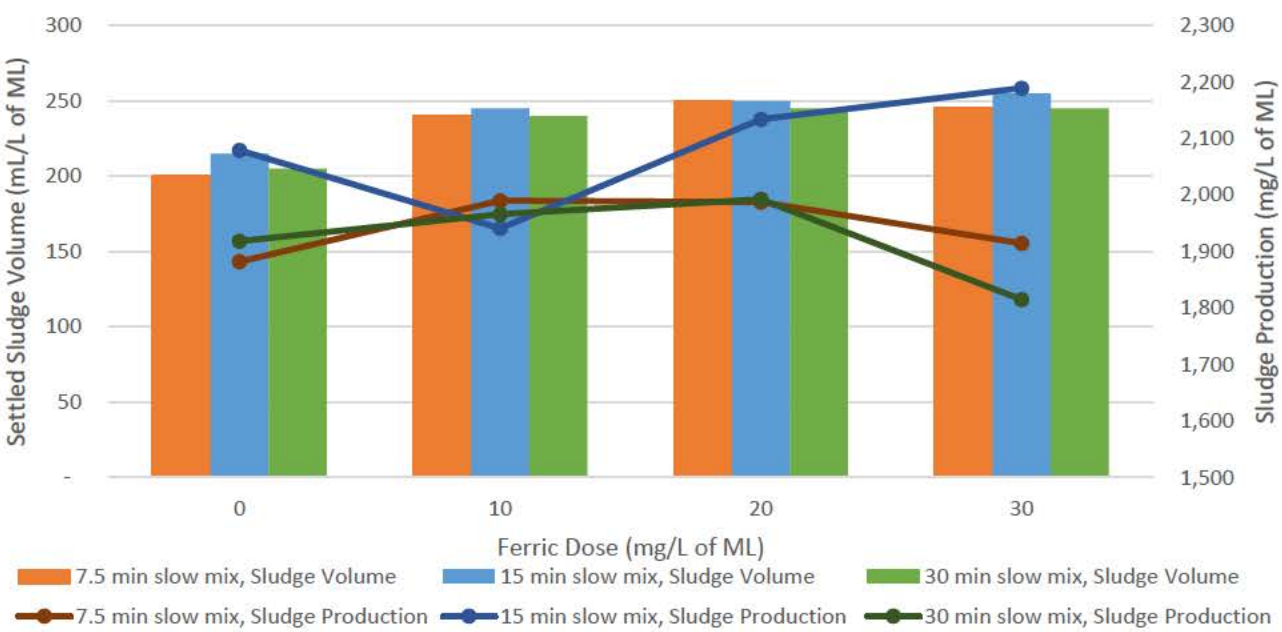

Figure 28: Settled Sludge Produced in Scenario 3 Phase 1 Jar Tests

Based on the scenario 3 Phase 1 jar tests, it was determined that a dose of 15 mg Fe/L be used for the Scenario 2 Phase 2 testing to achieve a soluble ortho phosphorus of 2.2 mg /L in the final effluent and 20 mg Fe/L to achieve a soluble ortho phosphorus of 0.8 mg /L in the final effluent, along with the control dose of 0 mg Fe/L and the BioWin-predicted dose of 10 mg Fe/L to achieve a soluble ortho phosphorus concentration of 2.2 mg PO_4-P/L in the final effluent.

3.2.2. Scenario 3 Phase 2

Samples from NEWPCC were collected on November 4 between 8:30 and 10:30 AM for Scenario 3 Phase 2 testing. Mixed liquor from the NE was collected from each train and combined in equal parts for testing. Primary sludge from the NE was collected from the sample port near the primary sludge transfer pumps while the pumps were running to ensure a fresh sample. Digested sludge samples were collected following digestion, prior to the second ferric dosing point. Sludge samples from the WE were collected from the sludge holding tank, prior to being hauled to the NE. ***Table 12*** summarizes the raw sample characteristics.

Table 12: Scenario 3 Phase 2 Raw Sample Characteristics

Parameter	Unit	NE Mixed Liquor	NE Mixed Liquor (Nov 2)	NE Primary Sludge	NE Digested Sludge	WE Sludge
pH		6.55	6.53	6.07	7.37	5.32
Alkalinity	mL $CaCO_3$/L	220	240	1180	2680	620
TS	mg/L	3,006	2,788	29,044	12,720	35,166
VS	mg/L	2,202	2,038	22,880	8,112	29,992
Ortho-P	mg/L	5.47	6.15	84.3	69.4	555
TP	mg/L	9.12	-	83.4	-	569

Jar testing was completed on mixed liquor for four different ferric doses based on Phase 1 testing and BioWin modeling. The four ferric doses used for Phase 2 testing were 0, 10, 15, and 20 mg Fe/L of mixed liquor. All Phase 2 jar tests were completed with 7.5 minutes of slow mixing (40 rpm). After 30 minutes of settling, the volume of settled sludge was recorded and sampled for further testing. Supernatant was sampled immediately following the 30 minutes of settling for further testing, with results outlined in ***Table 13***.

Table 13: Scenario 3 Phase 2 Supernatant Characteristics

Parameter	Unit	0 mg Fe/L	10 mg Fe/L	15 mg Fe/L	20 mg Fe/L
pH		6.7	6.59	6.54	6.47
Alkalinity	mL $CaCO_3$/L	220	210	200	190
Ortho-P	mg/L	5.47	2.67	1.53	0.679
TP	mg/L	9.12	3.95	2.47	1.46

Soluble ortho phosphorus concentration in the supernatant was as expected based on the Phase 1 testing. The ferric dose of 10 mg Fe/L of mixed liquor and 20 mg Fe/L of mixed liquor had ortho phosphorus concentrations of 2.66 mg PO_4-P/L and 0.68 mg PO_4-P /L, respectively, as shown in ***Figure 29***.

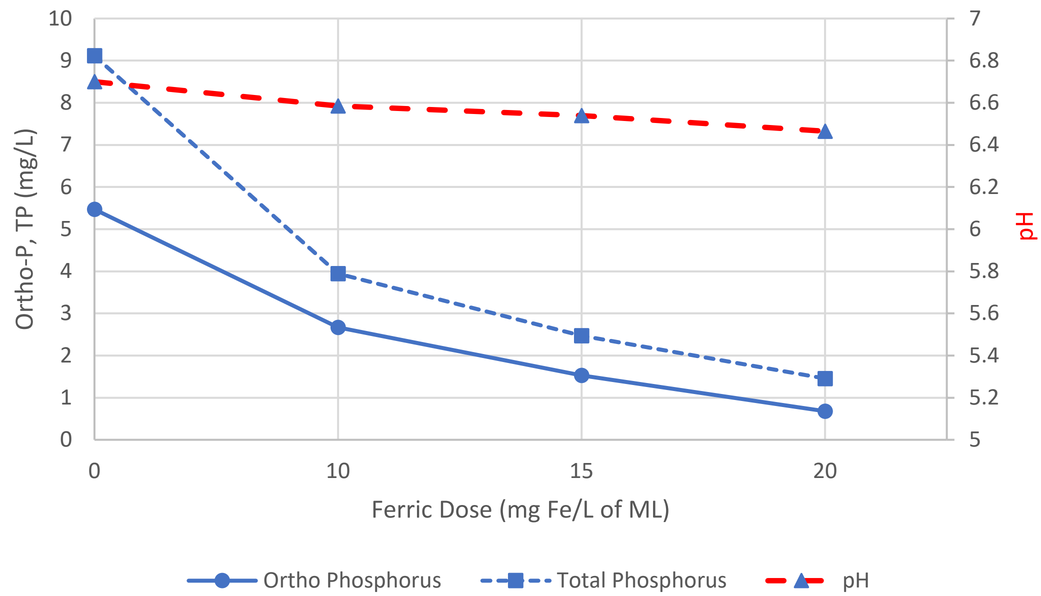

Figure 29: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 3 Phase 2 Jar Tests

Ultraviolet transmittance (UVT) was measured on all supernatant samples to determine if UV treatment would be inhibited. As the ferric dose to the mixed liquor increased, UVT increased, as shown in ***Figure 30***. The main reason was in decrease turbidity of the final effluent as the ferric dose increased.

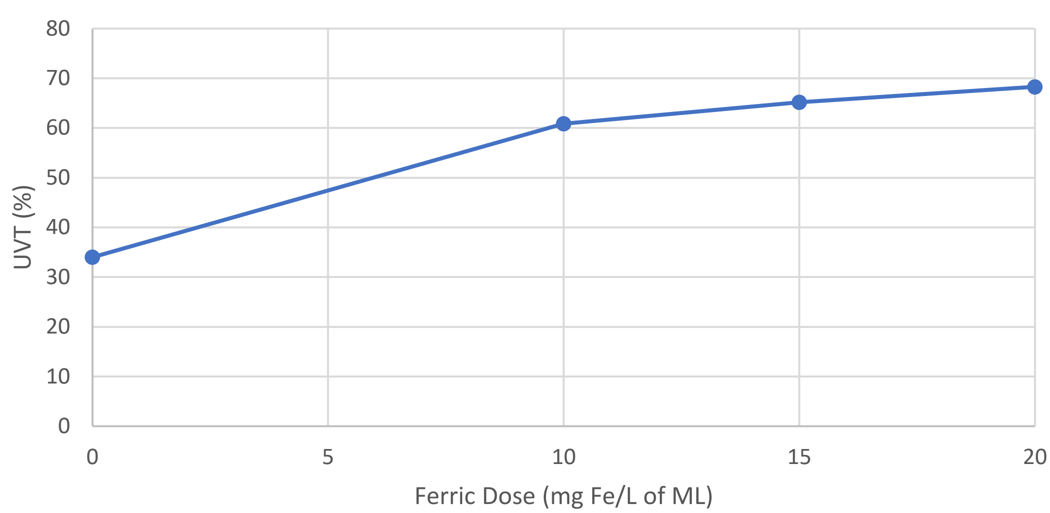

Figure 30: UVT for Scenario 3 Phase 2 Supernatant

The volume of settled sludge increased as well as the total sludge produced per liter of mixed liquor as the ferric dose increased, as shown in ***Figure 31***. The mass of sludge produced during precipitation, compared to the mass produced at zero dose, has increased by 7.9% for the 10 mg Fe/L dose and by 14.4% for the 20 mg Fe/L dose.

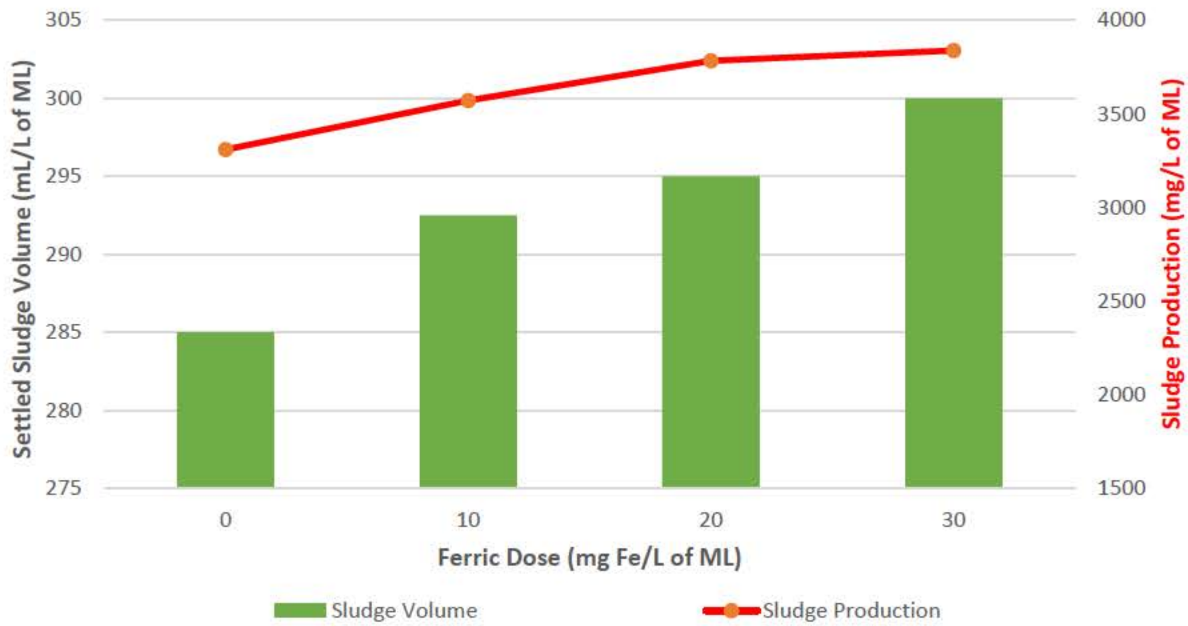

Figure 31: Scenario 3 Phase 2 Sludge Production

Sludge produced in the jar tests was then mixed with primary sludge at a ratio of 45:55. Seven parts of the mixed sludge was then mixed with three parts of West End Water Pollution Control Centre sludge sampled from the holding tank. The mixed sludge was then added to digester inoculum at a volumetric loading rate of 0.07 $m^3/m^3 * d$ and a 15-day BMP was started to record biogas production. Each bottle contained 500 mL of sludge, made up of 11.4 mL of sludge from the jar test, 13.6 mL of primary sludge, 10.7 mL of WE sludge, and 464.3 mL of digester inoculum.

Cumulative biogas production during the BMP test is shown in ***Figure 32***. Biogas was sampled and analyzed for gas composition 4 times throughout the 15 days. ***Figure 33*** shows the biogas composition throughout the BMP tests.

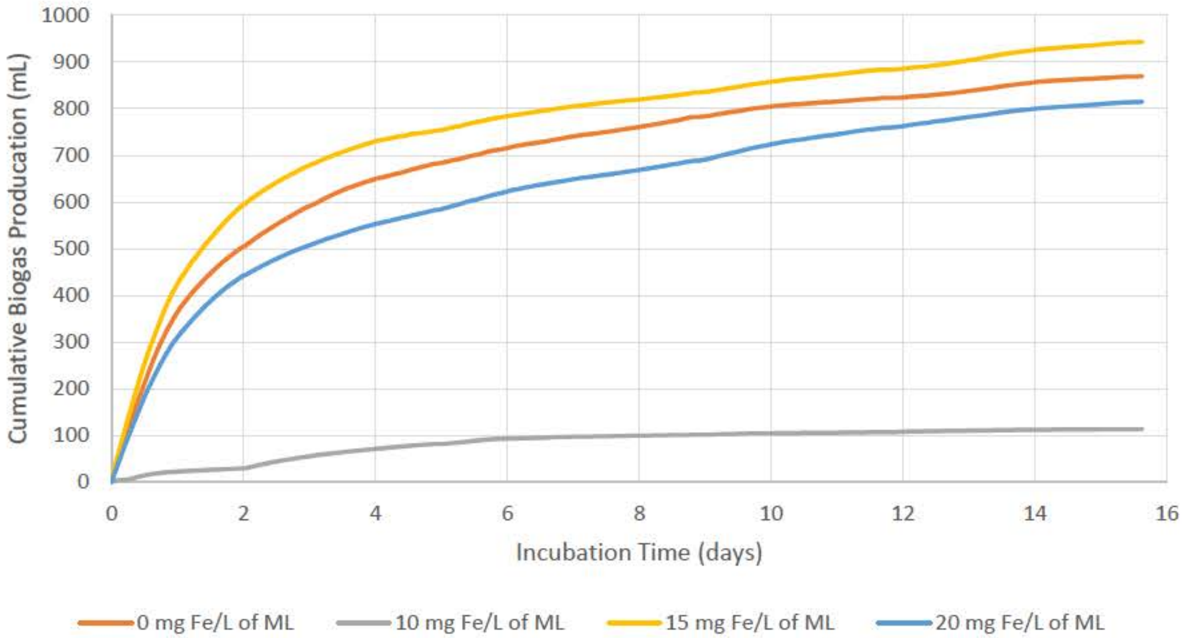

Figure 32: Scenario 3 Phase 2 Cumulative Biogas Production *(*Error in automatic biogas production recording for 10 mg Fe/L of ML and this curve should be disregarded).*

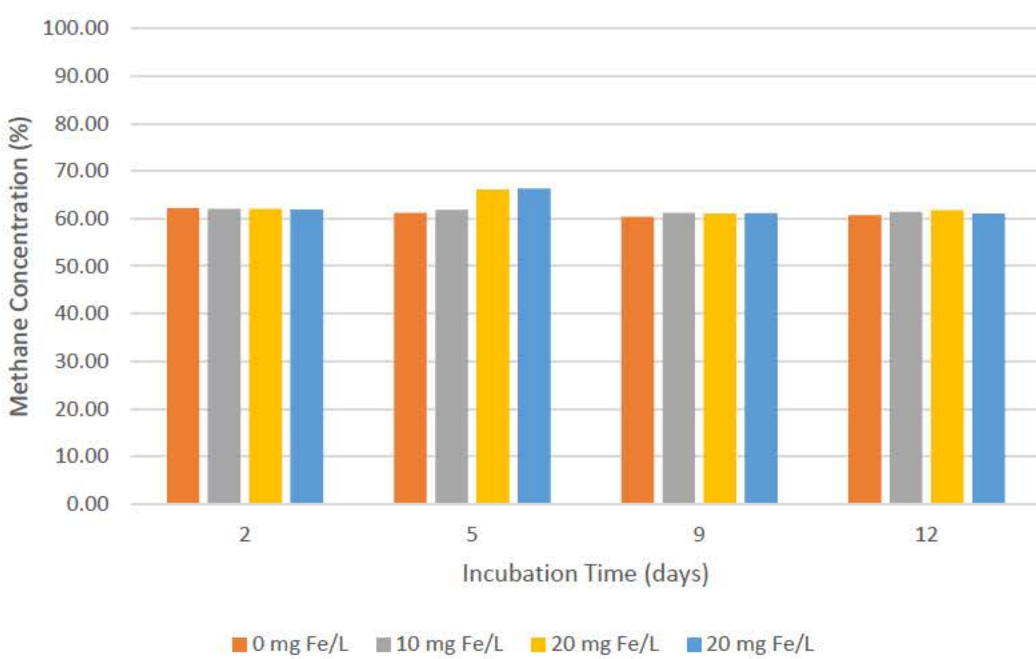

Figure 33: Scenario 3 Phase Biogas Composition

Table 14: Scenario 3 Phase 2 Biogas Composition

Ferric Dose to Primary Influent	Unit	Methane	Other
0 mg Fe/L	%	61.13	38.87
10 mg Fe/L	%	61.61	38.39
15 mg Fe/L	%	62.75	37.25
20 mg Fe/L	%	62.58	37.42

Based on the average methane content for each sample throughout the BMP test, as outlined in ***Table 14***, the methane yield for each sample over the 15-day BMP test is shown in ***Figure 34***.

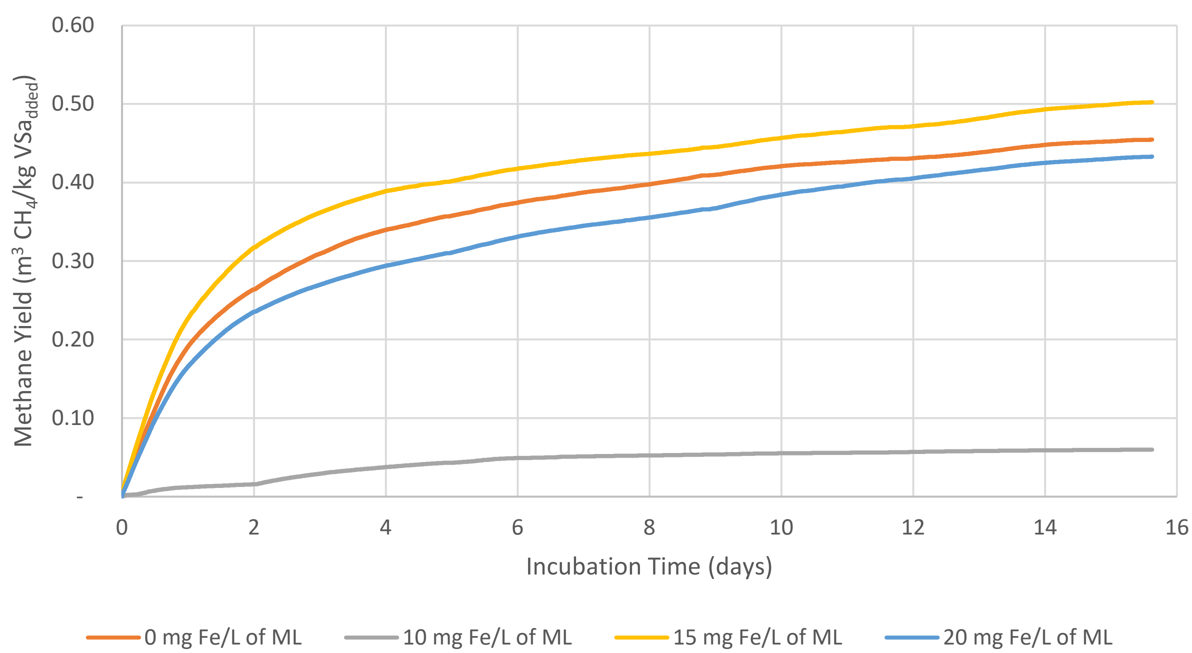

Figure 34: Scenario 3 Phase 2 Methane Yield *(*Error in automatic biogas production recording for 10 mg Fe/L of ML and should be disregarded)*

Soluble ortho phosphorus in the digested samples was found to be between 86 and 94 mg PO_4-P/L, a total phosphorus between 97 and 102 mg TP/L, all with a pH around 7.1, as shown in ***Figure 35***.

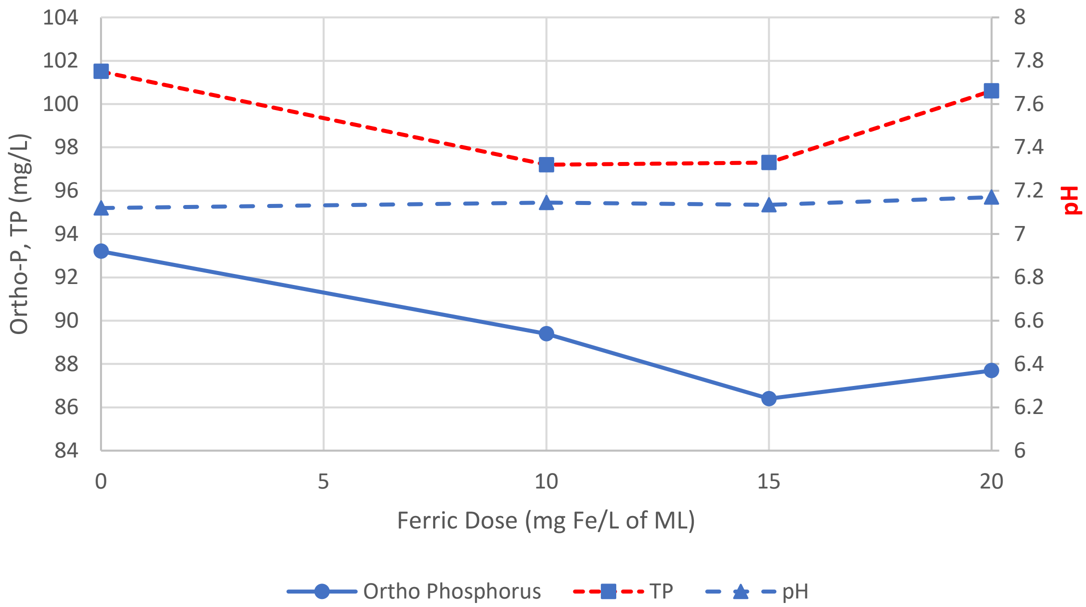

Figure 35: Soluble Ortho Phosphorus, Total Phosphorus and pH for Scenario 3 Phase 2, Post Digestion

Total solids and volatile solids destruction after the 15-day BMP test were found to be between 12-13% and 19-21%, respectively, as shown in ***Figure 36***.

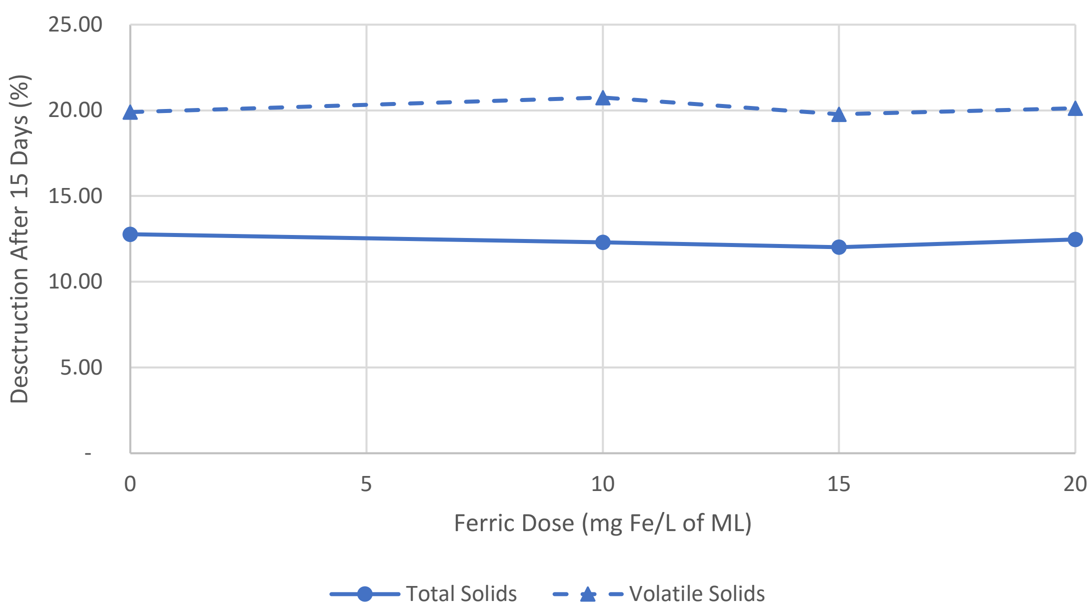

Figure 36: Scenario 3 Phase 2 Total Solids and Volatile Solids Destruction

Duplicate capillary suction time (CST) tests were completed on the sludge after digestion to determine the ferric dose effect on dewaterability. ***Table 15*** shows the average CST for each sample.

Table 15: Scenario 3 Phase 2 Capillary Suction Times After Digestion

Ferric Dose Before Digestion	Unit	CST
0 mg Fe/L	sec	214
8 mg Fe/L	sec	230
14 mg Fe/L	sec	224
18 mg Fe/L	sec	221

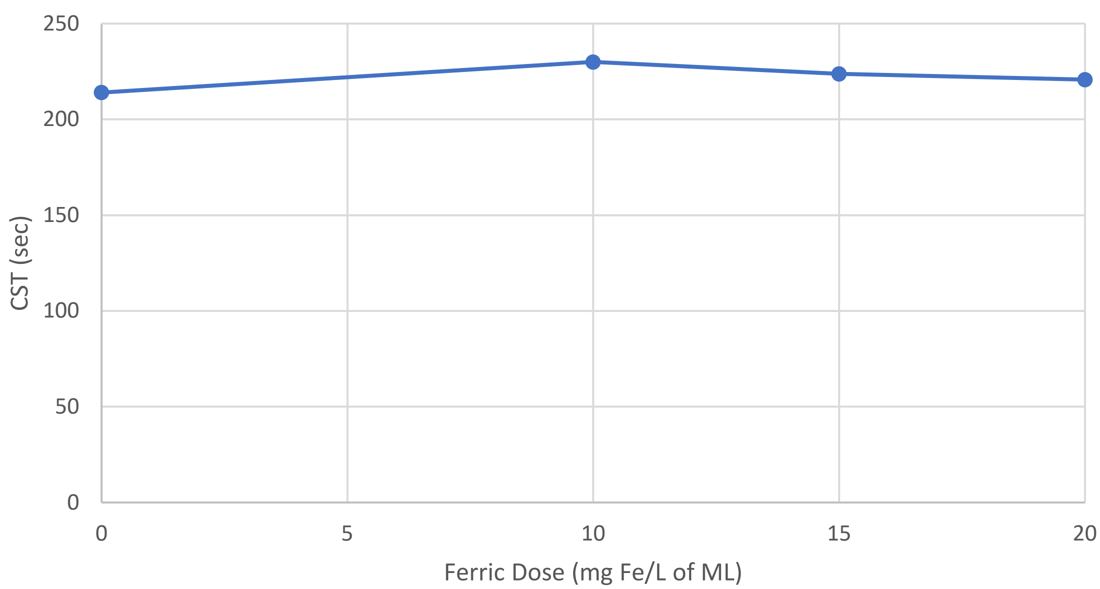

Figure 37: Scenario 3 Phase 2 Capillary Suction Time

4. Conclusions

Scenario 1 Side stream dosing of ferric chloride:

It was possible to achieve a soluble ortho phosphorus concentration of 20 mg PO_4-P/L or less in the supernatant by dosing ferric before and after digestion. Dosing a higher amount of ferric prior to digestion did not show a negative effect on biogas and methane production during anaerobic digestion. The pH of digested sludge was not affected, but further investigation for a continuous feed would need to be carried out to ensure the drop-in feed pH would not negatively affect the digester performance over time. Methane content in biogas produced by sludge that was adjusted to pH 6 and 7 prior to digestion was approximately 10% higher than methane generated from the sludge where pH was not adjusted in the jar test. Total and volatile destruction during the digestion process were not found to be affected by the higher ferric dose or the pH adjustment. The latter indicated that the digestion was not affected. Capillary suction time tests (CST) conducted on the digested sludge showed no impact of the higher ferric dose or of pH adjustment prior to digestion. The CST was significantly decreased after the second ferric dose of 200 mg Fe/L added post-digestion prior to dewatering.

Scenario 2 Chemically enhanced primary treatment:

Ortho phosphorus levels in the primary effluent can reach 2.2 and 0.8 mg PO_4-P/L with a ferric dose of 8 and 18 mg Fe/L of primary influent, respectively, with pH only dropping slightly below 7 for both ferric doses. Sludge production was shown to increase 20% and 50% from the control dose for ferric doses of 8 and 18 mg Fe/L of primary influent, respectively. Dosing ferric to the primary clarifiers did not show a negative effect on biogas and methane production during digestion. Total and volatile destruction during the digestion process was also not found to be affected by dosing ferric to the primary clarifiers. Capillary suction time on the digested sludge was not shown to be affected by t he ferric dosing to primary clarifiers. Specific oxygen uptake rate on the primary effluent/supernatant decreased as the ferric dose increased indicating a potential for reduction in aeration requirements in the downstream HPO reactors.

Scenario 3 Dosing ferric chloride into mixed liquor:

Ortho phosphorus levels in the secondary effluent can reach approximately 2.2 and 0.8 mg PO_4-P/L with a ferric dose of 10 and 20 mg Fe/L of mixed liquor, respectively, with pH only dropping slightly below 6.7 for both ferric doses. It was found that ultraviolet transmittance of the final effluent increased as the ferric dose increased, indicating UV treatment effectiveness would increase when dosing ferric to the HPO reactors. Sludge production was shown to increase 7.9% and 14.4% from the control dose, for ferric doses of 10 and 20 mg/L of mixed liquor, respectively. Dosing ferric to the HPO reactors did not show a negative effect on biogas and methane production during digestion. Total solids and volatile solids destruction during the digestion process were not found to be affected by dosing ferric to the HPO reactors. Capillary suction time tests on the digested sludge were not shown to be affected by the ferric dosing to HPO.