Appendix H

TM 2: Enhanced TP Removal Through Secondary Treatment Optimization

Enhanced Phosphorus Removal through Optimized Secondary Treatment

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Objectives

The objective of this technical memorandum (TM) is to summarize a desktop modelling analysis to determine the potential for increased total phosphorus (TP) removal at the Duffin Creek Water Pollution Control Plant (WPCP) through optimization and/or minor capital improvements to the existing secondary treatment process at its rated capacity of 630 ML/d.

It is important to note that the results obtained from this modelling exercise are limited by the assumptions that were made in model calibration and inputs for future projections, and therefore do not represent the full extent of possible operational variables and potential risks that could be experienced at the Duffin Creek WPCP in the future. It is recommended the assumptions and conclusions drawn from this desktop analysis are further validated by a field study at the Duffin Creek WPCP, which will aim to a) validate the projected achievable effluent TP concentrations by secondary treatment optimization discussed herein, and b) determine a margin of safety that would be appropriate for potential new effluent TP objectives and limits at the Duffin Creek WPCP.

At the time of this draft TM, a workplan for this proposed field study is in development. Following completion of this field study, a separate TM will be issued, which will summarize the results of the field study as well as a discussion on reasonable effluent objectives and limits that could be achieved under secondary treatment optimization, factoring in appropriate margins of safety.

Introduction

The Regional Municipalities of Durham and York (Regions) are undertaking a Phosphorus Removal Action Plan (PRAP) Study (Study) for the Duffin Creek WPCP. The principal goal of the Study is to address the PRAP requirements as outlined by the Ministry of the Environment and Climate Change (MOECC) Order for additional information dated April 4, 2016. The results of the Study will also provide the Regions with an understanding of the performance capability of the Duffin Creek WPCP with respect to TP removal for the current plant, an optimized plant, and/or tertiary treatment.

This TM documents the following activities:

- Assessment of achievable secondary effluent TP using chemical phosphorus removal based on benchmark results published in the literature and other plants in Ontario, including the nearby Skyway Wastewater Treatment Plant (WWTP) located in Burlington, Ontario.
- Use of the calibrated model presented in TM 1 to assess the potential for increased TP removal at the Duffin Creek WPCP through optimization and/or minor capital improvements to the secondary treatment process.
- Quantification of impacts of optimized TP removal on solids and liquids treatment trains.
- Summary of recommended field studies to verify the assumptions and conclusions drawn from the literature review and desktop modelling exercise.

Benchmarking Achievable TP Removal in Secondary Treatment

A review of the literature was performed to identify benchmarks for the level of TP removal that can be reliably achieved in "real world" secondary treatment plants. Because substantial information is available on "limit of technology" TP removal in tertiary treatment plants, this data has been considered but only insofar as it relates to the removal of the soluble reactive phosphorus (SRP). It would be inappropriate to use the TP removal performance of these plants as a benchmark because tertiary treatment includes a degree of polishing of particulate phosphorus which may not be possible to achieve through optimized secondary treatment.

Because both secondary and tertiary treatment rely on chemical addition to achieve limit of technology SRP removal, it is considered that the performance from tertiary treatment plants can inform the limits of SRP removal that can be achieved in secondary treatment plants. This being said, tertiary treatment facilities typically include a tertiary chemical dosing location that is not available in secondary treatment plants, and this likely confers a slightly higher SRP removal performance and reliability than could be achieved in secondary treatment plants. A tertiary chemical application point is also advantageous for enhanced chemical phosphorus removal, as an application point downstream of the secondary biological process does not need to be moderated to prevent phosphorus deficiency in the activated sludge process. Chemical addition upstream of the secondary activated sludge process must be closely monitored to avoid causing phosphorus deficient conditions which can have adverse effects on nutrient removal performance and sludge settleability.

For the purposes of this study, an evaluation of SRP removal in tertiary treatment plants is considered as an indicator of the level of SRP removal that could be approached but not fully achieved in secondary treatment plants.

Soluble Reactive Phosphorus Removal

A comprehensive study of nutrient removal plants designed and operated to meet very low total nitrogen (TN) and TP concentrations (as low as 0.1 mg/L TP) was recently undertaken by the Water Environment Federation (WEF) and the Water Environment & Reuse Federation (WE&RF). The purpose of this study was to "provide a database that will inform key decision makers about proper choices for both technologies and rationale bases for statistical permit writing" (WERF, 2011). Managers of 22 treatment plants (including 10 phosphorus removal plants) provided three years of operational data that were analyzed using a consistent statistical approach that considered both process reliability and the permit limits applied. Because this study focused on tertiary treatment (enhanced suspended solids removal) for TP removal, its conclusions regarding TP removal cannot be applied directly to the level achievable using secondary treatment at the Duffin Creek WPCP. Nevertheless, it does provide relevant information regarding SRP removal. For example, of the 10 phosphorus removal plants surveyed, 6 were operated with an effluent SRP objective of 0.1 mg P/L which was achieved with a reliability that averaged between 86 and 100 percent. Reported metal dosing ratios (as Fe or Al) at these facilities ranged from 0.5 to 3.1 mol of Fe or Al per mol influent P. Plants which dosed less than 1 mol Fe or Al per mol influent P were also using an enhanced biological phosphorus removal processes which accounted for some of the TP removal achieved.

Performance reliability was characterized in this study by the statistical distribution around the average treatment levels. For example, the 99th percentile daily effluent TP concentration was 2.9 to 5.4 times higher than the average annual effluent TP concentration for the 10 plants surveyed. In contrast, the 90th percentile annual average effluent TP concentration was 4 percent to 44 percent higher than the 50th percentile annual average effluent TP concentration. This finding supports the conclusion of the Monte Carlo analysis presented in TM 1 concerning the performance that can be achieved “on average”, compared to what can be achieved “reliably”, as well as the conclusion that effluent TP concentration variability decreases at longer averaging times: annual *vs.* monthly *vs.* daily.

A summary of operating parameters and effluent SRP concentrations from select facilities is presented in Table 1, including the nearby Skyway WWTP located in Burlington, Ontario and the Blue Plains Advanced WWTP (AWWTP) located in Washington, D.C. The Skyway WWTP is a tertiary treatment facility; however, the plant does not dose chemicals to its tertiary treatment stage and, therefore, its achievable effluent SRP is representative of what might be achieved in a secondary treatment plant. The performance data from the Blue Plains Advanced WWTP (AWWTP) is of interest because, with a rated capacity of 1,400 ML/d, it is a facility that is on the same scale as the 630 ML/d Duffin Creek WPCP. However, even though the Blue Plains plant does not dose chemicals to its tertiary filtration stage, it does operate a tertiary TN removal stage with methanol addition that may provide additional SRP removal downstream of the final Fe dosing point.

Table 1
Survey of Operating Parameters for Chemical Phosphorus Removal at Various Plants

Facility	Process	Dose (mol Fe/mol TP) To Primary	Dose (mol Fe/mol TP) To Secondary	Total Dose (mg/L)	Average Effluent SRP (mg/L)
Blue Plains AWWTP [1]	Tertiary, dual point ferric chloride	0.6	3.9	9.2	0.07
Skyway WWTP [2]	Secondary, dual point ferric chloride	0.97 (primary + secondary dose)		10.7	0.075
Duffin Creek WPCP [3]	Secondary, dual point ferrous chloride	0.6	1.3	10.7	0.24

[1] WERF, 2011
[2] Skyway WWTP operating data, 2011 to 2015.
[3] Duffin Creek WPCP operating data, 2011 to 2015

Based on a review of the data presented in Table 1, it is assumed that the Duffin Creek WPCP could achieve lower effluent SRP concentrations, which have historically been 0.2 mg P/L, to 0.1 mg P/L at the 50th percentile. While other facilities have demonstrated the ability to meet a 50th percentile SRP concentration of 0.05 mg P/L (WERF, 2011), the ability to operate the Duffin Creek WPCP at this efficiency cannot be determined without a year-long field study that covers the periods of particular risk including winter, and spring and fall “shoulder” seasons. In addition to the question of attainability, operating at SRP concentrations of much lower than 0.1 mg P/L creates a risk of phosphorus deficiency in secondary treatment. Phosphorus deficiency could have detrimental impacts on secondary treatment efficiency including nitrification and on sludge settling properties.

Based on these considerations, it is reasonable to assume that the Duffin Creek WPCP could operate to meet an effluent SRP concentration of 0.1 mg P/L at the 50th percentile, which is a higher level of treatment than anticipated in its Stage 3 Expansion design. This assumption is the basis of each of the model simulations of optimized plant performance presented in this TM. Figure 1 is provided to illustrate the relationship between effluent TSS and the maximum allowable SRP required to achieve a given effluent TP concentration. For example, assuming a 2.5 percent ratio of particulate P to TSS and an effluent SRP of 0.1 mg/L, this figure shows that the effluent TSS could not be higher than 10 mg/L to achieve an effluent TP of 0.35 mg P/L.

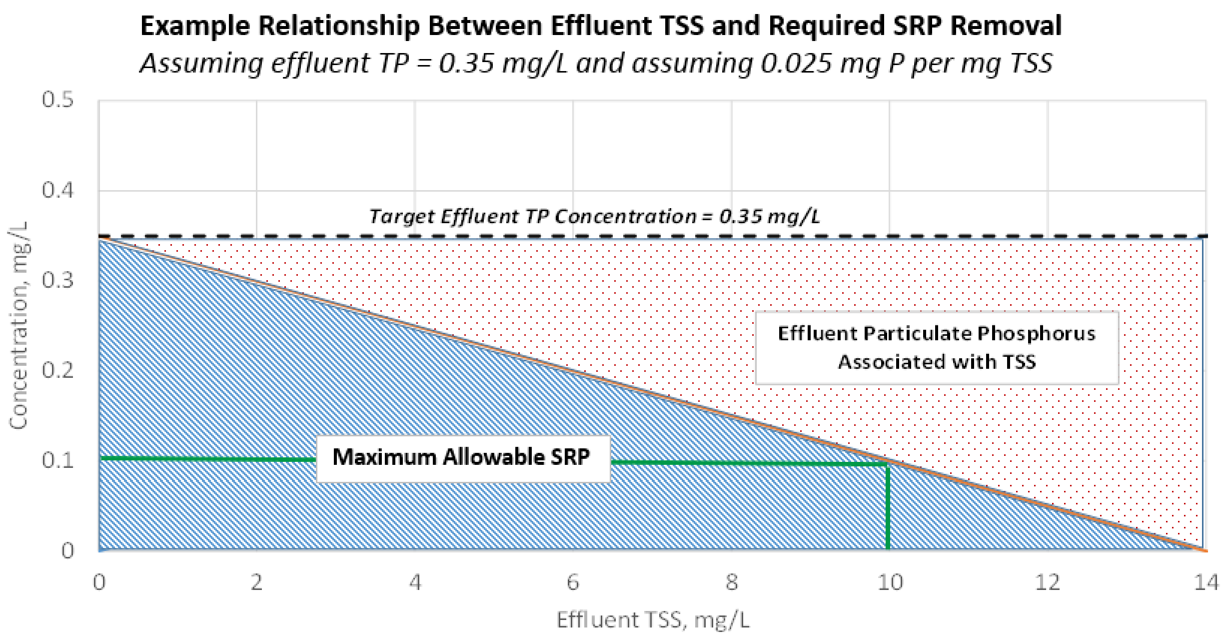

Figure 1
Relationship between Effluent TSS and Maximum Allowable Effluent SRP

Particulate Phosphorus Removal

Particulate phosphorus in secondary treatment effluent can be directly calculated as the product of the effluent TSS and the P/TSS ratio of the mixed liquor. High P/TSS ratios are observed in enhanced biological phosphorus removal (EBPR) plants or in plants that practice single point chemical phosphorus removal; however, these high ratios are not relevant to the assessment of the Duffin Creek WPCP where future plant optimizations include dual point chemical phosphorus removal with no EBPR. For the Duffin Creek WPCP, this ratio may be expected to vary in a range from 1.8 to 3 percent (0.018 to 0.03 mg particulate P/mg TSS) and can be calculated from a mass balance that accounts for the following factors:

- The ratio of P to TSS in the influent to the secondary treatment process, which itself is dependent on the relative capture (in the primary clarifiers) of the raw sewage P and TSS. This relative capture is impacted by the dosing rates of iron (and potentially also polymer) to enhance removal of SRP and colloidal organic matter, as well as the fractions of raw sewage influent TP and organic matter that are soluble.

- The sludge yield in the secondary process (kg TSS produced per kg TSS in the influent) which is dependent on the Sludge Retention Time (SRT) and the raw sewage wastewater fractions: primarily the inorganic suspended solids contribution to the TSS and the fraction of the influent organic matter that is unbiodegradable and particulate.
- The amount of the TP that leaves the secondary treatment in a soluble form i.e. the final effluent SRP.

The factors listed above are accounted for in the dynamic model which can therefore be expected to provide a robust prediction of the mixed liquor P/TSS ratio in simulations of the optimized plant.

An indication of the level of TSS removal performance that can be achieved from secondary treatment is provided in a 2008 US EPA survey of 100 publically owned treatment works with activated sludge secondary treatment only. This survey reported monthly average 50^{th} percentile effluent TSS concentrations of 8 mg/L and monthly average 95^{th} percentile effluent TSS concentrations of 20 mg/L (US EPA, 2013). Data from facilities that were unable to meet an effluent compliance limit of 30 mg/L were not included as part of these statistics, and the study did not distinguish the capacity utilization at which the plants were operating. For this reason, these data cannot be used to assess the level of treatment that could be expected from a facility operating at 100 percent of its rated capacity. As described in the following sections, historical performance and 1D flux modelling have been used to project effluent TSS concentrations at the Duffin Creek WPCP at its full treatment capacity.

Optimization Options

Five options for optimizing secondary treatment at the Duffin Creek WPCP have been identified based on the potential to switch from dual point ferrous chloride to dual point ferric chloride dosing, the ability to dose polymer to the secondary clarifiers, and the potential to dose polymers to the primary clarifiers. The five options are summarized in Table 2 below and described in detail in the following subsections.

The primary benefit of dosing polymer to the secondary clarifiers is expected to be controlling sludge blankets during periods of high clarifier loading rates, when the clarifiers are subject to thickening failure. This is how the benefit of dosing polymer to secondary treatment has been accounted for in model simulations although it is acknowledged that plant operations staff may operate this polymer dosing on a continuous basis as a matter of practice.

The primary benefit of dosing polymer to the primary clarifiers would be to improve the capture of TSS and colloidal organic matter in primary treatment, thereby allowing the plant to operate at a lower mixed liquor concentration while maintaining sufficient SRT. This benefit is captured in model simulations through the relationship between lower mixed liquor concentrations, lower secondary clarifier solids loading rates, and improved primary clarifier TSS capture.

Table 2
Options for Optimized Secondary Treatment

Option	Ferrous to Primary Treatment	Ferrous to Secondary Treatment	Ferric to Primary Treatment	Ferric to Secondary Treatment	Polymer to Primary Treatment	Polymer to Secondary Treatment
1	X	X				
2	X	X				X
3			X	X		
4			X	X		X

5	X	X	X	X

Option 1: Dual Point Ferrous Chloride Addition

In Option 1, ferrous iron salts (ferrous chloride) are added to the aerated grit system (upstream of primary clarifiers) and to the mixed liquor channels immediately upstream of the secondary clarifiers. This is consistent with the current operational practice at the Duffin Creek WPCP.

Ferrous iron is oxidized to ferric iron, which can precipitate as hydrous ferric oxide (HFO) and HFO-P complexes that can be removed in the primary sludge or become incorporated into the secondary treatment system mixed liquor and then be removed with the waste activated sludge. Some of the HFO and HFO-P complexes will carry through into the primary effluent where they will also become incorporated into the activated sludge and contribute to chemical sludge in the secondary treatment process. Ferrous iron that is not oxidized to ferric iron in the primary clarifier can precipitate phosphorus as “vivianite” ($Fe_3(PO_4)_2$) and be removed in the primary sludge. A cursory review of the vivianite solubility product, as well as iron and phosphate concentrations in the primary clarifiers, indicates vivianite is likely to precipitate in primary clarifiers; it is recommended that this be confirmed through field testing of iron phosphate(s) composition in the primary sludge. Ferrous iron that does not precipitate as vivianite remains soluble and is carried into the secondary treatment process where it is expected that all of it will be oxidized to HFO which will remove phosphorus according to the slow and fast SRP removal kinetics described in the dynamic process model.

The performance of this option was simulated using the parameter set from the 2015 calibration and assuming the same dosing locations. To achieve an annual effluent 50th percentile SRP concentration of 0.1 mg/L at 630 ML/d, the model required ferrous iron dosing at a rate of approximately 15 mg Fe/L of raw sewage flow, split equally between the primary and secondary treatment dosing points.

Option 2: Dual Point Ferrous Chloride Addition + Polymer to Secondary Clarifiers

The performance of this option was simulated using the same approach utilized in Option 1 except with a modification to secondary clarifier TSS performance to account for the effect of polymer dosing to aid in thickening/flocculation during periods of high loading when there is a risk of high effluent TSS from causes such as high overflow rates, blanket scouring, and thickening failure.

The cumulative probability distribution curves used to simulate the secondary clarifier effluent TSS with and without polymer addition are presented in Figures 2a and 2b, respectively. The probability distributions presented in Figure 2a were used to simulate Options 2, 4 and 5 (i.e. Options with polymer addition to secondary clarifiers). The probability distributions presented in Figure 2b were used to simulate Options 1 and 3 (i.e. Options without polymer addition to secondary clarifiers).

Predicted effluent TSS concentrations were developed based on secondary clarifier solids loading rates (SLR), which is the mass rate of solids to the clarifier per unit of clarifier surface area (i.e. the mass flux rate in the clarifier). In general, higher SLRs yield higher effluent TSS concentrations.

The probability distribution curves for predicted effluent TSS at secondary clarifier solids loading rates (SLR) less than 150 kg/m^2/d were developed using historical plant data from 2011 to 2015. The average day SLR during this period was 61 kg/m^2/d and the maximum day SLR was 148 kg/m^2/d. One-dimensional flux modelling was used as the basis for projecting clarifier effluent TSS concentrations at solids loading rates higher than those previously observed at the plant using Vesilind settling parameters representative of a range of sludge compositions ranging between “normal” sludge (Sludge Volume Index [SVI] <100 mL/g) and “bulking” sludge (SVI ≥150 mL/g) (Lee et al., 1983). Historical SVI’s at the

Duffin Creek WPCP have been less than 75 mL/g at the 50th percentile and approximately 140 mL/g at the 99th percentile. (Given the range of techniques for measuring SVI, including the use of stirred and diluted tests, it should be noted that SVI's at the Duffin Creek WPCP are run in 1 L graduated cylinders using undiluted mixed liquor.)

Based on analysis of the historical SVI data, it was determined that "normal" settling properties would occur 90 percent of the time, "bulking" conditions would occur 1 percent of the time, and conditions between "normal" and "bulking" would occur the remaining 9 percent of the time. These assumptions are reflected in the probability curves presented in Figure 2b. The probability curves presented in Figure 2a represent the impact of polymer on secondary clarifier performance and assume that bulking events could be fully mitigated by the use of polymer.

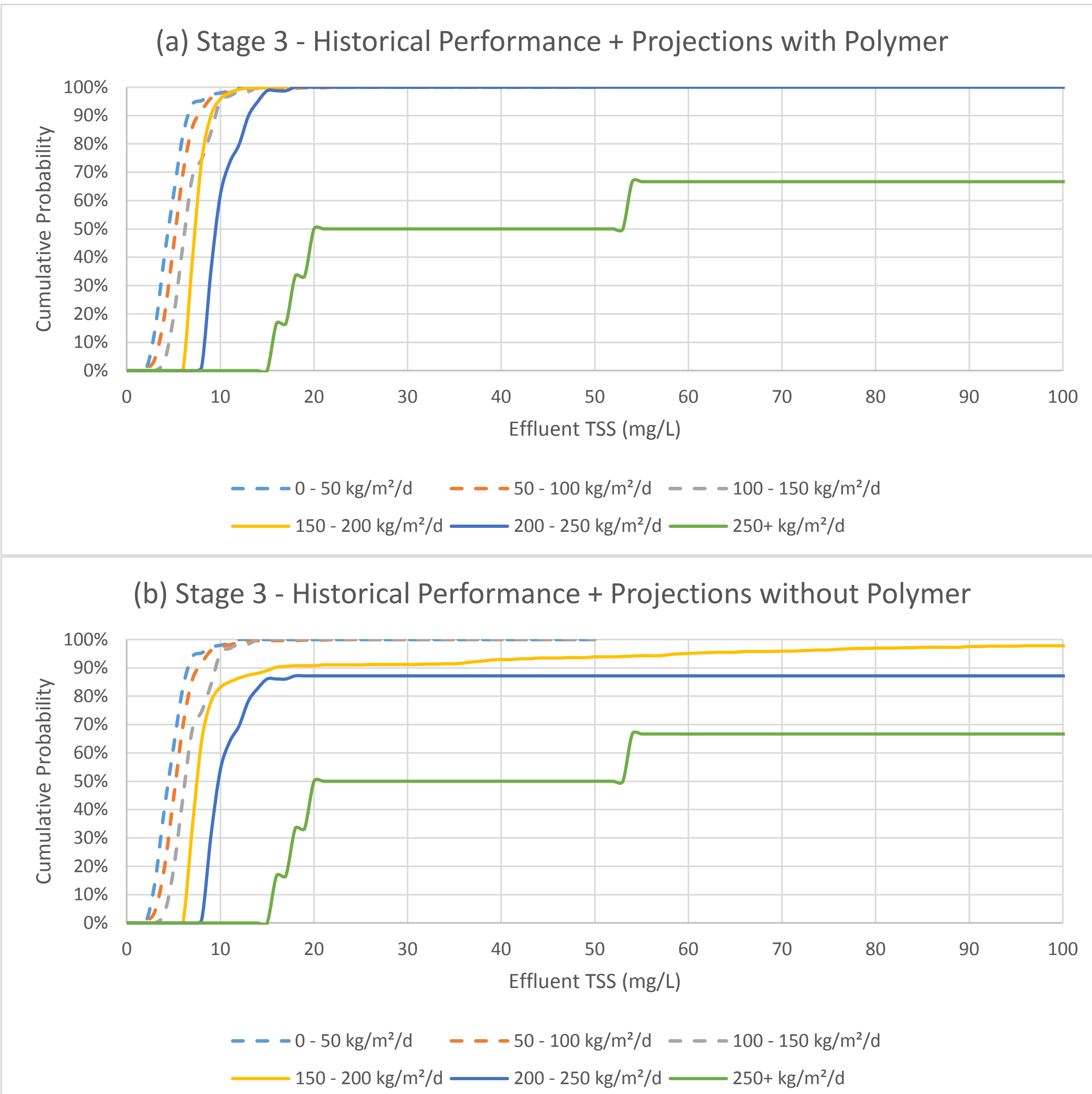

Figure 2
Projections of Secondary Clarifier Effluent TSS Probability in scenarios (a) with polymer addition to secondary clarifiers and (b) without polymer addition. Dashed lines represent historic performance at SLR's in the range of 0 to 150 kg/m^2/d and solid lines represent projections of performance at SLR > 150 kg/m^2/d based on one-dimensional clarifier flux modelling. All SLRs are based on daily flows.

Option 3: Dual Point Ferric Chloride Addition

Ferric iron salts are dosed to the aerated grit system (upstream of primary clarifiers) and the mixed liquor channels immediately upstream of the secondary clarifiers. The ferric iron can precipitate as HFO and HFO-P complexes with the fast and slow SRP removal kinetics described in the dynamic process model. It has traditionally been assumed that the efficiency of ferric iron for SRP removal is greater than ferrous because (stoichiometrically) 1 mole of ferric ion could remove 1 mole of P as iron phosphate while it takes 1.5 moles of ferrous ion to remove 1 mole of P. Accordingly, the Stage 3 Expansion design basis assumed that the required ferric iron dosage to achieve a given SRP was 70 percent of the ferrous iron dosage required. Since the iron precipitation model was calibrated and validated to the 2014 and 2015 data sets (during which ferrous iron rather than ferric iron was dosed) the calibrated model is representative of the efficiency of ferrous iron dosing rather than ferric iron dosing. However, because ferrous iron dosed to secondary treatment is fully oxidized to ferric iron, the efficiencies of ferrous and ferric iron for secondary dosing should be equal. The initial oxidation step required to convert ferrous to ferric iron may impact the amounts of fast and slow precipitation sites in the HFO and thereby impact removal efficiency of SRP. The fate and efficiency of ferrous iron dosed to primary treatment (aerated grit chambers) is less clear since conditions may not be sufficiently aerobic to allow oxidation of ferrous iron to ferric iron and thus precipitation may occur as ferrous phosphate (vivianite) or ferrous sulphide (FeS). For the purposes of this study, and to be consistent with assumptions made during the Stage 3 Expansion design, the required ferric iron dosage was assumed to be 70 percent of the required ferrous iron dosage. As a result, the ferrous iron dosing of 15 mg Fe/L required by the model to achieve an effluent SRP of 0.1 mg/L in Options 1 and 2, was reduced to 10.5 mg Fe/L for Options 3, 4 and 5 to account for the greater efficiency of dosing ferric iron. This dosage rate is within range of the ferric iron dosing at the Skyway WPCP where they have historically achieved an effluent SRP of 0.075 mg/L at the 50th percentile.

Option 4: Dual Point Ferric Chloride Addition + Polymer to Secondary Clarifiers

The performance of this option was simulated using the same approach as Option 3 except that secondary clarifier TSS removal was adjusted to account for the dosing of polymer during periods of high loading. The cumulative probability distribution curves used to simulate the secondary clarifier effluent TSS in this option are presented in Figure 2a.

Option 5: Dual Point Ferric Chloride Addition + Polymer to Primary and Secondary Clarifiers

This option is similar to Option 4 except that the addition of an anionic polymer to primary treatment enhances capture of colloidal material (both organic particles and inorganic phosphorus-containing particles) beyond what could be achieved through ferric iron addition alone. Anionic polymers are generally used because their positive charge allows them to react electrostatically with the negatively charged organic and inorganic colloidal particles in wastewater and flocculate them so that they can be removed more efficiently in the primary clarifiers. As a general rule, primary clarifier TSS removal can be increased to 80 percent. The increase in primary clarifier BOD removal can be as much as twofold with removal values up to 70 percent (WEF, 2010).

The term “chemically enhanced primary treatment”(CEPT) refers to this combined dosing of ferric iron and polymer to primary clarifier influent. The impact of CEPT in Option 5 on the secondary process was simulated using CH2M's Pro2D[2] process model. The model predicted that secondary sludge production and mixed liquor concentrations would decrease by 25 percent in this option compared to Options 1 through 4. The resulting decrease in secondary clarifier solids loading rates were accounted for in the dynamic model simulations. The impact of polymer addition to secondary treatment on secondary effluent TSS concentrations was estimated using Figure 2a.

Model Simulation Results

The simulation results for the five options described in the previous section are presented in Table 3 as well as a detailed discussion in the following sections. The results are summarized for the 99.9% confidence level (i.e. the results were achieved in 99.9 percent of the Monte Carlo simulations). The 99.9 percent is used as the key statistic for assessing plant performance because this is the level of confidence at which the Regions prefer to operate their plant.

Table 3

Model Projections for Achievable Performance of Optimization Options at 100 percent Capacity Utilization

	Effluent TP (mg/L)		**Effluent SRP (mg/L)**	
Condition	**Monthly Average**	**Annual Average**	**Monthly Average**	**Annual Average**
Design	0.8	0.5	N/A	N/A
Results from TM 1:				
Un-optimized plant	0.78	0.60	0.52	0.36
Optimized Plant:				
Option 1: Dual Point Ferrous Addition	0.45	0.32	0.16	0.12
Option 2: Dual Point Ferrous Addition + Polymer to Secondary Clarifiers	0.35	0.31	0.16	0.12
Option 3: Dual Point Ferric Addition	0.45	0.32	0.16	0.12
Option 4: Dual Point Ferric Addition + Polymer to Secondary Clarifiers	0.35	0.31	0.16	0.12
Option 5: Dual Point Ferric Addition with CEPT + Polymer to Secondary Clarifiers	0.30	0.26	0.14	0.11

Note: Performance of plant is assessed at the 99.9 percent confidence level

Option 1: Dual Point Ferrous Chloride Addition

The projected performance of this option is:

- Monthly TP limit that could be met at the 99.9 percent reliability would be 0.45 mg/L.
- Annual TP limit that could be met at the 99.9 percent reliability would be 0.32 mg/L.
- Iron dosing required to achieve this performance is approximately 15 mg Fe/L based on the entire influent flow. The associated chemical sludge production would be 18.9 dtpd assuming a ratio of 2 mg of solids per mg Fe.

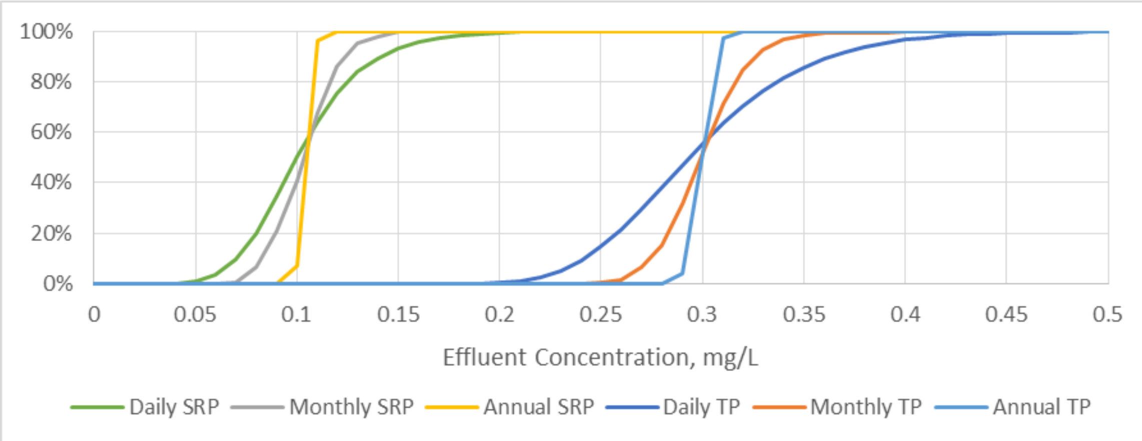

Figure 3

Model Simulations Results using Monte Carlo Analysis for Option 1

Option 2: Dual Point Ferrous Chloride Addition + Polymer to Secondary Clarifiers

The projected performance of this option is:

- Monthly TP limit that could be met at the 99.9 percent reliability would be 0.35 mg/L.
- Annual TP limit that could be met at the 99.9 percent reliability would be 0.31 mg/L.
- Iron dosing required to achieve this level of performance is approximately 15 mgFe/L, based on the entire influent flow. The associated chemical sludge production would be 18.9 dtpd assuming a ratio of 2 mg of solids per mg Fe.
- Polymer dose estimated as per Stage 3 Expansion design basis at 0.5 mg/L.

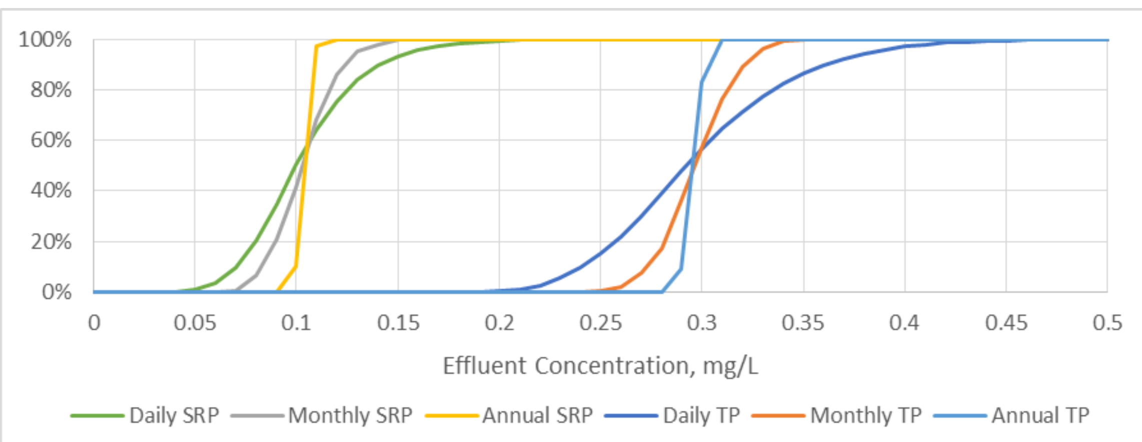

Figure 4

Model Simulations Results using Monte Carlo Analysis for Option 2

Option 3: Dual Point Ferric Chloride Addition

The projected performance of this option is:

- Monthly TP limit that could be met at the 99.9 percent reliability would be 0.45 mg/L.
- Annual TP limit that could be met at the 99.9 percent reliability would be 0.32 mg/L.

- Iron dosing required to achieve this performance is approximately 10.5 mgFe/L, based on the entire influent flow. The associated chemical sludge production would be 13.2 dtpd assuming a ratio of 2 mg of solids per mg Fe.

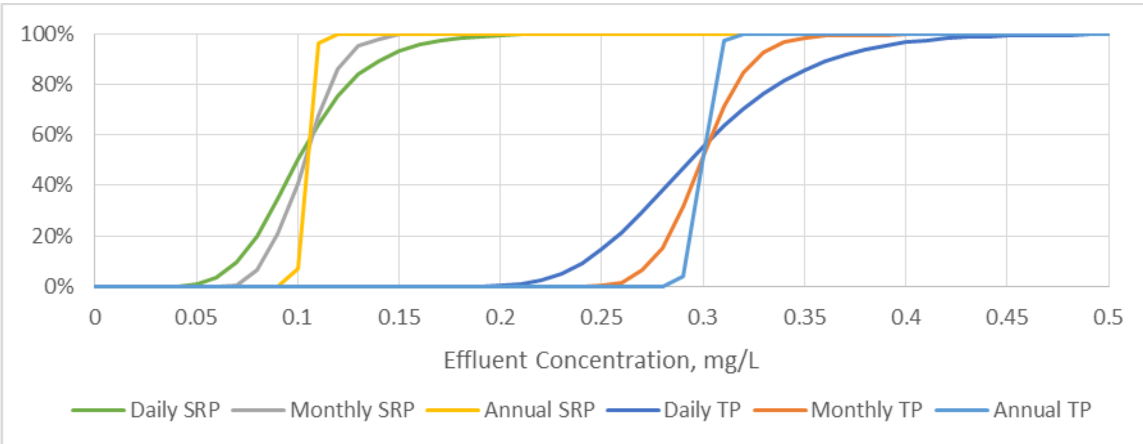

Figure 5
Model Simulations Results using Monte Carlo Analysis for Option 3

Option 4: Dual Point Ferric Chloride Addition + Polymer to Secondary Clarifiers

The projected performance of this option is:

- Monthly TP limit that could be met at the 99.9 percent reliability would be 0.35 mg/L.
- Annual TP limit that could be met at the 99.9 percent reliability would be 0.31 mg/L.
- Iron dosing required to achieve this level of performance is approximately 10.5 mgFe/L, based on the entire influent flow. The associated chemical sludge production would be 13.2 dtpd assuming a ratio of 2 mg of solids per mg Fe.
- Polymer dose estimated as per Stage 3 Expansion design basis at 0.5 mg/L.

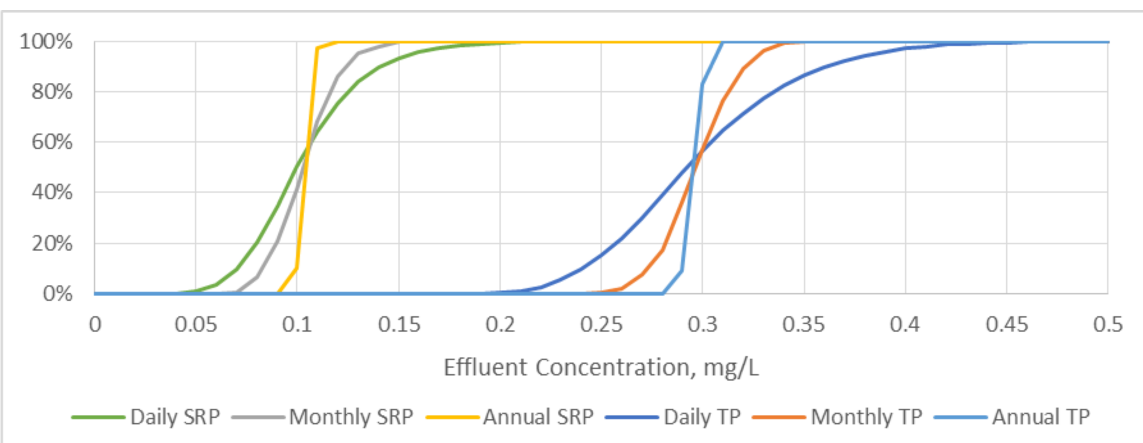

Figure 6
Model Simulations Results using Monte Carlo Analysis for Option 4

Option 5: Dual Point Ferric Chloride Addition + Polymer to Primary and Secondary Clarifiers

The projected performance of this option is:

- Monthly TP limit that could be met at the 99.9 percent reliability would be 0.30 mg/L.
- Annual TP limit that could be met at the 99.9 percent reliability would be 0.26 mg/L.
- Iron dosing required to achieve this level of performance is approximately 10.5 mgFe/L, based on the entire influent flow. The associated chemical sludge production would be 13.2 dtpd assuming a ratio of 2 mg of solids per mg Fe.
- Polymer dose to secondary treatment estimated as per Stage 3 Expansion design basis at 0.5 mg/L.
- Polymer dose to primary treatment estimated at 0.5 mg/L.

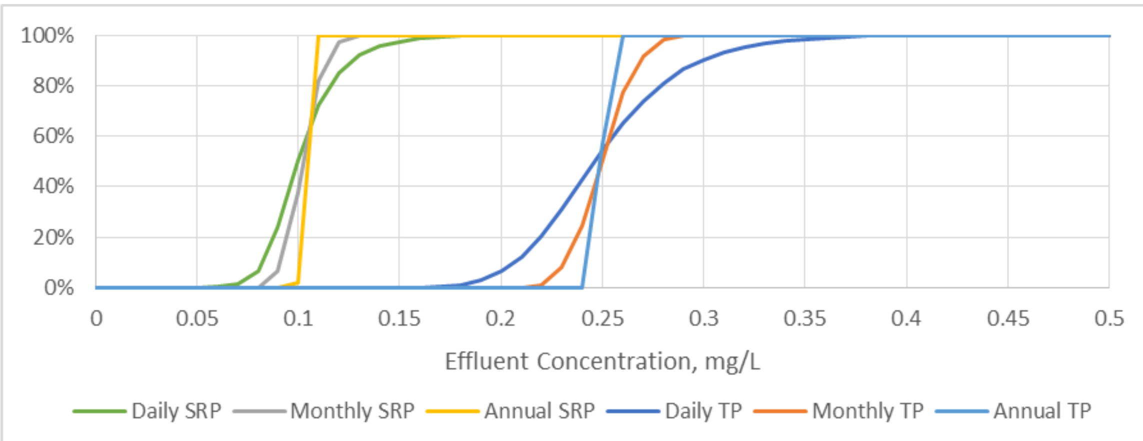

Figure 7
Model Simulations Results using Monte Carlo Analysis for Option 5

Projected Performance in *Cladophora* Growth Window

Table 4 summarizes the model projections during the months of April to August only. This time period is of interest to PRAP Study stakeholders as it is the timeframe in which *Cladophora* algal growth occurs in Lake Ontario. Documentation of the Cladophora growth window will be undertaken in a subsequent TM (TM 5 – *Cladophora* Growth Window). The results from the Cladophora growth window are generally consistent with the overall annual projections.

Table 4
Model Projections for Achievable Performance of Optimization Options at 100 percent Capacity Utilization During Cladophora Growth Season (April to August)

	Monthly Average (mg/L)	
Condition	**TP**	**SRP**
Results from TM1:		
Un-optimized plant	0.72	0.42
Optimized Plant:		
Option 1: Dual Point Ferrous Addition	0.45	0.15
Option 2: Dual Point Ferrous Addition + Polymer to Secondary Clarifiers	0.35	0.15

Table 4
Model Projections for Achievable Performance of Optimization Options at 100 percent Capacity Utilization During Cladophora Growth Season (April to August)

	Monthly Average (mg/L)	
Condition	**TP**	**SRP**
Option 3: Dual Point Ferric Addition	0.45	0.15
Option 4: Dual Point Ferric Addition + Polymer to Secondary Clarifiers	0.35	0.15
Option 5: Dual Point Ferric Addition with CEPT + Polymer to Secondary Clarifiers	0.29	0.13

Note: Performance of plant is assessed at the 99.9 percent confidence level

Summary and Conclusions

A dynamic model using Monte Carlo analysis was used to assess TP removal performance of the Duffin Creek WPCP at the 99.9 percent confidence level for five secondary treatment optimization options. These options account for the potential to switch from dual point ferrous chloride to dual point ferric chloride dosing, the ability to dose polymer to the secondary clarifiers, and the potential to dose polymers to the primary clarifiers.

The best performance the plant could achieve at a design annual average flow of 630 ML/d is predicted to be a secondary effluent TP concentration of 0.30 mg/L on an average monthly basis and 0.26 mg/L on an average annual basis. This level of performance was predicted for Option 5, which includes chemically enhanced primary treatment (CEPT) using ferric salt and polymer combined with ferric salt and polymer dosing to the secondary clarifiers. The performance of dual point ferric salt and polymer dosing to the secondary clarifiers, which was recommended as part of the Stage 3 Expansion, is predicted to achieve comparable performance: TP of 0.35 mg/L on an average monthly basis and 0.31 mg/L on an average annual basis.

The biggest difference in performance between each of Options 1 to 5 was the reduction in effluent particulate phosphorus achieved through dosing polymer to secondary treatment and the lower iron dosing requirements for ferric as compared to ferrous.

In each option, it was assumed that a 50^{th} percentile effluent SRP of 0.1 mg/L could be met. This has been achievable at other facilities using iron salts (including the nearby Skyway WWTP) but it has not been conclusively demonstrated at the Duffin Creek WPCP. In-plant testing is recommended to evaluate the feasibility of achieving ≤ 0.1mg P/L effluent SRP and (i) to determine whether the low secondary system SRP concentration causes activated sludge process upsets due to P deficiency, (ii) to confirm that the additional chemical sludge production does not have negative impacts on biosolids handling, and (iii) to determine whether iron salt dose point initial mixing conditions are adequate to promote efficient chemical phosphorus removal.

Summary of Recommendations for Future Field Study

The modelling assumptions and results described in this TM will be verified with a year-long, in-plant field study. Specifically, the field study will be undertaken to:

- Determine the lowest effluent total phosphorus (TP) concentration that can be reliably achieved at the plant with optimized secondary treatment (considering both soluble reactive phosphorus (SRP) removal and particulate phosphorus removal),

- Determine the plant's capability to reliably achieve an effluent SRP concentration of 0.1 mg/L or 0.05 mg/L on a monthly and annual average basis,
- Determine the primary effluent SRP and TP concentrations necessary to avoid adversely impacting the secondary treatment process,
- Characterize the performance and define the capacity of the primary and secondary clarifiers for total suspended solids (TSS) and particulate phosphorus removal,
- Establish primary and secondary dosing rates and locations for ferric chloride and polymer to reliably achieve the lowest effluent TP and SRP concentrations,
- Identify impacts of increased chemical dosing, if any, on the biological activated sludge process and solids handling processes (e.g. dewatering and incineration), and
- Determine plant performance (e.g. effluent water quality) under a variety of operational stresses to assess performance risk (e.g. chemical dosing pumps offline).

References

Lee, S.E., Koopman, B., Bode, H., Jenkins, D. (1983) Evaluation of Alternative Sludge Settleability Indices. Water Research. 17(10): 1421-1426.

US EPA (2013) "Report on the Performance of Secondary Treatment Technology" United States Environmental Protection Agency Office of Water. EPA-821-R-13-001.

WEF (2010) Design of Municipal Wastewater Treatment Plants: WEF Manual of Practice No. 8 ASCE Manuals and Reports on Engineering Practice No. 76, Fifth Edition. Water Environment Federation and the American Society of Civil Engineers/ Environmental and Water Resources Institute. Alexandria, VA.

WERF (2011) Nutrient Management Volume II: Removal Technology Performance & Reliability. Water Environment Research Foundation. NUTR1R06k. Alexandria, VA.

Attachment A

Comment Review Log

DELIVERABLE REVIEW LOG

Project:	**Duffin Creek WPCP Phosphorus Reduction Action Plan Study**			Agree - will make suggested changes	**1**
Deliverable:	**TM2 – Enhanced TP Removal through Secondary Treatment Optimization**	Requires response and/or action before acceptance	**1 (H)**	Agree - will provide alternate solution	**2**
Deliverable(s) Date:	**9/9/2016 (Workshop 1 Presentation), 4/1/2017 (Draft TM), 13/1/2017 (Workshop 2 Summary)**	Requires response during next phase	**2 (M)**	Disagree OR no action required	**3**
Log Date:	**8-Sep-17**	Editorial comment or question - does not require change	**3 (L)**	Additional information required	**4**

Reviewer to fill in these columns								**Consultant Response**			**Reviewer's Acceptance/Rejection**	
Comment No.	Deliverable	Page No.	Section	Drg/Fig/ Table No.	Reviewer Name	Review Comment	Comment Type Code (1 to 3)	Responder Name	Response Comment	Response Type Code (1 to 4)	Reviewer originating the comment enters either: **Accept** or **Reject** (provide reason for rejection).	Open/Closed
Comments												
1	Workshop 1 Presentation	Slide 31			M.T. Auer	Under benchmarking, with reference to “determination of limit of technology SRP removal for secondary treatment processes considering impacts to biological processes”, it will be necessary to clearly elucidate tradeoffs in dosing locations for optimizing biological processes vis-à-vis those for SRP removal.	1	CH2M	Text has been added to TM 2 in the section "Benchmarking Achievable TP Removal in Secondary Treatment" discussing secondary vs. tertiary chemical application points.	1	Accept	Closed
2	Workshop 1 Presentation	Slides 26, 27, 28, 29 30			M.T. Auer	Consider dosing iron salts downstream of bioreactor to avoid potential nutrient deficient condition.	1	CH2M	An investigation of the impacts of dosing iron upstream or downstream of the bioreactors will be undertaken during the field study, wherein the iron will be dosed to either the first pass of the aeration tanks or the mixed liquor channel upstream of the secondary clarifiers. In either case, however, the iron is recycled in the secondary process through the RAS. Iron dosing locations that are downstream of the secondary process (i.e. downstream of the secondary clarifiers) is considered a component of tertiary treatment and is therefore investigated further in TM 4.	1	Accept	Closed
3	Workshop 1 Presentation	N/A			M.T. Auer	The Town requests that stress testing be included during or upon conclusion of process optimization.	3	CH2M	Field testing to validate model assumptions is ongoing. Clarifier stress testing will be completed in a later phase of field testing.	3	Accept	Closed
4	Workshop 2 Summary	General			M.T. Auer	The Summary provided for Workshop 2 appropriately describes actions that will be taken by CH2M to address points raised by Town representatives with respect to TM2A.	3	CH2M	N/A	3	Accept	Closed
5	Workshop 2 Summary	General			M.T. Auer	Dr. Auer would like to compliment CH2M for their willingness to work with the Town in better understanding the plant modeling process, particularly with respect to interpretation of TM2 Figure 1. Please consider, however, the following design example with respect to DOP. ------------------------- Effluent TP Standard: 0.35 mgP/L 2° effluent SRP: 0.1 mg/L (to maintain healthy MLSS) 2° effluent DOP: 0.1 mg/L (pass-through pollutant) Required effluent PP: 0.15 mg/L (to meet TP standard), PP = TP – SRP – DOP 2° effluent PP/TSS: 0.025 (2.5%, TM1) Required effluent TSS: 6 mgTSS/L Inclusion of DOP in the calculation, a TP component that is not absorbed in chemical treatment or removed in the secondary clarifier, the effluent TSS requirement falls from 10 mg/L (in the absence of DOP) to 6 mgTSS/L.	3	CH2M	We acknowledge the example calculation as presented .	3	Accept	Closed
6	Workshop 2 Summary		3.5		M.T. Auer	Dr. Auer’s paper on Actiflo has been forwarded to the consultants as requested in the Workshop Summary.	3	CH2M	Confirmed.	3	Accept	Closed
7	Workshop 2 Summary		4.4		M.T. Auer	The Town’s proposal for sampling requirements and protocols, as requested in the Workshop 2 Summary has been forwarded to the consultants.	3	CH2M	Confirmed.	3	Accept	Closed
8	Workshop 2 Summary		5.4		M.T. Auer	CH2M to note in TM 2A that Option 5 provides the lowest achievable effluent TP for secondary treatment optimization based on the desktop study.	1	CH2M	Text has been added to TM 2 section "Summary and Conclusions".	1	Accept	Closed
9	Draft TM 2A	1	Objectives		Al Saikkonen (transcribed by M.T. Auer)	Will the WWTP model be re-run, accessing results available from the field study to add credibility to model projections? Clarify what will be carried forward for ranking Options, • Original model • Field study results • Re-run model	3	CH2M	Modelling of secondary treatment optimization will be revisited following the field study. The updated model methodology is to be finalized. In the assessment of secondary treatment optimization options, both the results of the field study as well as the updated model projections will be considered.	3	Accept	Closed
10	Draft TM 2A	4	Benchmarking Achievable TP Removal in Secondary Treatment		Al Saikkonen (transcribed by M.T. Auer)	Note that the Town has requested the data for P/TSS ratios and the TSS data themselves.	3	CH2M	The information was provided per Ajax's request.	1	Accept	Closed
11	Draft TM 2A	5	Optimization Options		Al Saikkonen (transcribed by M.T. Auer)	It is unclear if this dosing rate will be used across all 5 options. Please clarify.	1	CH2M	The projected iron dosing rate of 15 mgFe/L is consistent across all secondary treatment optimization options using ferrous chloride. The same level of performance is expected to be achieved with a lower iron dosing rate using ferric chloride (10.5 mgFe/L).	3	Accept	Closed