# METRO WWTP OPTIMIZATION ANALYSIS OF TOTAL PHOSPHORUS TREATMENT

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## EXECUTIVE SUMMARY

## INTRODUCTION AND BACKGROUND

The 4th Stipulation Amended Consent Judgment (ACJ) was ratified in November 2009 stipulating modified requirements for Onondaga County's combined sewer works to meet Clean Water Act requirements. One key requirement of the ACJ is that an Optimization Analysis of the Metropolitan Syracuse Wastewater Treatment Plant's (Metro WWTP's) current phosphorus treatment processes be completed.

Metro provides wastewater treatment for approximately 270,000 people and many industrial and commercial customers in the City of Syracuse and surrounding areas of Onondaga County. The Metro WWTP has a design capacity of 84.2 million gallons per day (mgd), and can provide full secondary and tertiary treatment for up to 126.3 mgd. Overall, WWTP influent undergoes preliminary treatment (screening and grit removal) followed by primary, secondary and tertiary treatment, as well as disinfection. Sludge thickening, digestion and dewatering also are performed at Metro. Phosphorus treatment and removal occurs in the primary clarifiers, secondary clarifiers and the tertiary high rate flocculated settling (HRFS) process. WWTP processes that can be impacted by phosphorus treatment are disinfection and sludge handling.

WEP constructed the $128-million state-of-the-art tertiary treatment facilities (completed in 2005) to meet very low effluent limits for ammonia and phosphorus as mandated by the ACJ. Ammonia removal is achieved using a biologically aerated filtration system (BAF). Phosphorus removal is provided using four parallel HRFS treatment trains. Ferric chloride, polymer and microsand are added within the HRFS process to promote formation and removal of phosphorus particles. The design of these process improvements was to a permit limit of 0.12 mg/L; however, the SPDES permit total phosphorus limit was reduced to 0.10 mg/L, effective November 16, 2010. Implementing tertiary treatment has resulted in a dramatic improvement in Onondaga Lake water quality. The phosphorus guidance level for the lake has been met three of the past four years (including summer 2011). However, the ACJ requires Metro to achieve an effluent total phosphorus limit of 0.02 mg/L, or other limit as established by the New York State Department of Environmental Conservation (NYSDEC).

The Onondaga County Department of Water Environment Protection (WEP) retained CRA Infrastructure & Engineering, Inc. (CRA) in October 2010 to complete the Optimization Analysis of phosphorus treatment. This effort involved evaluating actions at the Metro WWTP that would promote improving and optimizing phosphorus removal in terms of effluent concentration, operations and cost while staying within the operating parameters of the existing facility. These actions could include modifications to the existing processes, hydraulics, mixing, operations procedures and maintenance practices. This report summarizes the holistic evaluation and integration of the various investigations into the development of a recommended Metro WWTP Phosphorus Treatment Optimization Plan.

## DEFINITION OF OPTIMIZATION

Metro WWTP optimization is one facet of ACJ compliance and is complementary to other efforts performed in parallel by WEP. Because these efforts are inter-related, key definitions were developed to establish a consistent terminology and context. For these efforts, optimization is defined as determining the recommended modifications that promote conditions leading to improved treatment performance and reliability, while maintaining the ability of the WWTP to reliably meet all other treatment and performance requirements. The intent of optimization also is to identify opportunities for reducing effluent variability. Optimizing Metro may ultimately change the Limit of Technology (LOT) of the facility. The magnitude of this change cannot be determined until modifications are implemented and sufficient time provided to evaluate actual treatment performance.

## METRO WWTP OPTIMIZATION ISSUES AND EVALUATIONS

A two-day Process and Operations workshop was initiated to establish a detailed understanding of current phosphorus treatment at the Metro WWTP, as well as significant process, hydraulic, mixing operations and maintenance issues. Results from this workshop were used as guidance in identifying and evaluating modifications for optimizing current phosphorus treatment. A key workshop discussion point was that the Engineer’s Report and manufacturer state that the installed HRFS system was designed to meet an effluent total phosphorus limit of 0.12 mg/L, which is higher than the current SPDES permit limit of 0.10 mg/L.

Although recent operating data show that the Metro WWTP has been meeting the permit limit, effluent concentrations vary from day to day, sometimes significantly. This variability is to be expected for WWTPs that treat nutrients to very low phosphorus levels, and is especially true for facilities subject to significant wet weather variability, like Metro. The NYSDEC’s use of an annual rolling average is appropriate to facilitate attenuation of some process variability. However, the stated design limit, combined with inherent operational variability, raises concern for the ability of Metro to reliably meet a 0.10 mg/L permit limit or lower without optimization and addressing identified operating and maintenance concerns. Additionally, modifications made to address one issue often have unintended consequences. Based on the results of the workshop, several significant issues were identified for investigation as part of the

Optimization Analysis. These issues are detailed in Section 3.0 with investigations summarized in Sections 4.0 through 6.0.

## EVALUATION FINDINGS AND ALTERNATIVES DEVELOPMENT

Findings from the hydraulic, mixing and process evaluations were integrated with the Metro WWTP operations and maintenance issues to develop a series of alternatives that would promote conditions for optimizing Metro WWTP phosphorus treatment while mitigating potential impacts to other plant facilities. Based on the evaluations, optimization alternatives must enable the following:

1. Maintaining a specific secondary effluent total phosphorus range to both minimize the amount of phosphorus requiring removal in the HRFS system while providing sufficient phosphorus to permit effective ammonia removal in the BAF process.

2. To the extent possible, providing balanced dosing and effective initial mixing of coagulant for tertiary phosphorus removal.

3. Balancing hydraulic loading of the HRFS system to the extent possible to permit consistent performance across the trains and prevent overloading.

4. Optimizing the solids removal process within the HRFS trains.

5. Providing greater operational flexibility to enable maintenance to occur without process shutdown and maximize the amount of wastewater receiving tertiary treatment while reducing effluent variability.

6. Addressing operations and maintenance issues due to corrosion and impact to UV disinfection.

Seven optimization alternatives were developed for evaluation that would address the range of options in the above considerations. Key variables between each alternative included coagulant type, coagulant addition location, seasonal vs. year-round coagulant addition, mixing options and HRFS flow monitoring.

## METRO WWTP PHOSPHORUS TREATMENT OPTIMIZATION PLAN

Because of the complex inter-relationships described in the previous sections, a matrix-type analysis was performed for selecting the most appropriate optimization alternative. In addition to improving phosphorus treatment, the evaluation considered impact to other WWTP equipment and processes, as well as efforts to facilitate operations and maintenance. WEP was consulted when identifying evaluation parameters for the matrix, as well as ranking the importance of each parameter.

Based on the evaluation of alternatives presented in Section 7.0, Alternative 7 was recommended as the most appropriate for WEP to implement for optimizing phosphorus treatment at the Metro WWTP. The recommended alternative focuses on use of polyaluminum chloride (PAC) during the disinfection season, and ferric chloride during the rest of the year. Coagulant would be fed to the HRFS influent box. Baffles would be constructed within each influent box to promote thorough mixing. Coagulant feed would be flow paced based on flow meters located in the HRFS effluent launders. The existing ferric chloride feed system (pumps, piping and valves) would be replaced with a focus on reducing maintenance to the extent possible. In addition, a new PAC feed system would be provided. Other key modifications were recommended to enable maintenance of the HRFS and BAF system without complete shutdown, balancing flow and coagulant dosing to the HRFS system, improved HRFS mixing and addressing facilities impacted by corrosion. The estimated preliminary capital cost to construct these modifications is approximately $5,900,000 (2014 dollars), including a contingency allowance for construction as well as engineering, legal and administration fees.

A key benefit of the recommended alternative would be to reduce the impact to the lake from variability in effluent phosphorus that results from maintenance of the BAF, HRFS or connecting channels, and thereby maximizing the wastewater receiving tertiary treatment. However, a temporary shutdown of tertiary treatment would be essential to allow construction crews to safely and properly install the isolation wall for the BAF and HRFS units, inspect and rehabilitate the channel liner and install an access platform for the new isolation gates. Construction of the wall and liner replacement is made more complicated because confined space entry would be required. Additionally, time would be required to restart the BAF to effective treatment levels after an extended shutdown. Given these construction necessities, it is recommended that WEP pursue a temporary permit limit variance from the NYSDEC for ammonia and phosphorus that reflects the construction activity. This variance would be applied for during the design phase and prepared in accordance with Paragraph 29 of the ACJ. A construction sequence should be prepared that minimizes potential impacts to Onondaga Lake during construction. Example actions are described in Section 8.1. Efforts to minimize impact to the lake must allow for high-quality construction, meet plant operational needs, are in accordance with applicable Standards and follow standard engineering and construction practices.

Performing the Optimization Analysis has resulted in a significantly improved understanding of Metro WWTP phosphorus treatment processes and how inherent variability affects effluent concentrations. Additional issues and potential refinements were identified near the end of the evaluation that could not be studied within the framework of the ACJ mandated schedule for this project. While using PAC was shown to have equal performance to ferric chloride with respect to phosphorus removal, no testing was conducted to determine if PAC treated effluent would have similar bioavailability and settling characteristics as ferric chloride. Therefore, a study prior to implementation would be necessary to verify that PAC treated effluent would have the same particulate bioavailability as ferric chloride treated effluent. In addition to the bioavailability/settling analysis, studies that could provide beneficial information prior to and during the design phase include full-scale testing to evaluate a smaller effective size microsand; computational fluid dynamics (CFD) modeling to refine hydraulic improvements; and physical modeling or full-scale testing to refine HRFS mixing improvements. These pre-implementation studies are believed to be necessary before proceeding with final design.

## IMPLICATIONS OF LIMIT OF TECHNOLOGY ANALYSIS AND EFFECTIVE PHOSPHORUS

Two independent but inter-related efforts have been identified to potentially impact the Optimization Analysis for the existing Metro WWTP: results of the LOT Analysis of the existing Metro WWTP, and the concept of "effective phosphorus". The implications presented herein are based on the most up-to-date information. The implications are subject to change depending upon the final outcome of the TMDL.

The Metro Optimization Analysis for Phosphorus Treatment is closely linked to the LOT evaluation. The LOT evaluation involves using probability distribution analysis to establish Technology Performance Statistics unique to the Metro WWTP. A key advantage of this approach, which was accepted by the NYSDEC and ASLF, is that actual treatment performance data are used to objectively and quantitatively evaluate the phosphorus treatment capability at Metro and other WWTPs using high rate flocculated settling. It is important to note that the LOT is technology specific and plant specific – one treatment process will have a different LOT than another.

Initial results from the LOT Analysis (in progress), which is part of the separate Work Plan implementation efforts show the Metro WWTP is currently approaching the lower limit of phosphorus removal capability for its existing treatment processes. The statistical assessment for this analysis indicate that, although recent data show Metro is meeting the permit limit of 0.10 mg/L, the current reliable LOT appears to be closer to 0.12 mg/L due to effluent variability. It is anticipated that implementation of optimization improvements would reduce variability such that the plant could more reliably meet a permit limit of 0.10 mg/L. Because the current Metro processes are approaching their physical and practical limit for removing phosphorus, and due to the process variability inherent when targeting very low effluent concentrations, an extended period of data collection (at least three years) and associated engineering analysis would be necessary after optimization improvements are implemented to determine if a permit limit below 0.10 mg/L could be reliably met.

Scientific studies of the lake have demonstrated that only a portion of the total phosphorus, called "effective phosphorus", actually supports algae growth and in-lake primary production, and is thus the fraction that impacts the condition of the lake. Evaluations associated with determining the level of effective phosphorus from the Metro WWTP and key Onondaga Lake tributaries were required separately under the ACJ. Results from these evaluations showed that Metro WWTP effluent particles are almost entirely composed of unrecovered iron-rich media from the HRFS treatment process. Particulate phosphorus comprises about two-thirds of the residual total phosphorus load discharged from Metro Outfall 001; bioassay results show that particulate phosphorus from Metro Outfall 001 is essentially non-bioavailable. Therefore, it appears that the particulate phosphorus fraction of the Metro Outfall 001 load is not an "effective" load to Onondaga Lake and is not an "effective" load to the pelagic waters.

## REGULATORY AND PERMITTING CONSIDERATIONS

Onondaga Lake water quality has improved dramatically since Metro's HRFS process was constructed, primarily due to the significant reduction in total phosphorus and near elimination of particulate bioavailable phosphorus from Outfall 001 discharges. Based on conversations with the NYSDEC, the Optimization Analysis and complementary Work Plan efforts are considered integral components to the development of the TMDL and Metro's load allocation and resulting permit limit. Effluent variability must be taken into account when evaluating the TMDL allocations, and whether or not a lower effluent SPDES limit can be reliably achieved for the Metro WWTP. Maintaining a factor of safety between the targeted median effluent concentration and the permit limit is critical to allow for this variability, even at the most exemplary WWTPs.

The existing total phosphorus SPDES limit (0.10 mg total phosphorus [TP]/L) is almost 20 percent below the design rating of the HRFS system warranted by the manufacturer. Based on operating data from the past two years, Metro currently appears to be outperforming its design rating to successfully meet the permit limit. However, initial statistical assessment indicates that the current reliable LOT seems to be close to the design rating of 0.12 mg TP/L. Available results from the LOT Analysis show the Metro WWTP is currently approaching the lower limit of phosphorus removal capability for its existing treatment processes. For nutrient removal processes, it has been demonstrated that as the targeted concentration decreases, the effluent variability increases. Note that treating to permit limits of 0.12 mg TP/L and 0.10 mg TP/L represents phosphorus removals (average Metro influent of 2.45 mg TP/L) of 95.1 percent and 95.9 percent, respectively. A further permit reduction to, say 0.09 mg TP/L, would result in a 96.3 percent removal – an increase of 0.4 percent.

It is believed that the Metro WWTP is the largest HRFS facility in North America being required to achieve such very low effluent limits for phosphorus. The recommended optimization alternative is expected to more reliably meet a permit limit of 0.10 mg/L, but effluent variability cannot be eliminated even using an annual rolling average compliance basis. While improvements will likely result in reduction of total effluent phosphorus, preliminary determinations at this time show that reliably meeting a permit limit below 0.10 mg TP/L is likely unachievable.

Since the current Metro processes are approaching their physical and practical limit for removing phosphorus, and due to inherent process variability when treating to very low concentrations, an extended period of data collection (at least three years) would be necessary after optimization improvements are implemented to verify that a reduced permit limit could be reliably met. Therefore, it would be advisable to defer any additional reductions below the current SPDES phosphorus limit of 0.10 mg/L until a suitable and defendable scientific database can be developed to support such a decision - and that it is established that such a reduction will benefit Onondaga Lake. Water quality modeling is being performed to evaluate the benefit of phosphorus reduction - and particularly effective (bioavailable) phosphorus reduction - on lake water quality. It is noteworthy that optimizing Metro for phosphorus removal would primarily involve reductions in particulate phosphorus, which is non-bioavailable. Therefore, additional particulate phosphorus removal from Metro effluent would not be expected to significantly benefit the lake in terms of dissolved oxygen, clarity, chlorophyll production and other metrics. Use of an approach to predict what Metro can achieve risks significant consequences to the County given anti backsliding regulations. For example, without actual data from an optimized facility the ability to handle additional flow at Metro could be limited, which would impact the ability for growth in a struggling economy. An extended period of non-compliance, even with exemplary operation could require additional treatment at a significant cost.

## GLOSSARY

| | |
|---|---|
| ACJ | Amended Consent Judgment |
| Al | aluminum |
| ASLF | Atlantic States Legal Foundation |
| BAF | biological aerated filtration |
| BOD | biochemical oxygen demand |
| CFD | computational fluid dynamics |
| CFM | computational fluid mixing |
| County | Onondaga County |
| CRA | CRA Infrastructure & Engineering, Inc. |
| CSTR | continuously stirred tank reactor |
| DO | dissolved oxygen |
| EBPR | enhanced biological phosphorus removal |
| ELAP | Environmental Laboratory Approval Program |
| Fe | total iron |
| Fe-diss. | dissolved iron |
| ft. | feet |
| G | velocity gradient |
| GBT | gravity belt thickener |
| g/L | grams per liter |
| gpd | gallons per day |
| gpm | gallons per minute |
| HDPE | high-density polyethylene |
| hp | horsepower |
| HRFS | high rate flocculated settling |
| HRT | hydraulic retention time |
| kWh | kilo watt-hour |
| lbs. | pounds |
| lbs./day | pound per day |
| LOT | Limit of Technology |
| Metro WWTP | Metropolitan Syracuse Wastewater Treatment Plant |
| MG | million gallons |
| mgd | million gallons per day |
| mg/L | milligrams per liter |
| MLSS | mixed liquor suspended solids |

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|---|---|
| mmol | millimols |
| MS/MSD | matrix spike/matrix spike duplicate |
| | |
| NYCRR | New York State Code of Rules and Regulations |
| NYSDEC | New York State Department of Environmental Conservation |
| | |
| O&M | operations and maintenance |
| OLWQM/TRWQM | Onondaga Lake Water Quality Model and Three-Rivers Water Quality Model |
| | |
| PAC | polyaluminum chloride |
| PAOs | phosphorus accumulating organisms |
| | |
| QA/QC | quality assurance/quality control |
| | |
| RAS | return activate sludge |
| rpm | revolutions per minute |
| | |
| SCADA | Supervisory Control and Data Acquisition System |
| SEPS | Secondary Effluent Pump Station |
| SPDES | State Pollutant Discharge Elimination System |
| SRP | soluble reactive phosphorus |
| | |
| TIP | total inorganic phosphorus |
| TIP-diss, | dissolved inorganic phosphorus |
| TMDL | Total Maximum Daily Load |
| TOP | total organic phosphorus |
| TOP-diss. | dissolved inorganic phosphorus |
| TP | total phosphorus |
| TP-diss. | dissolved phosphorus |
| TPP | total particulate phosphorus |
| TPS | Technology Performance Statistic |
| TPS-14d | Ideal Technology Performance Statistic |
| TPS-50% | Median Technology Performance Statistic |
| TPS-95% | Reliable Technology Performance Statistic |
| TSS | total suspended solids |
| | |
| USEPA | United States Environmental Protection Agency |
| UV | ultraviolet light |
| | |
| VFD | variable frequency drive |
| | |
| WEP | Onondaga County Department of Water Environment Protection |
| WERF | Water Environment Research Foundation |
| WWTP | wastewater treatment plant |

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# 1.0 INTRODUCTION

## 1.1 AUTHORIZATION

Originally issued in January 1998, the 4th Stipulation Amended Consent Judgment (ACJ) between the New York State Department of Environmental Conservation (NYSDEC), the Atlantic States Legal Foundation (ASLF), and Onondaga County (County) was ratified in November 2009 stipulating modified requirements for the County's combined sewer works to meet Clean Water Act requirements. A key goal of the ACJ involves having the County's Metropolitan Syracuse Wastewater Treatment Plant (Metro WWTP) meet the Stage III effluent phosphorus limit by December 31, 2015. Based on the ACJ, this will be achieved either by meeting an effluent total phosphorus limit of 0.02 milligrams per liter (mg/L) or other limit established by the NYSDEC, diverting Metro WWTP discharge to the Seneca River, or implementing another engineering solution that meets Onondaga Lake water quality standards. Critical to note is that the effluent phosphorus limit, and resulting County actions necessary to meet this limit, rely upon development of the revised Total Maximum Daily Load (TMDL) by the NYSDEC.

Another key requirement of the 4th Stipulation ACJ is that an optimization analysis of the Metro WWTP's current phosphorus treatment processes shall be completed. The results of the analysis must be submitted to the NYSDEC, United States Environmental Protection Agency (USEPA) and ASLF for review no later than August 31, 2011, followed by approval of a finalized report by the NYSDEC. In addition, the Metro WWTP effluent total phosphorus limit was reduced from 0.12 mg/L to 0.10 mg/L, effective November 10, 2010.

To develop a final plan for complying with the ACJ, the County initiated two independent but inter-related evaluations for the Metro WWTP. One evaluation – the focus of this report – involves evaluating actions at the Metro WWTP that would promote optimizing phosphorus removal in terms of effluent concentration, operations and cost while staying within the operating limits of the existing facility. These actions could include modifications to the existing processes, hydraulics, operations procedures and maintenance schedules related to optimizing the current facility.

The parallel effort involves development and implementation of a Work Plan (CRA, 2010) to evaluate the limit of technology (LOT) of the existing Metro WWTP, supplementary treatment technologies potentially capable of achieving a 0.02 mg/L total phosphorus effluent limit, diversion of Metro WWTP effluent to the Seneca River, as well as other evaluations. The Work Plan studies are scheduled for completion by December 31, 2011 in accordance with the ACJ.

The Onondaga County Department of Water Environment Protection (WEP) retained CRA Infrastructure & Engineering, Inc. (CRA) to complete the optimization analysis of phosphorus treatment in October 2010. This report summarizes the evaluations performed and resulting recommendations for optimizing Metro WWTP phosphorus in support of ACJ compliance. Implementation of the recommended actions are intended to provide Metro operations staff with the tools for improving phosphorus treatment performance and reliability while reducing effluent variability.

## 1.2 KEY REPORT DEFINITIONS

Metro WWTP optimization is one facet of ACJ compliance and is complementary to other efforts being performed in parallel by WEP, particularly analysis of the facility's LOT and feasibility evaluation of additional phosphorus treatment technologies. Because these evaluations are inter-related, several key definitions were developed to establish a consistent terminology and context from which these evaluations are completed. Definitions were developed for *Limit of Technology, Reliability, Variability and Optimization*. These definitions are used within this report, as well as other ACJ-mandated evaluations associated with phosphorus treatment.

### 1.2.1 LIMIT OF TECHNOLOGY (LOT)

Until recently, the LOT has had different meanings applied depending upon the perspective of the stakeholder (e.g., designer, operator, regulator, environmental advocates, etc.). The definition of LOT can vary based on the parameters considered such as type of technology, concentrations, method and limit of measurement, controls, and cost. The Water Environment Research Foundation (WERF) has been performing extensive research over the past five years on treating nutrients from municipal WWTPs to very low levels. Part of this research has included development of a universal definition for LOT (Neethling, et al., 2009). Considering that this research has been specific to nutrient removal, it was recommended, and subsequently accepted to use the methodology established by WERF for objectively and quantitatively defining the LOT in the ACJ-mandated Work Plan for analyzing phosphorus removal technologies (CRA, 2010).

The LOT of a treatment technology or process is defined in this report using percentile statistics that are referred to as Technology Performance Statistics or TPSs (WERF, 2011). Three TPS levels are used to represent ideal, median, and reliably achievable performance. The approach can be applied to determine the ideal performance, the reliable performance, or other descriptor that allows for a rational interpretation of the results. The term TPS is used to describe the performance measured from a specific technology. Because the performance of a process can be manipulated by the operator and is affected by many factors, the TPS must be defined in terms of the specific conditions under which the data is collected. Specific conditions that influence the TPS values include treatment goal, evaluation period, data source, treatment capacity, scale (pilot, bench or full), solids handling, influent characteristics and other conditions. Hence, it is critical to note that LOT is specific to a particular WWTP and not readily transferable to other facilities.

The three TPS values used to characterize LOT for a particular treatment process are described as follows:

> **Ideal Technology Performance Statistic (TPS-14d):** This represents an unbiased value of the ideal performance of the technology when it is minimally influenced by all the factors that cause statistical variability in real plants. These conditions are ones that likely replicate those ideal conditions that might be obtained under controlled laboratory conditions with defined, treatable influents. For full-scale performance, the ideal TPS represents the lowest concentrations (idealistic performance) observed. WERF has defined TPS-14d as the performance that remains sustainable for a two-week period in one year or the 3.84th percentile in a log-normal probability distribution of treatment performance. An example of a probability distribution plot is shown on Figure 1-1. It is noteworthy that TPS-14d is exceeded 50 out of 52 weeks per year.
>
> **Median Technology Performance Statistic (TPS-50%):** The TPS represents a measure of the concentration that was achieved on a statistical annual average basis. The median value was suggested because it is impacted less by extreme values resulting from upset events. TPS-50% also is used to develop ratios from the ideal and reliable TPS values in order to indicate how much performance deviates from median performance. TPS-50% is statistically exceeded 26 out of 52 weeks per year.
>
> **Reliable Technology Performance Statistic (TPS-95%):** The reliable TPS does not represent a single percentile value for an averaging period. Rather, it is a selected percentile value depending upon the technology, the averaging period used in the permit and risk tolerance. For the purpose of this evaluation, the 95th percentile statistic has been selected as the basis for defining the reliability of plant

performance. This represents a risk of exceedance three times over a 60-month period.

The above statistical methods can be used to evaluate data from various treatment plants for assessing process reliability under varying conditions and the relationship between reliability and permit limits.

### 1.2.2 RELIABILITY

Reliability is essentially the probability that a WWTP will meet a specified permit limit. The example shown on Figure 1-2 presents how reliability was determined using a probability graph at the Iowa Hill WWTP in Breckenridge, Colorado. This example shows that the Iowa Hill plant has a 95.7 percent probability of meeting its 0.05 mg/L total phosphorus permit limit (annual rolling average). In other words, at an effluent total phosphorus concentration of 0.05 mg/L, the Iowa Hill facility has a reliability of 95.7 percent. However, extrapolating the best-fit line on this figure shows the estimated 100 percent reliability for phosphorus treatment at this facility to be approximately 0.25 mg/L.

The use of TPS values are extremely valuable in evaluating process performance and variability, but does not establish the reliability of a treatment system. Each Technology Performance Statistic represents a statistical risk, that of an exceedance. For many treatment facilities, a small risk of an exceedance is often considered acceptable during design to permit facilities to be completed within a reasonable budget. **For the Metro WWTP, the ACJ imposes fines for any permit exceedance of effluent total phosphorus. Therefore, 100 percent compliance, and hence 100 percent reliability, is mandated by the ACJ.** It is noteworthy that the NYSDEC's approach to levying fines is based on a number of factors, including past facility performance and other mitigating factors. However, since ASLF is a party to the ACJ, they have rights with the federal court to request that the penalty be imposed. Regardless, WEP takes the prudent approach of working to avoid non-compliance.

### 1.2.3 VARIABILITY

Treatment plants operate under variable conditions yet effluent water quality must continue to comply with permit requirements. Beyond daily diurnal variation, plants experience seasonal patterns. Shorter duration fluctuations are more difficult to manage and can include significant flow peaks from wet weather conditions, equipment and process maintenance, construction activities, equipment failure, chemical feed line plugging, etc. Load variations are difficult to predict and may not coincide with flow variations.

Variability can be statistically evaluated using the TPS values described in Section 1.2.1 by calculating the ratios of ideal to median performance and reliable to median performance. The ratio of TPS-14d/TPS-50% represents the difference between the average annual performance achievable compared to the ideal TPS-14d; as this value decreases, variability increases. The ratio of TPS-95%/TPS-50% represents the ability of a technology to meet reliable levels compared to annual values; as this value increases so does variability.

A major finding from WERF's nutrient research is that statistical variability is a characteristic of all plants treating to very low effluent nutrient levels (WERF, 2011). Therefore, addressing variability needs to be a key consideration in optimizing phosphorus treatment performance.

### 1.2.4 OPTIMIZATION

For this project, optimization is defined as determining the recommended modifications that promote conditions leading to improved treatment performance and reliability, while maintaining the ability of the WWTP to reliably meet all other treatment and performance requirements. The intent of optimization also is to identify opportunities for reducing effluent variability and to provide recommendations for realizing these potential opportunities. Optimizing the Metro WWTP may ultimately change the LOT of the facility. The magnitude of change to the TPS values cannot be determined until modifications are implemented and sufficient time provided to evaluate actual treatment performance.

## 1.3 PROJECT TASKS

Based on the ACJ requirements, WEP's Request for Proposal and understanding of the key phosphorus treatment processes at Metro, a holistic approach was developed to address the complexity and inter-relationship of optimization issues. In implementing this approach, the following tasks were completed:

1. Initiating a Process and Operations Workshop to determine the key optimization issues and their inter-relationship.

2. Analysis of hydraulic issues and modifications using computational fluid dynamics (CFD) modeling and other methods.
3. Evaluation of mixing processes.
4. Completion of a detailed process analysis including plant treatment performance profiling, bench-scale testing and full-scale demonstrations.
5. Identification of opportunities to facilitate operations and maintenance (O&M) of the phosphorus treatment facilities.
6. Integrating the hydraulic, process and O&M evaluations to establish a series of Metro WWTP optimization alternatives.
7. Evaluation of alternatives based on potential to improve phosphorus removal, reduce costs, minimize impact to adjacent WWTP process, and reduce O&M.
8. Preparation of a report summarizing the evaluations completed and recommending modifications to the Metro WWTP to optimize phosphorus treatment.

## 2.0 CURRENT METRO WWTP FACILITIES

The Metro WWTP provides wastewater treatment for approximately 270,000 people and many industrial and commercial customers in the City of Syracuse and surrounding areas of Onondaga County. The Metro WWTP has a design capacity of 84.2 million gallons per day (mgd), and can provide full secondary and tertiary treatment for up to 126.3 mgd. From 2007 to 2010, daily plant influent flows into the plant have averaged 60.8 mgd and have ranged from 30 to 207 mgd.

A process flow schematic and aerial map of the Metro WWTP are shown on Figures 2-1 and 2-2, respectively. Overall, WWTP influent undergoes preliminary treatment (screening and grit removal) followed by primary, secondary and tertiary treatment, and disinfection. Sludge thickening, digestion and dewatering also are performed at Metro. Phosphorus treatment and removal occurs in the primary clarifiers, secondary clarifiers and the tertiary high rate flocculated settling (HRFS) process. WWTP processes that can be impacted by phosphorus treatment are disinfection and sludge handling.

### 2.1 PHOSPHORUS REMOVAL IN PRIMARY TREATMENT

Phosphorus treatment at the Metro WWTP actually begins with the addition of ferrous chloride to key pumping stations in the tributary interceptor system. Ferrous chloride is added at the Burnet Avenue Chemical Feed Station, Liverpool Pump Station and Camillus Pump Station. The combined ferrous chloride use of the three facilities averages about 735 gallons per day (gpd). Although the primary objective of ferrous chloride addition is odor control, an ancillary benefit is removal of some phosphorus in the primary clarifiers.

Metro has eight primary clarifiers, each with a 135-ft. diameter, a 10-ft. side wall depth and a volumetric capacity of 1.07 million gallons (MG). The primary clarifiers are designed to handle a peak flow of 240 mgd. During wet weather flows, up to 126 mgd passes through to secondary and tertiary treatment, as well as seasonal disinfection followed by discharge to Onondaga Lake through Outfall 001; excess primary treated flow is conveyed to a chlorination/dechlorination tank for seasonal disinfection prior to discharge via Outfall 002.

## 2.2 PHOSPHORUS REMOVAL IN SECONDARY TREATMENT

Additional treatment of phosphorus is provided in the secondary treatment process. Metro uses activated sludge for the secondary treatment. Secondary treatment consists of eight aeration tanks and four clarifiers; two aeration tanks feed into each clarifier. The aeration tanks are 100-ft. wide, 130-ft. long and 14.2-ft. deep, with a volumetric capacity of 1.4 MG. Each secondary clarifier is 170 ft. square by 11-ft. deep, with a volumetric capacity of 1.83 MG.

Microorganisms in activated sludge require phosphorus for microbial cell synthesis and growth and then when these organisms are settled and removed as waste, some phosphorus is removed. Ferric chloride is added at a constant rate (150 gallons per day per train) to the secondary treatment process using the return activated sludge (RAS) pump discharge to further enhance removal. Therefore, ferric chloride dose within secondary treatment varies with flow.

Immediately downstream of secondary treatment is the Biologically Aerated Filter (BAF), which is designed to remove ammonia to meet an ACJ-mandated effluent concentration of level of 1.2 mg/L from June 1 to October 31 and 2.4 mg/L between November 1 and May 31 (30-day arithmetic mean). However, according to the manufacturer (Kruger/Veolia) the BAF process requires a minimum average orthophosphate concentration of 0.3 mg/L and available carbon to effectively operate without starving the BAF. Metro WWTP staff carefully control the mixed liquor suspended solids (MLSS) concentration to avoid excess carbon removal. MLSS concentrations are typically maintained between 1,100 and 1,300 mg/L with a sludge retention time of 3.0 to 3.5 days to prevent nitrification from occurring in secondary treatment.

## 2.3 PHOSPHORUS REMOVAL IN TERTIARY TREATMENT

The $128 million tertiary treatment facilities were completed in 2005 for the specific purpose of reducing ammonia and phosphorus levels, as well as providing ultraviolet light (UV) disinfection. A new Plant Operations Center and Supervisory Control and Data Acquisition (SCADA) system were also constructed as part of this project. Secondary effluent is pumped to the BAF system via the Secondary Effluent Pumping Station (SEPS). The BAF uses the BIOSTYR process developed by I. Kruger, Inc. (Kruger/Veolia) where nitrifying bacteria convert ammonia to nitrate and nitrite. The BAF process is comprised of 18 filter cells divided evenly into two trains. Each cell has a volume of about 273,000 gallons and contains polystyrene beads to serve as the filter media. Flow travels up through the filters and then into the BAF effluent channels (see Figure 2-3).

The channels downstream of the BAFs (BAF Effluent Channel, Cross Channel and HRFS Influent Channel) are used as the backwash supply to the filter cells. Metro operators have indicated backwash flow rates are limited by the need to avoid loss of the styrene media. Metro staff have indicated that a complete backwash cycle requires about two hours, including pumping out the backwash wastewater holding tanks, which equalize flow to the head of the plant. There are times, particularly during high flows, that the size of the holding tanks limits the ability to backwash filters as needed.

The BAF SCADA system typically controls which filters are online, idle and backwashed based on numerous factors, including SEPS flow, headloss, time in service and time idle. This leads to an apparent random operation of the filters where the filters in operation can become unbalanced between the two BAF trains. For example, one BAF train can have six filters operating while the other side has three. Plant staff have the ability to operate the filters manually; however, this is not preferred because BAF effectiveness can be impacted over time.

Phosphorus removal to very low effluent concentrations is provided using four HRFS treatment trains, each with a capacity of 31.5 mgd. Each train consists of an influent box, coagulation tank, injection tank, maturation tank and settling tank that contains a Lamella clarifier. The manufacturer's (Kruger/Veolia) O&M Manual states that the HRFS system is designed to achieve a total phosphorus effluent concentration of 0.12 mg/L based on a 30-day average, which is equivalent to a TPS-95% value (or 95 percent reliability). The effluent concentrations are based on a peak flow rate of 110 mgd and a maximum influent total phosphorus concentration of 0.75 mg/L.

Ferric chloride is currently added in the Cross Channel at a target dose of 30 mg/L about halfway between the BAF and HRFS units, as shown on Figure 2-3. The coagulant was originally added at the bottom of the HRFS influent box, but was moved to its current location to improve dispersion and phosphorus removal. Relocating the addition point reportedly has helped with mixing, but has not adequately resolved the dispersion issue. Relocation of the point also appears to have resulted in some unintended consequences. Metro WWTP operations staff has noted their concern that moving the addition point closer to the BAF units has occasionally resulted in migration of iron salts towards the BAF units. This is because the Cross Channel also serves as the reservoir for BAF backwash water. Corrosion of the HRFS influent gates, due to the iron salts, has also been observed.

Ferric chloride treated flow is distributed from the HRFS Influent Channel to the individual treatment trains. One HRFS train is located to the north of the Cross Channel and three are to the south. Once in the HRFS system, flow enters the coagulation tank where pin floc is formed. The coagulation tanks are 16.5-ft. long by 13.5-ft wide by 22.5-ft. deep and are equipped with a 20-horsepower (hp) downward pumping mixer.

Flow then overflows the coagulation tank to the injection tank where microsand is dosed and mixed. Metro uses a 134-micron effective size microsand at a constant dose of 5 grams/liter (g/L). Microsand attaches to the pin floc to help promote formation of large floc and serves as ballast during clarification. The injection tanks are 16.5-ft. long by 13.5-ft wide by 22.5-ft. deep and are equipped with a 20-hp downward pumping mixer.

The maturation tank, located downstream of the injection tank, is used for flocculation and to further increase floc size to facilitate settling. The maturation tanks are 24-ft. long by 28.6-ft wide by 22.5-ft. deep and are equipped with a 25-hp downward pumping mixer. Polymer (Nalco 7768) is added using a dose of 0.6 mg/L to promote flocculation. The polymer is injected adjacent to the two anti-vortex baffles near the bottom of the tank. Alternatively, polymer may be fed through a diffuser as flow enters the maturation tank or with the microsand in the injection tank. Polymer feed location is controlled through a manifold. It should be noted that during an inspection of the HRFS polymer system in 2011, it was found that the manifold had been mis-labeled and that polymer was actually being added to the diffuser where flow enters the maturation tank. Further, it was identified that the diffuser had no holes drilled and that polymer entered the tank through the end of the diffuser pipe. Metro staff have since relocated the polymer injection location to the baffles, re-labeled the manifold, and modified the diffuser pipe.

Flow passes from the maturation tank to a settling tank equipped with tube settlers and sludge removal equipment. Settled sludge is pumped to a hydrocyclone where the microsand is separated and re-applied at the injection tank. The HRFS sludge pumps are constant speed pumps that control sludge feed by turning on and off. HRFS sludge flow is approximately 2 mgd.

## 2.4 DISINFECTION

An ultraviolet light (UV) system is used to disinfect plant effluent between April 1 and October 15 in accordance with the SPDES permit. The UV system consists of 308 high intensity – medium pressure lamps with a power range of 800 to 2,400 watts per lamp. Visual observations indicated that the quartz sleeves become coated with iron scale. A chemical-based cleaning system is used to periodically clean the sleeves. Iron also absorbs UV light at the same wavelength as microorganisms; therefore, more energy is required when biological activity increases due to warmer temperatures.

## 2.5 SOLIDS HANDLING

Typically, sludge from the primary, secondary and HRFS processes are conveyed to the gravity thickeners as the first step in solids handling. Metro also receives sludge from its Brewerton, Meadowbrook, Wetzel Road and Oak Orchard WWTPs. Septage from private haulers is discharged into the plant headworks. During the summer months, secondary sludge is sometimes treated with a gravity belt thickener (GBT), based on operations needs. Thickener output (4 to 7 percent dry solids content) is subsequently blended and conveyed to an anaerobic digester. The digester has accumulated a significant amount of grit; WEP has initiated separate projects for cleaning the digesters and improving grit removal in the plant headworks. Digested sludge is dewatered (30 to 33 percent dry solids concentration) using a centrifuge and disposed of at a landfill. Metro's centrifuge is operated continuously. Thickener, GBT filtrate, centrate and BAF backwash wastewater are all returned to the head of the plant for re-processing.

## 3.0 METRO WWTP OPTIMIZATION ISSUES AND OBJECTIVES

A two-day Process and Operations workshop was initiated to establish a detailed understanding of current phosphorus treatment at the Metro WWTP, as well as significant hydraulic, process, operations and maintenance issues. The workshop included input from WEP's operations staff as well as mechanical and instrumentation/electrical staff. Results from this workshop were used as guidance in identifying and evaluating modifications for optimizing current phosphorus treatment.

A key discussion point was that the Engineer's Design Report (EEA, 2000) and Operation & Maintenance Manual state that the HRFS system was designed to meet an effluent total phosphorus limit of 0.12 mg/L (30-day monthly average or TPS-95%). Since commencing tertiary treatment in 2005, Metro WWTP effluent total phosphorus concentrations have decreased significantly and are currently meeting the current 0.10 mg/L limit (annual rolling average). Figure 3-1 presents the annual rolling average for the Metro effluent total phosphorus from 2007 to 2010. Over time, the rolling average has decreased and appears to have stabilized to its current range of 0.08 mg/L and 0.09 mg/L. However, daily operational data show that effluent concentrations are highly variable, as illustrated on Figure 3-2. While effluent phosphorus levels can fall to as low as 0.05 mg/L, concentrations as high as 0.20 mg/L were recorded in early 2011. This variability is common for WWTPs that treat nutrients to very low levels (Bott, et al., 2009; WERF, 2011). The NYSDEC's use of an annual rolling average is appropriate to facilitate attenuation of some inherent process variability. However, there are concerns regarding the ability to meet a 0.10 mg/L or lower limit with 100 percent reliability (as mandated by the ACJ) at the Metro WWTP without optimization and addressing operating and maintenance concerns. Additionally, modifications made to address one issue have been found to have unintended consequences.

Based on the results of the meeting, the following were identified as key issues that should be addressed to promote the conditions leading to improved treatment performance and reliability, while reducing the variability of current Metro WWTP phosphorus treatment:

1. **Hydraulic Issues:**

   - The hydraulic conditions between the BAF and HRFS system are highly dynamic. System hydraulics change based on BAF operational configuration (e.g., number of filters running, which filters operate, backwashing, etc.). This contributes to substantial and changing eddy formation in the Cross Channel and HRFS influent channel.
   - Visual observations show that flow appears to be unbalanced across the four HRFS trains.
   - Controlling flow and measurement of flow into each HRFS train is not currently available.
   - BAF backwashing reportedly results in ferric chloride being drawn back towards the BAF process. This is because the volume in the Cross Channel serves as the backwash water supply to the BAFs. Ferric chloride could negatively impact the BAF media.
   - A review of facility record drawings show that limited excess head is available for any proposed modifications.
   - Some microsand carries over into effluent channel. Microsand loss reportedly is greatest in Train 4, possibly from higher loading rates through that train.

2. **Process Issues:**

   - The impact of secondary treatment performance on HRFS performance is not known.
   - Secondary treatment ferric chloride dosages vary with flow because constant rate chemical feed is practiced.
   - The use of an iron-based coagulant interferes with the downstream ultraviolet light (UV) disinfection process through scaling on the quartz sleeves and absorption of UV light. Iron salts also have promoted corrosion. In addition, the most recent draft SPDES permit, dated August 17, 2011, proposes a Type II action level on iron discharges of 5,260 pounds/day (lbs./day). Therefore, ferric chloride dosing must account for this proposed action level.
   - WEP is open to consideration of aluminum-based coagulants to address concerns about corrosion and impacts to UV disinfection and proposed iron discharge action level.
   - Accurate and effective dosing of coagulant is dependent on flow rate, but flow to the HRFS trains is not individually monitored. Instead, HRFS chemical dosing is paced from the WWTP effluent flow meter. It is believed that flow

across the four HRFS trains is unbalanced; therefore, actual coagulant dose is inconsistent.

- The literature (Stensel, 2010) suggests that thorough dispersion of the coagulant is critical to optimizing phosphorus removal. No mixing equipment is provided in the Cross Channel and little ambient mixing is observed.

3. **Operations and Maintenance Issues:**

- Metro staff indicated that the length of time to perform a complete backwash cycle could be problematic. A full cycle requires two hours to complete a backwash and drain the backwash wastewater storage tank. During high flows, filters needing backwashing can become "stacked". This is because the higher flows result in faster filter clogging and more cells amassing filter time and reaching maximum filter hours.
- Operation of the BAF filters cannot currently be balanced due to continuously changing conditions. The BAF control program would need to be redesigned to have filters turn on and off in pairs, one from each train.
- No facilities are in place to allow one-half of the filters to be taken off line and permit maintenance of the channels between the BAF and HRFS units. The entire BAF and HRFS system must be taken off line, which requires sufficient notification of the NYSDEC in accordance with the New York Code of Rules and Regulations 6NYCRR Part 750-2.7. Higher effluent levels resulting from this action must be included in the permit compliance calculation. Removal of the BAF and HRFS units from service is limited to cold weather months to mitigate impact to the lake, except if an emergency arises.
- The liner in the BAF Effluent Channel, Cross Channel and HRFS Influent Channel is deteriorating. Metro staff and discussion with the liner manufacturer noted that improper surface preparation appears to be the likely cause of this issue. Liner repairs cannot be made without removing the BAF and HRFS systems from service for an extended period of time.
- The bypass sluice gate for the HRFS system is not working; the operating stem reportedly sheared with the gate in the partially open position. A steel plate has been placed over the opening in the HRFS influent channel to prevent flow from bypassing the HRFS system. If the HRFS system must be removed from service, the BAF must be deactivated as well.
- Aluminum surfaces are corroding due to ferric chloride. Effluent gates on all BAF cells are corroded. Metro staff also indicated that the RAS discharge lines and the interior portions of the HRFS sludge piping are corroded.

- The HRFS microsand slurry tank has deteriorated over time.
- Carryover of microsand into the UV channel results in some being sucked into the effluent water pumps, which has caused premature wear.
- The existing microsand sludge pumps are constant speed, which limits control.
- The ferric chloride diffuser pipe plugs up over time and must be opened up to restore effective chemical delivery. However, the diffuser pipe is over 28-ft. long and the Cross Channel, as well as the BAF and HRFS units must be taken out of service to perform this work.

The results from the process and operations workshop were used to finalize an Initial Evaluation Checklist, shown on Table 3-1 (at the end of the text). The checklist presents the key issues, potential solutions and associated benefits, as well as how one modification might impact another part of the Metro WWTP. From these impacts, the inter-relationship of the various issues was identified and considered in an integrated evaluation. This table was also used to refine how the hydraulic, process and O&M evaluations would be conducted. As the project progressed, new alternatives and inter-relationships were identified and evaluated. Summaries of these evaluations are presented in Sections 4.0 through 7.0.

# 4.0 HYDRAULIC AND MIXING EVALUATION

## 4.1 HYDRAULIC AND MIXING EVALUATION APPROACH

Effectively balancing flow across the HRFS trains, addressing the impact of continually changing BAF operation, optimizing initial coagulant mixing and identifying mixing improvements to the HRFS process were determined to be the primary hydraulic issues at the Metro WWTP. Balancing flow would enable effective coagulant dosing, mitigate hydraulic overloading of HRFS trains and minimize microsand carryover. Metro WWTP staff expressed concern that the varying BAF operation appears to impact which HRFS trains receive flow and backwashes seem to draw ferric chloride back to the filters. Thorough initial mixing of the coagulant has been identified as being critical to maximizing phosphorus removal. Optimizing mixing in the HRFS tanks may further promote improved phosphorus removal and/or reduced variability.

The hydraulic and mixing analysis was divided into evaluating the channels between the BAF and HRFS processes, initial coagulant mixing and HRFS tank mixing systems. Tools used to complete this analysis included:

- Three-dimensional computational fluid dynamics (CFD) modeling
- Flow monitoring
- Full-scale demonstrations, as appropriate
- Mathematical analysis
- Review of process evaluation results (summarized in Section 5.0)
- Discussion with manufacturers
- Coordination with WEP staff
- Consideration of O&M Improvements

## 4.2 EVALUATION OF HYDRAULICS BETWEEN BAF AND HRFS PROCESSES

A three-dimensional CFD model using FLUENT software was developed by HDR, Inc. to analyze current hydraulic conditions and evaluate alternatives to improve flow distribution across the HRFS trains and coagulant mixing. The model includes the effluent from the 18 BAF filters, BAF Effluent Channel, Cross Channel, HRFS Influent Channel and the influent weirs to each HRFS train. The model was constructed based on available record drawings. A survey was performed to confirm HRFS weir heights and lengths, as these are critical to developing a representative model. A separate model of the HRFS influent box was developed, which is described in Section 4.3.1.

The CFD model was used to perform a series of steady state analyses to simulate the hydraulic conditions. Flow enters the system via the BAF cells and exits over the four weirs leading into the HRFS. Any combination of BAF cells can be simulated, which allows for modeling of the dynamic hydraulic conditions present at the Metro WWTP. The CFD model was calibrated to match the measured flow distribution to each HRFS train under low, average and high flow conditions (40 mgd, 70 mgd and 130 mgd, respectively). Metro operations personnel installed velocity-area type flow meters in the effluent launders of the HRFS units – one flow meter per train. A detailed survey showed that the effluent launder elevations where the flow meters were installed were within 0.02 ft. of each other, which was considered acceptable. In general, the survey showed the elevation of six launders in each train varied little, although some variations were identified.

Flow meter data were validated by comparing the temporary flow meters in the effluent launders to the permanently installed SEPS and WWTP effluent flow meters. Flow variations induced by BAF backwashing were taken into account along with the time lag between the SEPS and HRFS effluent launders. The difference between calculating the total flow using the flow meters in the effluent launders and existing plant flow meters was typically less than 5 percent. Therefore, it was determined that measurements from the effluent launder flow meters were representative of actual plant flow and could be used to calibrate and verify CFD simulation results. The effluent launder flow meters were also used in verifying the effect of flow balancing changes and in the process evaluation (see Section 5.0).

### 4.2.1 CURRENT HYDRAULIC CONDITIONS

CFD model simulations were performed under five existing conditions to bound the hydraulic conditions expected between the BAF and HRFS units. The conditions, summarized on Table 4-1 cover the typical Metro operating range, as well as consider how channel hydraulics behave when the BAF filter operation is balanced between the two trains and unbalanced. While these simulations represent bounding conditions, unbalanced operation of filters is considered typical.

## TABLE 4-1
## CFD Modeling – Existing Conditions Simulation Parameters

| *Simulation* | *Flow Rate (mgd)* | *BAF Operation* | *BAF Units Operating* |
|---|---|---|---|
| 1 | 40 (Low) | Balanced | 3 North, 3 South |
| 2 | 70 (Average) | Balanced | 6 North, 6 South |
| 3 | 130 (High) | Balanced | 9 North, 9 South |
| 4 | 70 (Average) | Unbalanced | 0 North, 9 South |
| 5 | 70 (Average) | Unbalanced | 9 North, 0 South |

In general, the simulations show the hydraulic characteristics to be dynamic with respect to flow and BAF filter operation, and that HRFS flow balance is likewise affected. Table 4-2 summarizes the flow distribution across the four HRFS trains from the CFD simulations in terms of percent of total flow to the HRFS process.

## TABLE 4-2
## CFD Model Results – Flow Distribution Across HRFS Trains Under Existing Conditions.

| | *Simulated Flow Distribution (%)* | | | |
|---|---|---|---|---|
| *Simulation* | *Train 1* | *Train 2* | *Train 3* | *Train 4* |
| 1 | 20.9% | 26.6% | 26.6% | 26.0% |
| 2 | 22.8% | 24.5% | 24.2% | 28.5% |
| 3 | 23.5% | 23.8% | 23.3% | 29.4% |
| 4 | 22.5% | 26.8% | 25.2% | 25.5% |
| 5 | 22.6% | 22.5% | 23.8% | 31.1% |

Table 4-3 summarizes flow distribution as measured from the flow meters in the HRFS effluent launders in 10-mgd increments. Overall, the simulated results are similar to measured results. Therefore, the model was considered properly calibrated. A significant and varying flow imbalance across the four HRFS trains occurs under all conditions, which supports visual observations. In general, HRFS Train 4 receives the most flow and Train 1 receives the least. Under balanced BAF operation with average flow conditions, Train 4 receives 25 percent more flow than Train 1. In an unbalanced condition (Simulation 5), the difference can be almost 40 percent. Trains 2 and 3 tend to receive a similar amount of flow due to the proximity of their influent weirs. Train 4, receiving the most flow, also is consistent with observations that this train has the greatest microsand carryover.

**TABLE 4-3**
**Summary of Flow Distribution Across HRFS Trains from Flow Monitoring Data**

| *Total HRFS Flow* | *Average Flow Percentages* | | | |
|---|---|---|---|---|
| *mgd* | *Train 1* | *Train 2* | *Train 3* | *Train 4* |
| **< 29.9** | 24.7% | 27.0% | 33.2% | 15.1% |
| **30 to 39.9** | 24.2% | 26.1% | 31.0% | 18.8% |
| **40 to 49.9** | 22.8% | 25.9% | 30.0% | 21.4% |
| **50 to 59.9** | 22.5% | 25.6% | 28.9% | 22.9% |
| **60 to 69.9** | 21.9% | 25.4% | 26.9% | 25.8% |
| **70 to 79.9** | 20.7% | 25.2% | 24.9% | 29.2% |
| **80 to 89.9** | 20.7% | 25.6% | 24.6% | 29.1% |
| **90 to 99.9** | 21.7% | 25.5% | 24.2% | 28.6% |
| **100 to 109.9** | 21.7% | 24.9% | 23.6% | 29.9% |
| **110 to 119.9** | 21.0% | 24.6% | 23.4% | 31.1% |
| **120 to 129.9** | 21.5% | 24.5% | 23.3% | 30.7% |
| **> 129.9** | 24.2% | 23.6% | 22.3% | 29.9% |

The flow imbalance can be seen visually on Figure 4-1, which represents the velocity contours under Simulation 2. In this figure, red and yellow represent the highest velocities and green and blue represent the lowest.

Figures 4-2, 4-3 and 4-4 show the particle tracks generated by CFD Simulations 2, 4 and 5, respectively. Particle tracks simulate the path of a particle as it travels from the BAF effluent weir to the HRFS influent weir and provide an indication of the hydraulic flow lines within the system. The particle tracks show that little mixing energy is available within the Cross Channel where the ferric chloride is added. This supports observations that the ferric chloride is stratified in the channels and do not appear to be well mixed entering the HRFS trains.

CFD simulation results also show continuously changing flow patterns and eddies in the Cross Channel and HRFS influent channel. These flow patterns appear to be strongly influenced by BAF operation as shown in Figures 4-3 and 4-4. Visual observations show swirling flow patterns and that the ferric chloride moves back towards the BAF channels periodically. Data from a continuous Data Sonde pH meter installed in the Cross Channel upstream of chemical addition for this study was used to verify the occurrence of stratification. pH is not expected to fluctuate significantly throughout the day; however, as illustrated on Figure 4-5, the pH measured by the Data Sonde varies as ferric chloride (an acid) appears to pool near the coagulant diffuser under low flow and under certain BAF backwash events. The pH drop is particularly affected from the shutdown or backwash of Cells 1 through 9. pH levels then increase as flows increase or a backwash is completed.

### 4.2.2 EVALUATION OF FLOW BALANCING ALTERNATIVES

Unbalanced flow to the HRFS trains and dynamic hydraulic patterns within the Cross Channel represent non-optimal conditions. Poor mixing occurs in the Cross Channel where coagulant is currently added. Studies, as well as discussions with the HRFS manufacturer, have shown that rapid and thorough mixing is essential to optimizing phosphorus removal using coagulants (Bratby, 2006). Achieving proper mixing is complicated by the dynamic flow patterns influenced by BAF operation that changes based on many variables.

When the HRFS first started operating, insufficient mixing was identified with chemical injection located at the bottom of the influent box as it enters the coagulation tank. Another key concern was that the ferric chloride feed pumps are flow paced from the WWTP effluent flow meter rather than from flow into the individual HRFS trains because there was no flow monitoring into the individual HRFS trains. Balanced flow across the HRFS trains is needed to provide the same coagulant dose to each train. The unbalanced flow condition results in some trains being overdosed and others underdosed. Also, under higher flow conditions, Train 4 may become hydraulically overloaded because of the flow imbalance.

Balancing flow across the HRFS trains and managing dynamic hydraulic conditions is considered essential to Metro optimization to mitigate overloading of individual trains and providing options to further optimize. For example, flow balancing may permit relocating coagulant addition to the HRFS influent boxes, provided that sufficient mixing can be provided. Coagulant feed would be balanced, or even improved through the addition of flow monitoring. The current corrosion issues and the potential of coagulant entering the BAF during backwashing would be mitigated.

Based on the initial evaluation, alternatives were identified and screened for improving flow balancing, reducing the impact of dynamic hydraulic conditions in the Cross Channel and promoting improved mixing in the Cross Channel. In addition, the element of adding facilities to isolate the BAF and HRFS trains (discussed in Section 6.0) was incorporated into the analysis. Alternatives initially considered to achieve these goals included the following:

- Installing four pipes to serve individual trains and controlling flow distribution using modulating valves and flow meters.
- Using four Parmer-Bowlus or Parshall flumes to isolate flow to each train while upstream modulating gates and flow meters balanced flow.
- Modifying the BAF programming to provide balanced operation of the filters (BAF cells turned on and off in pairs, one per train).
- Installing weir gates in the HRFS influent boxes.
- Installing pumps in the HRFS Influent Channel to pump into the HRFS trains.
- Installing overflow weirs in the Cross Channel or HRFS Influent Channel.
- Constructing baffles in the Cross Channel to dampen dynamic hydraulic conditions and promote improved flow distribution.
- Installing a wall to isolate BAF trains and allow the HRFS process to continue operation while one BAF train is being maintained.
- Address the initial coagulant mixing issue only through the installation of baffles and motorized mixing equipment.

Alternatives were screened based on available excess headloss (determined to be less than 1 ft. based on record drawings), ease of operation, constructability and potential cost. For instance, the use of weir walls and in-channel flumes in the Cross Channel were eliminated because of excessive headloss. Also, the depth in the channels is typically less than 3 ft. so weir walls would have limited range. Pumping from the channels into each train was considered too costly, difficult to construct and operationally complex, particularly as less complex alternatives that could achieve the same goals appeared to be available.

The following potential modifications were initially evaluated using CFD modeling:

1. Installation of a wall in the BAF Effluent Channel to permit isolation of one half of the BAF system (CFD Simulation 6).
2. Installation of adjustable weirs to the inside face of the HRFS influent boxes to improve flow balancing (CFD Simulation 7).
3. Construction of a serpentine baffle within the Cross Channel to reduce dynamic hydraulic conditions and the influence of BAF operation (CFD Simulation 8).

Results from the simulations showed the following:

- Addition of the baffle wall (see Figure 4-6) appears to straighten out the flow lines under balanced flow conditions. However, this modification would not improve flow balancing or address the influence of BAFs under unbalanced conditions. The key benefit would be permitting isolation of the BAF system for maintenance, particularly if the wall were extended through the Cross Channel to the division wall between HRFS Trains 2 and 3. Because isolating the BAF system can serve to reduce downtime of the HRFS system, thus reducing effluent phosphorus variability, this alternative was incorporated into subsequent alternatives.
- Raising the HRFS Train 4 weir by 3 inches and the weir for Trains 2 and 3 by 1 inch was found to have a significant benefit in balancing flows (see Figure 4-7). Therefore, use of adjustable HRFS influent weirs appears to be capable of balancing flow through the operating range of the Metro WWTP. It should be noted that small changes in weir elevation could induce large changes in flow balance. Therefore, the use of modulating weirs would not be considered practical.
- The use of a serpentine baffle system in the Cross Channel appeared to reduce the influence of the BAF and stabilize hydraulic conditions (see Figure 4-8), which could permit the effective use of mixing devices. However, the flow balance across the HRFS trains was severely impacted and large dead spaces are predicted in the HRFS Influent Channel. Therefore, a serpentine baffle arrangement does not appear to provide an optimal mixing solution at Metro. Additional Cross Channel baffling alternatives, such as a series of staggered baffles or static mixers, would need to be evaluated to optimize coagulant addition in the Cross Channel.

Overall, the CFD analysis showed that using adjustable weirs at the HRFS influent boxes have excellent potential to balance flow to the HRFS trains under many different BAF operating conditions. Key advantages are that this option would be simple to operate and have a relatively low implementation cost. Because of these advantages, it was determined that performing a full-scale demonstration of adjustable weirs to verify that flow to the HRFS trains can be balanced under various BAF operating conditions. Also tested during full-scale testing were various coagulant feed configurations and process modifications, which are discussed in subsequent report sections.

The full-scale demonstration started in early-February 2011 and completed in July 2011. The NYSDEC was notified of this testing program prior to its commencement. An incremental approach was used for the demonstration to allow for changes to be properly evaluated. The flow meters in the HRFS effluent launders were used as the basis for evaluating impact to flow balancing. Initially, the HRFS Train 4 weir was raised 3 inches by Metro personnel to identify how changing weir heights can impact flow distribution. Data was collected from February 7 through February 17, 2011. Table 4-4 summarizes the HRFS flow distribution during this period, and shows that adjusting weirs by a few inches can have a significant impact. However, flow across the trains was still unbalanced, with Trains 2 and 3 being favored.

**TABLE 4-4**
**Summary of Flow Distribution Across HRFS Trains (2/7/11 to 2/17/11)**
**Train 4 Weir Raised 2 Inches**

| *Total HRFS Flow* | *Measured Flow Distribution (%)* | | | |
|---|---|---|---|---|
| *mgd* | *Train 1* | *Train 2* | *Train 3* | *Train 4* |
| **< 29.9** | 24.1% | 30.0% | 35.1% | 10.8% |
| **30 to 39.9** | 22.9% | 29.2% | 32.9% | 14.9% |
| **40 to 49.9** | 21.9% | 28.7% | 31.5% | 17.8% |
| **50 to 59.9** | 21.8% | 28.1% | 30.8% | 19.3% |
| **60 to 69.9** | 21.6% | 27.8% | 30.4% | 20.2% |
| **70 to 79.9** | 19.7% | 28.3% | 30.3% | 21.6% |
| **80 to 89.9** | 22.3% | 27.7% | 28.4% | 21.5% |
| **90 to 99.9** | 22.0% | 27.6% | 27.8% | 22.7% |
| **100 to 109.9** | 20.9% | 28.0% | 27.3% | 23.7% |
| **110 to 119.9** | 21.4% | 27.7% | 27.4% | 23.5% |
| **> 119.9** | 23.3% | 26.5% | 27.3% | 22.9% |
| **Average** | 22.0% | 28.2% | 29.9% | 19.9% |

Based on these initial results, the influent weirs to Trains 2 and 3 were raised by 1-inch (Train 4 still raised by 3 inches). A CFD run (Simulation 9) of this scenario at 70 mgd (see Figure 4-9) showed improved flow balance. The subsequent flow balancing test period started on March 1, 2011, with this configuration remaining in use. Table 4-5 summarized the HRFS flow distribution between March 1 and May 31, 2011. This time frame accounts for periods of dry weather and significant wet weather and therefore encompasses the changing BAF operational conditions that would be experienced at Metro. This table shows that the changes in flow balance, except at the lowest flow rates, are greatly reduced with the weir adjustments. More importantly, over this time period, on average the four HRFS trains operated in a reasonably balanced condition. The model results for 70 mgd (Figure 4-9) and the flow monitoring results (Table 4-5) were nearly identical. Therefore, the model was determined to reasonably predict flow balance across the HRFS trains.

**TABLE 4-5**
**Summary of Flow Distribution Across HRFS Trains (3/1/11 to 5/31/11)**
**Train 4 Weir Raised 2 Inches and Trains 2 and 3 Weirs Raised 1 Inch**

| *Total HRFS Flow* | *Measured Flow Distribution (%)* | | | |
|---|---|---|---|---|
| *mgd* | *Train 1* | *Train 2* | *Train 3* | *Train 4* |
| **< 40** | 25.7% | 26.8% | 28.5% | 19.1% |
| **40 to 49.9** | 24.9% | 24.9% | 27.9% | 22.3% |
| **50 to 59.9** | 25.2% | 24.6% | 27.5% | 22.8% |
| **60 to 69.9** | 25.5% | 24.7% | 26.8% | 23.1% |
| **70 to 79.9** | 25.6% | 24.9% | 26.2% | 23.2% |
| **80 to 89.9** | 25.0% | 25.2% | 25.6% | 24.1% |
| **90 to 99.9** | 24.3% | 25.2% | 25.4% | 25.0% |
| **100 to 109.9** | 23.7% | 25.1% | 25.5% | 25.8% |
| **110 to 119.9** | 24.2% | 24.7% | 25.1% | 25.9% |
| **120 to 129.9** | 25.6% | 24.3% | 24.3% | 25.7% |
| **130 to 139.9** | 27.0% | 24.0% | 23.9% | 25.1% |
| **> 139.9** | 28.0% | 23.7% | 23.6% | 24.6% |
| **Average** | 25.4% | 24.8% | 25.9% | 23.9% |

The full-scale demonstration supports the CFD modeling results in that installing an adjustable weir at each HRFS influent box would successfully balances flow across the HRFS trains. Flow monitoring could be implemented to verify that flow balance was occurring and provide a basis for minor weir adjustments during periods of low flow or when an HRFS train requires maintenance. The evaluation indicated that the HRFS effluent launders would be a suitable location for installing flow meters.

If it is determined that insufficient mixing would be provided in the HRFS influent box, coagulant addition would need to remain in the Cross Channel. Because the eddies are constantly changing, simply installing rapid mixing into the Cross Channel would not always promote an optimal mixing regime. A combination of baffling in the Cross Channel to address the BAF influence and eddies along with static or mechanical mixers would be necessary to provide suitable mixing conditions. However, this would not eliminate corrosion issues associated with ferric chloride unless a different coagulant was used. And, the concern about drawing coagulant into the filters would remain.

It is noteworthy that temporarily installing a wall to isolate the north and south sides of the BAF and HRFS trains could not be performed in the full-scale demonstration due to cost and construction time requirements. A series of CFD simulations were developed to evaluate the impact to flow balancing and Cross Channel hydraulics should the isolation wall extend from the BAF to the HRFS, effectively splitting the BAF and HRFS trains. The model was constructed with two 13-ft. wide slide gates; the gates were modeled as normally be open to allow for flow to pass to either side of the wall during unbalanced BAF operation. The model also incorporates the weir configuration being used in the full-scale demonstration (Train 4 weir raised 3 inches and Trains 2 and 3 weirs raised 1 inch). The simulations bounded the range of HRFS operation and considered unbalanced BAF operation, as shown on Table 4-6.

## TABLE 4-6
## CFD Modeling – BAF/HRFS Isolation Wall Evaluation Simulation Parameters

| *Simulation* | *Flow Rate (mgd)* | *BAF Operation* | *BAF Units Operating* |
|---|---|---|---|
| 10 | 40 (Low) | Balanced | 3 North, 3 South |
| 11 | 70 (Average) | Balanced | 6 North, 6 South |
| 12 | 130 (High) | Balanced | 9 North, 9 South |
| 13 | 70 (Average) | Unbalanced | 3 North, 9 South |
| 14 | 70 (Average) | Unbalanced | 9 North, 3 South |
| 15 | 70 (Average) | Unbalanced | 5 North, 7 South |
| 16 | 70 (Average) | Unbalanced | 7 North, 5 South |

The flow balance from the CFD runs, summarized in Table 4-7, indicate that the wall divides the hydraulics into two systems HRFS Trains 1/2 and HRFS Trains 3/4. In the balanced BAF operation cases, this is shown on Figure 4-10 for Simulation 11. Flow favors the train with the lower weir height; Train 3 weir is 2-inches lower than Train 4 and Train 1 weir is 1-inch lower than Train 2 weir.

## TABLE 4-7
## CFD Model Results – Flow Distribution Across HRFS Trains Under Existing Conditions

| | *Simulated Flow Distribution (%)* | | | |
|---|---|---|---|---|
| *Simulation* | *Train 1* | *Train 2* | *Train 3* | *Train 4* |
| 10 | 22.7% | 25.7% | 30.4% | 21.1% |
| 11 | 25.3% | 23.2% | 29.1% | 22.5% |
| 12 | 22.7% | 25.7% | 30.4% | 21.1% |
| 13 | 28.2% | 25.8% | 26.2% | 19.8% |
| 14 | 23.6% | 21.9% | 30.0% | 24.5% |
| 15 | 26.4% | 24.2% | 28.0% | 21.4% |
| 16 | 24.2% | 22.3% | 29.8% | 23.7% |
| No Wall | 26.0% | 25.0% | 26.0% | 23.0% |

The data also show that, under the configuration evaluated, BAF operation has some influence on flow distribution. Table 4-8 shows the flow distribution to each side of the isolation wall. Under balanced BAF operation (Simulations 10 - 12), the flow split to each side of the wall remains constant and reasonably balanced. Under unbalanced BAF operation (Simulations 13 - 16), the flow balance favors the side that has the most filter cells operating. However, the gates in the isolation wall serve to significantly dampen imbalance to the HRFS trains. For example, in Simulation 13, 75 percent of the flow comes from the BAFs on the side of HRFS Trains 1 and 2, but 46 percent of the flow passes through Trains 3 and 4. Flow from one side of the wall passes through the open gates, as illustrated in Figure 4-11.

**TABLE 4-8**
**CFD Modeling – BAF/HRFS Isolation Wall Evaluation**
**Flow Balance to Each Side of the Isolation Wall**

| *Simulation* | *HRFS Trains 1 & 2* | *HRFS Trains 3 & 4* |
|---|---|---|
| 10 | 48.4% | 51.5% |
| 11 | 48.5% | 51.6% |
| 12 | 48.4% | 51.5% |
| 13 | 54.0% | 46.0% |
| 14 | 45.5% | 54.5% |
| 15 | 50.6% | 49.4% |
| 16 | 46.5% | 53.5% |
| No Wall | 51% | 49% |

Modifying the weir heights appeared to improve the flow split to the HRFS trains. This is shown on Figure 4-12, which represents a CFD simulation of balanced operation from the BAF system at a flow of 70 mgd (Simulation 17). The weir for Train 2 was reset to its original height and Trains 3 and 4 weirs were set to 2-inches above original height. This resulted in a reasonable flow split under balanced BAF operation. It is expected that the presence of the wall would continue to impact flow split under unbalanced BAF operating conditions. However, WEP staff noted that having the wall in place would provide significant maintenance benefits and allow tertiary treatment to continue should any part of the BAF and HRFS systems require maintenance or repair. Therefore, options to promote further flow balancing with the isolation wall in place are warranted.

One option would be to reprogram the BAF control system to start and stop BAF cells in pairs, one cell in each train. This would force the BAF to generally operate in a balanced condition. Significant programming and debugging effort would be expected to implement this option. Adding a third gate in the isolation wall could further dampen the effects of unbalanced BAF operation. Additional CFD modeling to determine the optimal wall configuration to promote an even flow split to the HRFS trains under the bounding flow and BAF operational conditions would be beneficial during detailed design.

## 4.3 COAGULANT AND HRFS MIXING EVALUATION

Initial coagulant mixing was identified as another essential optimization issue. Currently, the current Cross Channel location for ferric chloride addition results in a poorly mixed condition. This is illustrated on Figure 4-13, where the photo shows stratified plumes within the Cross Channel. These plumes move around based on BAF operation. In addition to initial coagulant mixing, an evaluation of mixing in the HRFS process was performed to determine if changes to the mixing within the HRFS treatment trains would help promote conditions that would further optimize phosphorus treatment. The components evaluated included the influent box, coagulation tank, injection tank and maturation tank. These evaluations included a literature review, CFD modeling, review of the O&M manual, and discussions with Kruger/Veolia (manufacturer of the HRFS system) and Lightnin Mixer Corp. (manufacturer of the HRFS mixers).

### 4.3.1 INITIAL RAPID MIXING OF COAGULANT AND HRFS INFLUENT BOX

Rapid and thorough mixing of the coagulant must occur upstream of the coagulation tank for a period of time. Discussions with Kruger/Veolia indicated that it is intended for the coagulant to be thoroughly mixed prior to entering the coagulation tank. This is supported by the literature review, which indicates that velocity gradients (G values) between 300 $s^{-1}$ and 1,000 $s^{-1}$ are considered necessary to achieve thorough mixing (see Table 4-9). The target G value for the coagulation tank is 250 $s^{-1}$. Kruger/Veolia confirmed that the coagulation tank is intended for coagulation (not rapid mixing), the injection tank is intended for dispersion of the microsand and the maturation tank is for flocculation to promote floc formation prior to settling in the settling tanks.

## TABLE 4-9

## Summary of Suggested G (velocity gradient) and HRT (hydraulic retention times) for Rapid Mixing

| *Suggested Rapid Mix G (sec$^{-1}$)* | *Reference* |
|---|---|
| 300-600 | Design Approach for Phosphorus Removal by Chemical Addition, H. David Stensel, JB Neethling (WEFTEC Presentation)(2010) |
| 250-1,500 (Typical for Wastewater Treatment)<br>1,500-7,500 (Rapid Mixing in Contact Filtration Process) | McGraw-Hill Series in Water Resources and Environmental Engineering, Metcalf and Eddy, Inc. (1979) |
| 300-1,000 | Design of Municipal Wastewater Treatment Plants, WEF Manual of Practice No. 8 (1992) |
| 400-1,000 | Water Quality and Treatment, AWWA (1990) |
| No Recommendation for Rapid Mixing<br>10-75 (Flocculation, slow mixing) | Water Supply and Pollution Control, Warren Viessman, Jr., Mark J. Hammer (2005) |
| <1,000 | Water Treatment Principles and Design, James M. Montgomery, Consulting Engineers Inc. (1985) |
| 300 (Morrow and Rausch 1974) | Coagulation and Flocculation in Water and Wastewater Treatment, John Bratby (2006) |

As will be shown in Section 5.0, ferric chloride appears to react rapidly with phosphorus, so a short contact time would be sufficient. Based on record drawings, rapid mixing was originally performed in the HRFS influent box, which has a cross-section of 6 ft. by 12 ft. Specifically, ferric chloride was added to the bottom of the influent box at the opening to the coagulation tank. A 5-hp Water Champ eductor device was used to inject the ferric chloride. The Water Champ was oriented so that coagulant was injected parallel to the flow stream. During plant commissioning, the Water Champ was raised several feet up the influent box, but its orientation was not changed; the ferric chloride would be injected at the back wall of the conduit. Because raising the Water Champs did not appear to positively impact effluent phosphorus levels, the coagulant addition point was relocated to the Cross Channel.

Based on the original configuration of the Water Champ, it appears that ferric chloride was being injected almost directly into the coagulation tank, which was not designed for rapid mixing. Discussions with the Water Champ manufacturer (Siemens) indicated that the unit used at Metro WWTP appeared to be undersized for the cross-section of the conduit. A 5-hp unit would only provide coverage for about one-third of the area. Also, the injection should be made *opposite* the flow path to promote dispersion, not in its current configuration of parallel to the flow path. It also does not appear that an alternative means of chemical injection and mixing at the HRFS influent box was evaluated.

The original location was likely not optimal for phosphorus treatment. Because the iron-phosphorus chemical reaction is rapid, a short contact time does not appear to be a detriment to phosphorus removal, hence it may be possible to still use the HRFS influent box as the coagulant feed point. Visual observations indicate that hydraulic conditions may be suitable for proper mixing at the top of the influent box, particularly if coagulant could be added across the entire cross section of the influent box. Improved coagulant coverage could be accomplished using a diffuser pipe across the entire width of the influent box or multiple injection devices (such as a Water Champ). Injection would be made opposite of the process flow and at the top of the influent box, where a zone of high turbulence exists. A key benefit of locating coagulant injection at the HRFS influent is that impacts to corrosion and concerns about backfeeding coagulant into the BAF units would be addressed. Bratby (2006) also noted that initial mixing of coagulant, followed by a period of time before coagulation and flocculation, such as under current conditions, could negatively impact floc formation.

Three-dimensional CFD modeling of the HRFS influent box was used to identify if hydraulic conditions could be improved to promote thorough mixing of the coagulant. Figure 4-14 shows the predicted flow path in the influent box at a Metro flow of 70 mgd. This shows the flow path travelling to the back of the conduit and immediately downwards to the entrance of the coagulation tank; about half of the influent box would be considered unused. Installing four mixing baffles into the influent box, as shown on Figure 4-15 increases the effective volume used for mixing and would also increase hydraulic residence time. This indicates that the addition of baffles would improve mixing in the influent box.

Because of the potential benefits, a full-scale demonstration was performed to evaluate the feasibility of locating coagulant injection to the top of the HRFS influent box. Testing was performed as part of the demonstration to evaluate the effectiveness of adjustable influent weirs, which was discussed in Section 4.2.2. Specific objectives of this demonstration component were to:

- Confirm that returning ferric chloride addition to the HRFS influent box would result in equivalent phosphorus treatment to the current feed location in the Cross Channel.
- Determine if a particular chemical addition method would be better suited to adding coagulant to the HRFS influent box. The methods of coagulant addition tested were as follows:

  - Train 1 – A diffuser pipe across the conduit without dilution water
  - Train 2 – A diffuser pipe across the conduit with 10 gallons per minute (gpm) of dilution water
  - Train 3 – A single 5-hp Water Champ installed in the center of the conduit without dilution water
  - Train 4 - Three 5-hp Water Champs installed in the conduit without dilution water
- Verify that coagulant dose would be balanced across the HRFS trains if flow is balanced.

Metro operation personnel implemented the modifications required to relocate the chemical feed and install the diffusers at the top of the HRFS influent boxes. Ferric chloride addition was moved to the HRFS influent boxes on March 1, 2011. Results from the testing indicated that adjusting the influent weirs to balance flow across the four HRFS trains also resulted in improved balancing of iron concentrations in the injection and coagulation tanks. This indicates that coagulant dosing was better balanced. However, it should be noted that flow pacing of the individual trains using the HRFS flow monitoring results would be expected to provide the most accurate coagulant feed.

The specific details of the process monitoring results from the full-scale demonstration are discussed in Section 5.0. However, Metro effluent total phosphorus levels were generally at or lower than the levels when coagulant addition was located in the Cross Channel. Therefore, the results indicate that permanently locating coagulant addition to the HRFS influent boxes would be possible. Train 2 consistently had the best performance followed by Trains 4 and 1. Train 3 had significantly higher phosphorus levels, up to twice that of Train 2. Based on these results, it was determined that the use of a single 5-hp Water Champ would not provide the same level of coagulant injection as the other three methods tested. Also, because Train 2 consistently has the lowest effluent total phosphorus levels, all of the trains were converted to a diffuser pipe across the conduit with 10 gallons per minute of dilution water. The use of three Water

Champs may have provided equivalent dispersion, but this method was not selected because: 1) the use of mechanical equipment increases cost and operational complexity and 2) Metro staff have noted past maintenance concerns using the eductors.

Coagulant injection for HRFS Trains 1 and 3 was converted to the diffusers with dilution water on March 23, 2011. Conversion of Train 4 to a diffuser with dilution water occurred on April 13, 2011. Converting to a single method of chemical feed reduced the number of variables in the full-scale demonstration and allowed for evaluation of other issues, such as HRFS mixing and polyaluminum chloride.

### 4.3.2 COAGULANT, INJECTION AND MATURATION TANK MIXING

Initial evaluations of the HRFS process mixers included detailed discussions which were initiated with Lightnin Mixer Corp. (Lightnin) to discuss available methods for analyzing mixing effectiveness and potential improvements to mixing within the coagulant, injection and maturation tanks. These discussions were necessary because most of the information used in mixer design is proprietary. Three-dimensional computational fluid mixing (CFM), a derivative of CFD, is available to evaluate hydrodynamic improvements of the tanks. CFM could be used to identify dead spots, short-circuiting and the amount of pumping that a mixer provides in a tank. However, the focus of the three mixed HRFS tanks is particle interaction and formation. Because CFM can only model hydrodynamic conditions, it would not be suitable for determining if optimal treatment is occurring because these areas are dominated by physical/chemical particle interactions. Implementing mixing changes to improve hydrodynamics must be made with caution because of unanticipated issues, such as floc shear, which could degrade removal performance.

Physical modeling or full-scale testing of an entire HRFS train could be performed to evaluate improvements to optimize HRFS mixing. Kruger/Veolia and/or Lightnin would likely need to be included in this evaluation. In addition, many variables could have a greater impact on optimizing phosphorus removal. These include:

- Improving initial rapid mix
- Changing coagulant types and/or doses
- Changing residence time between initial mixing and coagulation/flocculation
- Sand recycle rates
- Polymer dosage, type and injection location

- Impact of iron recycle

Because of the large number of variables that could impact phosphorus removal, it was decided that physical modeling or full-scale testing would be better suited as an implementation task. Although likely more costly, full-scale testing would provide more representative results because physical modeling results would need to be scaled up.

It is noteworthy that Lightnin recommended the addition of a second propeller on the coagulation and injection tank mixers. Lightnin stated that this would increase pumping by about 40 percent versus a single impeller.

Full-scale demonstration and tracer testing results also provided input on parameters that affect mixing effectiveness. Full-scale testing data (see Section 5.0) have shown that Trains 2 and 4 typically have lower effluent phosphorus concentrations than Trains 1 and 3. Several modifications were evaluated to determine if the effluent concentrations could be made more balanced across the four trains. One approach was to modify the coagulant injection to match that of Train 2, the best performing. Another was to change the location of polymer addition. A third was to change the Train 3 sampler location to be more similar to the other three trains. While Train 3 effluent phosphorus concentrations appeared to decrease from the sampler relocation, Trains 1 and 3 have had higher mean effluent concentrations than Trains 2 and 4.

An analysis particularly focused on Trains 2 and 3 because their effluent phosphorus levels are significantly different even though their influent weirs are adjacent. Both trains receive similar amounts of flow and have received similar iron concentrations in the coagulation and injection tanks. Therefore, flow imbalance and iron levels were ruled out. However, one key difference was identified. The physical configuration of Trains 2 and 3 are mirror images of each other, but the mixers in both trains rotate in the same direction. Therefore, the mixing regimes in the coagulation and injection tanks are different in each train. As shown on Figure 4-16, Trains 2 and 4 have the same configuration and Trains 1 and 3 have the mirror image configuration.

Tracer testing was performed on the HRFS influent box and coagulation tank for Trains 2 and 3 on April 25, 2011. The goal of the test was to identify if the different configuration could have an impact on contact time. Based on their configuration, the HRFS influent box should behave like a plug flow reactor and the coagulation tank should behave as a continuously stirred tank reactor (CSTR). Ferric chloride was dosed at a continuous rate of 12 mg/L (as iron) to serve as the tracer. The tracer was injected at the top of the HRFS influent box and samples were collected every 30 seconds at the weir where the coagulation tank overflows into the injection tank.

Iron concentration versus time for predicted and actual testing on Trains 2 and 3 are presented on Figure 4-17. Because the influent box should have plug flow, iron should not be detected in the coagulation tank until after about a minute. Iron was measured in less than a minute, which supports the CFD modeling that predicts short circuiting existing in the influent box (see Section 4.3.1). Figure 4-17 also shows that some, but not extensive short circuiting is occurring in both tanks. However, the time difference to reach the predicted concentration was greater for Train 3 than Train 2. This suggests that Train 3 may have a greater amount of short circuiting.

Lightnin Mixers and Kruger/Veolia also were contacted regarding the mirror image configuration. Lightnin recommended reversing the mixer rotation on Trains 1 and 3 to match the two trains with the lower effluent phosphorus levels. A downward pumping action would need to be maintained, so the mixer blades would need to be replaced with mirror image propellers to offset the change in rotation. Kruger/Veolia indicated no opposition to reversal of the mixer rotation.

# 5.0 PROCESS EVALUATION

## 5.1 GOALS OF THE PROCESS EVALUATION

The primary objectives of the process evaluation were to establish the optimal treatment scheme for removing phosphorus at the Metro WWTP and provide design, operational and maintenance recommendations for reducing residual phosphorus and/or treatment variability. Secondary goals were to achieve the primary objectives through reduced chemical usage and reduced maintenance. A main component of the secondary goal involved evaluating the use of aluminum-based coagulants instead of using the current coagulant, ferric chloride.

## 5.2 METHODOLOGY

The process evaluation consisted of a methodical, comprehensive evaluation of all phosphorus monitoring and O&M data from treatment plant influent through HRFS effluent. In general, the basic steps performed included:

1. Establishing performance of the existing WWTP during each treatment step based on existing and supplemental process and O&M data.

2. Identifying optimal treatment conditions. For secondary treatment, trending reviews were conducted and a high-performing biological nutrient removal facility was contacted for comparison. For the HRFS system, other low-level phosphorus facilities were contacted to identify coagulants and polymers at exemplary facilities. Bench-scale testing of multiple chemical treatments was conducted.

3. Determining process inefficiencies and identifying potential modifications.

4. Conducting a full-scale demonstration to trial test some of the potential modifications.

### 5.2.1 TIMELINE OF OPERATIONAL CONDITIONS AND PROJECT MONITORING PERIODS

Since startup of the HRFS system in 2005, Metro staff has continuously implemented process adjustments with the goal of improving phosphorus treatment performance. Additionally, temporary modifications were performed and monitored during this project. A timeline summarizing major operational periods and monitoring dates is presented in Figure 5-1.

### 5.2.2 ROUTINE PROCESS MONITORING LOCATIONS AND PROTOCOL

Metro staff has monitored flow streams throughout the WWTP for total phosphorus and flow rate since the HRFS system was placed online. For this report, routine process monitoring data collected between January 1, 2007 and December 31, 2010 were used to establish averages and trends. Data collected prior to or after this period were used to support significant findings. A summary of routine sample locations and sampling frequency is shown on Figure 5-2. In general, all samples collected were 24-hour composite samples.

It should be noted that WEP's sample labeling convention for SPDES permit reporting was adhered to. As a result, "Metro influent", which is located downstream of the thickener flow return line, contains sewage, waste hauler septage, and Metro thickener overflow. To prevent confusion, a location identifier labeled "sewage plus septage" was added. The sewage plus septage location represents the contribution from residential, commercial, industrial and stormwater sources. Sewage plus septage flows and loadings were calculated by subtracting thickener overflow from Metro influent values.

Supplemental process monitoring data were collected from routine and additional sampling locations on November 22, December 7, and December 14, 2010. During supplemental sampling, locations of supplemental data collection points are illustrated on Figure 5-3. Data collected included phosphorus species, conventional parameters and metals concentrations.

Supplemental flow monitoring data were collected using Hach (Loveland, CO) Sigma flow meters and area velocity sensors installed in one launder of each HRFS clarifier. Additional details on flow monitoring are described in Section 4.0.

### 5.2.3 STANDARD COMPARATIVE BENCH-SCALE TESTING PROTOCOL

A standard jar testing procedure was followed, except as noted, for the comparative bench-scale tests. The standard protocol, shown in Figure 5-4, was developed by Kruger/Veolia and may be found in WEP's HRFS O&M manual. For the first round of bench-scale testing, a Phipps and Bird (Richmond, VA) PB-7790-400 six-paddle jar stirrer with 1-liter (L) round glass beakers was used by CRA staff at CRA's Niagara Falls, NY laboratory. For the second and third rounds of bench-scale testing, a programmable four-paddle jar stirrer with square, acrylic, 2-L testing jars was used. The second and third rounds were performed at the Metro WWTP. The source of coagulants, polymers, and microsands used during testing are summarized in Table 5-1.

**TABLE 5-1**
**Chemicals Used during Bench-scale Testing**

| *Chemical* | *Supplier* | *Location* |
|---|---|---|
| **Coagulants** | | |
| Ferric chloride | Kemira North America | Baltimore, MD |
| Commercial liquid alum | Holland Co. | Adams, MA |
| Nalco 2 | Nalco Company | Auburn, NY |
| EPIC-70 | Holland Co. | Adams, MA |
| Nalco 8187 | Nalco Company | Auburn, NY |
| STERNPAC-50 | Slack Chemical Co. | Carthage, NY |
| Praestol K2001 | Clean Waters Inc. | Plessis, NY |
| **Polymers** | | |
| Nalco 7768 | Nalco Company | Auburn, NY |
| Magnafloc 5250 | Applied Specialties | Avon Lake, OH |
| STAFloc 5466 | Slack Chemical Co. | Carthage, NY |
| **Microsand** | | |
| 110 micron effective size | Manley Bros. | Troy Grove, IL |
| 134 micron effective size | Manley Bros. | Troy Grove, IL |

### 5.2.4 FULL-SCALE DEMONSTRATION PROTOCOL

Full-scale demonstration testing was conducted to temporarily and sequentially test alternative modifications to the HRFS system on a full-scale basis. Modifications were developed with assistance from Metro staff, implemented by Metro staff, and tested for approximately at least one week. During PAC testing, one HRFS train typically served as the control and one train as the variable. Samples were collected at numerous locations from the control and variable trains. Analytical data were reviewed on a weekly basis to establish the next steps.

### 5.2.5 SAMPLING AND CHEMICAL ANALYSES

Samples labeled as "grab" were manually collected by Metro staff using the dip method. Composite samples were collected using autosamplers with sample collection starting at 8:30 a.m. Composites were flow weighted and results are reported by start date. Chain-of-Custody records were maintained for all routine and supplemental samples collected.

Most chemical analyses were performed by the WEP Environmental Lab following methods specified in Standard Methods 18th Edition (1992) and outlined in Table 5-2. WEP's laboratory is certified by New York State's Environmental Laboratory Approval Program (ELAP) to perform total phosphorus analyses. On-site field analyses for pH, turbidity and orthophosphate were performed by CRA's chemist during the first round of bench-scale testing.

**TABLE 5-2**
**Chemical Analyses Performed by OCDWEP Environmental Lab**

| *Compound* | *Symbol* | *Analytical Method* | *Reporting Limit (mg/L)* |
|---|---|---|---|
| **Phosphorus** | | | |
| Total phosphorus | TP | Standards Methods 18th Ed. (4500-P E) | 0.003 |
| Dissolved phosphorus | TP-diss | Standards Methods 18th Ed. (4500-P E) | 0.003 |
| Particulate phosphorus | TPP | Calculated:<br>TPP = TP – TP-diss | 0.003 |
| Inorganic phosphorus | TIP | Standards Methods 18th Ed. (4500-P E) | 0.003 |
| Organic phosphorus | TOP | Calculated:<br>TOP = TP – TIP | 0.003 |
| Soluble reactive phosphorus | SRP | Standards Methods 18th Ed. (4500-P E) | 0.001 |
| Dissolved inorganic phosphorus | TIP-diss | Standards Methods 18th Ed. (4500-P E) | 0.003 |
| Dissolved organic phosphorus | TOP-diss | Calculated:<br>TOP-diss = TIP – TIP-diss | 0.003 |
| **Conventional Parameters** | | | |
| Total suspended solids | TSS | Standards Methods 18th Ed. (2540 D) | 1 |
| **Metals** | | | |
| Aluminum | Al | EPA 1994 (200.7) | 0.08 |
| Iron | Fe | EPA 1994 (200.7) | 0.04 |
| Dissolved iron | Fe-diss | EPA 1994 (200.7) | 0.04 |

A strict quality assurance/quality control (QA/QC) protocol was followed by WEP's laboratory on all routine, supplemental, jar test, and pilot testing samples analyzed. For phosphorus species analyses, one matrix spike/matrix spike duplicate (MS/MSD) sample was collected and analyzed for every ten samples. For non-phosphorus analyses, MS/MSD analyses were performed on one out of every 20 samples.

### 5.2.6 STATISTICAL EVALUATION METHODOLOGY

In general, all data were accepted as recorded by Metro WWTP. Statistical evaluations including average, standard deviation and linear regression analyses were performed using MSExcel 2007.

## 5.3 EVALUATION OF EXISTING WWTP PERFORMANCE

Historic process and operational data were reviewed to develop an understanding of current phosphorus treatment performance at the Metro WWTP. Supplemental data were collected, as necessary, to clarify the relationship between key treatment interactions. Evaluation subtasks included:

- Creation of a total phosphorus profile and trending analysis across the Metro facility.
- An assessment of secondary treatment performance including coagulant addition and MLSS concentrations.
- A review of the effect of BAF operation and maintenance activities with respect to phosphorus treatment.
- An evaluation of the HRFS treatment process including a review of the coagulant addition point; coagulant, injection and clarifier tanks; and effects of the current operational and maintenance schedule. The HRFS evaluation included a review of phosphorus speciation and performance of each process train.
- An assessment of current sludge handling practices with respect to phosphorus treatment.

### 5.3.1 PHOSPHORUS PROFILE AND TRENDING ANALYSIS ACROSS THE METRO WWTP

As shown on the phosphorus loading profile (Figure 5-5), an average of 1,208 pounds (lbs.) of phosphorus are received as sewage and septage on a daily basis. The Metro influent load, which includes sewage plus septage and thickener overflow contains an average of 1,261 lbs. of phosphorus. Using the Metro influent load as a baseline, about one third of the phosphorus is removed during primary treatment and an additional 45 percent is removed using secondary treatment for an approximate 81 percent removal prior to tertiary treatment. Final effluent contains, on average, 47 lbs. of phosphorus per day, which represents approximately a 96 percent average reduction from the average influent loading.

In concentration terms, the average Metro influent phosphorus concentration is approximately 2.45 mg/L of total phosphorus (mg TP/L). Primary and secondary treatment effluents are reduced to averages of 1.65 and 0.46 mg TP/L, respectively. Following tertiary treatment through the HRFS system, final effluent contains approximately an average of 0.09 mg TP/L. However, it is critical to note that variability affects effluent concentrations and that the average concentrations should not be considered a measure of reliable treatment. Average, minimum and maximum total phosphorus concentrations are summarized below in Table 5-3. Percent removals were not calculated for concentrations due to the effect of flow changes associated with sludge and recycle streams.

**TABLE 5-3**
**Profile of Historic Total Phosphorus Concentrations**

| ***Location*** | ***2007 – 2010 Concentrations (mg TP/L)*** | | |
|---|---|---|---|
| | ***Average*** | ***Minimum*** | ***Maximum*** |
| Influent | 2.45 | 0.49 | 6.1 |
| Primary effluent | 1.65 | 0.44 | 3.46 |
| Secondary effluent | 0.46 | 0.05 | 1.29 |
| Final effluent | 0.09 | 0.03 | 0.35 |

A plot of secondary effluent total phosphorus concentration as a function of Metro influent concentration (Figure 5-6) shows that influent concentration is generally not a predictor of secondary effluent concentration ($R^2 = 0.002$). This indicates that other parameters, either individually or in combination, may be a more significant indicator of secondary effluent concentration.

Final effluent total phosphorus concentration is poorly correlated ($R^2 = 0.17$) with secondary effluent total phosphorus concentration. As shown on Figure 5-7, although there is a slight trend showing that effluent total phosphorus concentration increases with increasing secondary effluent phosphorus concentration, other factors, as discussed in Section 5.3.4, affect phosphorus removal through the tertiary treatment process.

### 5.3.2 EXISTING SECONDARY TREATMENT PHOSPHORUS REMOVAL PERFORMANCE ASSESSMENT

Metro WWTP's secondary treatment system uses a chemically enhanced activated sludge process. Phosphorus is removed both biologically and chemically, but biologically enhanced nutrient removal, including the luxury uptake of phosphorus through phosphorus accumulating organisms (PAOs), is not practiced by Metro operations staff. Generally, secondary treatment is considered optimized for phosphorus removal because the average effluent concentration of 0.46 mg TP/L is within range of BAF influent specifications (0.3 to 0.5 mg TP/L). Further secondary phosphorus reductions may hinder BAF performance and the ability of Metro to comply with its SPDES limit for ammonia (see Section 5.3.3).

Since the HRFS process was commissioned in 2005, Metro operators have periodically and incrementally adjusted secondary ferric chloride dosages between 0 and 550 gpd per process train. Over the past few years, Metro typically feeds about 150 gpd of ferric chloride per secondary treatment train. As shown on Figure 5-8, there does not appear to be any correlation between daily amount of iron dosed and percent phosphorus removed through secondary treatment. The dominant phosphorus removal mechanism in the secondary aeration process appears to be biological rather than chemical. This is further supported by evidence that suggests that biological process upsets negatively affect secondary and final effluent phosphorus concentrations.

Although there have been few secondary process upsets to review, it appears that periods of extreme cold temperatures, combined with low MLSS may negatively impact secondary treatment performance and subsequently influence final effluent phosphorus concentrations. Most recently, during January and early-February 2011, secondary effluent total phosphorus concentrations were at times greater than 1 mg TP/L and final effluent concentrations were as high as 0.16 mg TP/L. During this time frame, extremely cold temperatures were recorded and MLSS concentrations were lower. At this same time, maintenance staff were cleaning the digesters and returning some digested sludge to the head of the plant. It is theorized that the combination of colder temperatures and low MLSS concentrations may have reduced biological activity and hindered phosphorus removal at a time when phosphorus concentrations were likely higher than typical.

Poor phosphorus removal during extreme cold temperature has also been noted by the chief operator at the Village of Algonquin WWTP (Algonquin, IL), a non-chemical, enhanced biological phosphorus process (EBPR) treatment facility. To promote biological activity during colder temperatures, the Village of Algonquin WWTP maintains higher MLSS levels during winter, which has proven successful. Based on this information, Metro operators gradually raised the MLSS concentration and secondary effluent phosphorus concentrations returned to the target range. Benefits to final effluent or consequences to the BAF cannot be verified until next winter.

It should be noted that optimization of the secondary treatment system through implementation of an EBPR was reviewed and dismissed because an EBPR would offer no improvement to secondary effluent quality and may potentially increase variability while increasing operational complexity.

EBPR processes require cyclic anaerobic and aerobic phases and phosphorus accumulating organisms (PAOs). PAOs differ from typical, glucose accumulating organisms in that PAOs are acclimated to, first, releasing phosphorus under anaerobic conditions and then uptaking large amounts of phosphorus during aerobic conditions. Phosphorus is removed from the flow stream by removing the PAO organisms in the secondary clarifier. Some PAOs are recycled to the anaerobic phase to continue the process.

Although Metro could be a candidate for EBPR because the long hydraulic residence time in the sewers would likely produce the fermentation products needed during the anaerobic phase, the sewers are combined sewers and therefore, during wet weather periods, plant influent contains dissolved oxygen (DO). Discussions with operators at EBPR facilities indicate that even small amounts of DO in the influent or return streams prevent the anaerobic release of phosphorus from PAOs, thereby inhibiting phosphorus uptake during the aerobic phase. Essentially, Metro's ability to perform EBPR during wet weather events would be challenging if not limited, creating a significant source of variability and potential for process upset.

Furthermore, many high performing EBPR facilities achieve effluent qualities of 0.3 mg/L to 0.5 mg TP/L, which is approximately equal to Metro's current secondary effluent quality. Secondary effluent phosphorus levels in this range are necessary to maintain proper BAF operation. Greater phosphorus removal in secondary treatment would thus require the addition of orthophosphate to promote ammonia removal. If an EBPR were implemented, Metro would continue to need tertiary phosphorus removal to achieve its discharge permit limit.

## 5.3.3 REVIEW OF EXISTING BAF O&M ACTIVITIES

The purpose of the BAF is to convert ammonia nitrogen to nitrate through nitrification, a biological process that requires phosphorus to support microbial growth and treatment. Based on discussions with Kruger/Veolia, at least 0.3 mg/L orthophosphate is required for effective BAF operation. Concentrations below this amount may hinder nitrification and Metro's ability to comply with its ammonia discharge limitation.

A review of cumulative BAF influent and effluent phosphorus loads from January 1, 2007 through June 30, 2011 (Figure 5-9) shows that over time, the BAFs consume phosphorus and the influent load is greater than the effluent load. However, there are periods when the slope of the cumulative BAF effluent load is steeper than the slope of the cumulative BAF influent load. This condition signifies that the BAF effluent phosphorus load is greater than BAF influent phosphorus load. The most recent occurrence of this condition was during June 2011 when flows were unusually low, ammonia concentrations were correspondingly higher, and backwashing was performed less frequently due to the lower hydraulic load. Discussions with the BAF manufacturer indicated that this phenomenon has not been reported by other facilities, but could be caused by the sloughing off of phosphorus containing microorganisms that are subsequently carried into the BAF effluent and enter the HRFS system. Because the microbial particles may have a specific gravity near 1.0, they may not settle in the HRFS clarifiers and could contribute to higher phosphorus measurements. This hypothesis provides another example of internal and external conditions may contribute to variability in effluent phosphorus. To minimize sloughing of biogrowth, it may be possible to conduct backwashes more frequently or more vigorously during low flow periods. However, this requires changes to the input of the BAF control program. Backwash control may need to be quickly changed back to original settings should a large wet weather event suddenly occur (i.e., a series of intense thunderstorms).

## 5.3.4 EXISTING HRFS TREATMENT EVALUATION

### 5.3.4.1 EFFECTS OF LOCATING COAGULANT ADDITION TO THE CROSS CHANNEL

In 2005, during tertiary treatment system startup, ferric chloride coagulant was added at the bottom of the HRFS influent box as specified by the design engineer and HRFS manufacturer. Following more than one year of data and observation, Metro staff relocated the coagulant addition point to the Cross Channel in an effort to improve phosphorus removals by providing additional mixing and reaction time. Relocating the coagulant addition point theoretically provided up to 24 seconds of additional contact time at peak flow and 49 seconds at average flow. Immediately following the relocation, HRFS effluent phosphorus concentrations were reduced, which could signify that the process benefitted from longer ferric chloride mixing and contact time. However, a comparison of HRFS influent and effluent data during the period immediately before and after coagulant relocation reveals that during the 26-day period following the relocation (March 17, 2006), HRFS influent phosphorus concentrations were lower than the 26-day period prior to the relocation (see Figure 5-10). A 26-day comparison period was selected because operational conditions remained consistent. During this period, the average phosphorus removal by the HRFS from adding coagulant at the influent box and Cross Channel were virtually the same (76 percent vs. 75 percent). Since the removals are similar, it cannot be determined if additional contact time alone improves performance or that moving coagulant addition to the Cross Channel directly resulted in improved performance. Other factors, such as influent phosphorus concentration, speciation and effective initial mixing may play a greater role. In addition, the hydraulic evaluation (see Section 4.0) indicated that a different location and injection scheme in the influent box could provide sufficient mixing.

As noted in Section 4.0, ferric chloride addition and mixing within the Cross Channel visually appears to be inefficient. Rust-colored pools were routinely observed in the Cross Channel due to current eddies. The size and location of these pools varies depending on BAF unit operations (On/Off/Backwash) and affects coagulant dosing of the HRFS process trains (See Section 5.3.4.2). The presence of these pools indicates that ferric chloride is remaining in the Cross Channel rather than flowing to the HRFS system where it can effectively remove phosphorus. This also suggests that overdosing of ferric chloride could be occurring to compensate for the inefficient mixing.

Operator accounts and photographs taken of the Cross Channel during a maintenance inspection confirms that ferric chloride settles. As discussed in Section 6.0, ferric chloride accumulations have resulted in an increased need for maintenance. The Cross Channel also must be removed from service periodically to maintain the ferric chloride diffuser. The BAF and HRFS systems must be taken completely offline when the Cross Channel is drained, which results in short-term periods of elevated effluent ammonia and phosphorus discharges as secondary effluent is discharged directly without tertiary treatment. Relocating coagulant feed to the HRFS influent boxes would likely reduce Cross Channel maintenance requirements.

### 5.3.4.2 COAGULATION TANK EVALUATION

During the second and third rounds of supplemental data collection, grab samples were collected from each coagulation tank and analyzed for total iron in addition to phosphorus speciation. The iron concentration results, shown on Figures 5-11 and 5-12, support that the ferric chloride fed to each HRFS train was unbalanced. During both rounds, HRFS Trains 1 and 2 contained about 50 percent more iron than the iron dosed in the Cross Channel. These results support visual observations and CFD modeling results. Curiously, during the December, 7, 2010 monitoring event, iron was measured in HRFS Trains 1 and 2 predominantly as dissolved iron rather than particulate iron. It is not understood why this occurred.

Overall, the total amount of iron measured across the four trains during supplemental monitoring rounds 2 and 3 slightly exceeded the amount of iron dosed. Iron dosages are based on the total volume of ferric chloride used and daily flow rate. There are two potential causes for this discrepancy: 1) the chemical metering pumps all require recalibration, or 2) grab samples were collected during a period when previously pooled iron was being flushed from the Cross Channel.

### 5.3.5 INJECTION TANK EVALUATION

During the November 22, 2010 supplemental monitoring event, iron concentrations were measured in each HRFS injection tank. Surprisingly, the average iron concentration was more than double the amount of iron dosed. During the next two supplemental monitoring events, iron and phosphorus were monitored in both the coagulation and injection tanks. The results presented in Table 5-4 show total phosphorus and total iron concentrations increased from the coagulation tank to the injection tank. Since the only inputs to the injection tank are polymer and recycled microsand, the source of the extra phosphorus and iron is from recycled microsand that has not been thoroughly cleaned by the hydrocyclone. Recycling of iron-phosphate sludge does not appear to be detrimental. HRFS trains with iron concentrations of more than 25 mg/l achieved concentrations of 0.055 mg TP/L or less during the sampling events. HRFS trains with iron concentrations less than 18 mg/L had clarifier effluent phosphorus concentrations of more than 0.053 mg TP/L. Conversations with Kruger/Veolia indicate that iron recycling would be expected to improve phosphorus removal.

## TABLE 5-4
## Phosphorus and Iron Concentrations in the Coagulation and Injection Tanks

| *Train* | *Tank Sampled From* | *7-Dec-10* | | *14-Dec-10* | |
|---|---|---|---|---|---|
| | | *TP* | *Fe* | *TP* | *Fe* |
| | | *Concentration (mg/L)* | *Concentration (mg/L)* | *Concentration (mg/L)* | *Concentration (mg/L)* |
| **1** | Coagulation | 0.287 | 18.3 | 0.306 | 19.7 |
| | Injection | 0.555 | **35.3** | 0.535 | **36.4** |
| | Clarifier | **0.055** | 1.2 | **0.046** | 1.4 |
| **2** | Coagulation | 0.313 | 16.9 | 0.306 | 19.8 |
| | Injection | 0.514 | **25.8** | 0.543 | **26.4** |
| | Clarifier | **0.037** | 0.7 | **0.040** | 0.9 |
| **3** | Coagulation | 0.384 | 12.3 | 0.260 | 9.1 |
| | Injection | 0.392 | **18.2** | 0.652 | **14.1** |
| | Clarifier | **0.067** | 2.2 | **0.053** | 1.2 |
| **4** | Coagulation | 0.340 | 12.1 | 0.244 | 5.8 |
| | Injection | 0.415 | **12.5** | 0.346 | **9.2** |
| | Clarifier | **0.064** | 0.9 | **0.060** | 1.2 |

The amount of iron and phosphorus-rich sludge recycled with the microsand is reported by Kruger/Veolia to be a function of hydrocyclone apex tip diameter. Larger diameters are expected to recycle more sludge. Therefore, specifying a larger apex tip diameter to permit greater iron recycling into the injection tank could be a low-cost option for improving phosphorus removal. The apex tips installed on the hydrocyclones were originally 2 inches in diameter but have since increased because of abrasion, as shown on Table 5-5. However, there does not appear to be a correlation between tip area and iron increase at the injection tank indicating that other factors could affect iron recycling.

It is suggested the operations staff periodically monitor apex tip diameter, iron concentration in the injection, and effluent phosphorus concentration to track any changes that occur.

**TABLE 5-5**
**Effect of Apex Tip Diameter on Iron Recycling**

| *Process Train* | *Apex Tip Diameter* | *Apex Tip Area Increase* | *Average Iron Concentration (mg/L)* | | *Iron Increase* | |
|---|---|---|---|---|---|---|
| | *(in)* | *(%)* | *Coagulation Tank* | *Injection Tank* | *(mg/L)* | *(%)* |
| 1 | 2.75 | 84 | 10.8 | 21.7 | 10.9 | 101 |
| 2 | 2.60 | 65 | 13.6 | 16.8 | 3.2 | 23 |
| 3 | 2.64 | 70 | 12.4 | 21.8 | 9.4 | 75 |
| 4 | 2.57 | 61 | 16.2 | 28.2 | 12.0 | 74 |

A further review of injection tank data shows that during the three rounds of testing, the average injection tank iron concentrations were approximately equal (21.2 to 22.9 mg/L as Fe) but the influent phosphorus concentration varied, as shown on Table 5-6. For Round 1, the influent phosphorus concentration equaled 0.337 mg TP/L while Rounds 2 and 3 equaled 0.219 and 0.218 mg TP/L, respectively. Interestingly, about 76 percent of the influent phosphorus was removed in all three rounds. However, this should not be misconstrued as a statement that the HRFS units achieve 76 percent removal at an injection tank iron concentration of about 22 mg Fe/L. A review of the similarities and differences of the composition of the residual phosphorus is more revealing. The inorganic phosphorus fractions for all three rounds equaled about 0.028 mg/L, but the organic fractions varied depending on influent phosphorus concentration. The round with the highest influent phosphorus concentration had nearly double the residual organic phosphorus concentration as the two rounds with lower influent phosphorus concentrations. These results support that HRFS preferentially removes some phosphorus species and residual phosphorus concentrations will likely vary depending on what phosphorus species are present in the influent.

## TABLE 5-6

## Effect of HRFS Influent Phosphorus Concentration

| *Round* | *HRFS Influent TP Conc. (mg/L)* | *Injection Tank Iron Conc. (mg/L)* | *Effluent TP Conc. (mg/L)* | *Percent Removal (%)* | *Effluent Inorganic P Conc. (mg/L)* | *Effluent Organic P Conc. (mg/L)* |
|---|---|---|---|---|---|---|
| 1 | 0.337 | 22.3 | 0.083 | 75 | 0.030 | 0.053 |
| 2 | 0.219 | 22.9 | 0.052 | 76 | 0.026 | 0.026 |
| 3 | 0.218 | 21.2 | 0.050 | 77 | 0.027 | 0.023 |

**Notes:** Based on grab sample data.

Values shown are average process train concentrations for that round.

A third factor that may affect phosphorus removal through HRFS is the state that iron is in. A review of soluble reactive phosphorus (SRP) data, summarized in Table 5-7, indicates that SRP generally reacts quickly with iron. For two of the samples that were not as reactive (denoted with an asterisk), iron samples collected from the injection tank indicate that the iron was more than 90 percent dissolved (See Figures 5-11 and 5-12). Results of other tests indicate iron is typically up to 99 percent particulate.

## TABLE 5-7

## Soluble Reactive Phosphorus Data

| *HRFS Influent Concentration (mg/L)* | *Injection Tank Concentration (mg/L)* | | | |
|---|---|---|---|---|
| | *Train 1* | *Train 2* | *Train 3* | *Train 4* |
| 0.098 | 0.031* | 0.04* | 0.002 | 0.003 |
| 0.065 | 0.006 | 0.003 | 0.002 | 0.04 |

**Note:** * Corresponding iron results were comprised of more than 90 percent dissolved iron.

### 5.3.6 HRFS SETTLING TANK EVALUATION

Particulate, SRP, and non-reactive soluble phosphorus were monitored in the HRFS settling tank effluent during Round 3 of supplemental data collection. The results shown in Figure 5-13 indicate the following:

- All four trains yield approximately equal amounts of SRP (0.001 mg/L to 0.004 mg/L) and soluble non-reactive phosphorus fractions (0.013 mg/L to 0.017 mg/L).
- Trains 1 and 2 yield similar amounts of particulate phosphorus (approximately 0.027 mg/L)
- Trains 3 and 4 yield similar amounts of particulate phosphorus (approximately 0.039 mg/L) which is about 50 percent greater than levels measured in Trains 1 and 2.

The main differences between the two sets of trains are that Trains 1 and 2 had higher iron concentrations in the injection tanks and the HRFS settling tanks were cleaned the day before sampling. Trains 3 and 4 had lower iron concentrations in the injection tanks and the HRFS settling tanks had not been cleaned in ten days.

Data from the full-scale demonstration suggests that if cleaned settling tanks improve HRFS performance, the improvement is short-lived. As shown on Table 5-8, performance improved on March 8, the day the settling tanks were cleaned, but returned to pre-cleaning levels the next day. Metro operators indicate that when the settling tanks are cleaned, sludge is flushed to the hydrocyclone, which appears to cause a spike in iron concentration in the injection tank. As discussed previously, this may be a key factor in phosphorus removal.

## TABLE 5-8
## HRFS Settling Tank Effluent Monitoring (Concentrations in mg/L)

| *Date* | *Train 1* | | | *Train 1* | | |
|---|---|---|---|---|---|---|
| | *Iron Concentration* | | *Effluent TP Concentration* | *Iron Concentration* | | *Effluent TP Concentration* |
| | *Coag. Tank* | *Injection Tank* | | *Coag. Tank* | *Injection Tank* | |
| 3/6/11 | Not sampled | 20.5 | 0.08 | Not sampled | 16.8 | 0.06 |
| 3/7/11 | 10.95 | 22.3 | 0.08 | 12.6 | 15.5 | 0.06 |
| 3/8/11 | 10.9 | 39.3 | 0.03 | 12.4 | 20 | 0.02 |
| 3/9/11 | 10.02 | 20.3 | 0.12 | 14.1 | 17.3 | 0.04 |
| 3/10/11 | 10.7 | 21.2 | 0.13 | 13.7 | 15.4 | 0.08 |

To further establish the effect of settling tank cleaning on HRFS performance, effluent total suspended solids and phosphorus concentrations were compared with respect to the most recent cleaning date for each of the three rounds of supplemental data collection. As shown on Table 5-9, there does not appear to be any correlation between performance and date on which clarifiers were last cleaned. For example, for the first two rounds of data, HRFS Trains 1 and 2 were last cleaned on November 14. Samples collected for the second round had a better water quality than samples collected for the first round. Therefore, it seems that settling tank performance had not degraded during the additional two weeks of processing.

## TABLE 5-9

## HRFS Clarifier Effluent Monitoring (Concentrations in mg/L)

| *Test Date (2010)* | *Train 1* | | | *Train 2* | | | *Train 3* | | | *Train 4* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **TSS** | **TP** | **Most Recent Cleaning** | **TSS** | **TP** | **Most Recent Cleaning** | **TSS** | **TP** | **Most Recent Cleaning** | **TSS** | **TP** | **Most Recent Cleaning** |
| 11/22 | 6 | 0.094 | 11/14/10 | <4 | 0.068 | 11/17/10 | 4 | 0.107 | 11/5/10 | 4 | 0.063 | 11/5/10 |
| 12/7 | 5 | 0.039 | 11/14/10 | <4 | 0.037 | 11/17/10 | 5 | 0.067 | 12/4/10 | 6 | 0.064 | 12/4/10 |
| 12/14 | <4 | 0.046 | 12/13/10 | <4 | 0.04 | 12/13/10 | 5 | 0.053 | 12/4/10 | <4 | 0.06 | 12/4/10 |

These analyses collectively suggest that iron concentration in the injection tank is a more significant variable than settling tank-cleaning frequency. It also suggests that the current cleaning schedule is adequate and more frequent cleaning would not improve performance.

### 5.3.7 OVERALL COMPARISON OF PROCESS TRAINS

Based on the three rounds of supplemental data collection, HRFS Train 2 appears to perform the best. It most consistently achieves the lowest effluent phosphorus concentration. HRFS Train 3 appears to perform the worst. Train 1 performs well at times; however, the iron concentrations in the injection tank are much higher than the other process trains so better performance would be expected.

### 5.3.8 EFFECT OF RETURNING SLUDGE HANDLING STREAMS

Metro WWTP thickens, anaerobically digests, and dewaters sludge from the primary, secondary, and HRFS systems along with sludge that it receives from four other WEP facilities. Thickener overflow and centrate (reject water from the centrifuge) streams are returned to the head of the plant, combined with sewage and septage and reprocessed through the WWTP. Although it is well-documented that anaerobic digestion releases phosphorus from the sludge to the return streams (EPA, 2010) and that management of recycle flows is a key performance factor for facilities achieving low phosphorus levels (EPA, 2008), routine monitoring data show that return streams represent a minor load to the WWTP when compared to the influent concentration. Thickener overflow contributions represent approximately 4 percent (52 lbs) of the total phosphorus load to the primary treatment system. Centrate contributions are approximately 142 lbs per day (11 percent). Generally, the majority of centrate contributions are well below 142 lbs per day (See Figure 5-14). However, as with other treatment processes, there appears to be periods when process upsets occur. The most extended of these periods occurred during mid-February 2010. During the worst of this upset, centrate loads approached 1,500 lbs per day, nearly ten times greater than average. It should be noted that although centrate loads were exceptionally high during this period, final effluent was not negatively affected. In fact, final effluent loads were about 10 lbs per day below average. A review of other days with high centrate supports this. Final effluent concentrations on days of high centrate loads were generally well below the average final effluent load.

It is postulated that sludge return streams represent a minor load and do not significantly impact Metro effluent phosphorus concentrations for three reasons.

1. On molar basis, Metro overdoses coagulant in the HRFS system. Excess metal is returned to the anaerobic digesters where it is available to react with released phosphorus.

2. WEP previously implemented a sludge management plan to equalize overflow thickener and centrate return streams. Although WEP accepts sludge from four other WEP facilities, these sludges are equalized in the thickened sludge blend tank before digesting.

3. Secondary treatment streams appear to be optimized and further secondary treatment phosphorus reductions could impair BAF performance and ammonia compliance.

## 5.4 COMPARATIVE BENCH-SCALE TESTING PROGRAM

Three rounds of comparative bench-scale testing were conducted on HRFS influent to evaluate if a modified treatment scheme could promote the conditions for optimizing phosphorus removal. Source water was collected in the Cross Channel, upstream of the coagulant diffuser. As a precaution, coagulant feed was turned off prior to sample collection. The standard jar testing procedure and sources of chemicals are provided in Section 5.2.2. The goals of each round of testing along with sample collection date are outlined in Table 5-10. It is noteworthy that in terms of the LOT definition, bench-scale testing represents ideal conditions and the results should be considered to the ideal Technology Performance Statistic (TPS-14d).

**TABLE 5-10**
**Summary of Bench-Scale Sample Dates and Test Objectives**

| *Round No.* | *Sample Date* | *Test Objective* |
|---|---|---|
| 1 | 12/15/2010 | a. Evaluate the effect of coagulant type and dose and polymer type on phosphorus removal. Ferric chloride, alum (Holland CLA), sodium aluminate (Nalco 2) and four types of PAC (Holland EPIC-70, Nalco 8187, Praestol K2001, and STERNPAC-50) were tested as coagulants. Three polymers were tested: Nalco 7768, Magnafloc 5250, and STAFloc5466.<br>b. Evaluate the effect of microsand size on phosphorus removal.<br>c. Identify chemical combinations that perform equal to or better than the current chemical combination.<br>All tests during this round simulated adding coagulant at the drop box |
| 2 | 1/4/2011 | a. Test and compare the most promising chemical combinations from the first round to further support their effectiveness<br>b. Evaluate the effect of microsand size and dose on phosphorus removal.<br>All tests during this round simulated adding coagulant at the drop box. |
| 3 | 1/18/2011 | a. Evaluate the effect of coagulant reaction time on total phosphorus removal and residual SRP concentration.<br>b. Identify possible coagulant addition locations based on reaction times needed for optimal chemistry. |

### 5.4.1 SUMMARY OF THE FIRST ROUND OF COMPARATIVE BENCH-SCALE TESTING

Results from the first round of comparative bench-scale testing are contained in Appendix A and summarized below. Source water used for all tests contained 0.197 mg TP/L. On the day the source water was collected, final effluent at Metro WWTP contained 0.066 mg TP/L. Jar testing of the source water using the current dosing combination (ferric chloride at 30 mg/L, Nalco 7768 polymer at 0.6 mg/L, and 5 g/L of 134 micron effective size sand) yielded a supernatant with a residual phosphorus concentration of 0.033 mg TP/L. A comparison of these two results shows that jar testing did not accurately predict final effluent concentrations. However, because results are similar, jar testing was used as a comparative test for evaluating multiple coagulants, polymers, and effective microsand sizes.

Results using Praestol K2001 and Nalco-2 are not presented in the following sections because the test data showed that these coagulants at the dosages tested are inappropriate for the Metro WWTP. Residual phosphorus concentrations for Praestol K2001 and Nalco-2 were consistently more than four times the residual concentrations of the other coagulants tested. Results for these two coagulants are, however, included in Appendix A.

### 5.4.1.1 COMPARISON OF VARIOUS COAGULANTS AND POLYMERS

Jar testing of the various coagulants at the manufacturer's recommended dosage showed that ferric chloride, alum, and polyaluminum chloride (PAC) performed similarly with residual concentrations in the range of 0.029 to 0.055 mg TP/L (see Table 5-11). Any of the coagulants shown in combination with any of the three polymers listed would be appropriate for low level phosphorus removal at Metro WWTP.

**TABLE 5-11**
**Comparison of Various Coagulants and Polymers**

| *Coagulant* | *Coagulant Dose (mg/L)* | *Residual Phosphorus Concentration (mg TP/L)* | | |
|---|---|---|---|---|
| | | *Polymer* | | |
| | | *Nalco 7768* | *Magnafloc 5250* | *STAFloc 5466* |
| Ferric chloride | 30 | 0.033 | 0.035 | 0.032 |
| Alum (CLA) | 50 | 0.036 | 0.032/0.044 | 0.032 |
| PAC (EPIC-70) | 30 | 0.029 | 0.030 | 0.032 |
| PAC (Nalco 8187) | 30 | 0.040 | 0.044 | 0.046 |
| PAC (STERNPAC-50) | 30 | 0.055 | 0.046 | 0.043 |

**Test Conditions:**

Coagulant was dosed at the manufacturer recommended concentration
Polymer was dosed at 0.6 mg/L
Microsand with an effective size of 134 microns was dosed at 5 g/L

The best performing coagulant for the first round was PAC (EPIC-70) in combination with Nalco 7768 polymer. The residual phosphorus concentration for this combination was 0.029 mg TP/L, slightly lower than the residual concentration for Metro WWTP's current coagulant/polymer combination. EPIC-70 performed well with Magnafloc 5250 and STAFloc 5466 polymers. Ferric chloride and alum performed nearly as well as the EPIC-70 with residual concentrations ranging between 0.032 and 0.044 mg TP/L.

Residual concentrations for the other PAC types, Nalco 8187 and STERNPAC-50, were slightly higher. If WEP were to proceed with either of these two coagulants, additional testing would be required to refine dosages and establish optimal conditions.

The three polymers tested performed similarly with concentrations differing by less than 0.03 mg TP/L for most coagulants. Any of the three polymers appear to be appropriate for use at Metro WWTP. Alternate polymers may also be appropriate. It was identified that WEP consider a requirement for alternate polymer suppliers to conduct jar testing with the proposed coagulant to verify acceptable performance prior to submitting cost proposals during the required competitive bid process.

#### 5.4.1.2 EFFECT OF DOUBLING THE COAGULANT DOSE

Coagulant dosages were doubled to evaluate the improvement that could be expected with large excesses of coagulant present. Generally, improvements of less than 0.01 mg TP/L were recorded and residual phosphorus concentrations were reduced to less than 0.025 mg TP/L when Magnafloc 5250 and STAFloc 5466 polymers were used (see Tables 5-12 and 5-13). No improvement was shown by doubling the coagulant dose when the current polymer Nalco 7768 was used (see Table 5-14).

**TABLE 5-12**
**Effect of Doubling Coagulant Dose Using Magnafloc 5250 Polymer**

| *Coagulant* | *Coagulant Manufacturer Recommended Dose (mg/L)* | *Residual Phosphorus Concentration (mg/L)* | |
|---|---|---|---|
| | | *Coagulant Dose* | |
| | | *At the Manufacturer Recommended Dose* | *At Twice the Manufacturer Recommended Dose* |
| FeCl3 | 30 | 0.035 | 0.026 |
| Alum (CLA) | 50 | 0.032/0.044 | 0.022 |
| PAC (EPIC-70) | 30 | 0.030 | 0.023 |
| PAC (Nalco 8187) | 30 | 0.044 | 0.043 |
| PAC (STERNPAC-50) | 30 | 0.046 | 0.031 |

**Test Conditions:**

Magnafloc 5250 polymer was dosed at 0.6 mg/L
Microsand with an effective size of 134 microns was dosed at 5 g/L

Note: During testing of the ferric chloride/Magnafloc 5250 sample (identified as sample 630742-2-1 in Appendix A), jar test procedures were modified (see below for discussion) and the sample was retested. Results for both tests are reported below.

**TABLE 5-13**
**Effect of Doubling Coagulant Dose Using STAFloc 5466 Polymer**

| *Coagulant* | *Coagulant Manufacturer Recommended Dose (mg/L)* | *Residual Phosphorus Concentration (mg/L)* | |
|---|---|---|---|
| | | *Coagulant Dose* | |
| | | *At the Manufacturer Recommended Dose* | *At Twice the Manufacturer Recommended Dose* |
| FeCl3 | 30 | 0.032 | 0.026 |
| Alum (CLA) | 50 | 0.032 | 0.024 |
| PAC (EPIC-70) | 30 | 0.032 | 0.024 |
| PAC (Nalco 8187) | 30 | 0.046 | 0.037 |
| PAC (STERNPAC-50) | 30 | 0.043 | 0.033 |

**Test Conditions:**

STAFloc 5466 polymer was dosed at 0.6 mg/L
Microsand with an effective size of 134 microns was dosed at 5 g/L

**TABLE 5-14**
**Effect of Doubling Coagulant Dose Using Nalco 7768 Polymer**

| *Coagulant* | *Coagulant Manufacturer Recommended Dose (mg/L)* | *Residual Phosphorus Concentration (mg/L)* | |
|---|---|---|---|
| | | *Coagulant Dose* | |
| | | *At the Manufacturer Recommended Dose* | *At Twice the Manufacturer Recommended Dose* |
| FeCl3 | 30 | 0.033 | 0.041 |
| Alum (CLA) | 50 | 0.036 | 0.084 |
| PAC ( EPIC-70) | 30 | 0.029 | 0.101 |
| PAC (Nalco 8187) | 30 | 0.040 | 0.161 |
| PAC (STERNPAC-50) | 30 | 0.055 | 0.049 |

**Test Conditions:**

Nalco 7768 polymer was dosed at 0.6 mg/L
Microsand with an effective size of 134 microns was dosed at 5 g/L

Although increasing the coagulant dose slightly improved phosphorus removal using some of the polymers, there is a point of diminishing returns. As an example, theoretically, 1 mol of metal coagulant reacts with 1 mol of phosphorus (Bratby, 2008). The source water used for this test contained 0.006 mmol of phosphorus. Coagulant dosages were set at 0.2 mmol of metal; either iron or aluminum. The metal to phosphorus ratio during this test was 30:1. Using one of the best performing coagulant/polymer combinations under both sets of coagulant dosages (EPIC-70 and Magnafloc 5250), phosphorus removals increased from 85 percent at a 30:1 metal to phosphorus ratio to an 88 percent phosphorus removal at a 60:1 ratio. If implemented, this minor improvement would result in a significant operating cost increase. Depending on coagulant selected by WEP, annual HRFS coagulant usage and sludge disposal costs could be expected to double, approaching nearly $4,500,000 per year combined.

### 5.4.1.3 IMPACT OF EFFECTIVE MICROSAND SIZE

During HRFS, microsand serves as ballast that phosphorus-containing floc adheres to. By decreasing the effective size of the microsand while maintaining the same density, more microsand particles are available and the chances of particle collision and the potential to remove more particulate phosphorus increases. During the first round of sampling, two effective sand sizes, 110 and 134 microns, were tested at a dose of 5 g/L. Coagulant was dosed at the chemical manufacturer recommended concentration. Magnafloc 5250 was dosed at 0.6 mg/L. The results, contained on Table 5-15, show that reducing effective sand size improved phosphorus removal in all but one sample.

**TABLE 5-15**
**Effect of Microsand Size**

| *Coagulant* | *Coagulant Dose (mg/L)* | *Residual Phosphorus Concentration (mg/L)* | |
|---|---|---|---|
| | | *Effective Size Microsand* | |
| | | *134* | *110* |
| FeCl3 | 30 | 0.035 | 0.030 |
| Alum (CLA) | 50 | 0.032/0.044 | 0.027 |
| PAC (EPIC-70) | 30 | 0.030 | 0.025 |
| PAC (Nalco 8187) | 30 | 0.044 | 0.038 |
| PAC (STERNPAC-50) | 30 | 0.046 | 0.046 |

**Test Conditions:**
Magnafloc 5250 polymer dosed at 0.6 mg/L
Microsand dosed at 5 g/L

Though the improvements are similar to removals observed by doubling the coagulant dose (Section 5.4.1.2), the cost to implement this change would be expected to be relatively minor. According to Manley Bros. of Indiana, Metro WWTP's current microsand supplier, both microsands cost the same. Microsand losses would be expected to increase though, if a smaller size was used and replacement costs would increase accordingly. Smaller size microsand settles more slowly and therefore carryover from the HRFS clarifier to downstream equipment would likely increase, especially at high flows. Phosphorus removals would be expected to decrease at higher flows.

One observation recorded during jar testing reveals the importance of baffling in the mixing tanks. Some of the larger microsand settled at all mixing rates including rapid mixing at 300 revolutions per minute (rpm) and could only be suspended by placing a spatula in the jar to serve as a baffle. Tests were conducted without baffling. The smaller size microsand remained suspended at all mixing rates. To be effective, the microsand must remain in suspension during mixing. Visual examination of the settled particles following jar testing indicated that the microsand and floc appeared to be physically separate. In a ballasted flocculation system, the microsand and floc form a physical bond. Operators have noted that settled particles removed from the HRFS clarifier are physically attached.

#### 5.4.1.4 MOST PROMISING COAGULANT AND POLYMER COMBINATIONS

The five best results (0.025 mg TP/L phosphorus or less) were achieved using the dosing combinations shown on Table 5-16. The first four combinations used a coagulant dose of twice the amount recommended by the manufacturer. The fifth used a more reasonable coagulant dose equal to the amount recommended by the manufacturer, but relied on a smaller effective sand size to achieve the low residual phosphorus.

**TABLE 5-16**
**Five Best Test Results for Comparative Bench Testing Round 1**

| *Coagulant Type* | *Coagulant Dose (mg/L)* | *Polymer Type (all at 0.6 mg/L)* | *Sand Size (all at 5 g/L)* | *Supernatant Phosphorus Concentration (mg/L)* |
|---|---|---|---|---|
| Alum (CLA) | 100 | Magnafloc 5250 | 134 | 0.022 |
| PAC (EPIC-70) | 60 | Magnafloc 5250 | 134 | 0.023 |
| Alum (CLA) | 100 | STAFloc 5466 | 134 | 0.024 |
| PAC (EPIC-70) | 60 | STAFloc 5466 | 134 | 0.024 |
| PAC (EPIC-70) | 30 | Magnafloc 5250 | 110 | 0.025 |

Based on the results of the first round of comparative bench-scale testing, the most promising combinations for reducing phosphorus are:

- Coagulants: PAC (EPIC-70) and Alum (CLA)
- Polymers: Magnafloc 5250 and STAFloc 5466
- Sand Size: 110 micron

### 5.4.2 SUMMARY OF THE SECOND ROUND OF COMPARATIVE BENCH-SCALE TESTING

The second round of comparative bench-scale testing was conducted on two microsand sizes (110 and 134 microns) using four coagulant/polymer combinations:

- Ferric chloride dosed with 0.6 mg/L Nalco 7768 polymer (current coagulant and polymer)
- PAC (EPIC-70) dosed with Magnafloc 5250 polymer dosed at 0.6 mg/l
- PAC (EPIC-70) dosed with STAFloc 5466 polymer dosed at 0.6 mg/l or
- Alum (CLA) dosed with Magnafloc 5250 polymer dosed at 0.6 mg/l

Results of the second round of comparative bench-scale testing are contained in Appendix A and summarized in the sections that follow. Source water used for all tests contained 0.172 mg/L total phosphorus. On the day the source water was collected, final effluent at Metro WWTP contained 0.062 mg/L phosphorus. Jar testing of the source water dosed with Metro WWTP's current combination (ferric chloride at 30 mg/L, Nalco 7768 polymer at 0.6 mg/L, and 5 g/L of 134 micron effective size microsand) yielded a supernatant with a residual phosphorus concentration of 0.070 mg TP/L.

#### 5.4.2.1 COMPARISON OF THE MOST PROMISING COAGULANT AND POLYMER COMBINATIONS

Jar testing of the four coagulant and polymer combinations were conducted using three coagulant dosages and microsand with an effective size of 110 microns. The results are presented in Figure 5-15. Tests were repeated for three of the combinations using Metro WWTP's current microsand (134 micron effective size). Results are presented in Figure 5-16. In general, EPIC-70 combined with Magnafloc 5250 and ferric chloride combined with Nalco 7768 achieved good phosphorus removals. Alum dosages appear to be too low to achieve similar results. EPIC-70 with STAFloc polymer performed poorly in comparison with the other coagulant/polymer combinations.

The two plots, Figures 5-15 and 5-16, show a trend between coagulant dose and residual phosphorus concentration. Because the PAC and ferric coagulant concentrations selected for this round of testing were within range of the metal molar concentration currently applied by Metro WWTP (0.2 mmol metal), it is possible that phosphorous removal improvements could be achieved by increasing the coagulant dosage within this range. This could be most beneficial during periods when upstream process upsets occur or during periods when Metro WWTP's rolling annual average is approaching the permitted discharge level.

#### 5.4.2.2 <u>EFFECT OF MICROSAND SIZE ON PHOSPHORUS RESIDUAL</u>

Microsands with two effective sizes (110 and 134 microns) were compared by jar testing three coagulant and polymer combinations at three coagulant dosages each. For all paired samples but one, the smaller microsand aided in removing more phosphorus than the larger size microsand with improvements averaging 0.012 mg TP/L (see Table 5-17). These results in combinations with results from the first round of comparative bench-scale testing (Section 5.4.1.3) support that microsand replacement may be beneficial in reducing phosphorus residuals. However, caution is warranted. A full-scale demonstration on one HRFS train would be necessary because smaller-sized microsand carryover may increase from the HRFS clarifier to downstream equipment. The amount of carryover would need to be evaluated and benefits/disadvantages evaluated before microsand is replaced in all four HRFS trains.

## TABLE 5-17
## Comparison of Two Microsand Sizes on Phosphorus Residual

| *Coagulant* | *Coagulant Dose (mg/L)* | *Total Phosphorus Concentration (mg/L)* | | |
|---|---|---|---|---|
| | | *Effective Microsand Size (microns)* | | *Improvement from Using Smaller Size Microsand* |
| | | **134** | **110** | |
| Ferric chloride | 24 | 0.069 | 0.052 | 0.017 |
| | 30 | 0.070 | 0.048 | 0.022 |
| | 36 | 0.056 | 0.044 | 0.012 |
| PAC (EPIC-70) | 24 | 0.070 | 0.064 | 0.006 |
| | 30 | 0.068 | 0.058 | 0.010 |
| | 36 | 0.053 | 0.040 | 0.013 |
| Alum (CLA) | 30 | 0.090 | 0.077 | 0.013 |
| | 40 | 0.087 | 0.075 | 0.012 |
| | 50 | 0.063 | 0.064 | -0.001 |
| | | | **Average** | **0.012** |

**Test Conditions:**

Magnafloc 5250 polymer was dosed at 0.6 mg/L

### 5.4.2.3 EFFECT OF MICROSAND DOSE

Microsand with an effective size of 110 microns was dosed at four concentrations to establish the effect of sand dose on phosphorus removal. The results, shown on Table 5-18 show no discernible trend and little difference between residual phosphorus concentrations when microsand is dosed in the range of 3 to 9 g/L. Metro's current practice of maintaining a microsand concentration of 5 g/L appears adequate and performance would likely not improve if higher microsand concentrations were maintained. Results show that routinely operating below this range is not effective and may be detrimental if operators are unable to replenish sand in a timely manner.

**TABLE 5-18**
**Effect of Microsand Dose**

| *Microsand Dose (g/L)* | *Total Phosphorus Concentration (mg/L)* |
|---|---|
| 3 | 0.056 |
| 5 | 0.058 |
| 7 | 0.051 |
| 9 | 0.054 |
| Average | 0.055 |
| Standard Deviation | 0.003 |

**Test Conditions:**
PAC (EPIC-70) was dosed at 30 mg/L
Magnafloc 5250 polymer was dosed at 0.6 mg/L
Sand effective size was 110 microns

### 5.4.3 SUMMARY OF THE THIRD ROUND OF COMPARATIVE BENCH-SCALE TESTING

The third round of jar testing was used to evaluate the effect of relocating the coagulant addition point on phosphorus treatment. Relocating the coagulant addition point further upstream would increase coagulant reaction and mixing time. Testing was conducted using three coagulant/polymer combinations: PAC (EPIC-70) with Magnafloc 5250, alum (CLA) with Magnafloc 5250, and ferric chloride with Nalco 7768. PAC testing was performed using four coagulant dosages. Alum and ferric chloride testing was conducted using three coagulant dosages. All coagulant dosages were within range of the molar dose currently applied by Metro WWTP (0.2 mmol metal). Testing was conducted using microsand with an effective size of 110 microns and a dose of 5 g/L. The three mixing scenarios simulated were:

1. Coagulant addition at the HRFS influent box
2. Coagulant addition at the Cross Channel diffuser header under peak flow conditions
3. Coagulant addition at the Cross Channel diffuser header under average flow conditions

To simulate chemical addition and mixing within the Cross Channel, the standard jar test procedure described in Section 5.2.2 and shown on Figure 5-4 was modified by providing additional flocculation mixing time at 215 rpm prior to the start of the standard jar test procedure. For Mixing Scenarios 2 and 3, the additional flocculation mixing time provided was 24 and 49 seconds, respectively. These times represent the approximate length of time required for a particle to travel from the existing coagulant diffuser header to the HRFS influent box of Train 3 under their respective flow conditions. Calculation of these times assumed that equalized flow distribution would occur across the Cross Channel. Figures depicting the modified jar test procedures for Mixing Scenarios 2 and 3 are provided as Figures 5-17 and 5-18, respectively.

Results of the third round of comparative bench-scale testing are contained in Appendix A and summarized in the sections that follow. Source water used for all tests contained 0.31 mg TP/L. On the day the source water was collected, final effluent at Metro WWTP contained 0.095 mg TP/L. Jar testing of the source water dosed with the current coagulant/polymer/microsand combination (ferric chloride at 30 mg/L, Nalco 7768 polymer at 0.6 mg/L, and 5 g/L of 134 micron effective size sand) was not performed - rather a smaller microsand size was used. Supernatant results for the smaller microsand were 0.065 mg TP/L.

#### 5.4.3.1 COMPARISON OF COAGULANT TYPE AND DOSE ON PHOSPHORUS REMOVAL

As shown on Figure 5-19, coagulant type and concentration impacted residual phosphorus concentration. As with previous rounds of jar testing and observations from the literature, residual phosphorus concentrations decreased as coagulant concentration increased. The lowest residual phosphorus concentrations were achieved using EPIC-70 coagulant in the dosage range of 24 to 36 mg/L. Residual phosphorus concentrations for this coagulant ranged from 0.03 to 0.06 mg TP/L. Results for ferric chloride and CLA were higher. Ferric chloride at a dose of 30 mg/L yielded phosphorus concentrations of 0.064 to 0.073 mg TP/L. CLA at a dosage range of 42.5 to 70 mg/L yielded residual phosphorus concentrations of 0.043 to 0.08 mg TP/L.

#### 5.4.3.2 EFFECT OF REACTION TIME ON TOTAL PHOSPHORUS REMOVAL

As shown on Figure 5-19 residual phosphorus concentration generally decreased with an increase in reaction time for the two aluminum-based coagulants, EPIC-70 and CLA. This supports manufacturer's observations at other facilities. For EPIC 70, this difference appears to be more pronounced at lower coagulant concentrations.

The time dependency of aluminum-based coagulant may be a result of changing temperature. Discussions with Holland Co., the PAC and alum supplier, indicated that other facilities have noticed a temperature effect associated with aluminum-based coagulants. Since bench-scale testing was conducted during January, it is highly possible that the reaction time dependency may reduce during warmer temperatures.

Comparative bench-scale data for ferric chloride are insufficient to establish a time-based trend. Although similar residual phosphorus concentrations were achieved under Mixing Scenarios 1 and 3, the residual TP for Mixing Scenario 2 was about 12 percent higher than the other two samples. Given that iron is generally considered more reactive than aluminum and iron appeared to react quickly with SRP (see Section 5.3.5), there may not be a correlation between iron reaction time and phosphorus removal.

#### 5.4.3.3 EFFECT ON SRP

SRP results are provided in Appendix A and ranged from less than 0.001 to 0.017 mg SRP/L. In general, results were inconsistent for coagulant type and dose and for reaction time.

#### 5.4.3.4 POTENTIAL LOCATIONS FOR COAGULANT ADDITION

Comparative bench-scale testing results support that performance of aluminum-based coagulants appears to improve with additional reaction time. Therefore, if PAC or alum is selected as the coagulant on a year-round basis, lower effluent phosphorus concentrations might be achieved by dosing coagulant in the Cross Channel rather than at the HRFS drop box. Relocating the coagulant addition point even further upstream to provide additional reaction and mixing time is not possible. Kruger/Veolia, the manufacturer of the BAFs which are located upstream of the HRFS system, was contacted for their input on potential BAF performance issues. Other than increases in headloss that could cause excessive backwashing, Kruger Veolia was concerned that too much phosphorus would be removed if coagulant were dosed upstream of the BAFs and the minimum orthophosphate concentration required for BAF performance (0.3 mg/L) could not be maintained.

PAC appears promising as an alternative coagulant because it provides good phosphorus removal. However, the reaction time dependency poses a challenge, particularly during colder months. Iron recycled with the microsand in the injection tank may improve HRFS performance. If PAC is used, there may be insufficient reaction time to realize this benefit. A full-scale, side-by-side comparison was conducted using PAC and ferric chloride as the coagulants to establish if PAC could be dosed at the

HRFS influent box without hindering phosphorus treatment performance. The results of this evaluation are contained in Section 5.7.6.

## 5.5 SUMMARY OF ALTERNATIVE PROCESS MODIFICATIONS

Results of the process evaluation were divided into three categories: 1) operational, 2) optimal treatment scheme, and 3) effects on the HRFS process from hydraulic and mixing conditions. Alternatives for operational improvements and optimizing the treatment scheme are discussed in the following sections. Effects on the HRFS process due to hydraulic and mixing conditions, such as uneven flow distribution, poor coagulant mixing, and imbalanced dosing of the coagulant, are more thoroughly discussed in Section 4.0.

### 5.5.1 ALTERNATIVE PROCESS MODIFICATIONS - OPERATIONAL

The existing process review presented in Section 5.3 identified numerous operational-related issues that can lead to process variability or upsets. Table 5-19 summarizes alternative operational adjustment for consideration in reducing phosphorus treatment variability.

**TABLE 5-19**

**Summary of Operational Recommendations**

| *Operational Challenge* | *Operational Modification Alternative* |
|---|---|
| Periods of colder temperatures and low MLSS concentrations can result in increased phosphorus concentrations. | Maintain elevated MLSS concentration during winter months. |
| Phosphorus release from the BAFs is possible during low flow periods and when spikes in influent ammonia occur. | Increase backwash frequency during low flow periods.<br>Increase air scour during backwash. |
| Reduced separation of sand from sludge in the HRFS due to abrasion of the hydrocyclone tips. | Hydrocyclone apex tip abrasion may benefit phosphorus removal by recycling unused coagulant back to the HRFS system.<br>Periodic tracking of hydrocyclone tip size, iron concentration in the injection tank, and phosphorus residual could facilitate phosphorus removal. |
| Centrifuge process upsets could release additional phosphorus to the head of the plant. | None. Although centrifuge process upsets may affect secondary treatment, final effluent does not appear to be affected. |

### 5.5.2 ALTERNATIVE PROCESS MODIFICATIONS – OPTIMAL CHEMICAL TREATMENT SCHEME

Comparative bench-scale testing was used to identify promising coagulant, polymer, and microsand combinations that may improve phosphorus treatment, as well as alleviate some operational and maintenance concerns associated with the UV disinfection system and corrosion. Table 5-20 summarizes alternative chemical treatment schemes that may be implemented in the HRFS system.

**TABLE 5-20**

**Optimal Chemistry Guidelines**

| *Parameter* | *Alternative Treatment Scheme* | *Comments* |
|---|---|---|
| Coagulant type and dose | PAC (EPIC-70) at 30 mg/L<br>or<br>Ferric chloride at 30 mg/L<br>or<br>Alum (CLA) at 60 mg/L | Adjust dose depending on effluent quality to maintain rolling annual average permit requirements.<br>Prior to switching from ferric chloride to an alum-based coagulant, a full-scale demonstration (Section 5.7.6) is required to verify performance and location of coagulant addition. |
| Polymer type and dose | All three polymers tested (Magnafloc 5250, STAFloc 5466, and Nalco 7768) performed well at a dose of 0.6 mg/L. | Additional polymers may also be appropriate. WEP should continue testing jar alternative polymers during the polymer bid process to verify performance. |
| Microsand effective size | 110 microns<br>134 microns | Further testing on one HRFS train is recommended to determine if excessive microsand losses could occur and to verify treatment effectiveness. |
| Microsand dose | 5 g/L | Range of 3-9 g/L is appropriate. |

### 5.6 FULL-SCALE DEMONSTRATION OF HRFS PROCESS RECOMMENDATIONS

Although optimization alternatives were identified, caution in drawing early conclusions was required because many of the optimization elements listed in the alternatives are based on CFD modeling, bench-scale testing and supplemental data collection. A full-scale facility, particularly the size of Metro, can perform differently than predicted in smaller scale evaluations. It was determined that results from full-scale testing would aid the evaluation of how alternative modifications would optimize phosphorus treatment and reduce variability.

A full-scale demonstration was conducted with significant assistance from WEP personnel on the HRFS system from February 5 to July 13, 2011 to test the feasibility of certain hydraulic and process alternatives identified during the optimization evaluation. During the demonstration, nine test conditions were studied. Test conditions, including operational parameters and test variables, are summarized on Table 5-21 (following text). A timeline highlighting testing periods and dates of process issues, minor operational changes, and equipment maintenance is contained in Figure 5-21. Although the demonstration study included hydraulic and mixing improvements, as well as process modifications, this section focuses on the effects of these modifications on process performance. Detailed discussion of the hydraulic and mixing evaluations are included in Section 4.0.

### 5.6.1 GENERAL COMPARISON BETWEEN DEMONSTRATION RESULTS AND BASELINE CONDITIONS

Baseline conditions are represented by and calculated from the period between January 1, 2007 and December 31, 2010. Baseline conditions are considered non-optimal because of uneven flow distribution, poor coagulant mixing, and unbalanced dosing of the coagulant. The average secondary treatment effluent phosphorus concentration during the baseline period was 0.46 mg TP/L. The average HRFS influent concentration during the demonstration period was similar, at 0.52 mg TP/L; however, during Test Conditions 8 and 9, HRFS influent concentrations were unusually high, averaging 1.15 mg TP/L and 1.02 mg TP/L, respectively. A comparison of the baseline secondary effluent and average HRFS influent concentration during each test condition is shown on Figure 5-22.

The average final effluent concentration during the baseline period was 0.09 mg/L. Average final effluent concentrations recorded during the demonstration period are about the same (Figure 5-22). It is interesting that Condition 9, considered the most optimized case, on average had effluent concentrations greater than non-optimized baseline conditions but with lower influent concentration yielding slightly lower effluent concentrations. This illustrates that while opportunities to optimize exist, Metro WWTP is already operating close to its envelope of phosphorus removal and should be considered an exemplary plant. The predictive analysis and short-term data testing data sets used for the optimization analysis are unable to define effluent TP levels that would reliably be achieved once Metro WWTP optimization is implemented. To more reliably establish the LOT for the facility, an extended dataset would be needed (up to two years) after implementation of the selected optimization project modifications.

### 5.6.2 DEMONSTRATION CONDITION 1

Prior to commencing Demonstration Condition 1, the weir on HRFS Train 4 was raised 3 inches to promote flow balancing across the four trains. Demonstration Condition 1 involved relocating the coagulant addition point from the Cross Channel to the HRFS influent boxes. Each HRFS train had a different coagulant diffuser configuration and was intended to be dosed with 11.4 mg/L of iron (33 mg/L as ferric chloride), assuming equal flow to all HRFS trains. As shown on Figure 5-23, the measured iron concentrations in HRFS Trains 1 through 3 ranged between 10 and 15 mg Fe/L based on the average of two daily grab samples. Note that some markers for HRFS Train 1 are hidden behind the marker of another train because of equal concentrations. Measured iron concentrations in HRFS Train 4 were significantly higher with concentrations ranging between 19 and 26 mg Fe/L. These higher concentrations were the result of uneven flow distribution across the four trains. In all cases, measured iron concentrations were greater than the iron dose the operators intended to apply. From a process perspective, the inability to dose the trains with known quantities in a balanced manner leads to inefficient use of chemicals and promotes process variability.

Recycling of iron-rich sludge increased the amount of iron available for reaction by approximately 60 percent to 90 percent as shown on Table 5-22. HRFS Train 4, with a concentration of 36.7 mg Fe/L, had the highest concentration.

**TABLE 5-22**
**Demonstration Condition 1 – Measured Iron Concentrations in the HRFS Trains**

| *HRFS Train* | *Iron Concentration (mg/L)* | | | *Change in Concentration* |
|---|---|---|---|---|
| | *Coagulation Tank* | *Injection Tank* | *Difference* | |
| 1 | 11.2 | 21.4 | 10.2 | 91% |
| 2 | 13.5 | 21.6 | 8.1 | 60% |
| 3 | 11.6 | 19.9 | 8.2 | 71% |
| 4 | 21.2 | 36.7 | 15.5 | 73% |

HRFS clarifier effluent phosphorus results (see Figure 5-24) were highly scattered with concentrations ranging between 0.07 mg TP/L and 0.26 mg TP/L. A review of the plot, shows one trend: HRFS Train 4 has the lowest effluent phosphorus concentration on each day samples were analyzed. This is likely due to the higher iron dosage.

### 5.6.3 DEMONSTRATION CONDITION 2 – FLOW EQUALIZATION

Prior to commencing Demonstration Condition 2, the weirs on Trains 2 and 3 were raised one inch (along with Train 4 weir raised 3 inches) to enhance flow balancing across the four trains. Flow balancing is more thoroughly discussed in Section 4.2. Iron concentrations appeared to be more equalized with average concentrations in the coagulation tanks ranging between approximately 11 and 16 mg Fe/L (see Table 5-23).

**TABLE 5-23**

**Demonstration Condition 2 – Measured Iron Concentrations in the HRFS Trains**

| *HRFS Train* | *Iron Concentration (mg/L)* | | | *Change in Concentration* |
|---|---|---|---|---|
| | *Coagulation Tank* | *Injection Tank* | *Difference* | |
| 1 | 10.7 | 22.6 | 12.0 | 112% |
| 2 | 13.1 | 16.6 | 3.5 | 27% |
| 3 | 12.6 | 21.2 | 8.6 | 68% |
| 4 | 16.1 | 28.7 | 12.5 | 77% |

Measured iron dosages were equalized across the four trains during this period, but coagulant appeared to be poorly dispersed in the HRFS influent box for Trains 1 and 3 as evidenced by the rust-colored streaks of ferric chloride coagulant observed in the flow through the HRFS influent box. Dispersion in HRFS Train 4 appeared more equal although coagulant appeared to concentrate in the areas near the three water champs used for coagulant dispersion. The flow in the influent box of HRFS Train 2 was light rust-colored throughout indicating that the coagulant was well dispersed, likely as a result of the coagulant diffuser set-up, a diffuser with dilution water added at 10 gpm, may provide the most equal dispersion. Based on these visual observations, it was established that the next Demonstration Condition would be to modify the coagulant feed in HRFS Trains 1 and 3 to diffusers with 10 gpm of dilution water to match the coagulant set-up in HRFS Train 2.

Improved flow and iron dosing balancing reduced HRFS clarifier effluent variability in HRFS Trains 2 and 4. From Figure 5-25, effluent phosphorus concentrations in these trains are approximately equal and range between 0.026 and 0.094 mg TP/L, excluding March 15 and 16, 2011 when the polymer was offline due to a supply issue. HRFS Train 1 performed slightly worse with an average effluent concentration of approximately 0.1 mg TP/L. Effluent phosphorus concentrations in HRFS Train 3 were noticeably higher than in the other three trains.

### 5.6.4 DEMONSTRATION CONDITION 3 – DIFFUSER MODIFICATIONS

For Demonstration Condition 3, coagulant diffusers in HRFS Trains 1 and 3 were modified to the same configuration as HRFS Train 2: a diffuser with 10 gpm dilution water added. These changes appeared to yield a more dispersed coagulant in the HRFS influent boxes of Trains 1 and 3 but did not appear to affect iron concentrations in the coagulant and injection tanks. Concentrations remained approximately the same as concentrations measured during Demonstration Condition 2 (Table 5-24).

**TABLE 5-24**
**Comparison of Iron Concentrations in HRFS Trains 1 and 3**
**Before and After Diffuser Modifications**

| *HRFS Train* | *Average Measured Iron Concentration (mg/L)* | | | |
|---|---|---|---|---|
| | *Coagulation Tank* | | *Injection Tank* | |
| | *Demonstration Condition 2* | *Demonstration Condition 3* | *Demonstration Condition 2* | *Demonstration Condition 3* |
| 1 | 10.7 | 11.1 | 22.6 | 19.9 |
| 3 | 12.6 | 13.4 | 21.2 | 23.8 |

The diffuser modifications may have reduced some variability associated with effluent phosphorus concentrations, as shown by comparing Figures 5-25 and 5-26. However, average effluent phosphorus concentrations for HRFS Trains 1 and 3 were approximately the same during Demonstration Conditions 2 and 3, as was the average final effluent phosphorus concentration. Based on these results, it appears that improving coagulant dispersion did not affect HRFS performance. However, as discussed in Section 5.4.3.2, iron is considered more reactive than aluminum and HRFS performance appears to improve with additional reaction and mixing time when aluminum-based coagulants are used. Therefore, if coagulant is dosed in the HRFS influent box, it was determined that the diffuser across the entire channel provided the better method of chemical dispersion.

### 5.6.5 DEMONSTRATION CONDITIONS 4 THROUGH 6 - POLYMER MODIFICATION TESTING

On March 24, 2011, the polymer make-up units clogged and HRFS performance was significantly impaired. Effluent phosphorus measurements from the HRFS clarifiers averaged between 0.21 mg TP/L and 0.27 mg TP/L. As a result, modifications to the polymer injection system were scheduled and the changes implemented throughout Demonstration Condition 4. The coagulant diffuser set up in HRFS Train 4 was also modified from three water champs to a diffuser with dilution water to match the other three HRFS trains. Results obtained during this eight-day period were not reviewed because polymer adjustments were made throughout the eight-day period.

During Demonstration Condition 5, polymer was relocated from the T-header diffuser to a point in front of both anti-vortex baffles in the maturation tanks, which appeared to improve performance. Except for April 20, 2011, the first day of this condition, HRFS clarifier effluent for all trains was clustered between 0.03 mg TP/L and 0.11 mg TP/L (see Figure 5-27. Iron dosages continued to remain stable with average iron concentrations in the coagulation tanks ranging between 12.0 mg Fe/L and 14.4 mg Fe/L.

Continuing with evaluating the effect of polymer dosing locations, polymer addition was relocated to the T-header diffuser at the maturation tank. During inspection, Metro staff found that the diffuser has no holes and that flow was exiting at a single point; this was corrected before testing began. From May 9 through June 5, 2011, HRFS performance was similar to that during Demonstration Condition 5. HRFS clarifier effluent phosphorus concentrations generally ranged between 0.034 mg TP/l to 0.1 mg TP/L (see Figure 5-28). Following this initial period of peak performance, HRFS clarifier effluent concentrations escalated to phosphorus concentrations ranging between 0.075 mg TP/L and 0.24 mg TP/L.

### 5.6.6 DEMONSTRATION CONDITIONS 7 THROUGH 9 – PAC PERFORMANCE TESTING

For Demonstration Conditions 7 through 9, the ferric chloride coagulant in HRFS Train 4 was replaced with PAC (EPIC-70) coagulant to verify PAC performance as recommended in Section 5.4.3.4. HRFS Train 1 served as the control. Visually, HRFS Train 4 clarifier effluent appeared clear and colorless throughout the PAC performance testing. HRFS Train 1 appeared generally clear with a light rust-colored hue.

During Demonstration Conditions 7 and 8, PAC dosing problems were encountered as a result of SCADA programming and existing coagulant pump limitations. From June 28 through July 4, 2011, PAC was overdosed by approximately 70 percent and as a result, HRFS Train 4 outperformed the other three HRFS trains (Figure 5-29).

From July 5 to July 8, 2011, PAC dosages were reduced to an average of 5.8 mg/L (0.21 mmol aluminum/L) which is the molar equivalent to the average iron dose in HRFS Train 1 (11.9 mg Fe/L, 0.21 mmol Fe/L). However, during this period extremely low flows were recorded and coagulant pump operation was intermittent when WWTP flow decreased to less than 40 to 50 mgd. Therefore, there were overnight periods when PAC was not dosed to HRFS Train 4. Performance suffered, but is still within range of the other HRFS trains that were continuously dosed with iron (Figure 5-30).

During Demonstration Condition 9, flows continued to remain extremely low overnight. To compensate for the reduced flow, HRFS Train 3 was placed out of service when WWTP flow decreased below 40 to 50 mgd. The results, shown on Figure 5-31 suggest that PAC performs equal to or better than an equivalent dose of iron and may be used by Metro WWTP at the HRFS influent box in the future. However, it could not be established through this demonstration project if PAC is suitable throughout the year. As discussed in Section 5.4.3.2, PAC performance may be affected by cold temperatures and additional mixing and reaction time may be necessary to achieve equivalent results.

## 6.0 OPERATIONS AND MAINTENANCE EVALUATION

The Metro Optimization Analysis included an evaluation of O&M related issues associated with phosphorus removal, as well as the potential impact of plant modifications on adjacent processes. Optimization improvements must perform as intended after implementation, so consideration must take into account the means used to effectively operate the treatment plant. Facilitating plant operations would be expected to help reduce effluent variability, as operations staff would have better tools to predict and manage issues that could result in higher effluent phosphorus levels. Any modifications made to enhance phosphorus treatment also must not inhibit the WWTPs ability to meet other SPDES limits, or the ability to operate another process. In other words, efforts to maximize removal of one contaminant must continue to allow the facility to effectively meet other permit limits.

The most important focus of the Metro Optimization Analysis was involvement of Metro O&M staff throughout the project. This started with the Process and Operations Workshop described in Section 3.0, and continued through hydraulic and process analysis and testing, as well as alternatives development. Staff knowledge of equipment capabilities and issues and process interactions was essential to holistically evaluating optimization issues. The O&M evaluation also was based on review of O&M manuals and observations made throughout the project. Key issues associated with O&M and adjacent processes are discussed in the following sections.

### 6.1 UV DISINFECTION SYSTEM

Residual iron from ferric chloride is known to coat and eventually foul quartz sleeves. To address this, a chemical cleaning system is used to periodically remove foulants from the sleeves. Iron also absorbs UV light at the same wavelength that inactivates microorganisms. This requires plant staff to operate the UV system at 100 percent intensity for 15 out of 28 weeks to meet the plant SPDES limit for fecal coliform and results in rapid lamp wear. The lamps at Metro require replacement annually and the sleeves after five years. By comparison, lamps at the WEP’s Wetzel Road WWTP, which uses alum, are able to last about 12,000 hours (approximately twice as long) and the sleeves do not become coated.

Increasing the ferric chloride dose could further impact UV system effectiveness and operating cost. Additionally, Metro’s recently issued draft SPDES permit proposes a Type II Action Level of 5,260 lbs/day, which could prevent excess dosing. Changing to an aluminum-based coagulant would be expected to mitigate the effect of lamp coating and UV light absorption; the UV system also could operate at a lower intensity resulting in reduced electricity use. Elimination of ferric chloride also would result in reduced residual iron in the effluent.

## 6.2 CORROSION IMPACTS

Ferric chloride is a highly corrosive chemical. One unintended consequence of relocating coagulant feed to the Cross Channel was corrosion of metallic materials, most notably the aluminum slide gate at the HRFS influent. These gates need to be replaced due to iron corrosion; a corrosion resistant material (e.g., stainless steel or fiberglass) would be used. Relocating the coagulant feed to the HRFS influent box or changing to an aluminum-based coagulant would alleviate future corrosion issues. WEP staff also noted that the exposed portions of the HRFS sludge line within the tertiary treatment and sludge thickener structures require replacement. Although this line is fabricated of stainless steel, it has been reported that a lower quality piping may have been installed during facility construction.

Ferric chloride addition to secondary treatment has caused corrosion of the four, carbon steel RAS lines. Metro staff has reported the need to repair the lines, which are deteriorating. A longer-term method to address the corrosion issue would be to replace the RAS piping with either high-density polyethylene (HDPE) or Schedule 10 stainless steel materials. It should be noted that HDPE is flexible and would require continuous support where installed within a pipe gallery.

## 6.3 SHUT DOWN OF BAF, HRFS AND UV DISINFECTION SYSTEMS

There is currently no means to isolate the BAF Effluent Channel, Cross Channel or HRFS Influent Channel for maintenance. Further complicating issues is that the HRFS bypass sluice gate has a damaged stem and is not operational. Therefore, if any channel must be shut down or the HRFS system must be shut down, the entire tertiary treatment system (BAF, HRFS and UV systems) must be taken out of service. When this happens, elevated levels of ammonia and phosphorus are discharged. Some options are available during a shutdown, such as increasing MLSS concentrations to promote nitrification in the secondary treatment or increasing ferric chloride dosage to the RAS lines. However, an extended shutdown could impact permit compliance efforts.

The need to provide maintenance to the tertiary treatment facilities is one example of why effluent concentrations at WWTPs are variable. Examples of maintenance needs include:

- Periodic cleaning of the coagulant diffuser pipe.
- Maintenance of the liner in the channels. This liner has reportedly been deteriorating, possibly as a result of poor surface preparation. The entire liner requires inspection and possibly replacement.
- Calibration and maintenance of instruments in the channels.
- With coagulant feed in the Cross Channel, some floc forms and settles in the HRFS Influent Channel. Accumulated floc must be cleaned from the channel.
- Inspection and maintenance of the BAF cells and HRFS trains.
- Inspection and maintenance of 72 BAF cell isolation gates. Many reportedly may be in need of repair or replacement.

Repair of the HRFS bypass gate would permit the BAFs and UV system to operate while the HRFS system is removed from service. However, the channels could not be maintained. Installation of a wall splitting the channels between the BAF and HRFS processes would allow for maintenance of the channels, BAFs, and HRFS system without removing the entire tertiary treatment system from service. When maintenance is performed under lower flow conditions, Metro effluent would receive full tertiary treatment, which would help with SPDES permit compliance.

Installation of a wall to isolate the BAF trains could impact flow balancing, as discussed in Section 4.0. Installation of gates in the isolation wall would be essential to offset the impact of varying BAF operation. Also, the BAF control system could be modified to have filter cells turn on and off in pairs, one per train. However, this action would require significant programming and debugging.

## 6.4 MICROSAND CARRYOVER

Discussions with Kruger/Veolia indicate that some microsand loss occurs due to carryover to the HRFS effluent channel. This possibly happens from microsand tied in with the small amount of floc that does not settle in the HRFS clarifier. Studies (UFI, 2010) have shown that the residual particles entrained in the Metro effluent rapidly settle upon entry into the lake and do not enter into the pelagic zone. This turns out to be a benefit because phosphorus is bound with the particles. However, the microsand particles are also drawn into the plant effluent water pumps and reportedly cause premature wear.

Hydraulically balancing the HRFS trains would serve to mitigate microsand carryover. CFD modeling (see Section 4.0) showed that HRFS Train 4 tends to receive the most flow and thus could be experiencing microsand carryover. The modeling also showed that adjusting influent weir heights could promote balanced flow conditions. Another change is to relocate the suction pipe location for the plant effluent pumps, which are used to furnish non-potable service water to the Metro WWTP. The suction is located just behind the UV overflow weir. Review of record drawings indicates this could be an area where residual floc particles can become trapped, thus making them available to be drawn into the pump suction. Relocating the pump suction to another location where trapping of particles is less likely would serve to reduce the amount of microsand drawn into the pumps. One possible location is just upstream of the UV system where more turbulent water exists; however, this would require a shutdown to install the pipe and could still be subject to microsand wear. The new pipe would need to pass through two walls and care would be needed during design and construction to prevent leakage through the new wall penetrations. Another option could be to use the HRFS Influent Channel upstream of coagulant addition. WEP staff have indicated that the plant effluent pumps would require replacement as well.

Bench-scale testing showed that use of a smaller effective size microsand could enhance phosphorus removal. However, the smaller microsand could promote additional solids carryover, hence increase microsand use cost and result in more microsand being drawn into the plant effluent pumps. Full-scale testing and monitoring of microsand loss would be warranted prior to fully committing to using smaller effective size microsand.

## 6.5 BAF BACKWASHING IMPACT

A key concern expressed by Metro operation staff is the potential to draw coagulant into the BAF cells during a backwash. Discussions with Kruger/Veolia indicate that ferric or aluminum-based coagulants could negatively impact the filters. This issue would be eliminated by returning coagulant feed to the HRFS influent boxes. If Cross Channel feed must still be performed, moving the feed location closer to the HRFS Influent Channel would reduce the potential for backfeeding of coagulant to the filters; however, improved mixing would be essential to promote phosphorus removal optimization.

Installation of a wall to isolate the BAF trains would reduce the volume available in the channels for filter backwashing, particularly when one side is down for maintenance and the isolation gates are down. An analysis of the impact that a backwash would have on water level in the channels was performed. Assumptions were that one half the filters are out of operation, Metro is treating minimum flow (40 mgd) and that backwashing procedures are similar to current practice. The analysis showed that sufficient water was being produced in the BAFs to offset losses through a filter backwash. Therefore, the water level would not be impacted. However, channel water level could be impacted if backwash flows were increased substantially.

## 6.6 SLUDGE HANDLING

Any changes to the phosphorus removal processes could have an impact to the sludge handling processes. Metro has had excellent success with ferric chloride and has managed the plant well with respect to sludge handling. One downside with ferric chloride is that phosphorus can be released in the anaerobic digesters and returned to the head of the plant. However, process profiling suggests that the quantity of phosphorus returned to the head of the plant from side streams does not significantly impact effluent phosphorus concentrations.

The use of aluminum-based coagulants can result in lower sludge production and less release of phosphorus in anaerobic digesters. However, aluminum sludges are also known to be more difficult to dewater. WEP uses alum at its Wetzel Road and Oak Orchard WWTP. According to WEP staff, sludge handling performance does not appear to be impacted by the use of alum, including dewatering. This may be in part because sludges from the primary and secondary treatment processes are produced in significantly greater quantities, thus the impact potential is smaller. Discussions with other WWTPs using aluminum-based coagulants for phosphorus removal (including HRFS facilities) also have not indicated issues with sludge handling. Based on these results, it does not appear switching coagulant types would negatively impact Metro sludge handling. However, it is important to note that no specific testing of potential impacts has been performed on Metro sludges and that each facility is unique.

During the review of HRFS operations, it was noted that the HRFS sludge pumps used constant speed operation. The addition of variable frequency drives (VFDs) could allow for improved control of sludge draw off better tuned to actual flow rates encountered at Metro.

## 6.7 DIFFUSER PLUGGING

Scale accumulates on the coagulant feed diffusers and requires routine cleaning. If neglected, diffuser holes can plug, thus resulting in unbalanced dosing. The diffuser located in the Cross Channel is 28-ft. long and cannot be removed. Plant staff must take the channel down to access the diffuser. The temporary diffusers installed at the HRFS influent box as part of the full-scale demonstration are only 12-ft. long and were designed to facilitate removal and cleaning. If coagulant feed were to remain in the Cross Channel, means to provide improved access would be beneficial.

One of the full-scale tests involved adding PAC to HRFS Train 4. PAC was fed into a dilution water stream (consisting of plant effluent water) prior to being discharged through the diffuser. After about three weeks of operation, the piping downstream with the combined PAC/plant effluent water mixture was becoming significantly plugged. After discussions with the PAC manufacturer, it was determined that the best means to feed PAC would be without the use of dilution water.

## 6.8 COAGULANT FEED CONTROL

Ferric chloride feed to the secondary treatment system is a constant rate of 150 gpd per train. Actual coagulant dose varies with flow, with dose decreasing as flow increases and the reverse with decreasing flow. There may be periods of time when increasing the dosage may facilitate phosphorus dosage. Full-scale testing also suggests that biological processes may be more important that coagulant addition in secondary treatment and dosages could possibly be decreased.

Coagulant feed to the HRFS facility is flow paced based on the final effluent flow meter. This means that all of the feed pumps deliver the same amount of coagulant to the HRFS system regardless of the flow balance. Even with weir adjustments, CFD modeling and full-scale testing shows that the flow balance changes somewhat depending upon plant flow and BAF operation. Therefore, dosing to the individual HRFS trains is approximate. Full-scale testing has shown that accurate flow measurements are achievable with flow meters installed into the HRFS effluent launders. Coagulant feed to each train could be more accurately controlled using these individual flow meters and better address variations in flow balance across the HRFS system.

## 6.9 PROCESS CONTROL

The process evaluation summarized in Section 5.0 clearly shows the process control challenges faced by Metro staff in maximizing phosphorus removal while meeting all of the other SPDES permit requirements. In particular, efforts to remove ammonia and phosphorus to low levels in the same plant are difficult regardless of the facility (WERF, 2010). At Metro, efforts to remove phosphorus and ammonia can lead to ineffective operation of the BAFs, thus elevated effluent ammonia levels. Careful process control to prevent MLSS concentrations from becoming too high and maintaining secondary effluent phosphorus concentrations between 0.3 and 0.5 mg/L is practiced to keep effective BAF operation. This in turn facilitates excellent removal of phosphorus using the HRFS system, especially the near elimination of soluble reactive phosphorus, which is bioavailable. Data evaluation indicates that sudden changes in influent ammonia concentrations can cause variability in effluent phosphorus levels.

Metro operations staff also noted that some modifications to the SCADA program would facilitate flexibility. For example, operators do not have the ability to take a BAF cell out of the backwash queue once the SCADA program has established a backwash is necessary. To clear a filter from the queue, a filter must undergo a complete backwash cycle or WEP's SCADA programmer must be notified to access the software. Implementation of improvements for optimizing phosphorus treatment would provide an opportunity to modify the SCADA programming to increase operational flexibility.

# 7.0 ALTERNATIVES EVALUATION

## 7.1 INTEGRATED SUMMARY OF OPTIMIZATION ANALYSIS

Findings from the hydraulic, mixing and process evaluations were integrated with the Metro WWTP operations and maintenance issues to develop a series of alternatives that would promote conditions for optimizing Metro WWTP phosphorus treatment while mitigating potential impacts to other plant facilities. Key findings considered in developing the alternatives included:

- Flow across the four HRFS trains must be balanced to mitigate hydraulic overloading of individual trains. CFD modeling and full-scale testing showed that the use of non-modulating, manually adjustable weirs appears to be a means to promote improved flow balancing. Because small changes in weir height can induce large changes in flow, modulating weirs would be operationally complex and likely not successful. Full-scale testing indicated that, on average, a single weir setting reasonably balanced flow across the four trains (see Figure 4-5). However, there could be an opportunity to have additional settings to refine flow balancing during periods of extended low of high flow.

- Full-scale testing showed that balancing flow also resulted in equalizing coagulant dosing across the HRFS trains. Flow pacing of individual trains would further enhance chemical dosing accuracy.

- The hydraulic dynamics in the Cross Channel due to BAF operation could be reduced and flow balancing facilitated by adjusting the SCADA system programming. Filters would turn on and off in pairs (one in each train) so that an equal number of filters from each train are typically running. A small imbalance would continue to occur when a filter is being backwashed.

- Effective flow monitoring of the individual HRFS trains would allow verification that flow balancing is occurring.

- Improving initial mixing of the coagulant is essential to optimizing treatment performance.

- If coagulant addition remains at its current location in the Cross Channel, baffling and mixing would be required to address the dynamic hydraulic conditions, eddying and influence of the BAF.

- Ferric chloride and orthophosphate appear to react rapidly with each other. This suggests that ferric chloride addition could be returned to the HRFS influent box. This modification would address corrosion issues and the potential of backfeeding coagulant into the BAFs. Maintenance requirements of the Cross Channel would be reduced, hence reducing the frequency needed to take the HRFS system out of service.

- The physical configuration of HRFS Trains 1 and 3 are mirror images of Trains 2 and 4; however, the mixing rotation is the same for all four trains, which results in a different mixing regime between Trains 1/3 and Trains 2/4. Full-scale testing suggests that this difference would be a factor in Trains 2 and 4 having lower effluent phosphorus levels than Trains 1 and 3. Modifying the coagulation and injection tank mixers in Trains 1 and 3 could equalize the mixing regime in all four HRFS trains.

- Discussions with mixer manufacturers indicate that adding a second propeller to the coagulation and injection tank mixers may facilitate chemical-particle interactions.

- Full-scale testing indicated that perforated diffusers across the cross-section of the HRFS influent performed well and easily accessible for maintenance, but were subject to clogging. Routine inspection and maintenance would be necessary to mitigate the impact of diffuser clogging.

- Recycling iron-rich sludge to the injection tanks may enhance phosphorus removal. Hydrocyclone apex tip size controls the amount of sludge returned with the sand. Operators must routinely monitor clarifier effluent quality. Long-term excessive carryover without explanation may indicate that hydrocyclone apex tip size has increased beyond the optimal value. At that point, the hydrocylcone apex tip should be replaced with a 2.5-inch diameter tip.

- Bench-scale and full-scale testing indicated that polyaluminum chloride appears to have at least equal performance to ferric chloride. Changing to aluminum-based coagulants would mitigate scaling and absorption issues associated with iron on the UV disinfection system. However, bench-scale testing suggests that formation of aluminum phosphates may be temperature dependent with additional reaction time needed during colder weather. Therefore, the polyaluminum chloride feed would need to remain upstream in the Cross Channel during colder temperatures. No testing has been performed on Metro WWTP effluent to verify that the current benefit of additional phosphorus removal due to recycling of ferric chloride in the injection tank would be realized using polyaluminum chloride. Another key unknown is if the aluminum-phosphorus precipitant would have similar characteristics to the current iron-phosphorus particles in terms of non-bioavailability and insignificant contribution of effective particulate phosphorous to Onondaga Lake. Additional testing of the temperature dependency of PAC, as well as bioavailability and settling characteristics would be beneficial should WEP choose to use this coagulant.

- Installing a wall and gates to isolate half of the BAF and HRFS process would allow maintenance to the BAF, BAF Effluent Channel, Cross Channel, HRFS Influent Channel and HRFS trains. This would allow more wastewater to receive tertiary phosphorus removal at all times and reduce effluent phosphorus variability, as HRFS process shutdowns would be reduced. An evaluation showed that current BAF backwashing practice would generally not be impacted by this modification.

- Maintaining a target secondary effluent phosphorus range of 0.3 mg TP/L to 0.5 mg TP/L at all times would promote the HRFS influent conditions for optimizing phosphorus treatment while maintaining BAF influent nutrient requirements. This could be accomplished through maintenance of a seasonal based minimum MLSS.

- Bench-scale testing suggested that use of a smaller effective microsand size may improve phosphorus treatment, provided that increased sand and particle washout does not result. Phosphorus removal is independent of microsand dose.

- Metro WWTP side streams do not appear to impact Metro effluent phosphorus concentrations, particularly as a minimum amount of phosphorus is required for effective BAF operation.

## 7.2 OPTIMIZATION ALTERNATIVES

Based on the evaluations, optimization alternatives must enable the following:

1. Maintaining a target secondary effluent phosphorus range of 0.3 to 0.5 mg TP/L to both minimize the amount of phosphorus requiring removal in the HRFS system while providing sufficient phosphorus to permit effective ammonia removal in the BAF process.

2. To the extent possible, providing balanced dosing and effective initial mixing of coagulant for tertiary phosphorus removal. This step maximizes the amount of phosphorus that can be removed, plus maximizes removal of SRP.

3. Balancing hydraulic loading of the HRFS system to the extent possible to permit consistent performance across the trains and prevent overloading that could lead to microsand/solids carryover.

4. Optimizing the solids removal process within the HRFS trains in terms of floc formation and clarifier performance.

5. Providing greater operational flexibility to enable maintenance to occur without process shutdown to maximize the amount of wastewater receiving tertiary treatment and reduce effluent variability.

6. Addressing operations and maintenance issues due to corrosion, dynamic hydraulic condition, equipment wear and process control, which could also reduce variability.

Seven optimization alternatives were developed for evaluation that would address the range of options in the above considerations. Elements common to each alternative include:

- Installation of motorized non-modulating adjustable weirs at the HRFS influent boxes to balance flow across the four HRFS trains.

- Construction of an isolation wall along the entire length of the Cross Channel to the division wall between HRFS Trains 2 and 3 to permit isolation of one-half the BAFs and HRFS train for maintenance while maintaining tertiary treatment system operation. Gates would be installed in the wall upstream of coagulant addition. Also, the SCADA programming for the BAF would be adjusted to require the filters to be turned on and off in pairs, one per train.

- Reversal of the mixer rotation in the coagulation and injection tanks for HRFS Trains 1 and 3 to match the mixing regime of HRFS Trains 2 and 4. This would require replacement of the mixer propellers to maintain downward acting flow.

- Installation of a second propeller on the coagulation and injection tank mixers to promote additional chemical-particle interactions.

Key variables for the alternatives include coagulant type, coagulant addition location, mixing location, HRFS flow monitoring location, etc. A summary of the seven alternatives is presented on Table 7-1 and described as follows:

**Alternative 1: PAC Addition to Cross Channel Option A –** Under this alternative, PAC would be added to the Cross Channel downstream of the slide gates in the new BAF isolation wall, as shown on Figure 7-1. Flow pacing would be provided by permanent flow meters located in the HRFS effluent launders. An in-channel static mixer would be used to disperse the PAC into the flow stream. The existing ferric chloride bulk storage tanks and transfer pumps would be reused for PAC. A new chemical feed system would be installed, as PAC requires about one-fifth the flow rate of ferric chloride.

**Alternative 2: PAC Addition to Cross Channel Option B –** PAC would be added to the Cross Channel downstream of the slide gates in the new BAF isolation wall, as shown on Figure 7-2. Four flow channels would be used with each conduit containing a static mixer and flow meter. Individual flow pacing of coagulant into each channel would be based on this flow meter. The existing ferric chloride bulk storage tanks and transfer pumps would be reused for PAC. A new chemical feed system would be installed, as PAC requires about one-fifth the flow rate of ferric chloride.

**Alternative 3: Ferric Chloride Addition to Cross Channel Option A –** This alternative is similar to Alternative 1, except that ferric chloride would remain as the coagulant. Ferric chloride would be added to the Cross Channel downstream of the slide gates in the new BAF isolation wall, as shown on Figure 7-1. Flow pacing would be provided by permanent flow meters located in the HRFS effluent launders. An in-channel static mixer would be used to disperse the coagulant into the flow stream. The existing ferric chloride feed system (pumps, piping, valves and diffuser) would be replaced with a focus on reduced maintenance to the extent possible.

**Alternative 4: Ferric Chloride Addition to Cross Channel Option B –** Similar to Alternative 2, coagulant (ferric chloride) would be added to the Cross Channel downstream of the slide gates in the new BAF isolation wall, as shown on Figure 7-2. Four flow channels would be used with each conduit containing a static mixer and flow meter. Individual flow pacing of coagulant into each channel would be based on this flow meter. The existing ferric chloride feed system (pumps, piping, valves and diffuser) would be replaced with a focus on reduced maintenance to the extent possible.

**Alternative 5: Ferric Chloride Addition to the HRFS Influent Box –** Under this alternative, ferric chloride would be added via diffusers above the HRFS influent boxes, which is illustrated on Figure 7-3. Baffles would be constructed within each influent box to promote initial mixing. Coagulant feed to each train would be flow paced based on flow meters located in the HRFS effluent launders. The existing ferric chloride feed system (pumps, piping, valves and diffuser) would be replaced with a focus on reduced maintenance to the extent possible.

**Alternative 6: Seasonal Use of PAC and Ferric Chloride Option A –** Switching to PAC can have significant benefits such as mitigating impacts to UV disinfection and reducing corrosion; however, PAC is more costly than ferric chloride. Alternative 6 would involve using PAC only between April 1 and October 15, when disinfection must be practiced. PAC would be fed to a diffuser in the Cross Channel, where it would be dispersed using a static mixer, as shown on Figure 7-4. Ferric chloride would be used during colder temperatures and be added via a diffuser above the HRFS influent box. Baffles would be constructed within each influent box to promote initial mixing. Coagulant feed would be flow paced based on flow meters located in the HRFS effluent launders. The existing ferric chloride feed system (pumps, piping, valves and diffuser) would be replaced with a focus on reduced maintenance to the extent possible. In addition, a new PAC feed system would be provided.

**Alternative 7: Seasonal Use of PAC and Ferric Chloride Option B –** Alternative 7 also involves seasonal use of PAC and ferric chloride. However, as shown on Figure 7-3, both coagulants would be added via a diffuser above the HRFS influent box. Baffles would be constructed within each influent box to promote initial mixing. Coagulant feed would be flow paced based on flow measured by meters located in the HRFS effluent launders. The existing ferric chloride feed system (pumps, piping, valves and diffuser) would be replaced with a focus on reduced maintenance to the extent possible. In addition, a new PAC feed system would be provided.

## TABLE 7-1
## Metro WWTP Phosphorus Optimization Alternatives Matrix

| Modification | Alternative | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **HRFS Coagulant** | | | | | | | |
| Ferric Chloride | | | ■ | ■ | ■ | ■ | ■ |
| Polyaluminum Chloride | ■ | ■ | | | | ■ | ■ |
| **Coagulant Feed Location** | | | | | | | |
| Cross Channel | ■ | ■ | ■ | ■ | | ■ | |
| HRFS Influent Box | | | | | ■ | ■ | ■ |
| **Coagulant Feed System Modifications** | | | | | | | |
| Flow Pace Secondary Treatment Ferric Chloride Feed | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Replace Ferric Chloride Chemical Feed System | | | ■ | ■ | ■ | ■ | ■ |
| Install PAC Feed Pumps/Piping | ■ | ■ | | | | ■ | ■ |
| **Cross Channel Modifications** | | | | | | | |
| BAF Isolation Wall - ends at HRFS Influent Box | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| In-Channel Static Mixing | ■ | | ■ | | | ■ | |
| Channeled Baffles w/Static Mixing | | ■ | | ■ | | | |
| Conduits in Cross Channel for Flow Meters | | ■ | | ■ | | | |
| Concrete Channel Liner Rehabilitation | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Flow Measurement** | | | | | | | |
| Effluent Launders & SEPS | ■ | | ■ | | ■ | ■ | ■ |
| Influent (New Channels) | | ■ | | ■ | | | |
| **Flow Balancing** | | | | | | | |
| Non-Modulating Weirs | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Trains 1 & 3 Mixer Rotation | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Install Second Propeller in Coag and Injection Tanks | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Other Modifications** | | | | | | | |
| Replace HRFS Influent Gates | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Convert HRFS Sludge Pump to VFD Operation | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Replace HRFS Sludge Piping | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Rehabilitate Microsand Slurry Tank | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Replace RAS Lines | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Relocate Effluent Pump Suction Piping | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Replace Plant Effluent Pumps | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Repair HRFS Bypass Sluice Gate | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| **Modifications Under Future Considerations** | | | | | | | |
| Replace Microsand with Smaller Size Material | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Implement HRFS Sludge Recycle to Injection Tank | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

A number of other modifications also would likely be added to the selected alternative to address specific operations and maintenance issues associated with the HRFS system. The O&M related modifications under consideration include:

- Replacing the secondary treatment return activated sludge (RAS) lines corroded by ferric chloride from the suction side isolation valve of the RAS pump to its discharge. A corrosion resistant piping material, such as high-density polyethylene (HDPE) or Schedule 10 stainless steel would be used.

- Installation of VFDs on the HRFS sludge pumps to improve control.

- Replacement of all exposed HRFS sludge piping within the HRFS building and thickener complex with corrosion resistant materials.

- Replacement of the liner in the Cross Channel, BAF effluent channel and HRFS influent channel.

- Repair of the HRFS bypass sluice gate.

- Relocation of the suction for the effluent water system pumps upstream of coagulant addition to protect the pumps from uptake of microsand. Also, replacement of the plant effluent water supply system.

- SCADA programming changes to facilitate BAF, HRFS and coagulant feed control based on operational experience.

- Rehabilitation of the microsand slurry tank in the HRFS trains.

Another operational change that showed potential for enhancing phosphorus removals was the use of a smaller effective size microsand. However, this modification could not be demonstrated at a full-scale level within the schedule allowed by the ACJ. WEP is currently considering how this can be effectively tested.

## 7.3 ALTERNATIVES COST ANALYSIS

A life cycle cost analysis was completed as part of the overall evaluation of alternatives. The focus was to develop the estimated annual cost for each alternative based on a 20-year life cycle. The cost analysis included capital costs annualized at a 4 percent interest rate over 20 years plus key annual O&M costs (e.g., coagulant use, UV disinfection cost, Cross Channel maintenance and sludge disposal.

Preliminary capital cost estimates were primarily based on equipment and materials quotes from manufacturers, bid tabulations from construction projects of similar size and complexity, 2011 Means cost estimating data and engineering judgment. Escalation factors were added to account for mobilization, electrical and instrumentation work and contractor overhead and profit. A 20 percent contingency allowance and an additional allowance of 18 percent for engineering, legal and administrative fees also were incorporated. Details of the preliminary capital cost estimates are included in Appendix B. Note that the costs are presented in 2014 dollars to reflect the assumed mid-point of construction; the 2011 costs were converted to 2014 assuming a 2.1 percent inflation rate, which is the average for the past five years based on the Consumer Price Index.

Operations and maintenance cost estimates were based on an average annual Metro WWTP flow of 70 mgd. The basis for the O&M costs are as follows:

**Coagulant Use**

- Coagulant dose of ferric chloride and PAC is 30 mg/L.
- Ferric chloride is applied year round for Alternatives 3, 4 and 5.
- PAC is applied year round for Alternatives 2 and 3.
- Under Alternatives 6 and 7, PAC is applied from April 1 to October 15, while ferric chloride is applied for the remainder of the year.

**UV System Costs**

- Lamps are replaced annually under Alternatives 3, 4 and 5 because of the high intensity use to offset the impacts of ferric chloride. Lamps are replaced every other year for Alternatives 1, 2, 6 and 7 where PAC is used during disinfection season. One week of labor for two people at $40 per man-hour is needed to replace the lamps.
- Quartz sleeves are replaced every five years for Alternatives 3, 4 and 5 due to ferric chloride use. The sleeves would be replaced on a 10-year schedule when PAC is used.
- Currently, the UV system must be operated at full intensity for 15 weeks while using ferric chloride. It was assumed that using PAC would reduce the high intensity operational requirement to 8 weeks.
- Electrical costs average approximately $0.12 per kilowatt-hour (kWh).

**Cross Channel Maintenance**

- Under Alternatives 1, 2, 3 and 4, it was assumed that a crew of four would need five days per year to clean and maintain the Cross Channel, primarily because some precipitants would settle in the channel. Where coagulant would be added in the HRFS influent box (Alternatives 5, 6 and 7), Cross Channel maintenance would require two days per year.

**Sludge Disposal**

- Coagulant dose of ferric chloride and PAC is 30 mg/L.
- Ferric chloride is applied year-round for Alternatives 3, 4 and 5.
- PAC is applied year-round for Alternatives 2 and 3.
- Under Alternatives 6 and 7, PAC is applied from April 1 to October 15, while ferric chloride is applied for the remainder of the year.
- The final sludge cake has an average dry solids concentration of 32 percent.
- The cost for landfilling the sludge cake is $50 per wet ton

A summary of the life cycle cost analysis (2014 dollars) is presented on Table 7-2. Many of the cost elements are the same for the seven alternatives, which are necessary to address O&M issues, such as corrosion. Although the difference between the highest (Alternatives 2 and 4) and lowest capital cost is about a million dollars, this difference decreases to $80,000 per year when annualized. While PAC purchases would be more costly than ferric chloride, savings would be achieved because of reduced UV system operating costs and lower estimated sludge production. Overall, the alternatives have a similar annual cost – ranging between $3.0 and $3.1 million per year, with Alternative 7 the lowest.

## TABLE 7-2

## Metro WWTP Optimization Analysis for Phosphorus Treatment
## Life-Cycle Cost Analysis of Alternatives (2014 Dollars)

| | *Alternative* | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | | | | | | | |
| Preliminary Capital Cost | $5,600,000 | $6,600,000 | $5,600,000 | $6,600,000 | $5,300,000 | $6,200,000 | $5,900,000 |
| Annualized Preliminary Capital Cost | $410,000 | $490,000 | $410,000 | $490,000 | $390,000 | $460,000 | $430,000 |
| | | | | | | | |
| Preliminary Annual O&M Costs | | | | | | | |
| Coagulant Use | $1,980,000 | $1,980,000 | $1,830,000 | $1,830,000 | $1,830,000 | $1,910,000 | $1,910,000 |
| UV System Operation | $370,000 | $370,000 | $470,000 | $470,000 | $470,000 | $370,000 | $370,000 |
| Cross Channel Maintenance | $10,000 | $10,000 | $10,000 | $10,000 | $5,000 | $5,000 | $5,000 |
| Sludge Disposal | $250,000 | $250,000 | $350,000 | $350,000 | $350,000 | $300,000 | $300,000 |
| Total Annual O&M Cost | $2,610,000 | $2,610,000 | $2,660,000 | $2,660,000 | $2,655,000 | $2,585,000 | $2,585,000 |
| | | | | | | | |
| **Total Annual Cost** | **$3,020,000** | **$3,100,000** | **$3,070,000** | **$3,150,000** | **$3,045,000** | **$3,045,000** | **$3,015,000** |

1. Preliminary capital cost includes 20% for Contingency/Allowances and 18% for Engineering, Legal and Administrative Fees
2. Assumes 20-year bond at 4% interest

**Alternative Key:**
Alternative 1: PAC Addition to Cross Channel Option A
Alternative 2: PAC Addition to Cross Channel Option B
Alternative 3: Ferric Chloride Addition to Cross Channel Option A
Alternative 4: Ferric Chloride Addition to Cross Channel Option B
Alternative 5: Ferric Chloride Addition to the HRFS Influent Box
Alternative 6: Seasonal Use of PAC and Ferric Chloride Option A
Alternative 7: Seasonal Use of PAC and Ferric Chloride Option B

## 7.4 EVALUATION OF ALTERNATIVES

Cost is but one element of recommending the best optimization alternative. As introduced at the beginning of this report, optimization involves determining the recommended modifications that promote conditions leading to improved treatment performance and reliability, while maintaining the ability of the WWTP to reliably meet all other treatment and performance requirements. The intent of optimization also is to identify opportunities for reducing effluent variability.

Because of the complex inter-relationships described in the previous sections, a matrix-type analysis was performed for selecting the most appropriate optimization alternative. In addition to improving phosphorus treatment, the evaluation considered impact to other facilities and efforts to facilitate O&M. Ultimately, these evaluation elements promote reducing operational variability by Metro personnel thereby improving treatment performance. WEP was consulted when identifying evaluation parameters for the matrix, as well as ranking the importance of each parameter. From this information a matrix table was developed and scores applied. A weighting factor was applied to each score depending upon the importance to WEP staff; weighting factors were either 1 for lowest importance, 2 or 3 for highest importance. Ordinal number scores were then applied to each alternative on a scale of 1 to 5, with 1 being the lowest benefit and 5 being the highest. These scores were then multiplied by the weighting factor and input into the matrix. The alternative with the highest score would be considered the most appropriate optimization solution for the Metro WWTP. The evaluation parameters and associated comparison of alternatives is summarized as follows:

**Preliminary Annual Cost Impact**

- Cost was considered to be of median importance, particularly considering that annual costs were within 5 percent of each other.
- All alternatives received the same score.

**Reducing Impact to UV System Scaling and Interference**

- This parameter is of high importance as UV system effectiveness is critical to maintaining SPDES permit compliance.
- Alternatives using ferric chloride (3, 4 and 5) were assigned the lowest score because there would be no improvement to UV system performance and operation.

- Alternatives where PAC is used during disinfection season (1, 2, 6 and 7) received the highest score because the iron-related impact to the UV system would be eliminated.

**Improving Effectiveness of HRFS Flow Monitoring**

- Effective monitoring of HRFS train flow was determined to be critical to permit accurate flow pacing of coagulant to individual trains and verify that flow balancing is occurring.
- All alternatives would achieve the ability to verify that flow balancing is occurring, thus achieving at least a median score.
- Alternatives 1 and 3 did not score higher because the location of coagulant feed does not allow for individual flow pacing.
- Alternatives 2 and 4 received the highest score because individual flow pacing would be provided and flow metering would be most accurate.
- Alternatives 5, 6 and 7 received a higher score because individual flow pacing would be provided but the flow meter in the effluent launders is not expected to be as accurate as the meters located in a dedicated channel.

**Increase to Upstream Head**

- This parameter was viewed as less significant, but headloss could reduce the flexibility of future modifications.

**Reducing Potential to Backfeed Coagulant into the BAF System**

- The impact of this parameter was considered to be moderate.
- Chemical feed in Alternatives 1 through 4 would be relocated further away from the BAFs but would remain in the Cross Channel.
- Alternatives 5 and 7 would completely eliminate the potential of backfeeding coagulant into the BAFs.
- Alternative 6 could result in backfeeding when coagulant is added to the Cross Channel.

**Reducing Corrosion into the HRFS System**

- The impact of this parameter was considered to be moderate because many of the modifications common to each alternative would involve the use of corrosion resistant materials.

- Alternatives continuing year-round use of ferric chloride (3, 4 and 5) scored the lowest.
- Alternatives involving year-round use of PAC (1 and 2) scored the highest.
- Alternatives that use seasonal PAC (6 and 7) use scored slightly lower than those with year-round PAC use.

**Potential Impact to Sludge Handling Performance**

- Based on discussions with WEP staff, their experience indicates iron- and aluminum-based coagulants appear to perform similarly in sludge handling facilities. Therefore, sludge handling was considered to have a lower significance.

**Reduction in Sludge Production**

- Changing the use of coagulant can have an impact on sludge production, but it was considered to be a parameter of lower significance.
- Year-round use of ferric chloride would result in no reduction in sludge production and received the lowest score.
- Year-round use of PAC would result in reduced sludge production, thus receiving a moderate score.
- Seasonal use of PAC results in a slightly lower score than year-round use.

**Reducing Sand Carryover Potential**

- Relocating the plant effluent pumps eliminates a key negative impact of microsand carryover. Also, balancing flow across the HRFS trains should reduce some of the carryover. Therefore, this parameter was considered to be of lower importance. All alternatives scored the same.

**SCADA/Control System Impact**

- This parameter is considered to be the level of complexity added to control phosphorus removal operations, and is considered to be of moderate importance.
- Alternatives 1, 3, 5 and 7 were considered less operationally complex to operate than Alternatives 2, 4 and 6, and therefore received a higher score.

**Impact to Iron Discharges**

- Metro is facing a proposed Type II Action Level for effluent iron in its most recent draft SPDES permit, and was considered to be of moderate importance.
- Alternatives 3, 4 and 5 scored the lowest because iron discharges would not be reduced.
- Alternatives 1 and 2 scored the highest because use of ferric chloride in tertiary treatment would be eliminated.
- Alternatives 6 and 7 were assigned a moderate score because iron concentrations would be reduced half the year.

**Reducing Cross Channel Maintenance**

- Cross Channel maintenance would reduce the availability of the facility for full tertiary treatment should a peak flow event occur when maintenance is performed. Also, chemical addition in the Cross Channel would result in settled floc that requires periodic cleaning. This parameter was considered to be of moderate importance.
- Alternatives 1 through 4 involve coagulant addition in the Cross Channel, thus achieving a lower score than the alternatives with HRFS influent box feed a (5, 6 and 7). Alternative 6 scored slightly lower because the option of feeding coagulant in the Cross Channel would be provided.

**Diffuser Maintenance**

- Maintaining the diffusers is considered to be of moderate importance because clean diffusers are essential for proper delivery of coagulant to the flow stream.
- Alternatives 1 through 4 were assigned the lowest score because access to the diffuser in the Cross Channel would be difficult.
- Alternatives 5 and 7 scored highest because the individual diffusers in the influent boxes are easier to handle and readily accessible. Alternative 6 scored a little lower because the option of feeding coagulant in the Cross Channel would be provided.

**Operational Flexibility**

- Operational flexibility is important to Metro staff and was thus assigned a moderate weighting.
- Alternatives 1 through 5 provide for feeding one type of coagulant at one location, and therefore received lower scores.

- Alternative 7 was assigned a higher score because ferric chloride or PAC could be used.
- Alternative 6 received the highest score because two coagulant types and feed locations would be provided.

**Improved Flow Balancing and Reduced Hydraulic Dynamics**

- Better flow balancing and reducing dynamic conditions in the Cross Channel were considered to be important to the success of optimization. This parameter was assigned a moderate weighting.
- All of the alternatives would achieve the goals of this parameter. However, it is anticipated that the four-channel configuration of Alternatives 2 and 4 could increase the complexity of efforts to balance flow across the HRFS trains and therefore received lower scores.

A summary of the alternatives evaluation scoring matrix is presented on Table 7-3. In general, the alternatives involving the use of PAC scored significantly higher than those using year-round ferric chloride addition. Key reasons for the scoring difference is because PAC mitigates UV system performance issues, reduces iron discharges, results in lower sludge production and reduces corrosion impacts. The two alternatives that would employ seasonal PAC addition to the HRFS influent box (6 and 7) had the highest scores because of improved operational flexibility, more accurate coagulant dosing and easier maintenance of the diffusers and Cross Channel. Alternative 7 scored higher than 6 because some of the benefits achieved by adding coagulant to the HRFS influent box would be lost if chemical feed were moved back to the Cross Channel.

## TABLE 7-3

## Metro WWTP Optimization Analysis for Phosphorus Treatment Alternatives Evaluation Scoring Matrix

| | *Weighting* | *Alternative Score* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Evaluation Parameter* | *Factor* | *1* | *2* | *3* | *4* | *5* | *6* | *7* |
| | | | | | | | | |
| Preliminary Annual Cost Impact | 2 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Reducing Impact to UV System Scaling/Interference | 3 | 15 | 15 | 3 | 3 | 3 | 15 | 15 |
| Improving Effectiveness of HRFS Flow Monitoring | 3 | 9 | 15 | 9 | 15 | 12 | 12 | 12 |
| Increase to Upstream Head | 1 | 3 | 2 | 3 | 2 | 4 | 3 | 4 |
| Reducing Potential to Backfeed Coagulant into BAF | 2 | 6 | 6 | 6 | 6 | 10 | 8 | 10 |
| Reducing Corrosion in HRFS System | 2 | 10 | 10 | 2 | 2 | 6 | 8 | 8 |
| Potential Impact to Sludge Handling Performance | 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Reduction in Sludge Production | 1 | 3 | 3 | 1 | 1 | 1 | 2 | 2 |
| Reducing Microsand Carryover Potential | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| SCADA/Control System Impact | 2 | 6 | 3 | 6 | 3 | 6 | 3 | 6 |
| Impact to Iron Discharges | 2 | 10 | 10 | 2 | 2 | 2 | 6 | 6 |
| Reducing Cross Channel Maintenance | 2 | 6 | 6 | 6 | 6 | 10 | 8 | 10 |
| Diffuser Maintenance | 2 | 2 | 2 | 2 | 2 | 8 | 6 | 8 |
| Operational Flexibility | 2 | 4 | 4 | 4 | 4 | 4 | 10 | 8 |
| Improved Flow Balancing/Reduced Hydraulic Dynamics | 2 | 8 | 6 | 8 | 6 | 8 | 8 | 8 |
| **Total Evaluation Score** | | 96 | 96 | 66 | 66 | 88 | 103 | 111 |

**Note:** A higher score indicates that alternative is more preferred.

# 8.0 RECOMMENDATIONS AND IMPLICATIONS OF RELATED ACJ COMPLIANCE ISSUES

Performing the Optimization Analysis has resulted in a significantly improved understanding of Metro WWTP phosphorus treatment processes and how inherent variability affects effluent concentrations. These efforts served to identify alternative opportunities for optimizing Metro's process, hydraulics, operations and maintenance to improve the reliability of phosphorus treatment and provide the conditions that would promote further phosphorus removal. This section summarizes the recommended Metro WWTP Phosphorus Treatment Optimization Plan. Implications that could affect the outcome of Metro optimization, particularly in establishing a final effluent phosphorus permit limit include the most recent results from the separately performed evaluations on the Metro WWTP Limit of Technology and determination of effective phosphorus, along with regulatory and permitting requirements.

## 8.1 METRO WWTP PHOSPHORUS TREATMENT OPTIMIZATION PLAN

The goal of this extensive evaluation was to recommend the set of modifications that best promote conditions leading to improved treatment performance and reliability, as well as reducing effluent variability while maintaining the ability of the WWTP to reliably meet all other treatment and performance requirements. Based on the evaluations presented herein, the recommended modifications must enable the following:

1. Maintaining a target secondary effluent phosphorus range of 0.3 to 0.5 mg TP/L to both minimize the amount of phosphorus requiring removal in the HRFS system while providing sufficient phosphorus to permit effective ammonia removal in the BAF process.

2. To the extent possible, balancing dosing and effective initial mixing of coagulant for tertiary treatment of phosphorus. This step maximizes the amount of phosphorus that can be removed, plus maximizes removal of SRP.

3. Balancing hydraulic loading of the HRFS system to the extent possible to permit consistent performance across the trains and prevent overloading that could lead to microsand/solids carryover.

4. Optimizing the solids removal process within the HRFS trains in terms of floc formation and clarifier performance.

5. Providing greater operational flexibility to enable maintenance to occur without process shutdowns to maximize the amount of wastewater receiving tertiary treatment and reduce effluent variability.

6. Addressing operations and maintenance issues due to corrosion, dynamic hydraulic conditions, equipment wear and process control, which could also reduce variability.

Based on the evaluation of alternatives presented in Section 7.0, Alternative 7 would be the most appropriate for WEP to implement for optimizing phosphorus treatment at the Metro WWTP. The recommended alternative focuses on use of PAC during the disinfection season, and ferric chloride during the rest of the year. Coagulant would be fed to the HRFS influent box (see Figure 7-3). Baffles would be constructed within each influent box to promote initial mixing. Coagulant feed would be flow paced based on flow meters located in the HRFS effluent launders. The existing ferric chloride feed system (pumps, piping and valves) would be replaced with a focus on reducing maintenance to the extent possible. In addition, a new PAC feed system would be provided. Other modifications included with the recommended alternative include:

- Installation of motorized non-modulating adjustable weirs at the HRFS influent boxes.
- Construction of an isolation wall along the entire length of the Cross Channel to the division wall between HRFS Trains 2 and 3. Also, the SCADA programming for the BAF would be adjusted to require the filters to be turned on and off in pairs, one per train.
- Reversal of the mixer rotation in the coagulation and injection tanks for HRFS Trains 1 and 3.
- Installation of a second propeller on the coagulation and injection tank mixers.
- Replacing the secondary treatment RAS lines from the suction side isolation valve of the six RAS pumps to their discharge.
- Installation of VFDs on the HRFS sludge pumps to improve control.
- Replacement of all exposed HRFS sludge piping within the HRFS building and thickener complex.
- Replacement of the liner in the Cross Channel, BAF effluent channel and HRFS influent channel.
- Repair or replacement of the HRFS bypass sluice gate.

- Relocation of the suction for the effluent water pumps upstream of coagulant addition and replacement of the plant effluent water supply system.
- SCADA programming changes to facilitate BAF, HRFS and coagulant feed control based on operational experience.
- Rehabilitation of the microsand slurry tank in the HRFS trains.

The estimated preliminary capital cost to install these modifications is approximately $5,900,000 (2014 dollars), including a 20 percent construction contingency allowance, and an additional allowance of 18 percent for engineering, legal and administration fees.

A preliminary implementation schedule for the recommended improvements is shown on Figure 8-1. During development of this schedule, consideration was given to minimizing the water quality impact to Onondaga Lake during construction. A key benefit of the recommended alternative would be to reduce the impact to the lake from variability in effluent phosphorus that results from maintenance of the BAF, HRFS or connecting channels, and thereby maximizing the wastewater receiving tertiary treatment. However, a temporary shutdown of tertiary treatment would be essential to allow construction crews to safely and properly install the isolation wall for the BAF and HRFS units, inspect and rehabilitate the channel liner and install an access platform for the new isolation gates. Construction of the wall and liner replacement is made more complicated because confined space entry would be required, which impacts time. Another issue is that colder temperatures and a higher humidity environment lengthen the cure time for the liner, although cure times can be accelerated with the use of a temporary enclosure with heaters and dehumidifiers. Additionally, time would be required to restart the BAF to effective treatment levels after an extended shutdown.

Given these construction necessities, it is recommended that WEP pursue a temporary permit limit variance from the NYSDEC for ammonia and phosphorus that reflects the construction activity. This variance would be applied for during the design phase and prepared in accordance with Paragraph 29 of the ACJ to minimize process downtime. The following should be considered as part of the variance application to minimize the potential impact to Onondaga Lake:

- Require the contractor to focus all efforts on rapidly constructing the isolation wall and inspecting the existing liner. Once the wall is complete, one half of the tertiary treatment facilities could be restored to service while construction focused on the other half. It is expected that wall construction could require three or four months to complete depending upon the fabrication time needed for the isolation gates. To reduce lead-time requirements, WEP could pre-purchase the gates near the end of the design phase. Requiring the gates to be delivered prior to tertiary treatment shutdown or requiring multiple shift construction are other options to reduce downtime. Limit full shutdown of tertiary treatment to between October 15 and April 1. UV disinfection would not be required and this time frame is outside the critical period for phosphorus and ammonia. This time frame also takes advantage of the short hydraulic retention time in the lake.

- Temporarily modify operation of secondary treatment to promote nitrification and phosphorus removal to the extent possible. Efforts could include increasing MLSS concentrations, sludge retention time and increased ferric chloride addition.
- Although total shutdown of tertiary treatment would be minimized, half of the BAF and HRFS units would remain out of service for an extended period to allow completion of construction. Tertiary treatment would be provided except during times of peak flows (wet weather conditions) when a partial bypass would be required.

Efforts to minimize impact to the lake must allow for high-quality construction, meet plant operational needs, are in accordance with applicable Standards and follow standard engineering and construction practices.

Additional issues and potential refinements were identified near the end of the evaluation that could not be studied within the framework of the ACJ mandated schedule for this project. Potential pre-implementation evaluations to consider are summarized below. These pre-implementation studies are believed to be necessary before proceeding with final design, which is reflected in the preliminary implementation schedule.

- Bench-scale testing showed that improved phosphorus removal may be possible using a smaller effective-size microsand. However, bench testing does not simulate continuous flow conditions where benefits of a smaller particle could be offset by increased solids carryover. Full-scale testing using one of the HRFS trains could be performed to compare treatment effectiveness using the smaller microsand with respect to the current product.

- Consideration of an evaluation of the impact of temperature of PAC on floc. The full-scale demonstration showed that PAC could be added at the HRFS influent boxes during periods of warmer temperatures. However, bench-scale testing suggested that additional contact time would be needed during colder temperatures. Bench-scale testing could be performed to evaluate if a temperature dependency would exist at the Metro WWTP. If no dependency were found, WEP would have the flexibility to perform year-round PAC addition to the HRFS influent box. If a temperature dependency were found, the approximate water temperature at which this dependency becomes significant could be determined. This would provide operations staff with key information regarding the timeframe to start PAC addition. It is anticipated that bench-scale testing would be performed in the winter, spring and summer to account for seasonal temperature variations.

- Additional CFD modeling to refine the design of the isolation wall between the BAF and HRFS systems. The objective of modeling would be to identify the wall configuration that minimizes the need to change HRFS weir positions as the flow changes. For the purposes of budgeting, modeling of up to six different wall/operational configurations are anticipated with low, average and peak flow conditions tested for each configuration. Configurations could include balanced vs. unbalanced BAF operation, open vs. closed isolation gates, size and/or number of isolation gates. The primary metric for this evaluation would be how the HRFS flow distribution changes over a fixed configuration.

- Consideration of a physical modeling or full-scale evaluation to confirm mixer blade sizing in the injection and coagulation tanks to verify that improvements would not promote floc shear. Because more representative results would be obtained, performance of full-scale testing is anticipated. A second propeller would be installed in the coagulation and injection tanks for one HRFS train and compared to the results of a train with a single propeller. Data collection may include phosphorus, SRP, iron plus a particle size analysis to identify if floc shear is occurring.

- While using PAC was shown to have equal performance to ferric chloride with respect to phosphorus removal, no testing was conducted to determine if PAC treated effluent would have similar bioavailability and settling characteristics as ferric chloride. Therefore, a study prior to implementation would be necessary to verify that PAC treated effluent would have the same particulate bioavailability as ferric chloride treated effluent. Data would be obtained from a full-scale test using PAC in one HRFS train. Effluent samples from the train using PAC and a train using ferric chloride would be analyzed for bioavailability and settling characteristics.

## 8.2 IMPLICATIONS OF LIMIT OF TECHNOLOGY ANALYSIS AND EFFECTIVE PHOSPHORUS

Two independent but inter-related efforts have been identified to potentially impact the Optimization Analysis for the existing Metro WWTP: results of the Limit of Technology (LOT) Analysis of the existing Metro WWTP, and the concept of "effective phosphorus". The implications presented herein are based on the most up-to-date information. The implications are subject to change depending upon the final outcome of the TMDL.

### 8.2.1 LIMIT OF TECHNOLOGY ANALYSIS

The Metro Optimization Analysis for Phosphorus Treatment is closely linked to the LOT evaluation being completed in parallel under the Work Plan entitled "Metropolitan Syracuse Wastewater Treatment Plant – Analyzing Phosphorus Removal Technologies and Metro Wastewater Treatment Plant Diversion to the Seneca River" (Work Plan [CRA, 2010]). The LOT evaluation involves using probability distribution analysis to establish Technology Performance Statistics (TPS) unique to the Metro WWTP (defined in Section 1.2.1). This approach was developed under the Work Plan result and was accepted by the NYSDEC and ASLF. A key advantage of this approach is that actual treatment performance data are used to objectively and quantitatively evaluate the phosphorus treatment capability at Metro and other WWTPs using high rate flocculated settling. It is important to note that the LOT is technology specific and plant specific – one treatment process will have a different LOT than another. However, a multi-variate analysis can be used to identify variables that are statistically significant along with an estimation of optimum values for controlled variables.

Initial results from the LOT Analysis (in progress) show the Metro WWTP is currently approaching the lower limit of phosphorus removal capability for its existing treatment processes. The statistical assessment for this analysis shows that, although recent data show that Metro is meeting the permit limit of 0.10 mg TP/L, the current reliable LOT appears to be closer to 0.12 mg TP/L due to effluent variability. However, it is anticipated that implementation of optimization improvements would reduce variability such that the plant could more reliably meet a permit limit of 0.10 mg TP/L. Because the current Metro processes are approaching their physical and practical limit for removing phosphorus, and due to the process variability inherent when targeting very low effluent concentrations, an extended period of data collection (at least three years) and associated engineering analysis would be necessary after optimization improvements are implemented to determine if a permit limit below 0.10 mg/L could be reliably met.

The LOT Analysis is expected to be completed in fall 2011, including the results of the multi-variate analysis. The LOT Analysis also will consider the implications of effective phosphorus loading with respect to treatment improvements benefiting Onondaga Lake water quality.

### 8.2.2 EFFECTIVE PHOSPHORUS LOADING

Historically, phosphorus loading has most often been represented in terms of total phosphorus. Scientific studies (UFI, 2010) of the lake have demonstrated that only a portion of the total phosphorus called "effective phosphorus" actually supports algae growth and in lake primary production, and is thus the fraction that impacts the condition of the lake. Evaluations associated with determining the level of effective phosphorus from the Metro WWTP and key Onondaga Lake tributaries were required separately under the ACJ. These evaluations were completed at the end of 2010 and the results have been shared with the NYSDEC and WEP. In summary, the evaluations of factors relating to effective phosphorus loading (UFI, 2010) showed the following:

- Metro Outfall 001 particles are almost entirely composed of unrecovered iron-rich floc from the HRFS treatment process. Moreover, these iron-rich particles include phosphorus.
- Particulate phosphorus comprises about two-thirds of the residual total phosphorus load discharged from Metro Outfall 001.
- Bioassay results show that particulate phosphorus from Metro Outfall 001 is essentially non-bioavailable.
- It appears that the particulate phosphorus fraction - of the Metro Outfall 001 load is not an "effective" load to the pelagic waters.

The results of these evaluations are being used to assist NYSDEC's TMDL development efforts and finalize the Onondaga Lake Water Quality Model and Three-Rivers Water Quality Model (OLWQM/TRWQM). The linked OLWQM/TRWQM are mathematical models designed to simultaneously simulate the impacts from phosphorus loads (including Metro) to Onondaga Lake and the Seneca River. Validation runs for the model are currently being performed, after which modeling can be completed. Model simulations (performed under the Work Plan efforts) will be performed to compare the predicted changes to Onondaga Lake water quality with respect to baseline conditions and predicted reductions to Metro effluent phosphorus. Model outputs are expected to be graphically compared against applicable standards, guidance values, and "likely future criteria," including total phosphorus, total nitrogen and nitrate concentrations, Chlorophyll-a concentrations, Secchi disc transparency, and dissolved oxygen (DO) concentrations.

## 8.3 REGULATORY AND PERMITTING CONSIDERATIONS

Onondaga Lake water quality has improved dramatically since Metro's HRFS process was constructed, primarily due to the significant reduction in total phosphorus and near elimination of particulate bioavailable phosphorus from Outfall 001 discharges. Based on conversation with the NYSDEC, the Optimization Analysis and complementary Work Plan, efforts are considered integral components to the development of the TMDL and Metro's load allocation and resulting permit limit. Effluent variability must be taken into account when evaluating the TMDL allocations, and whether or not a lower effluent SPDES limit can be reliably achieved for the Metro WWTP. Maintaining a factor of safety between the targeted median effluent concentration and the permit limit is critical to allow for this variability, even at the most exemplary WWTPs.

When reviewing the data presented herein from the Optimization Analysis, the following must be included in the context of developing TMDL load allocations and the resultant SPDES permit:

- The existing total phosphorus SPDES limit (0.10 mg TP/L) is almost 20 percent below the design rating of the HRFS system (0.12 mg TP/L) as established by the Engineer's Report and warranted by HRFS manufacturer. Based on operating data from the past two years, Metro currently appears to be outperforming its design rating to successfully meet the permit limit. However, initial statistical assessment indicates that the current reliable LOT seems to be close to the design rating of 0.12 mg TP/L. Metro's compliance values (annual rolling average) for effluent total phosphorus exceeded 0.10 mg TP/L every month in 2007; was at or above 0.09 mg TP/L every month in 2008; and was at or above 0.09 mg TP/L three months in 2010. Note that treating to permit limits of 0.12 mg TP/L and 0.10 mg TP/L represents phosphorus removals (average Metro influent of 2.45 mg TP/L) of 95.1 percent and 95.9 percent, respectively. A further permit reduction to, say 0.09 mg TP/L, would result in 96.3 percent removal – an increase of 0.4 percent.
- Initial results from the LOT Analysis show the Metro WWTP is currently approaching the lower limit of phosphorus removal capability for its existing treatment processes. For nutrient removal processes, it has been demonstrated that as the targeted concentration decreases, the effluent variability increases (Neethling, et al., 2009). Therefore, the process becomes more difficult to control. A contributor

to this variability is the need to maintain plant processes and equipment. For example:

  - BAF and HRFS systems currently need to be taken out of service for maintenance (e.g., clean diffusers and Cross Channel), inspection or repair.
  - The HRFS polymer feed lines and coagulant diffusers can plug, which negatively impacts floc formation.
  - Necessary maintenance in other parts of the plant such as digester cleaning can return large amounts of phosphorus during short time periods.
  - The amount of iron provided in bulk deliveries varies.

  All of these events, which can be managed but not eliminated, can have an impact on Metro effluent phosphorus concentrations. Phosphorus removal in the secondary treatment system must be balanced with the need to treat for ammonia in the BAF process. The BAF must have a minimum level of orthophosphate and carbon to perform effectively. Maximizing phosphorus treatment in the activated sludge process would reduce orthophosphate and carbon levels below the minimum level needed for nitrogen removal in the BAF.

- Due to the high level of process variability when treating to very low nutrient limits, an extensive database of long-term effluent monitoring – at least three years – under full-scale conditions is essential to verify that modifications result in lower phosphorus discharges.

- While opportunities have been identified for promoting conditions that would optimize phosphorus treatment, the evaluation shows that Metro operations personnel are highly responsive to addressing increases in effluent phosphorus.

- Onondaga Lake water quality has improved dramatically since Metro's HRFS process was constructed, primarily due to the significant reduction in total phosphorus and near elimination of particulate bioavailable phosphorus from effluent discharges.

It is believed that the Metro WWTP is the largest HRFS facility in North America being required to achieve such very low effluent limits for phosphorus. While the recommended optimization alternative is expected to reduce effluent variability and more reliably meet a permit limit of 0.10 mg TP/L, effluent variability cannot be eliminated. Having an annual rolling average for a permit limit helps to offset some of this variability, but historical data still shows variation in rolling average results from the Metro WWTP effluent. While improvements will likely result in reduction of total effluent phosphorus, preliminary determinations at this time show that reliably meeting a permit limit below 0.10 mg TP/L is likely unachievable. As defined in Section 1.0, reliability must assume 100 percent permit limit compliance because of ACJ mandates.

Since the current Metro processes are approaching their physical and practical limit for removing phosphorus, and due to inherent process variability when treating to very low concentrations, an extended period of data collection (at least three years) would be necessary after optimization improvements are implemented to verify that a reduced permit limit could be reliably met. This is especially the case with a large, wet weather facility such as Metro. Therefore, it would be advisable to defer any additional reductions below the current SPDES phosphorus limit of 0.10 mg/L until a suitable and defendable scientific database can be developed to support such a decision. Use of an approach to predict what Metro can achieve risks significant consequences to the County given anti backsliding regulations. For example, without actual data from an optimized facility the ability to handle additional flow at Metro could be limited, which would impact the ability for growth in a struggling economy. An extended period of non-compliance, even with exemplary operation could require additional treatment at a significant cost.

Additionally, changes to permit levels should be based on establishing that such a reduction will benefit Onondaga Lake. The phosphorus guidance level for the lake has been met three of the past four years (including summer 2011). Water quality modeling is being performed to evaluate the benefit of phosphorus reductions - and particularly effective (bioavailable) phosphorus reduction - on lake water quality. It is noteworthy that optimizing Metro for phosphorus removal would primarily involve reductions in particulate phosphorus, which is non-bioavailable. Therefore, additional particulate phosphorus removal from Metro effluent would not be expected to improve Onondaga Lake water quality.

## 9.0 REFERENCES

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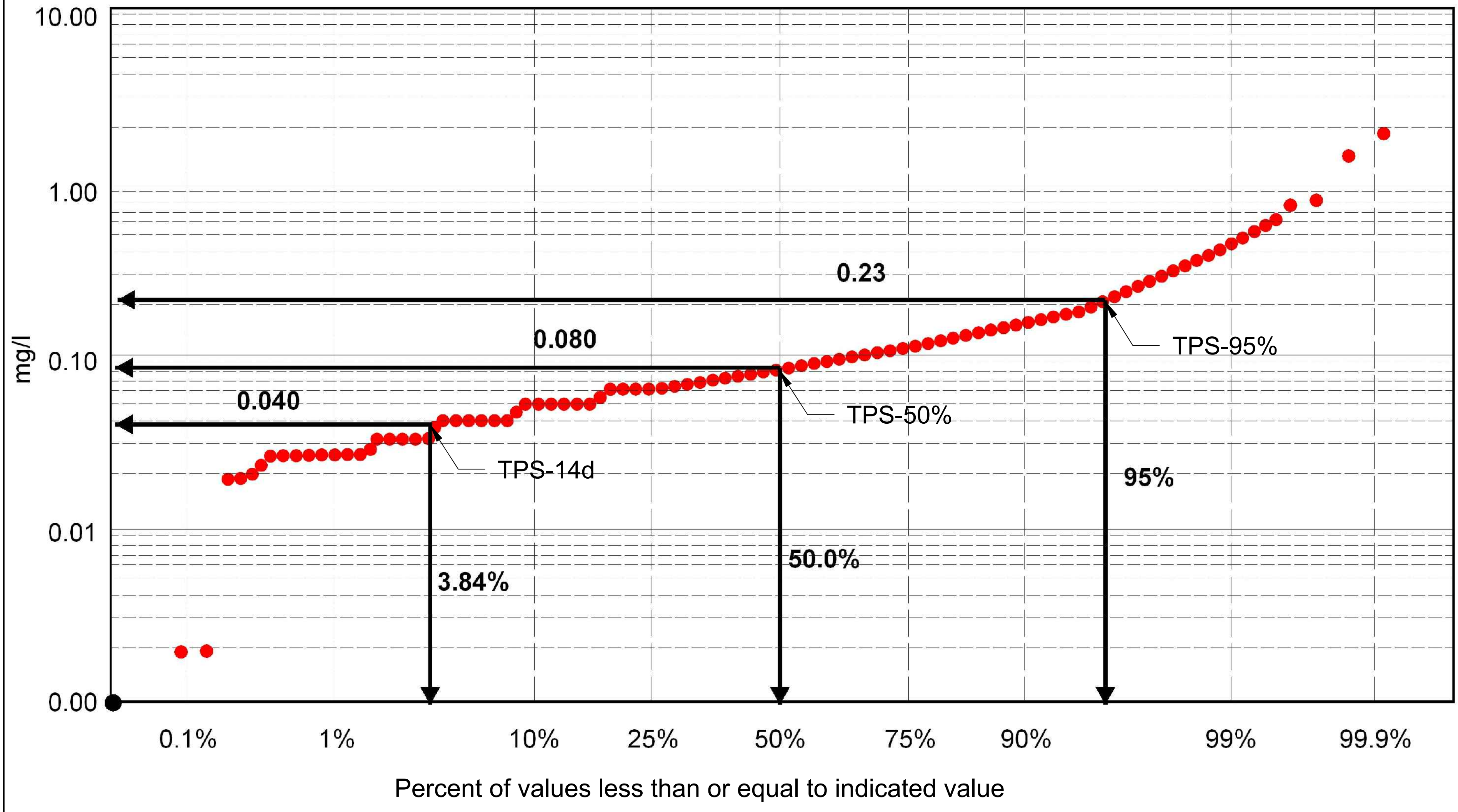
# FIGURES

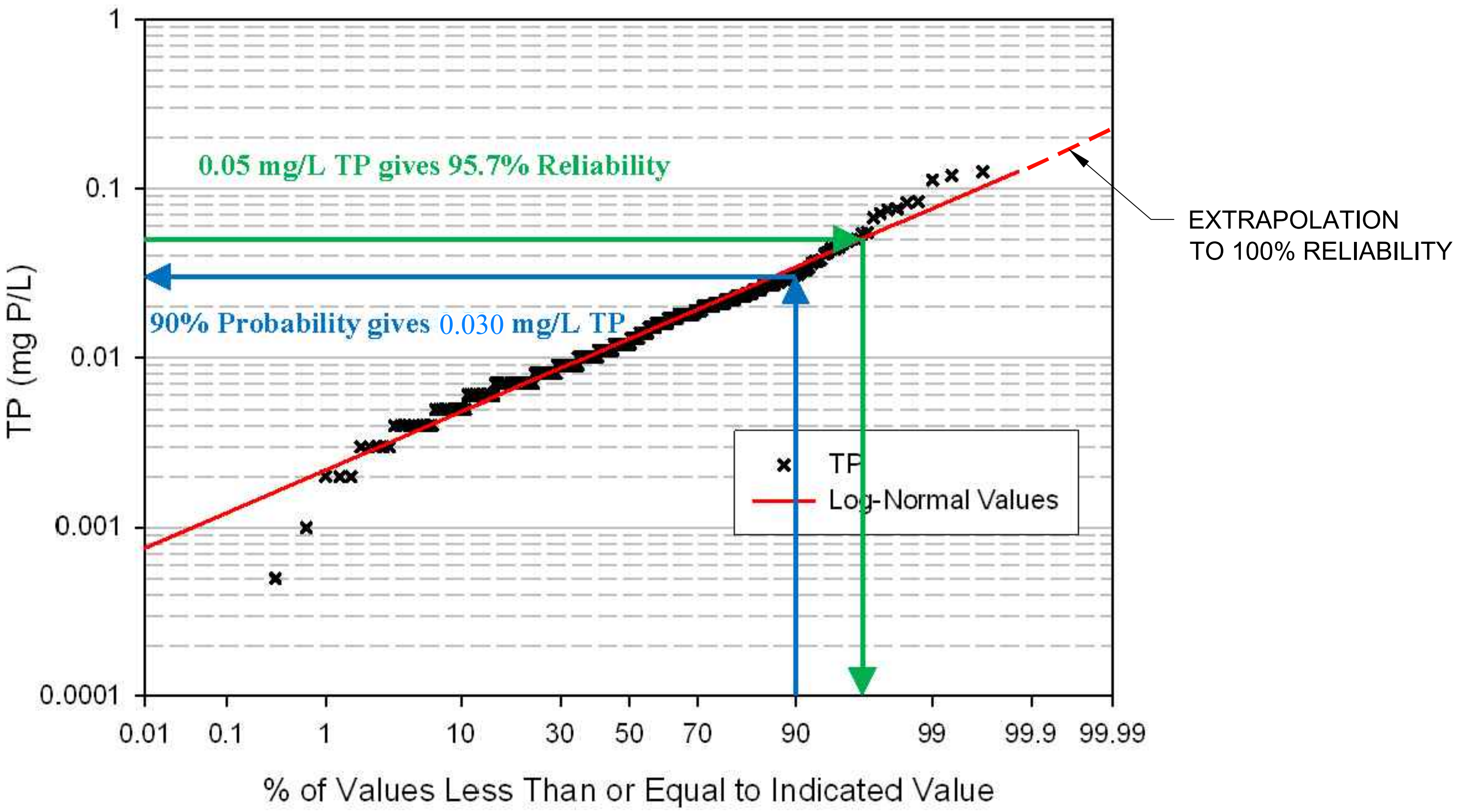


SOURCE: NEETHLING, ET. AL, 2009

NOTE: TPS = TECHNOLOGY PERFORMANCE STATISTIC

Figure 1-1

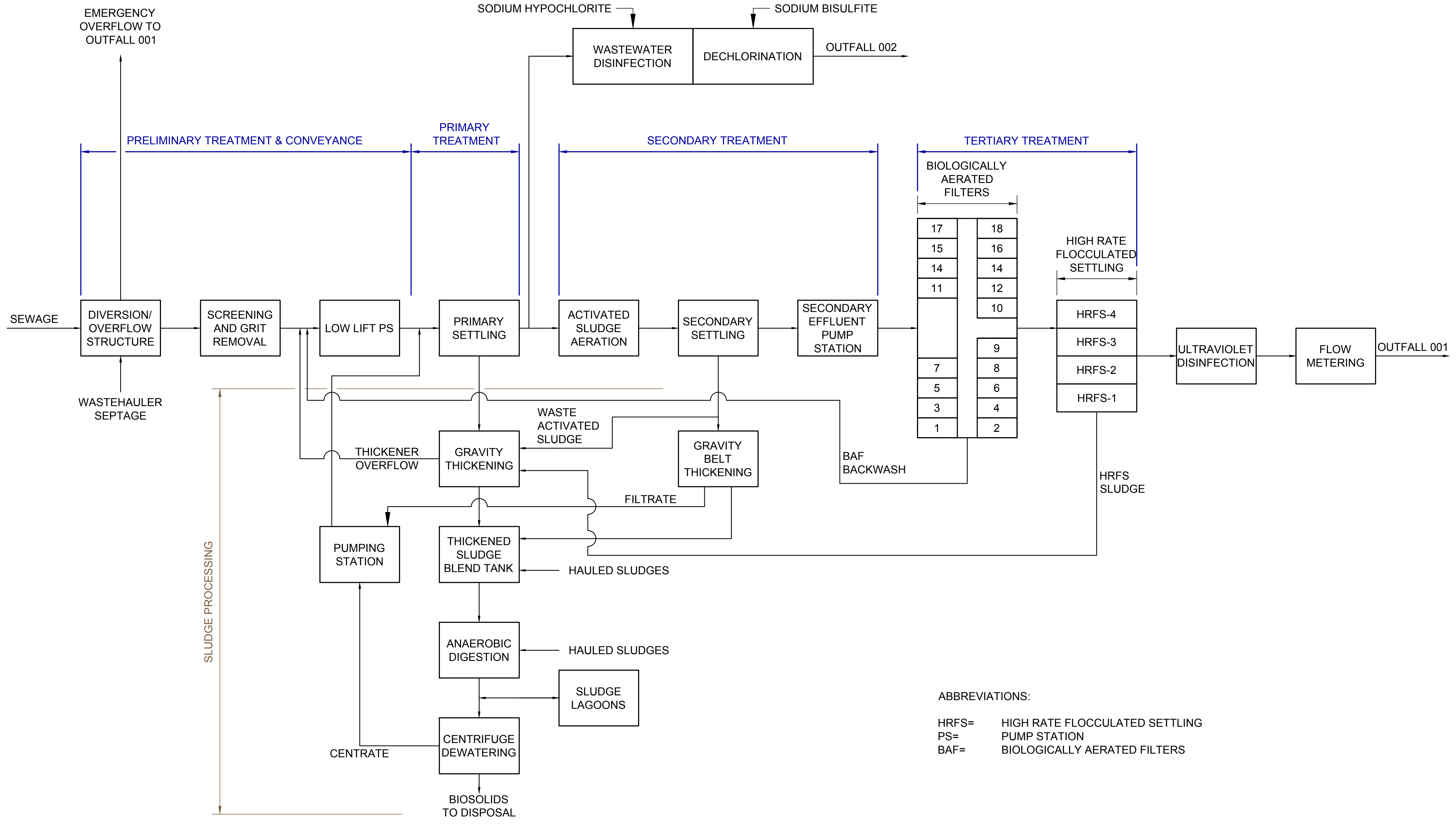
SAMPLE OF PROBABILITY SCALE PLOT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



SOURCE: WERF, 2011

Figure 1-2

PROBABILITY GRAPH FOR DETERMINING PROCESS RELIABILITY
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



ABBREVIATIONS:

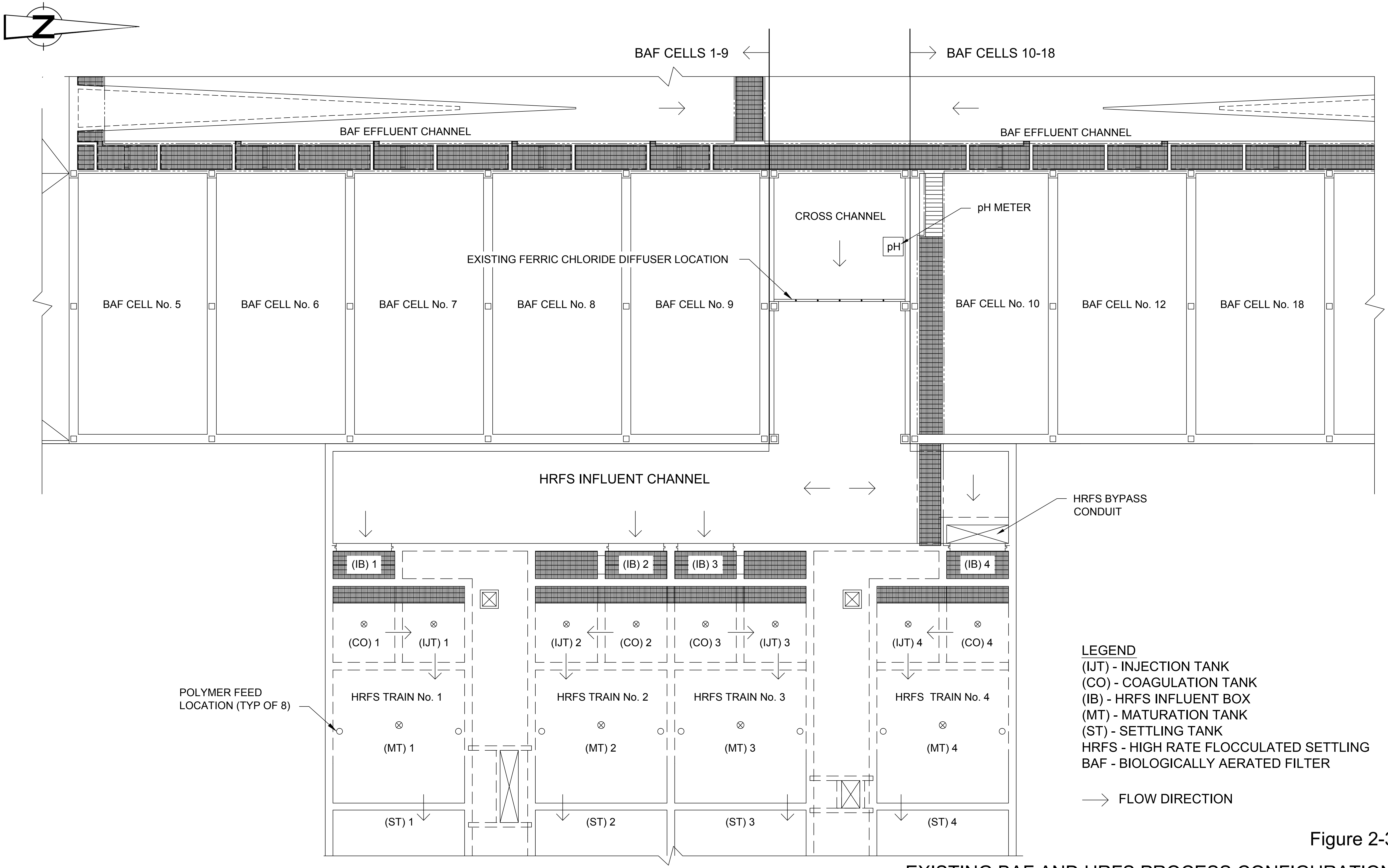
| | |
|---|---|
| HRFS= | HIGH RATE FLOCCULATED SETTLING |
| PS= | PUMP STATION |
| BAF= | BIOLOGICALLY AERATED FILTERS |

Figure 2-1

METRO WWTP EXISTING PROCESS FLOW SCHEMATIC
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

Figure 2-2

METRO WWTP EXISTING SITE PLAN
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



LEGEND
(IJT) - INJECTION TANK
(CO) - COAGULATION TANK
(IB) - HRFS INFLUENT BOX
(MT) - MATURATION TANK
(ST) - SETTLING TANK
HRFS - HIGH RATE FLOCCULATED SETTLING
BAF - BIOLOGICALLY AERATED FILTER

→ FLOW DIRECTION

Figure 2-3

EXISTING BAF AND HRFS PROCESS CONFIGURATION
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

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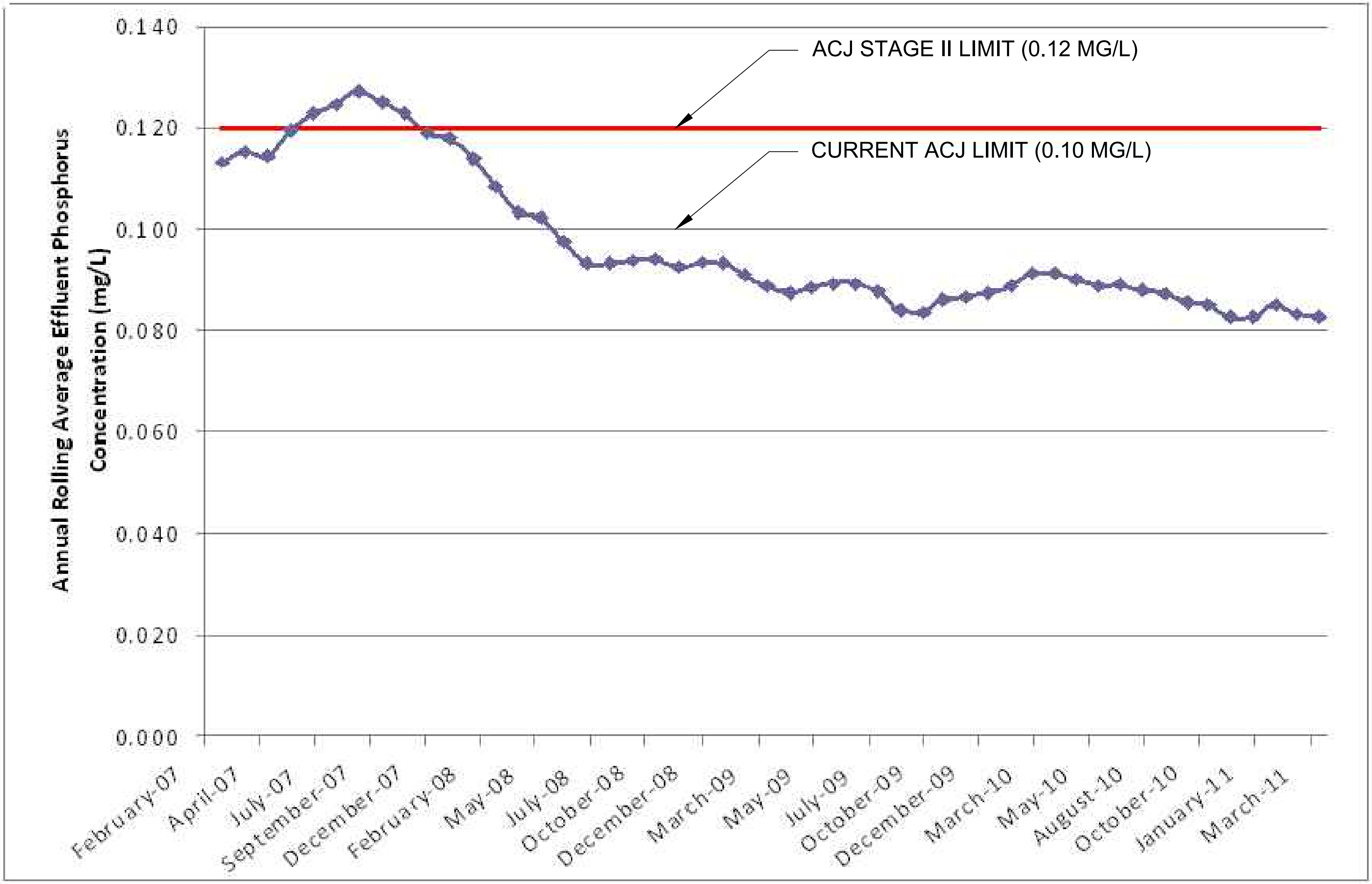


Figure 3-1

METRO WWTP EFFLUENT TOTAL PHOSPHORUS CONCENTRATION (2007-2010)
ANNUAL ROLLING AVERAGE BASIS
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

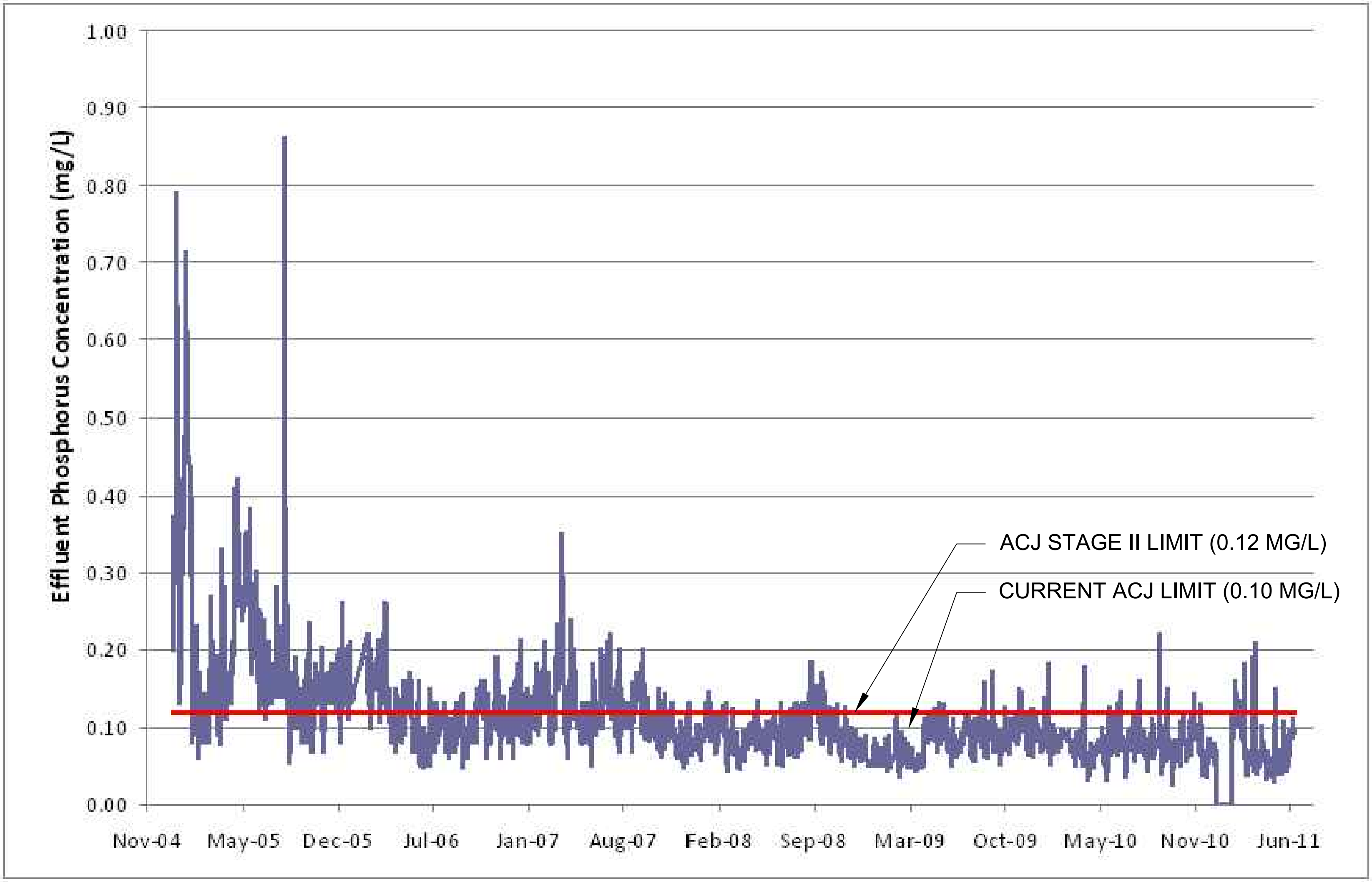


Figure 3-2

METRO WWTP DAILY EFFLUENT CONCENTRATION MEASUREMENTS
(NOVEMBER 2004 - JUNE 2011)
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

CRA

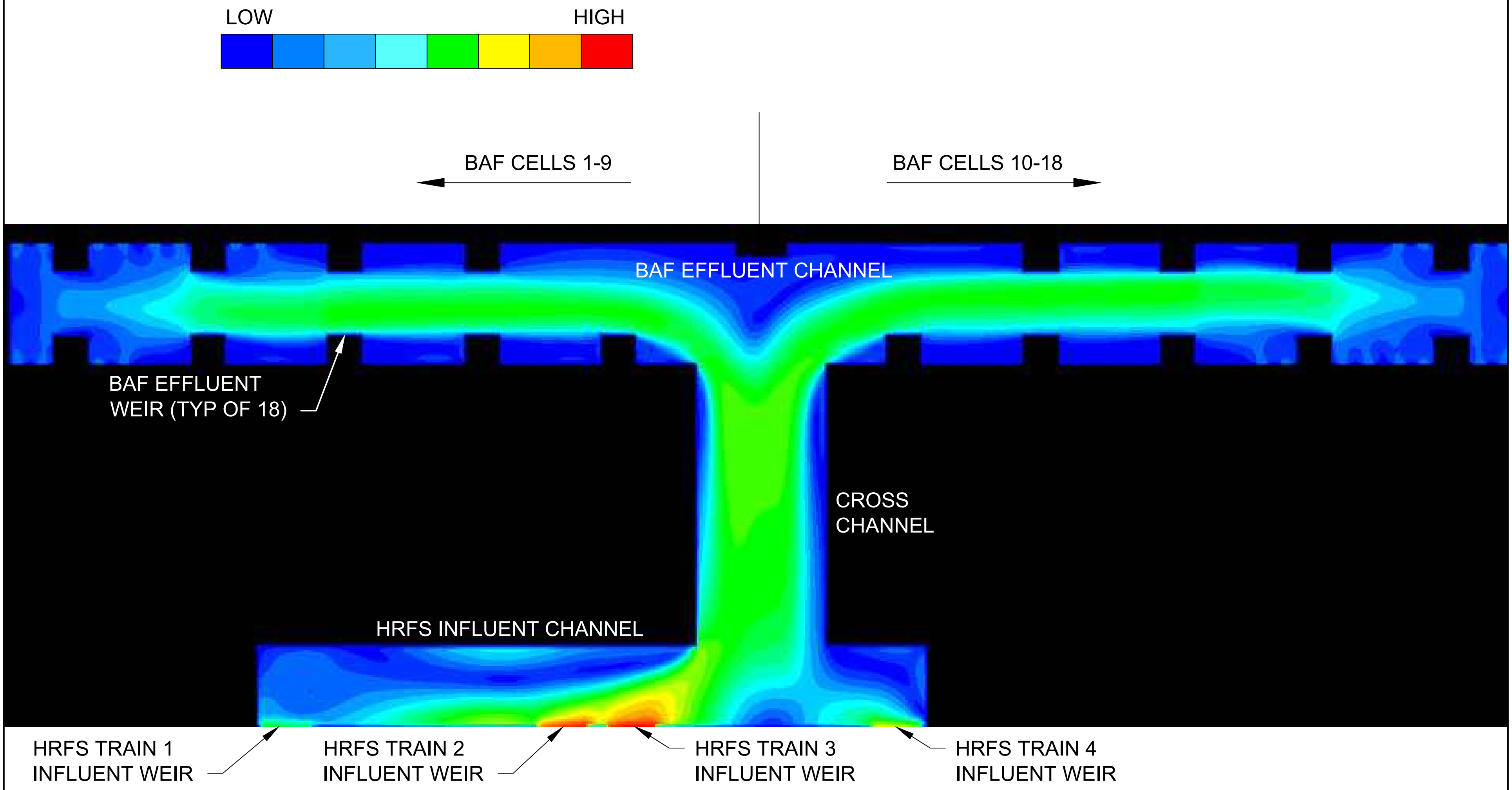


Figure 4-1

VELOCITY CONTOURS FROM CFD SIMULATION 2
BALANCED FLOW CONDITION AT METRO WWTP FLOW OF 70 MGD
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

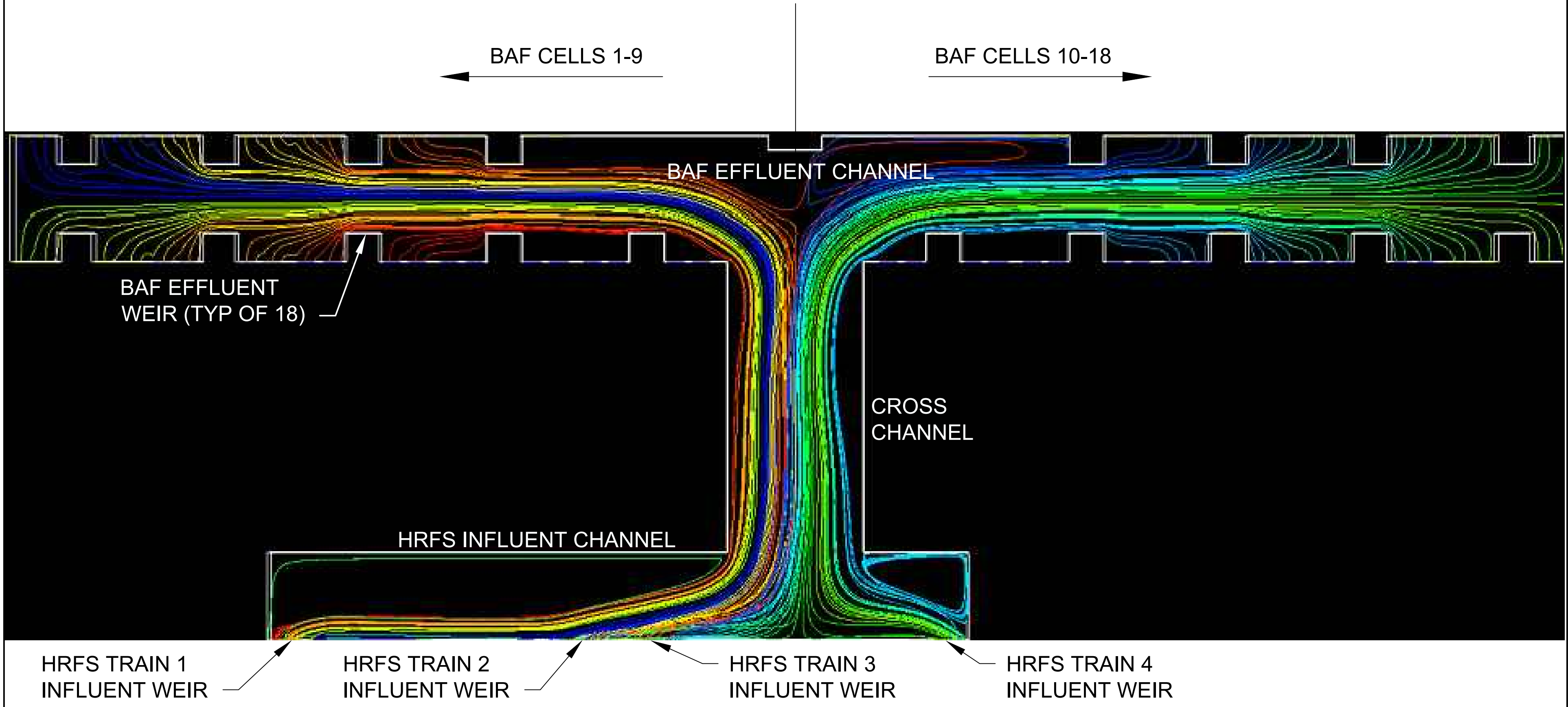


Figure 4-2

PARTICLE TRACKS FROM CFD SIMULATION 2
BALANCED FLOW CONDITION AT METRO WWTP FLOW OF 70 MGD
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

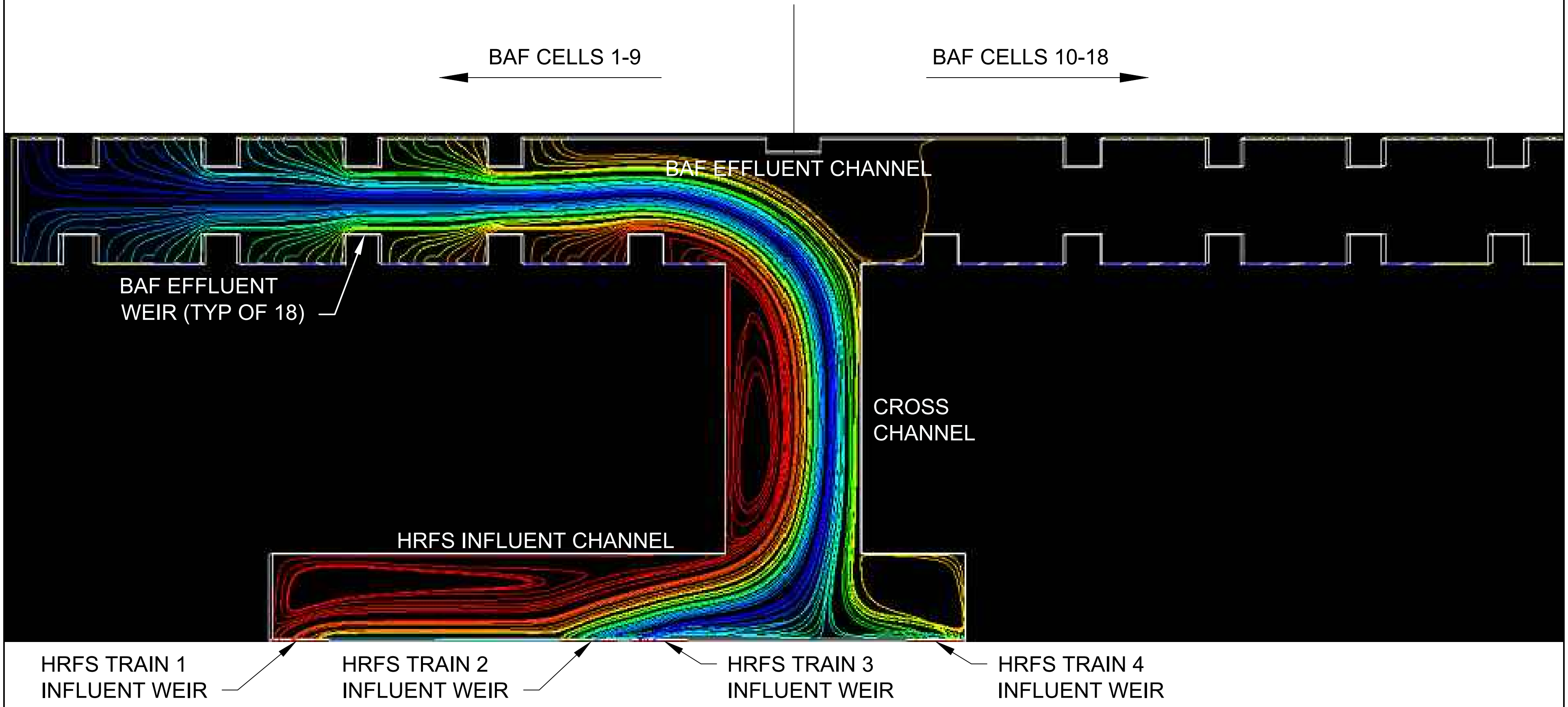


Figure 4-3

PARTICLE TRACKS FROM CFD SIMULATION 4
UNBALANCED FLOW CONDITION (ALL FLOW FROM SOUTH) AT METRO WWTP FLOW OF 70 MGD
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

CRA

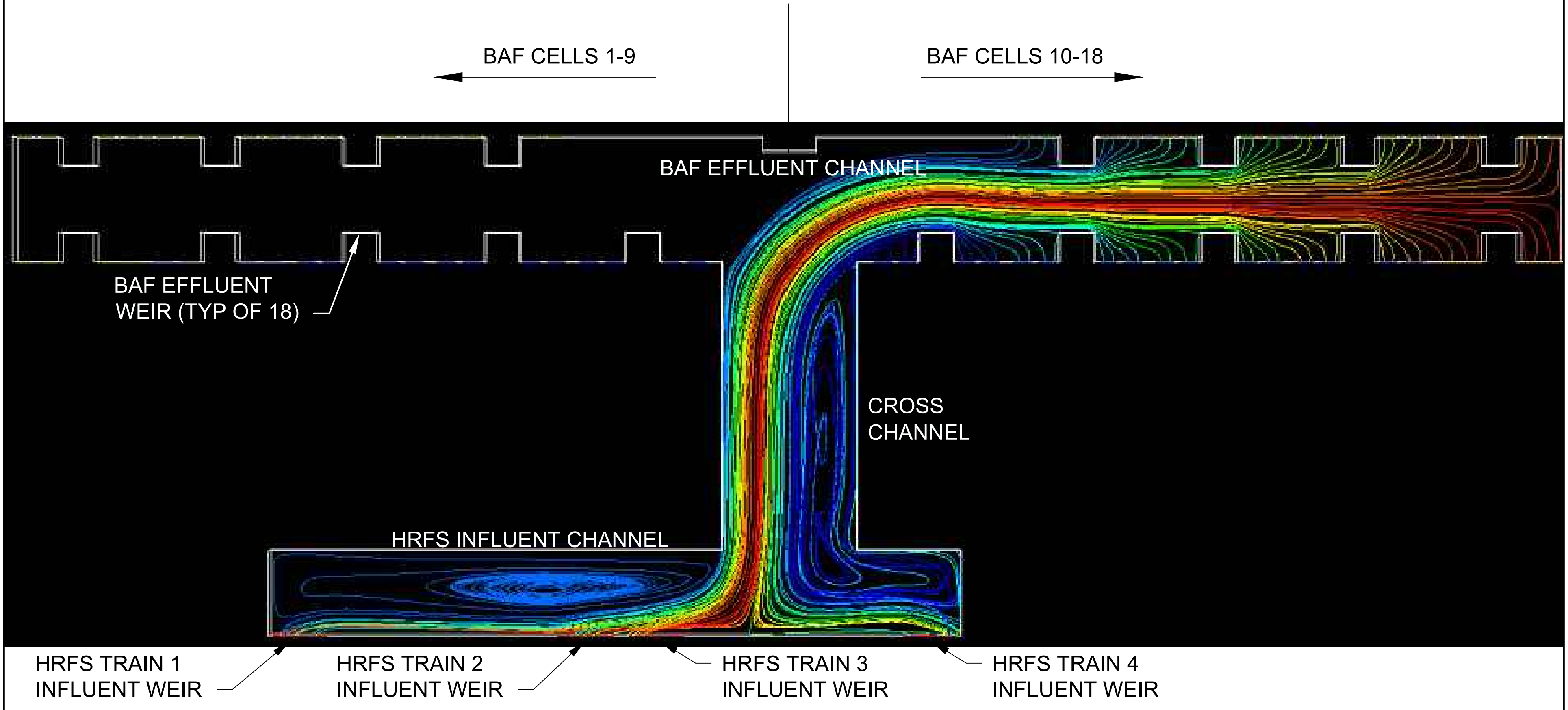


Figure 4-4

PARTICLE TRACKS FROM CFD SIMULATION 5
UNBALANCED FLOW CONDITION (ALL FLOW FROM NORTH) AT METRO WWTP FLOW OF 70 MGD
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

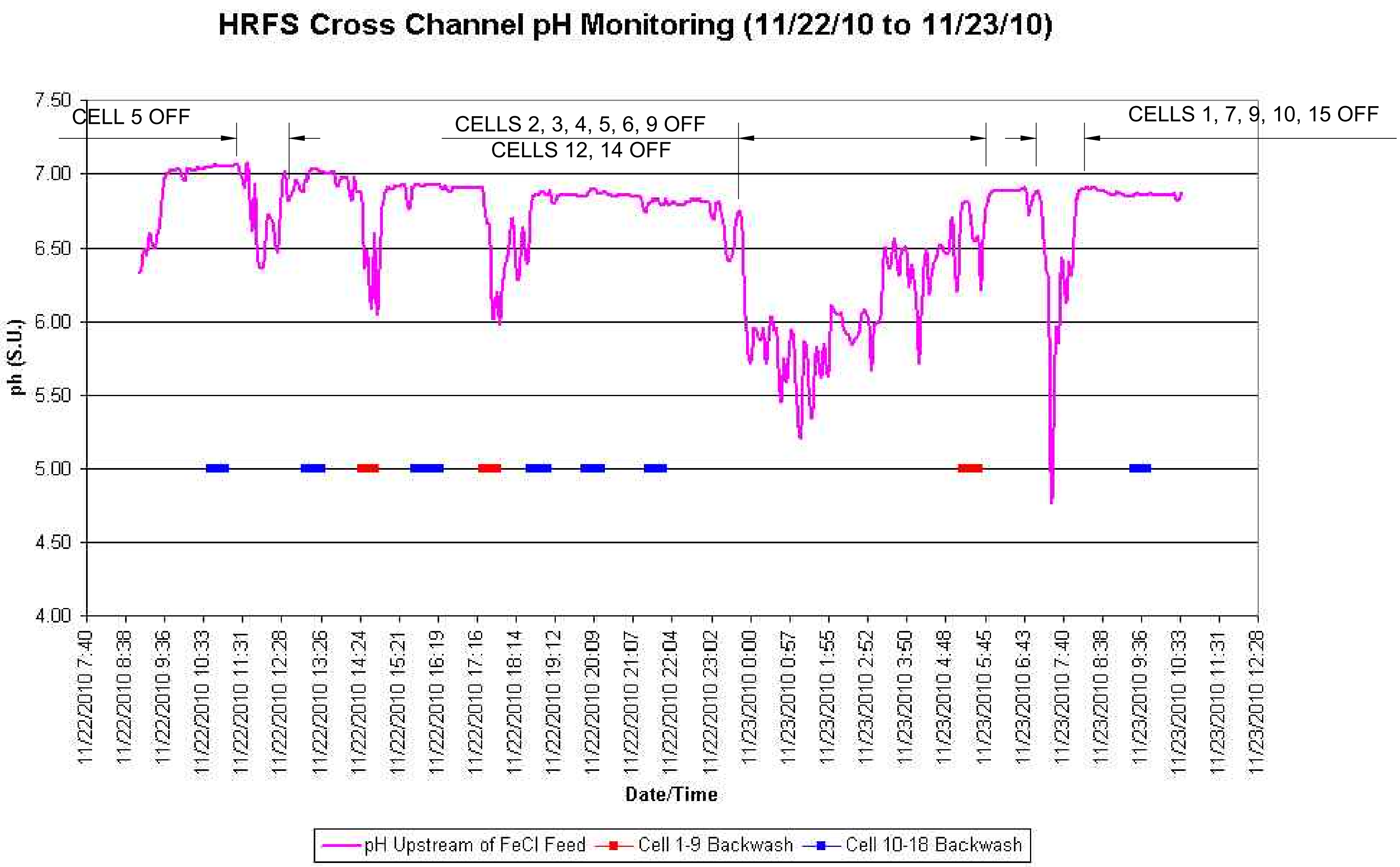
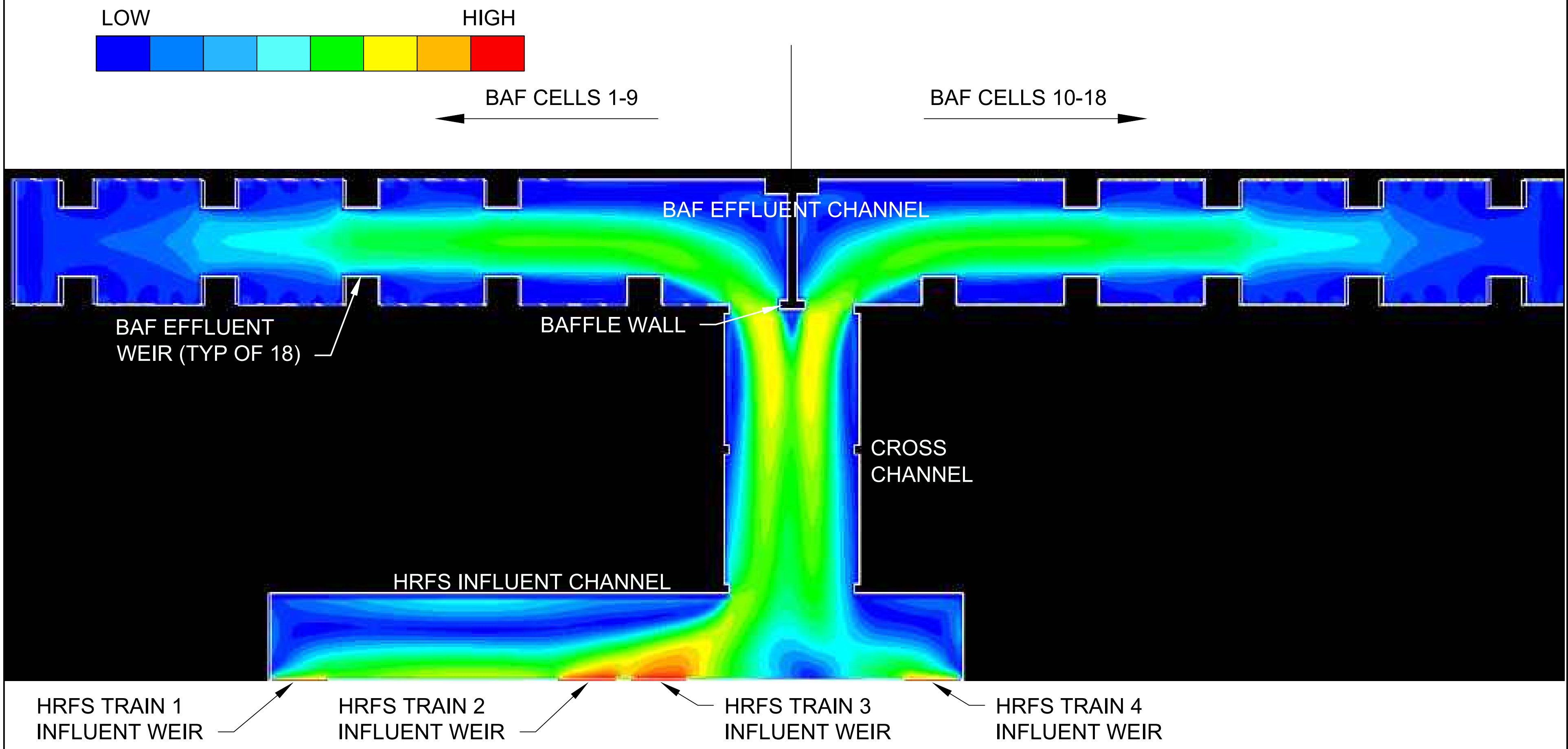


Figure 4-5

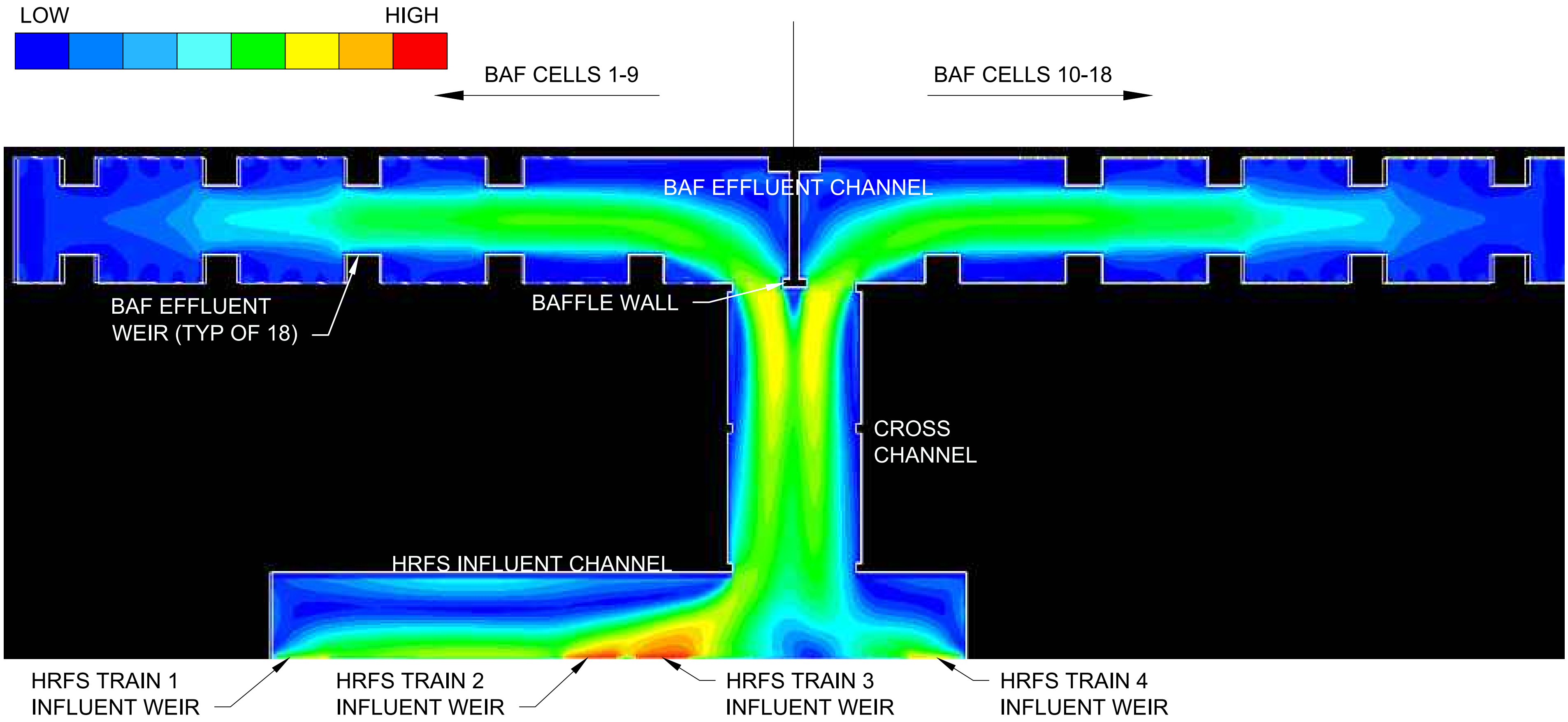
pH MONITORING UPSTREAM OF FERRIC CHLORIDE ADDITION
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



| | HRFS FLOW DISTRIBUTION | | | |
|---|---|---|---|---|
| | TRAIN 1 | TRAIN 2 | TRAIN 3 | TRAIN 4 |
| WITH ISOLATION WALL: | 23% | 24% | 24% | 29% |
| WITHOUT ISOLATION WALL: | 22% | 25% | 25% | 28% |

Figure 4-6

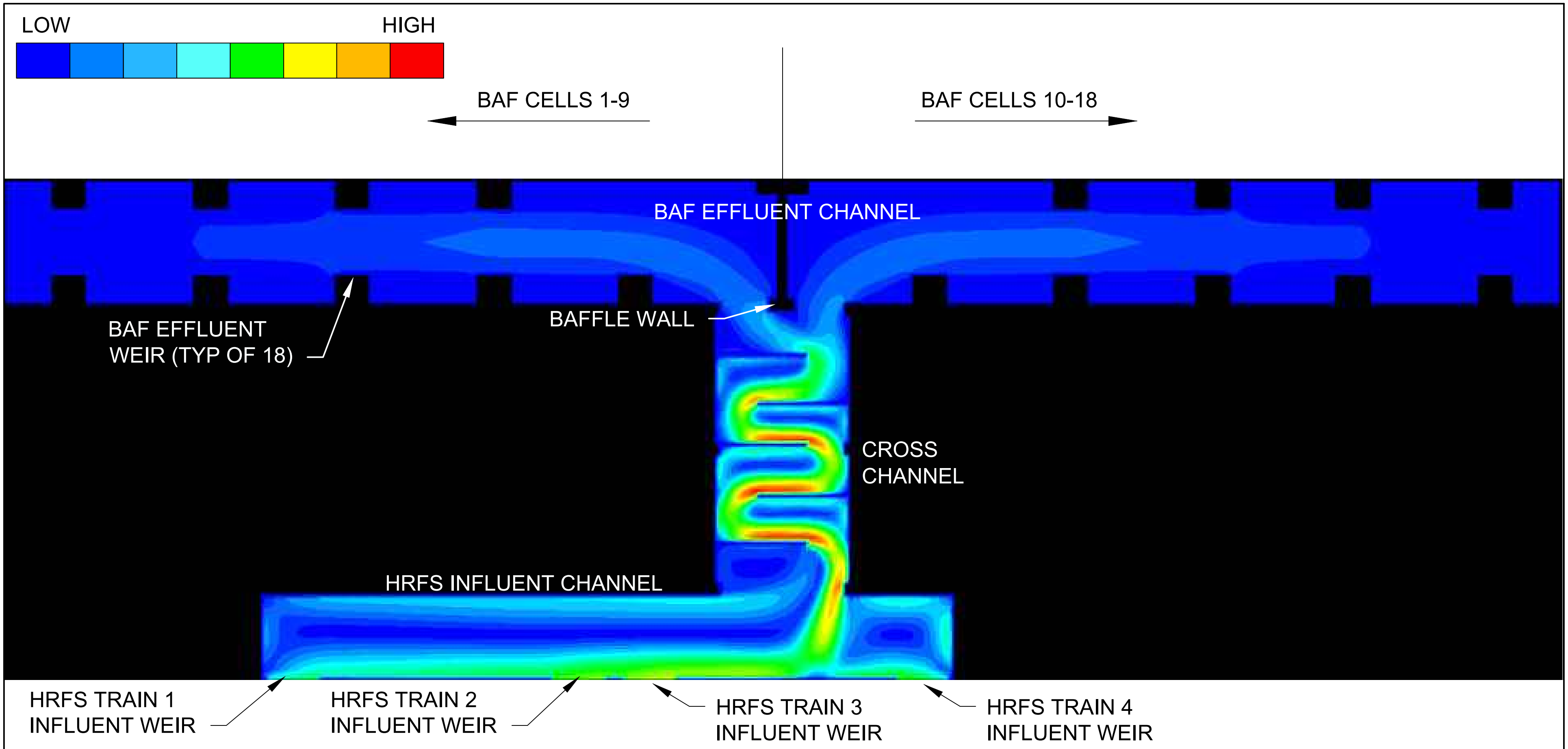
VELOCITY CONTOURS FROM CFD SIMULATION 6
BALANCED FLOW CONDITION AT METRO WWTP FLOW OF 70 MGD - BAF ISOLATION WALL ADDED
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



| | HRFS FLOW DISTRIBUTION | | | |
|---|---|---|---|---|
| | TRAIN 1 | TRAIN 2 | TRAIN 3 | TRAIN 4 |
| 40 MGD: | 24.5% | 28.0% | 27.0% | 21.0% |
| 70 MGD: | 24.5% | 26.5% | 25.5% | 23.5% |
| 130 MGD: | 25.5% | 25.5% | 24.4% | 24.4% |

Figure 4-7

VELOCITY CONTOURS FROM CFD SIMULATION 7
BALANCED FLOW CONDITION AT METRO WWTP FLOW OF 70 MGD-WEIR FOR HRFS TRAIN 4 RAISED 4"
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



| HRFS FLOW DISTRIBUTION | | | |
|---|---|---|---|
| TRAIN 1 | TRAIN 2 | TRAIN 3 | TRAIN 4 |
| 37% | 21% | 15% | 27% |

Figure 4-8

# VELOCITY CONTOURS FROM CFD SIMULATION 8
# BALANCED FLOW CONDITION AT METRO WWTP FLOW OF 70 MGD
# ADDITION OF SERPENTINE BAFFLE IN CROSS CHANNEL
# METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT

*Onondaga County WEP*

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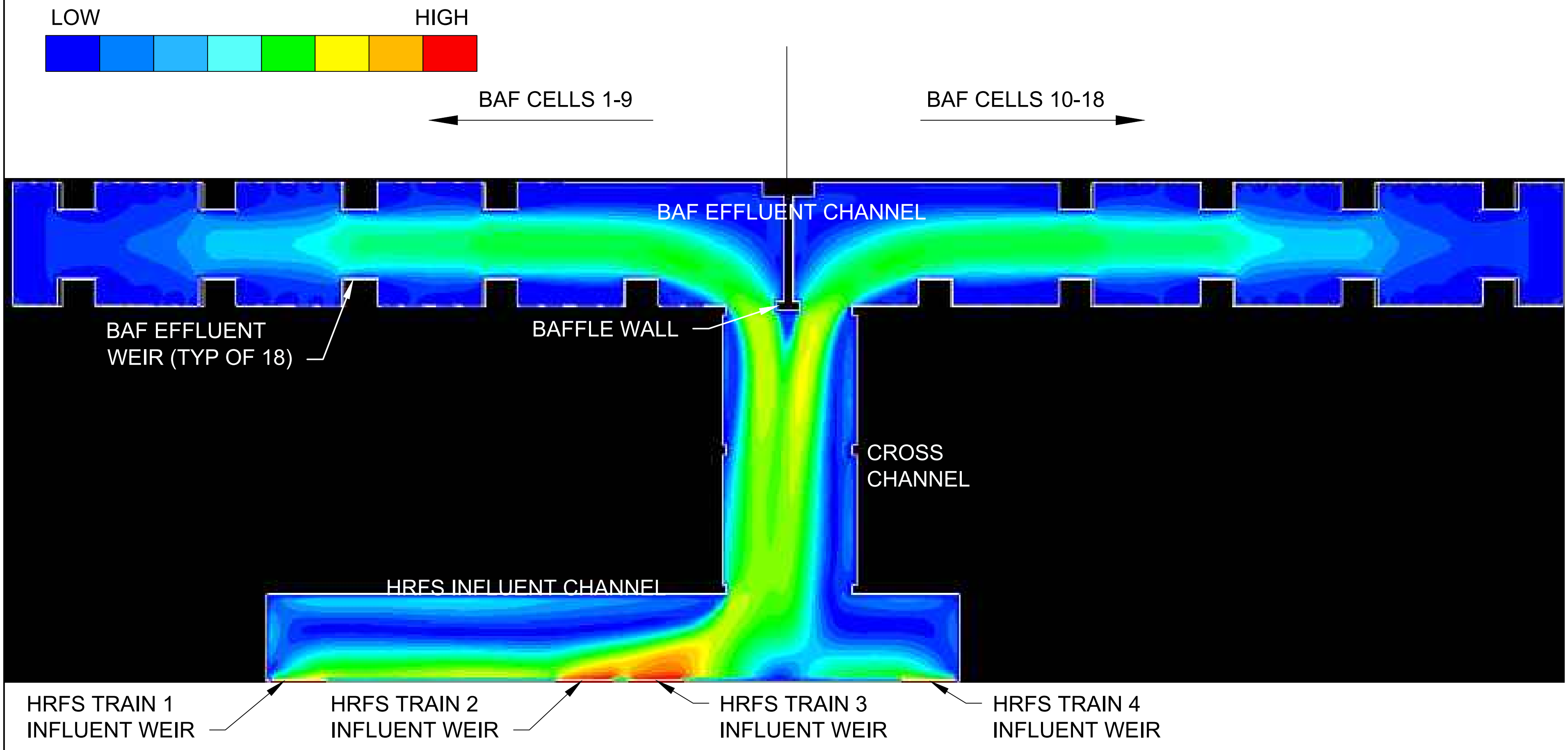


| | HRFS FLOW DISTRIBUTION | | | |
|---|---|---|---|---|
| | TRAIN 1 | TRAIN 2 | TRAIN 3 | TRAIN 4 |
| 70 MGD | 26% | 25% | 26% | 23% |

Figure 4-9

VELOCITY CONTOURS FROM CFD SIMULATION 9
BALANCED FLOW CONDITION AT METRO WWTP FLOW OF 70 MGD
HRFS TRAIN 4 WEIR RAISED 4", HRFS TRAINS 2 AND 3 WEIRS RAISED 1"
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

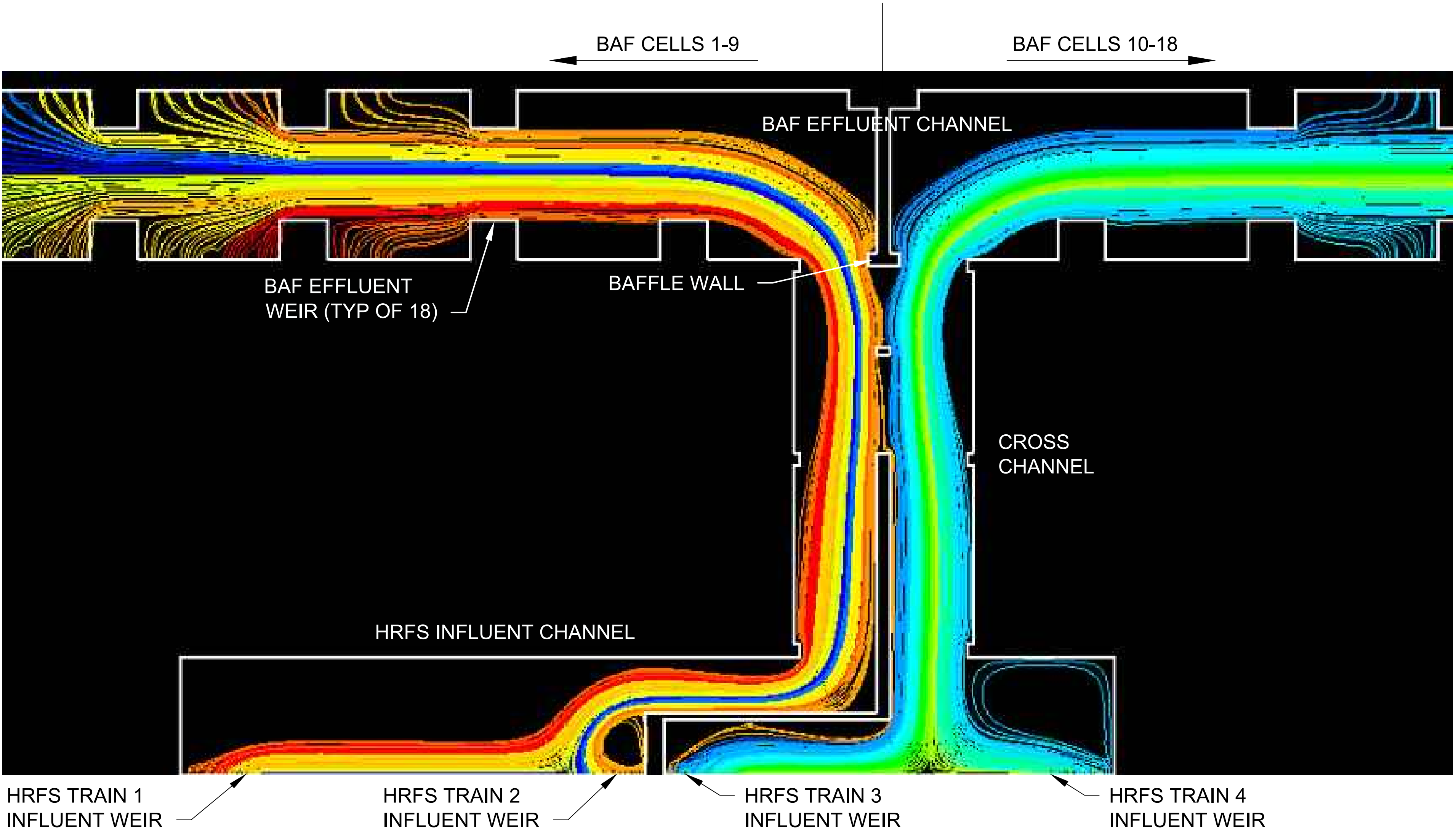
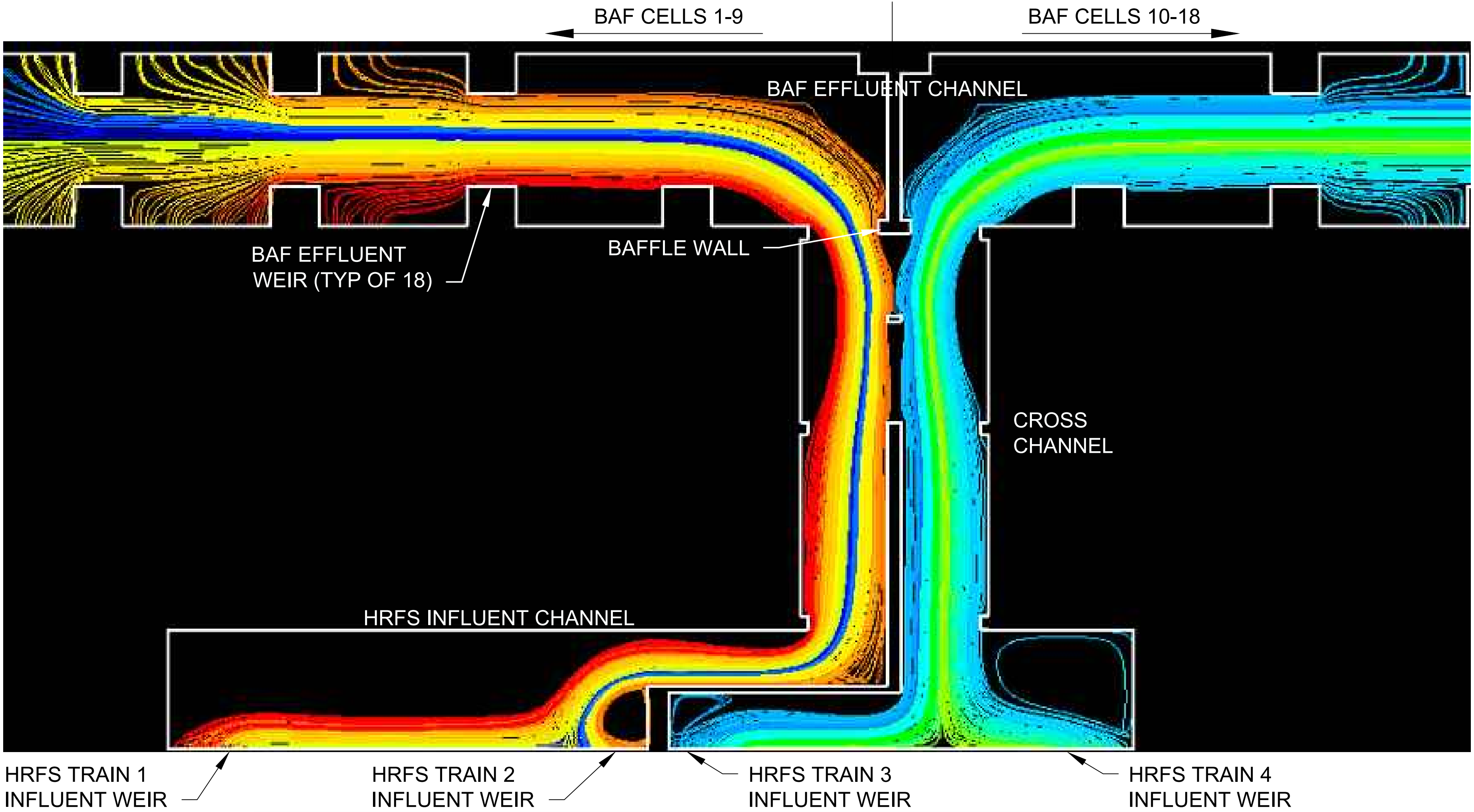


Figure 4-10

PARTICLE TRACKS FROM CFD SIMULATION 11-BALANCED FLOW CONDITION AT METRO WWTP
FLOW OF 70 MGD ADDITION OF ISOLATION WALL FROM BAF TO HRFS SYSTEM
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

Figure 4-11

PARTICLE TRACKS FROM CFD SIMULATION 13-UNBALANCED FLOW CONDITION AT METRO FLOW OF 70 MGD 75% OF FLOW FROM SOUTH BAF TRAIN, 25% OF FLOW FROM NORTH BAFS
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



HRFS FLOW DISTRIBUTION

| | TRAIN 1 | TRAIN 2 | TRAIN 3 | TRAIN 4 |
|---|---|---|---|---|
| 70 MGD | 25.1% | 24.0% | 26.1% | 24.8% |

Figure 4-12

PARTICLE TRACKS FROM CFD SIMULATION 17-BALANCED FLOW CONDITION AT METRO WWTP
FLOW OF 70 MGD ADDITION OF ISOLATION WALL, HRFS TRAINS 3 AND 4 WEIRS RAISED 2"
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

Figure 4-13

HRFS CROSS CHANNEL FERRIC CHLORIDE ADDITION
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

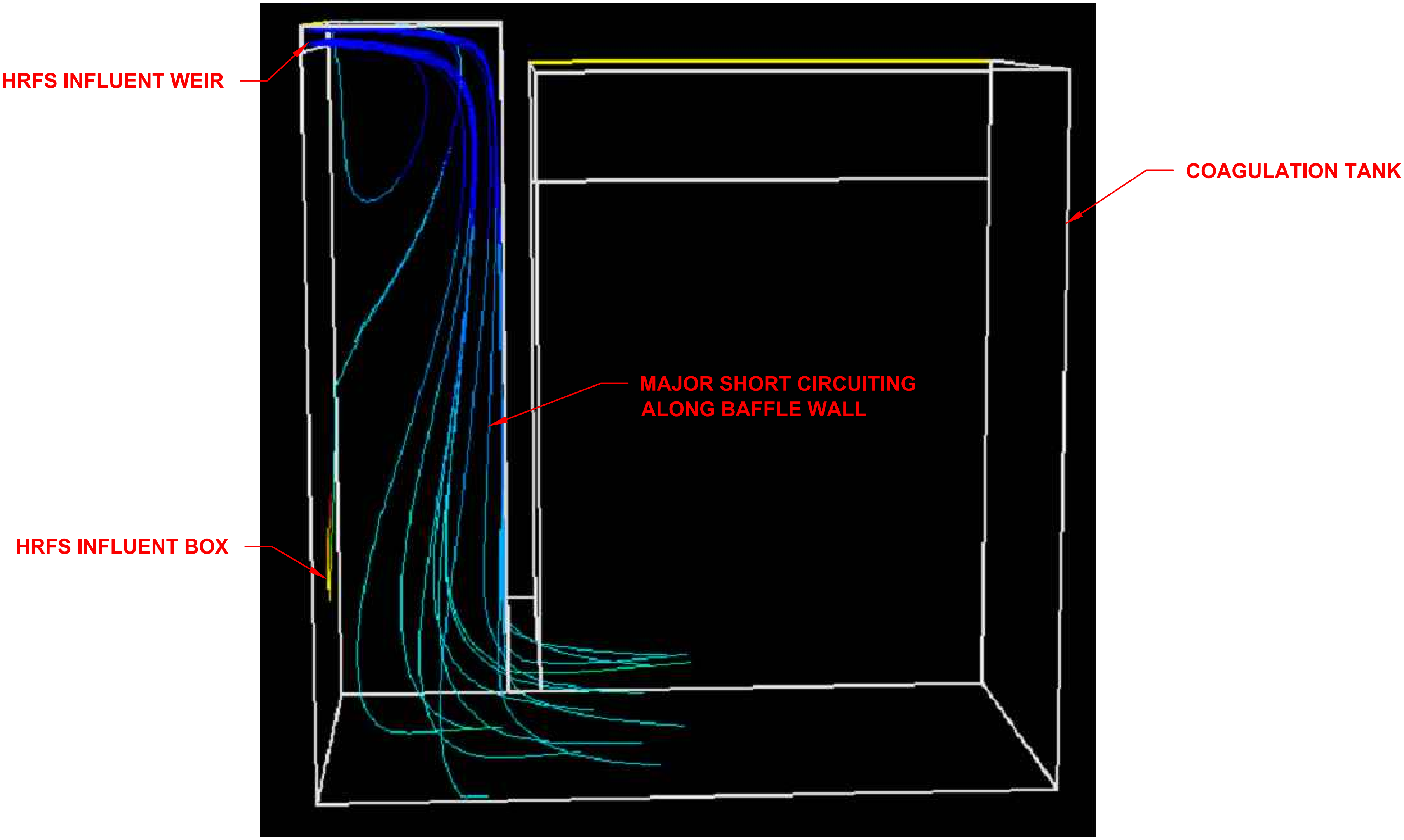


Figure 4-14

PARTICLE TRACK FROM CFD SIMULATION
HRFS INFLUENT BOX - EXISTING CONDITIONS
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

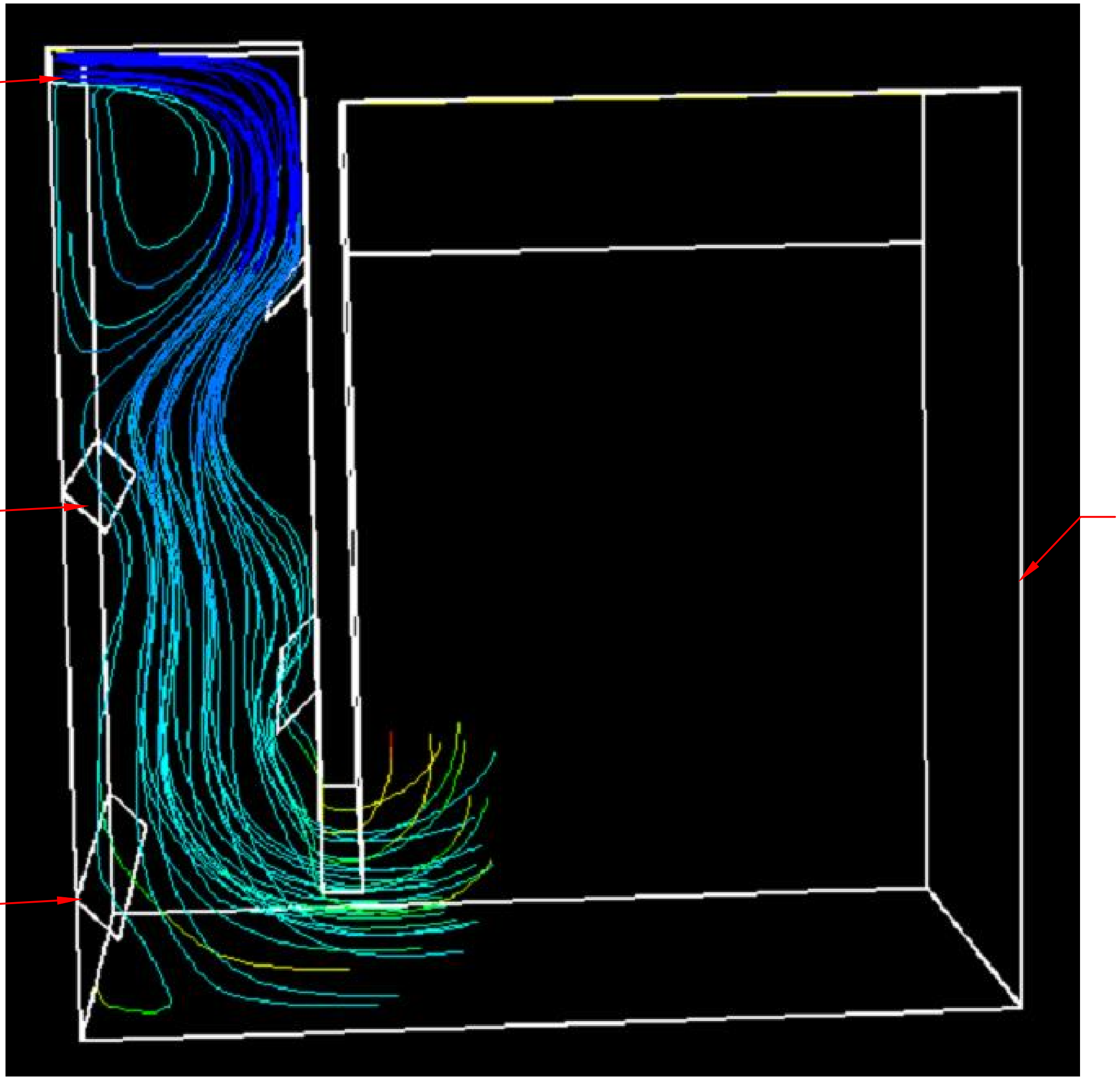


Figure 4-15

PARTICLE TRACK FROM CFD SIMULATION
HRFS INFLUENT BOX WITH MIXING BAFFLES
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

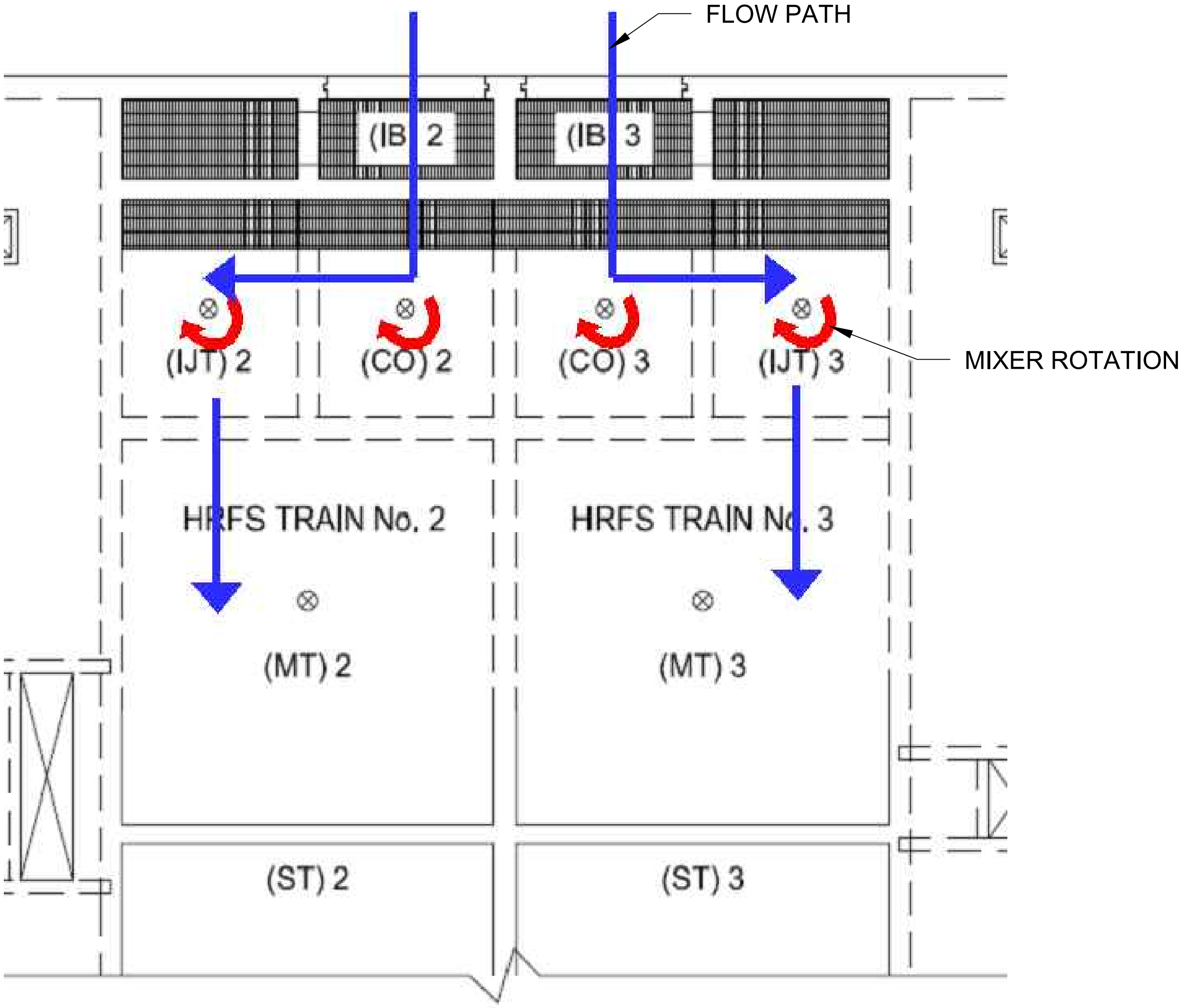


Figure 4-16

HRFS TRAINS 2 AND 3 FLOW AND MIXER CONFIGURATIONS
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

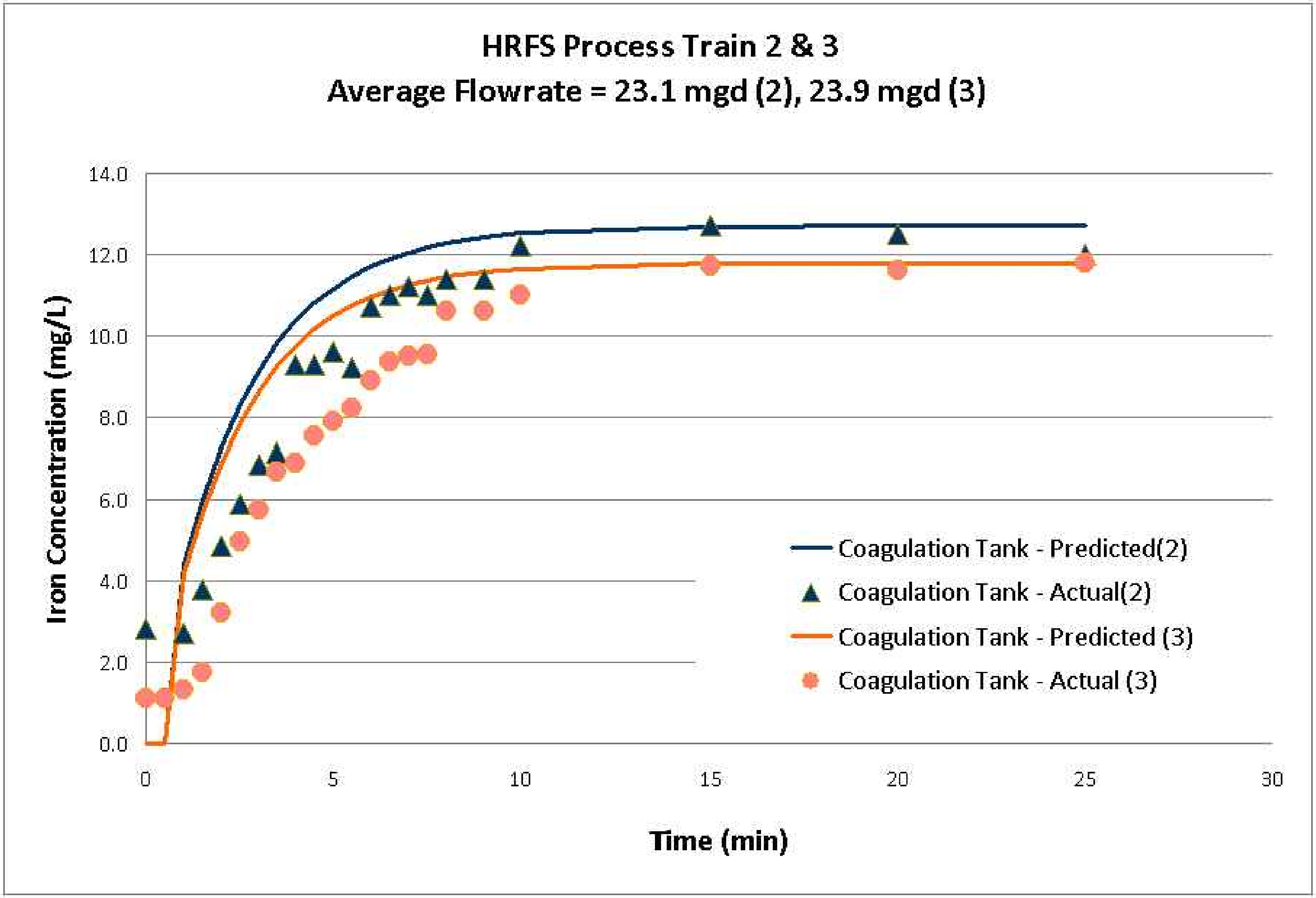
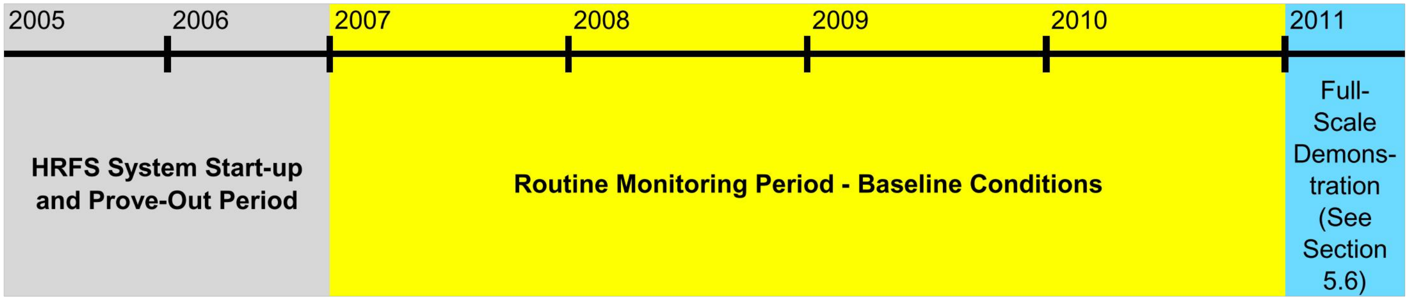


Figure 4-17

TRACER TESTING RESULT OF HRFS TRAINS 2 AND 3
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



**Process Upsets and O&M**

| Date | Description |
|---|---|
| 2005 - 3/15/2006 | HRFS Coagulant feed located at HRFS influent box |
| 3/15/2006 | HRFS system off line for maintenance |
| 3/21/2006 | HRFS system on line. HRFS Coagulant feed relocacted to Cross Channel |
| 2/5/2011 | HRFS Coagulant feed located at HRFS influent box |
| 2/18/2011 | HRFS Coagulant feed located at HRFS influent box |
| 2/28/2011 | HRFS Coagulant feed located at HRFS influent box |

**Special Testing and Monitoring Periods**

| Date | Description |
|---|---|
| 11/22/2010 | Supplemental Monitoring Round 1 |
| 12/7/2010 | Supplemental Monitoring Round 2 |
| 12/14/2010 | Supplemental Monitoring Round 3 |
| 12/15/2010 | Comparative Bench-Scale Testing Round 1 |
| 1/4/2011 | Comparative Bench-Scale Testing Round 2 |
| 1/18/2011 | Comparative Bench-Scale Testing Round 3 |
| 2/5/2011 | Full-scale Demonstration Testing Starts |
| 7/13/2011 | Full-scale Demonstration Testing Ends |

Figure 5-1

TIME LINE
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

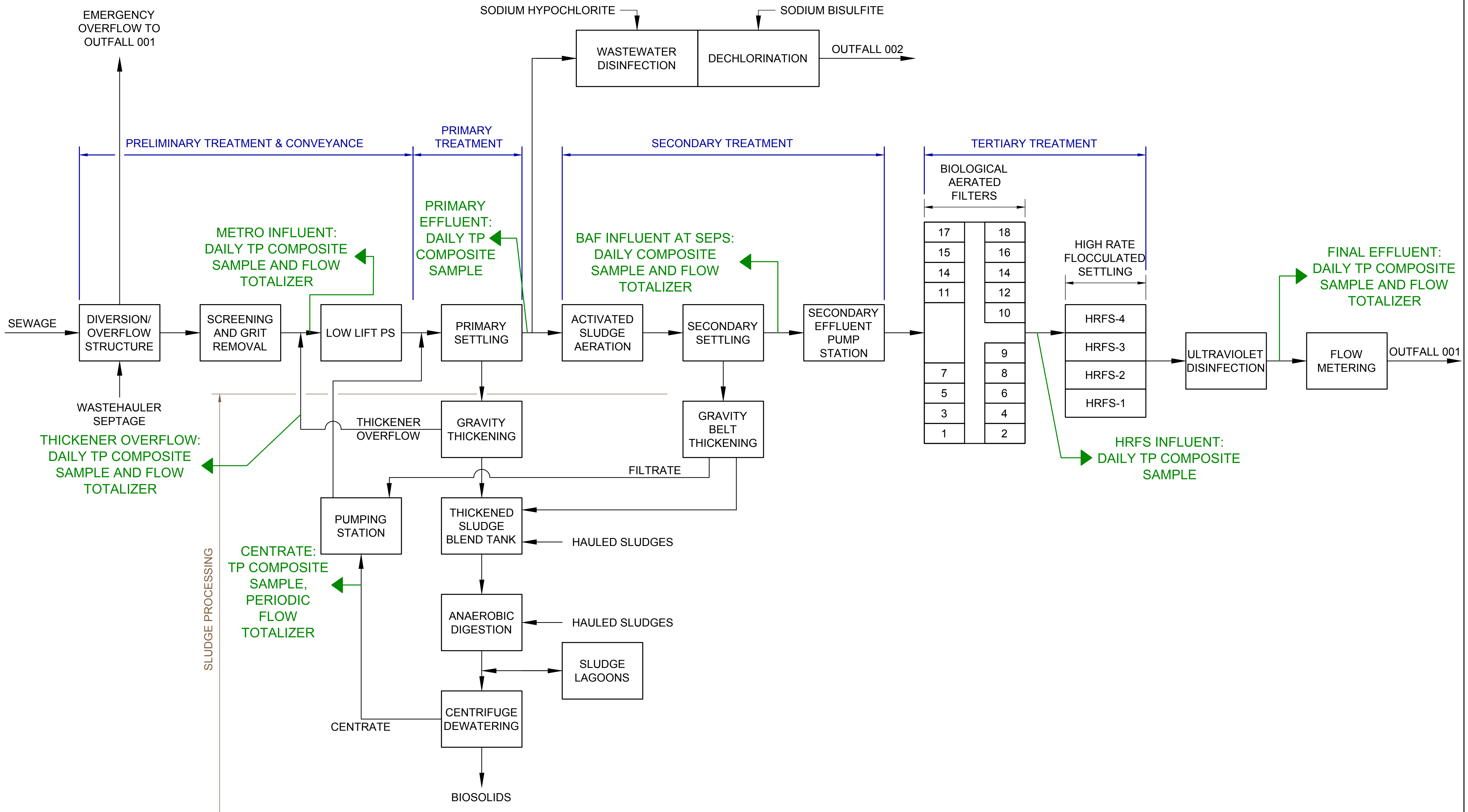


Figure 5-2

LOCATIONS OF ROUTINE TP SAMPLES AND FLOW TOTALIZERS
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

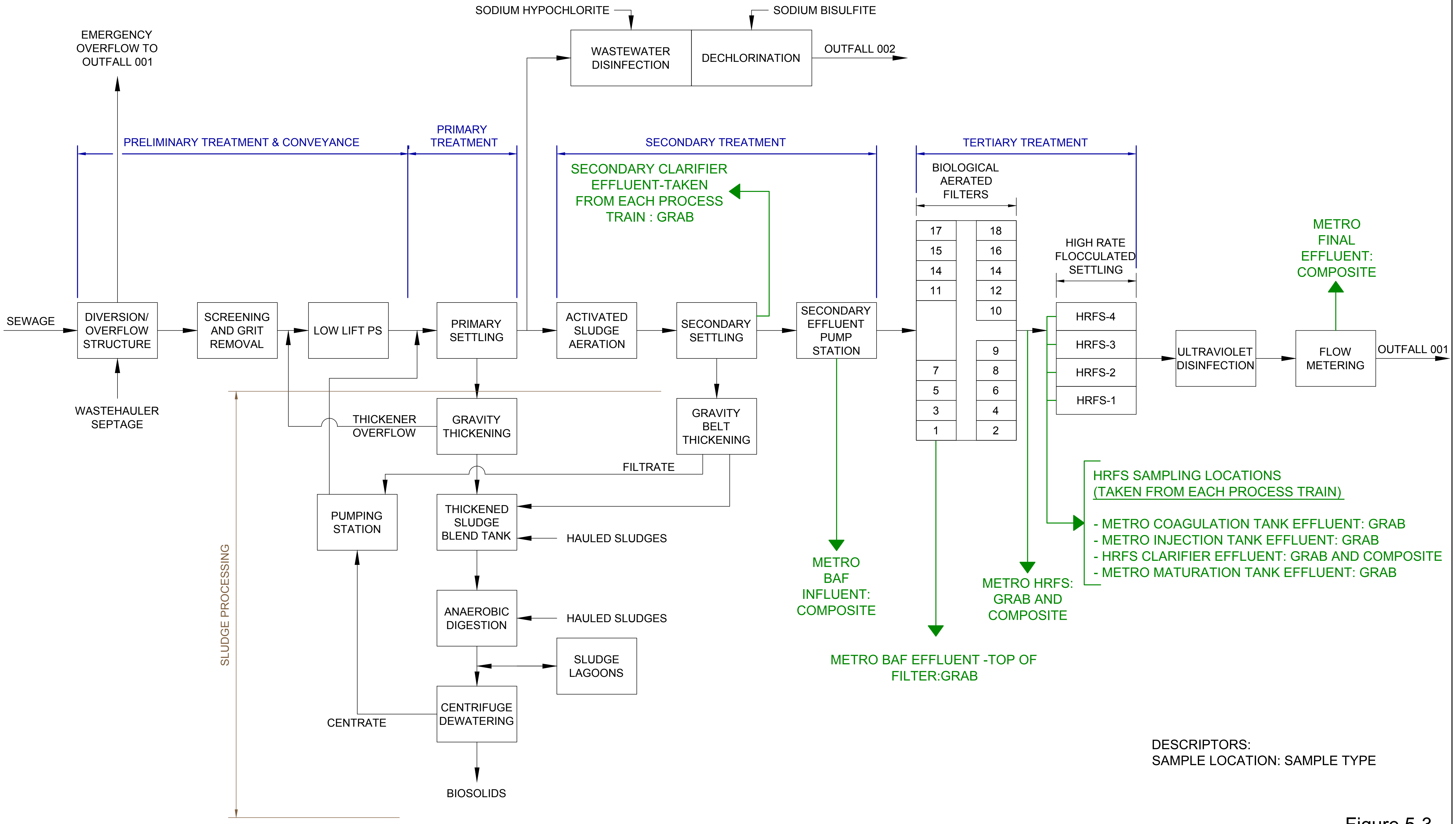


Figure 5-3

SUPPLEMENTAL PROCESS MONITORING LOCATIONS AND SAMPLE TYPE
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

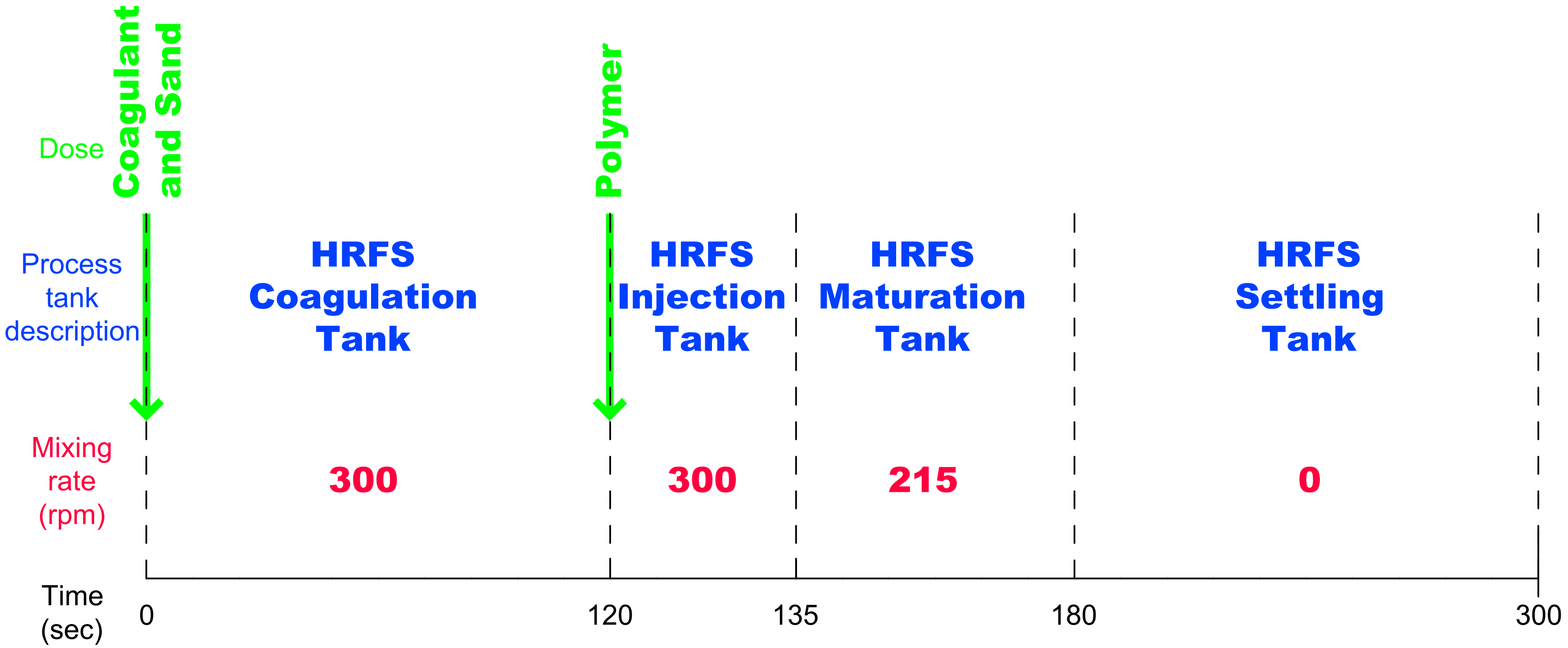
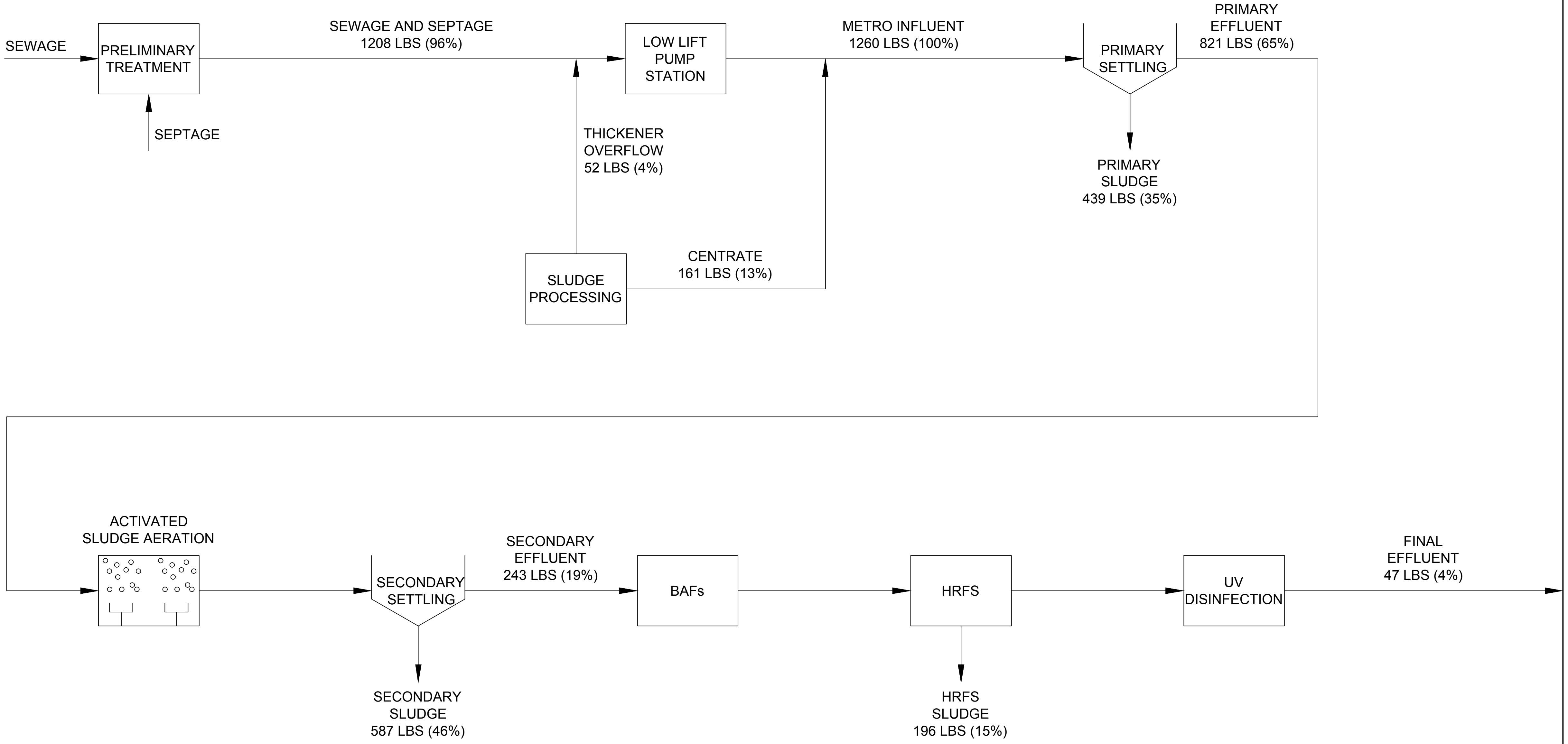


Figure 5-4

STANDARD JAR TESTING PROTOCOL
SIMULATES COAGULANT ADDITION AT THE INFLUENT BOX
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



NOTE:
XXX LBS (XX%) REPRESENTS THE AVERAGE PHOSPHORUS LOAD IN THE FLOW STREAM AND THE AMOUNT OF PHOSPHORUS IN THE STREAM ON A PERCENTAGE OF METRO INFLUENT BASIS.

Figure 5-5

PHOSPHORUS AVERAGE DAILY LOADING PROFILE
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

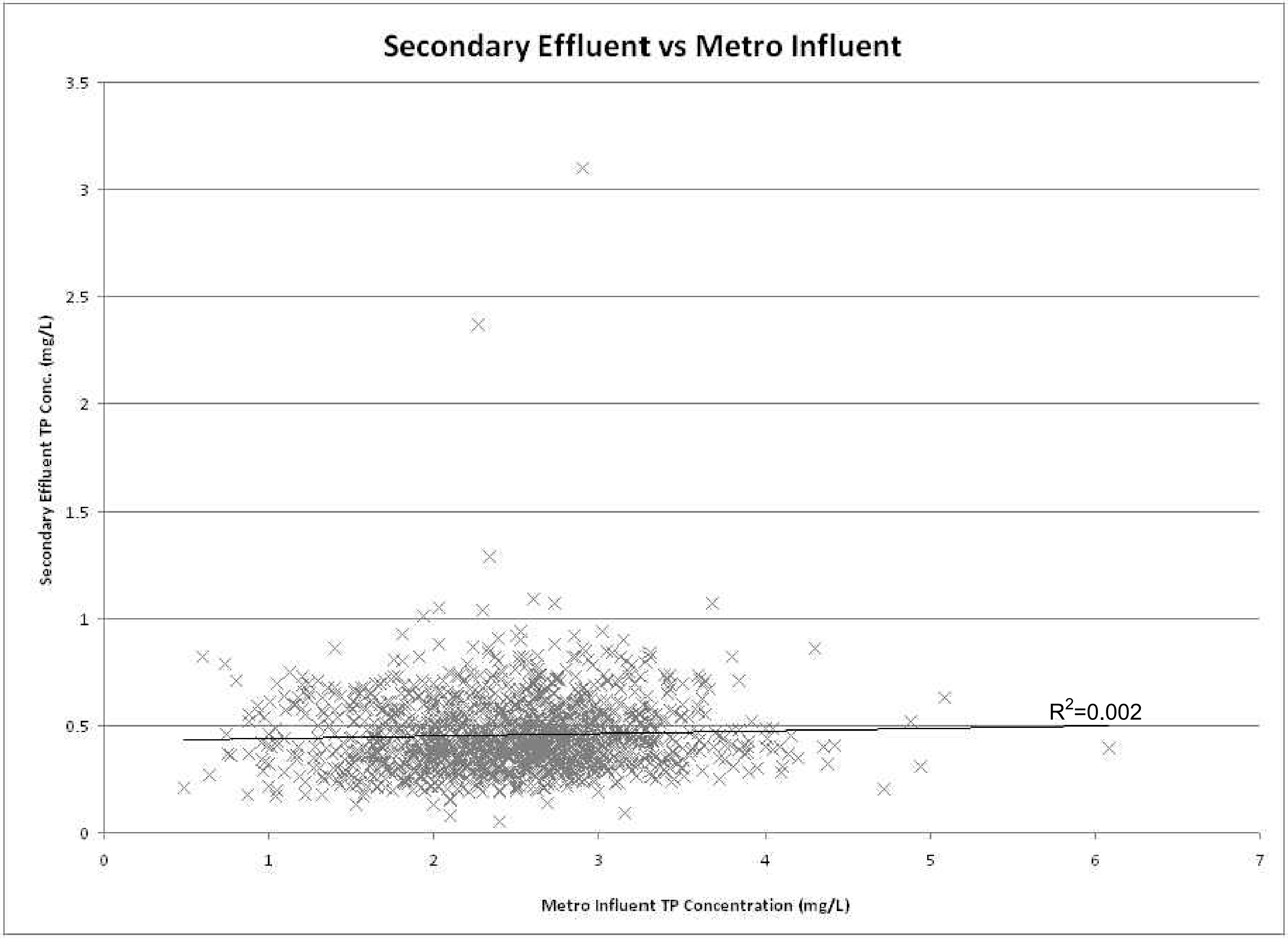


Figure 5-6

SECONDARY EFFLUENT TP VS METRO INFLUENT TP
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

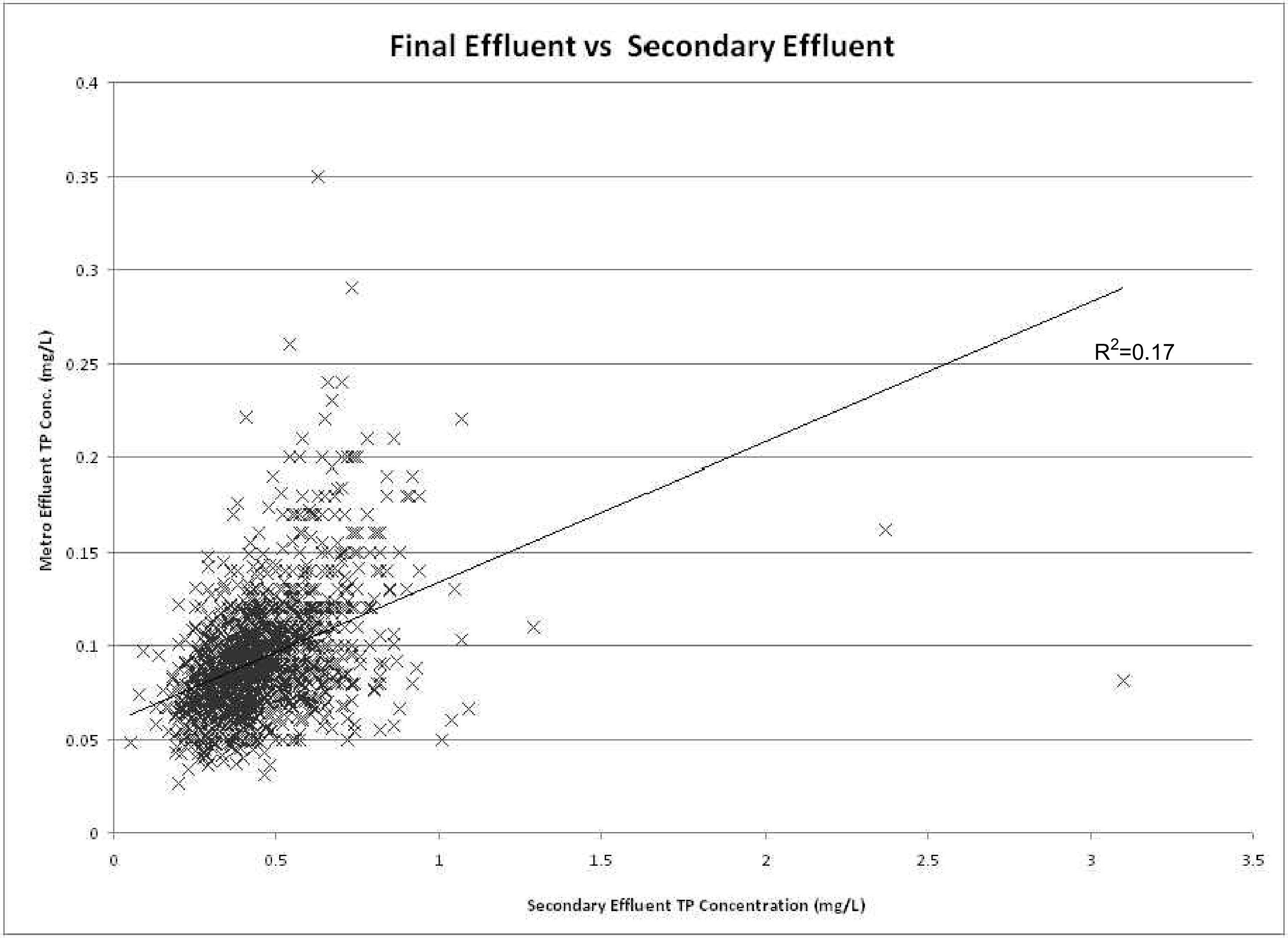


Figure 5-7

FINAL EFFLUENT TP VS SECONDARY EFFLUENT TP
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

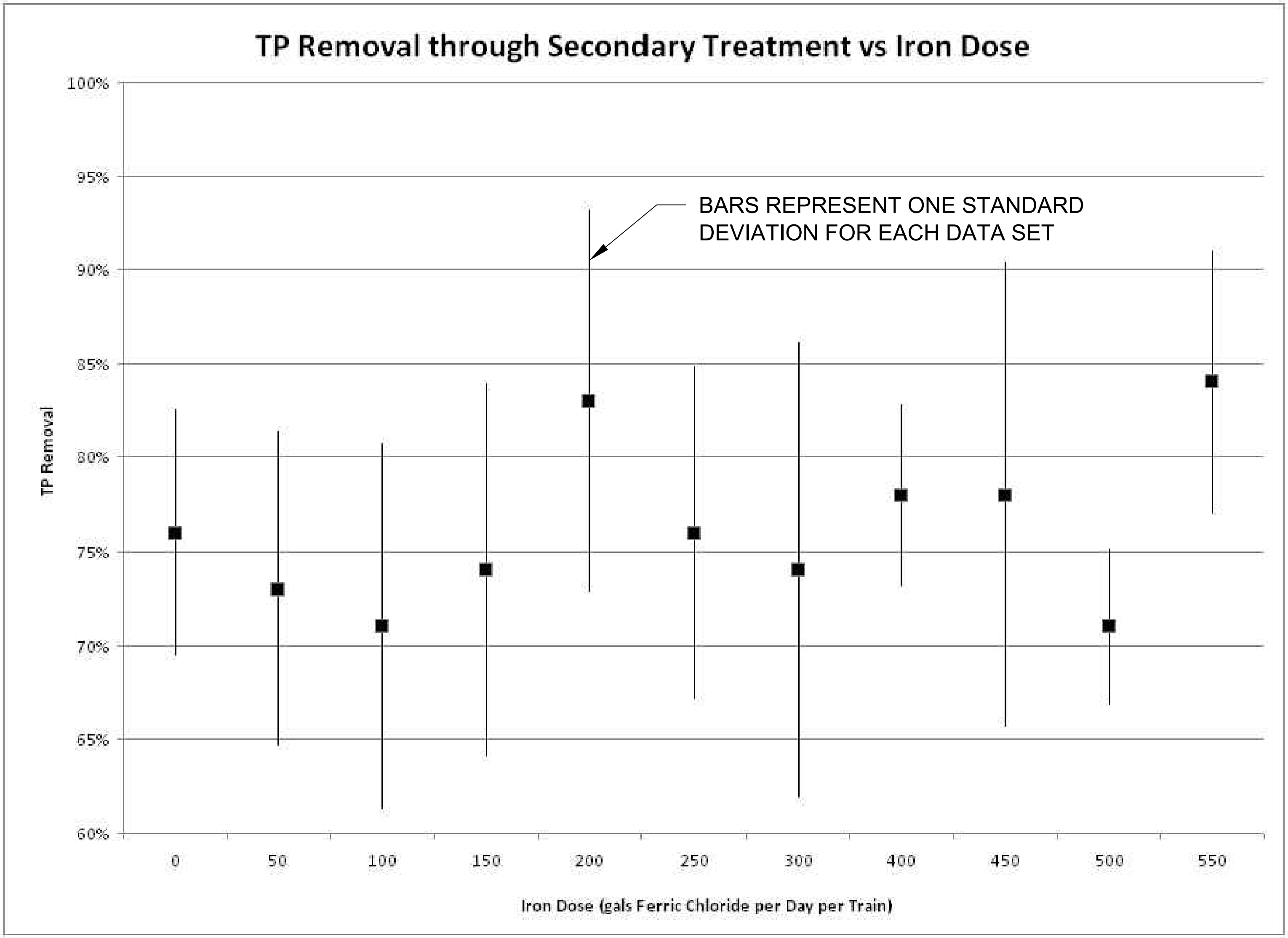


Figure 5-8

SECONDARY TREATMENT AVERAGE TP REMOVAL VS IRON DOSE
PLUS/MINUS ONE STANDARD DEVIATION SHOWN
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

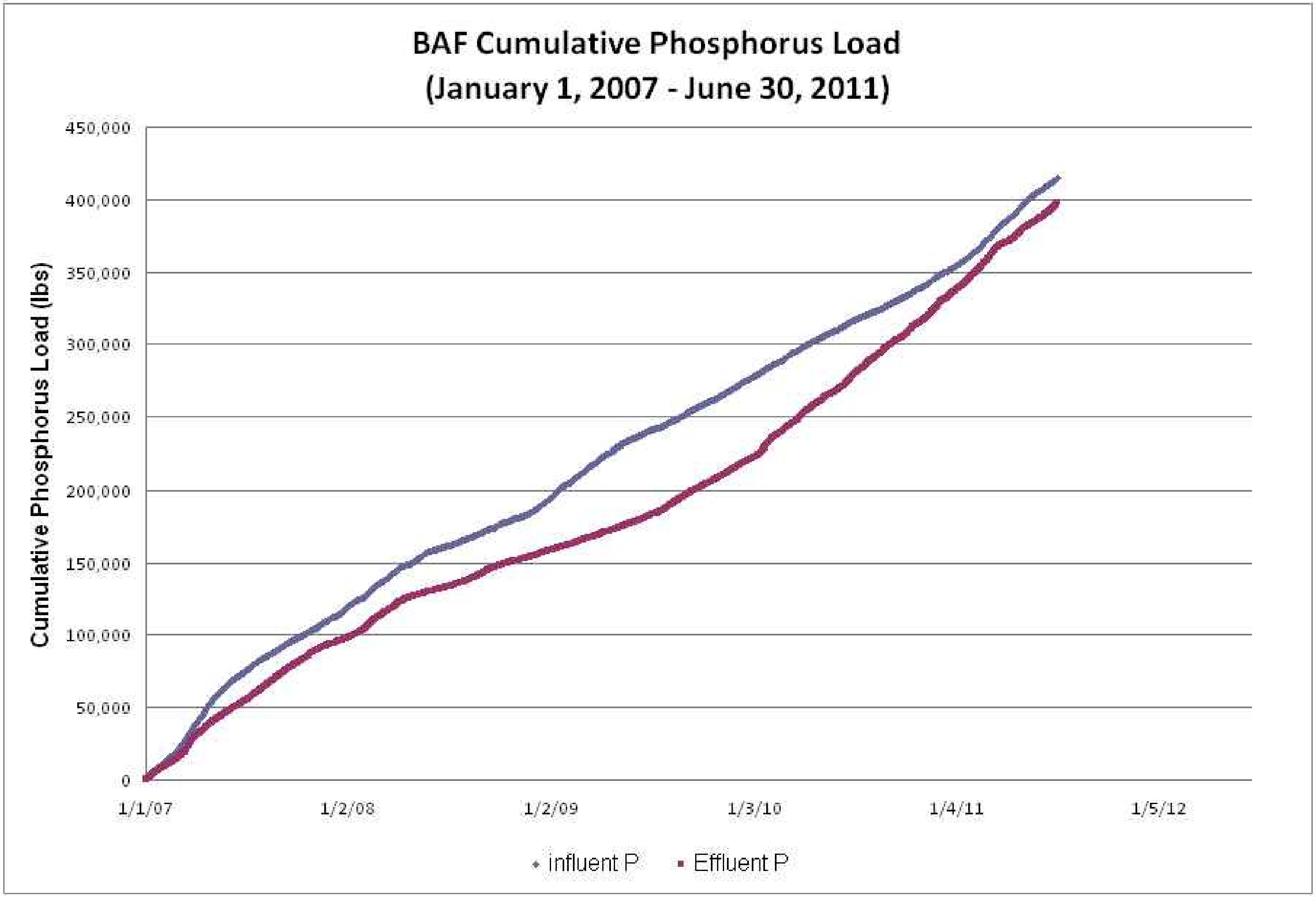


Figure 5-9

BAF CUMULATIVE PHOSPHORUS LOAD
(JANUARY 1, 2007 - JUNE 30, 2011)
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

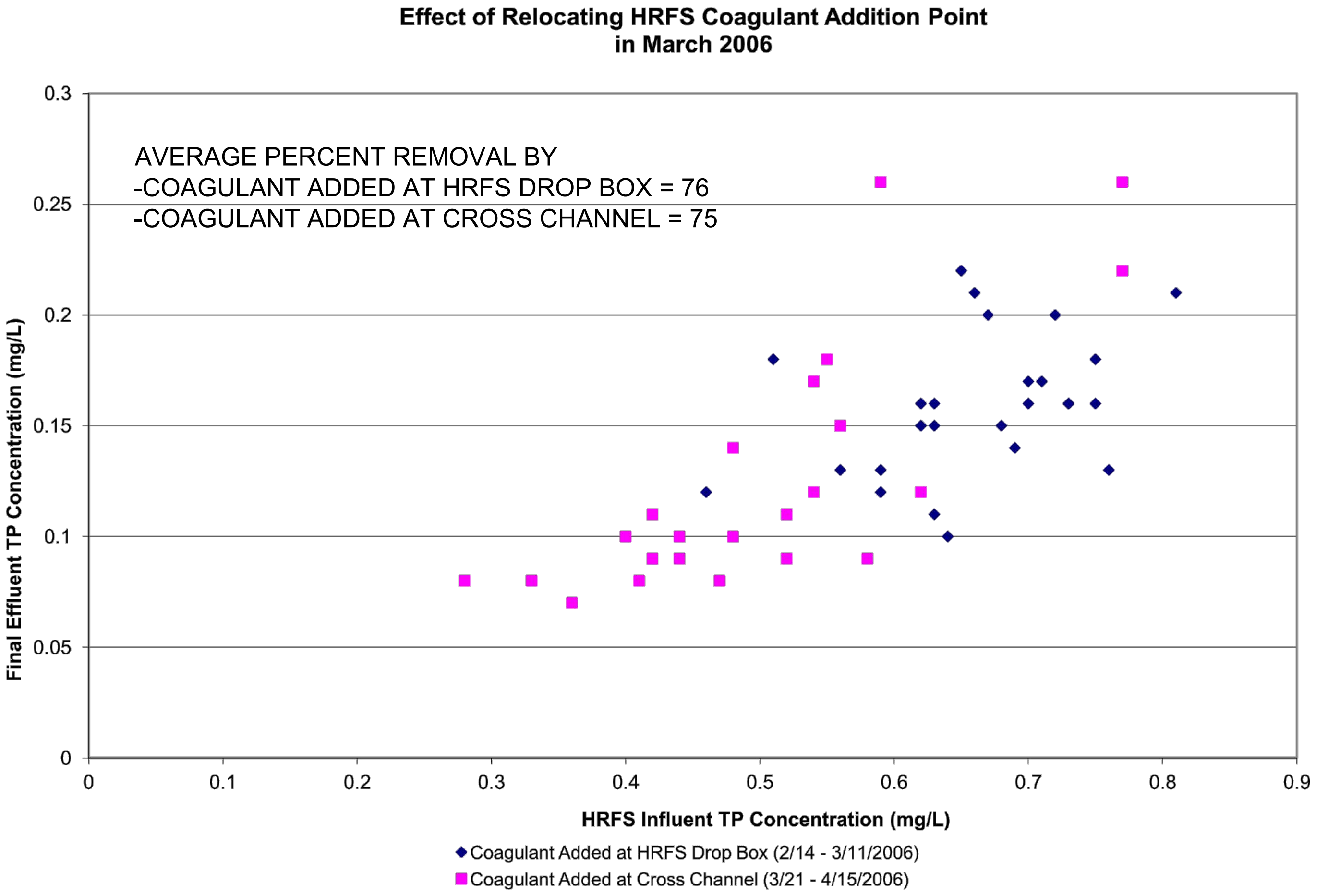


Figure 5-10

EFFECT OF RELOCATING HRFS COAGULANT ADDITION POINT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

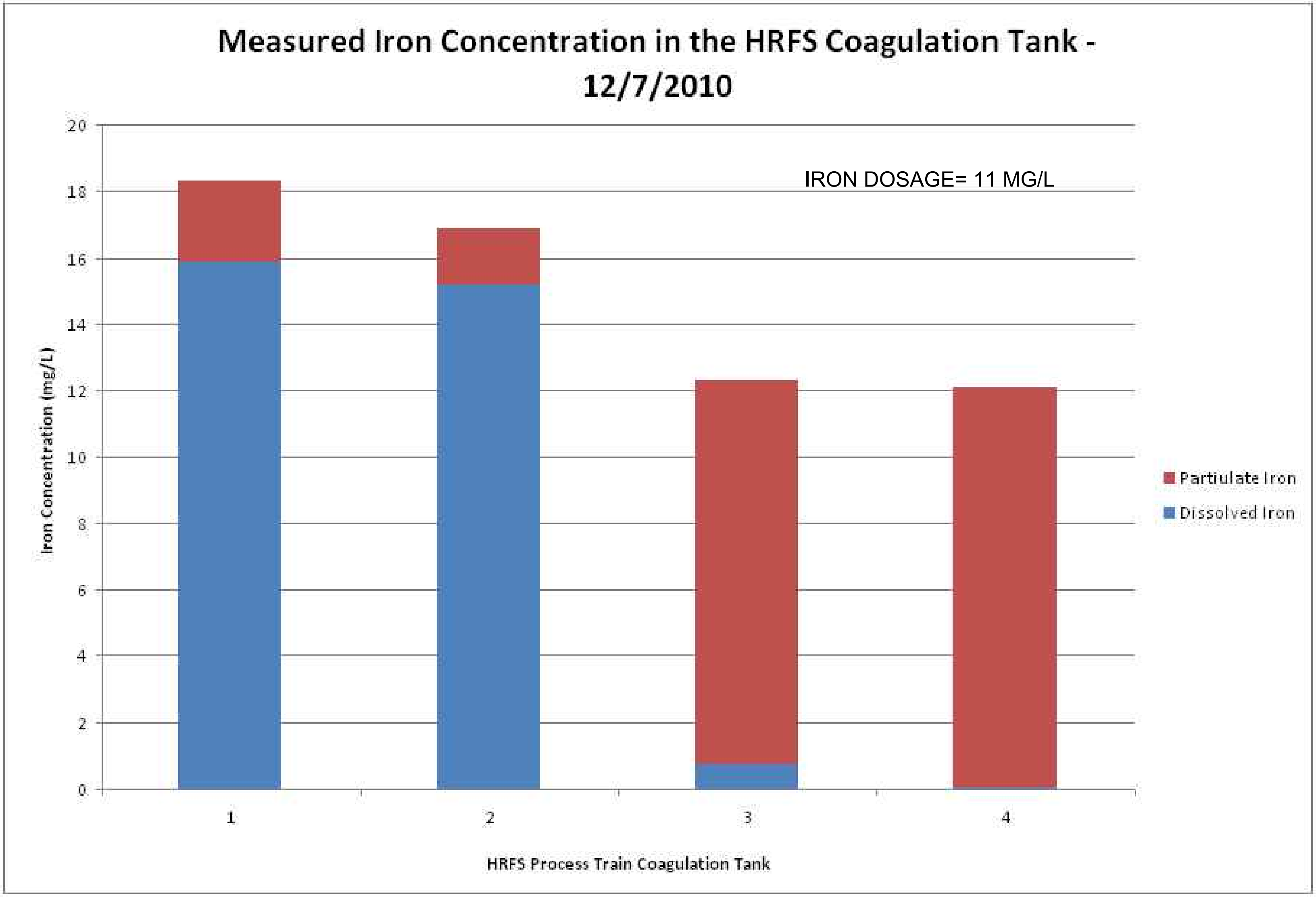


Figure 5-11

MEASURED IRON CONCENTRATION IN THE HRFS COAGULATION TANK
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

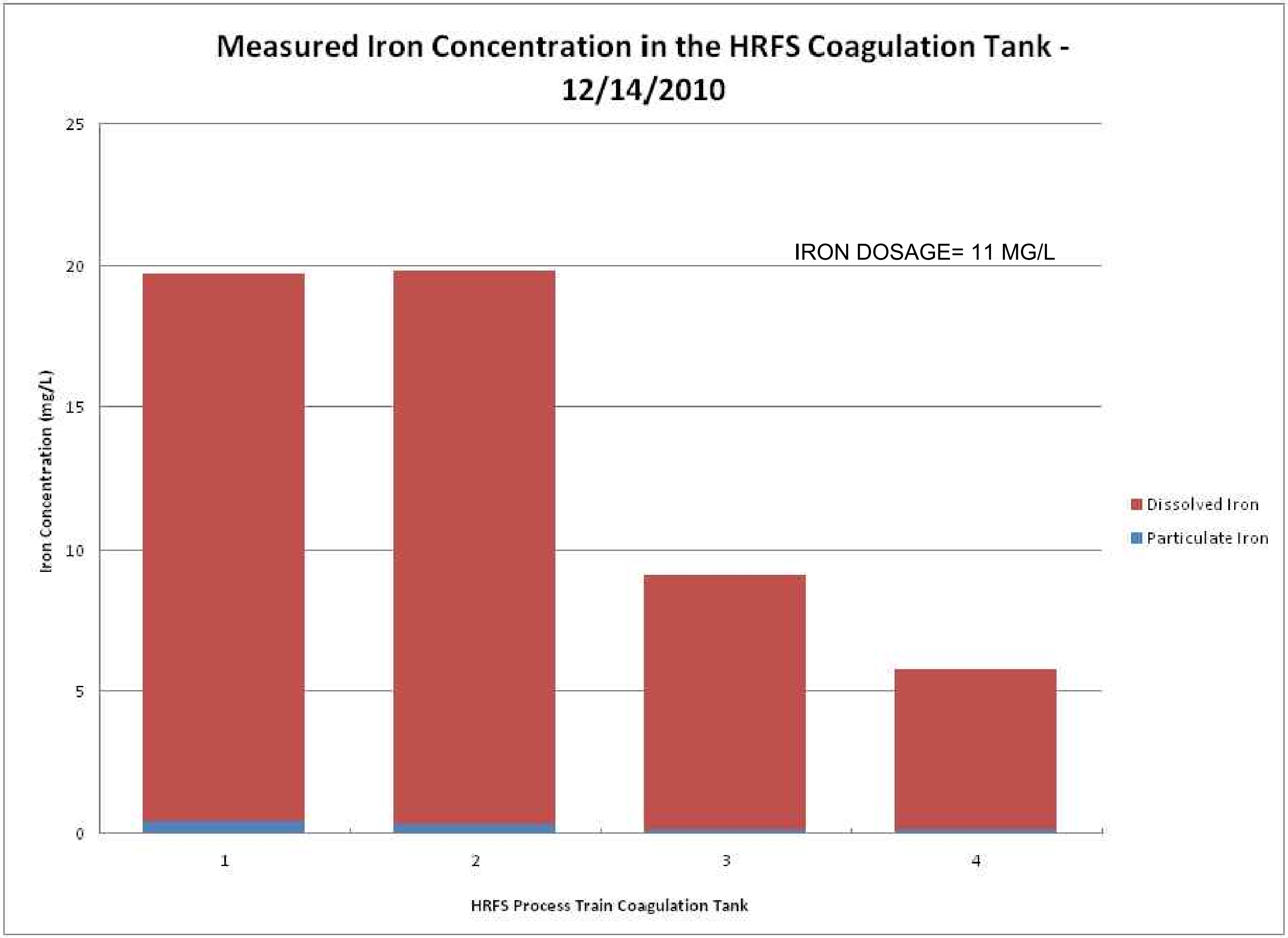


Figure 5-12

MEASURED IRON CONCENTRATION IN THE HRFS COAGULATION TANK
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

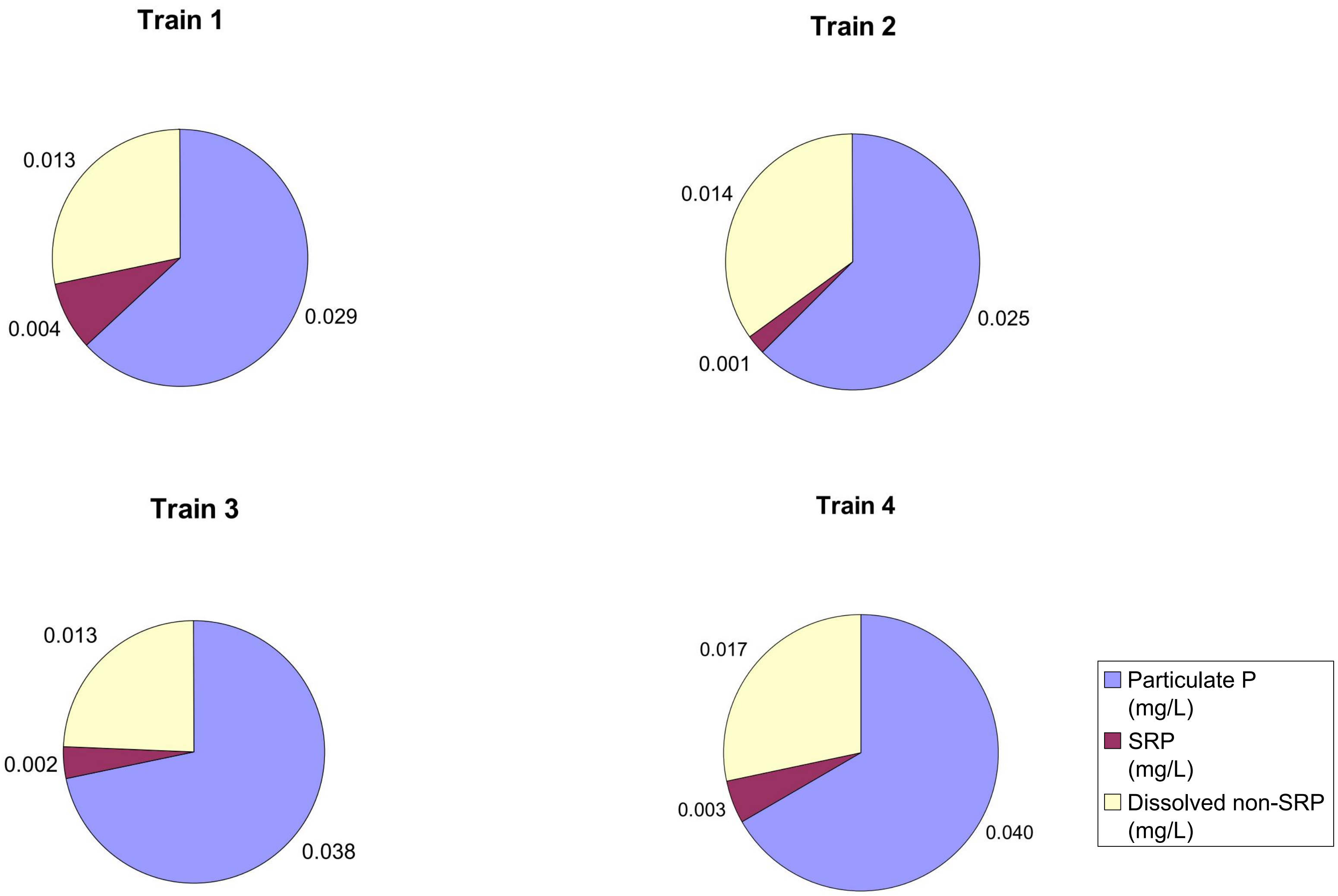


Figure 5-13

ROUND 3 SUPPLEMENTAL DATA COLLECTION
PHOSPHORUS SPECIATION IN HRFS SETTLING TANKS
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

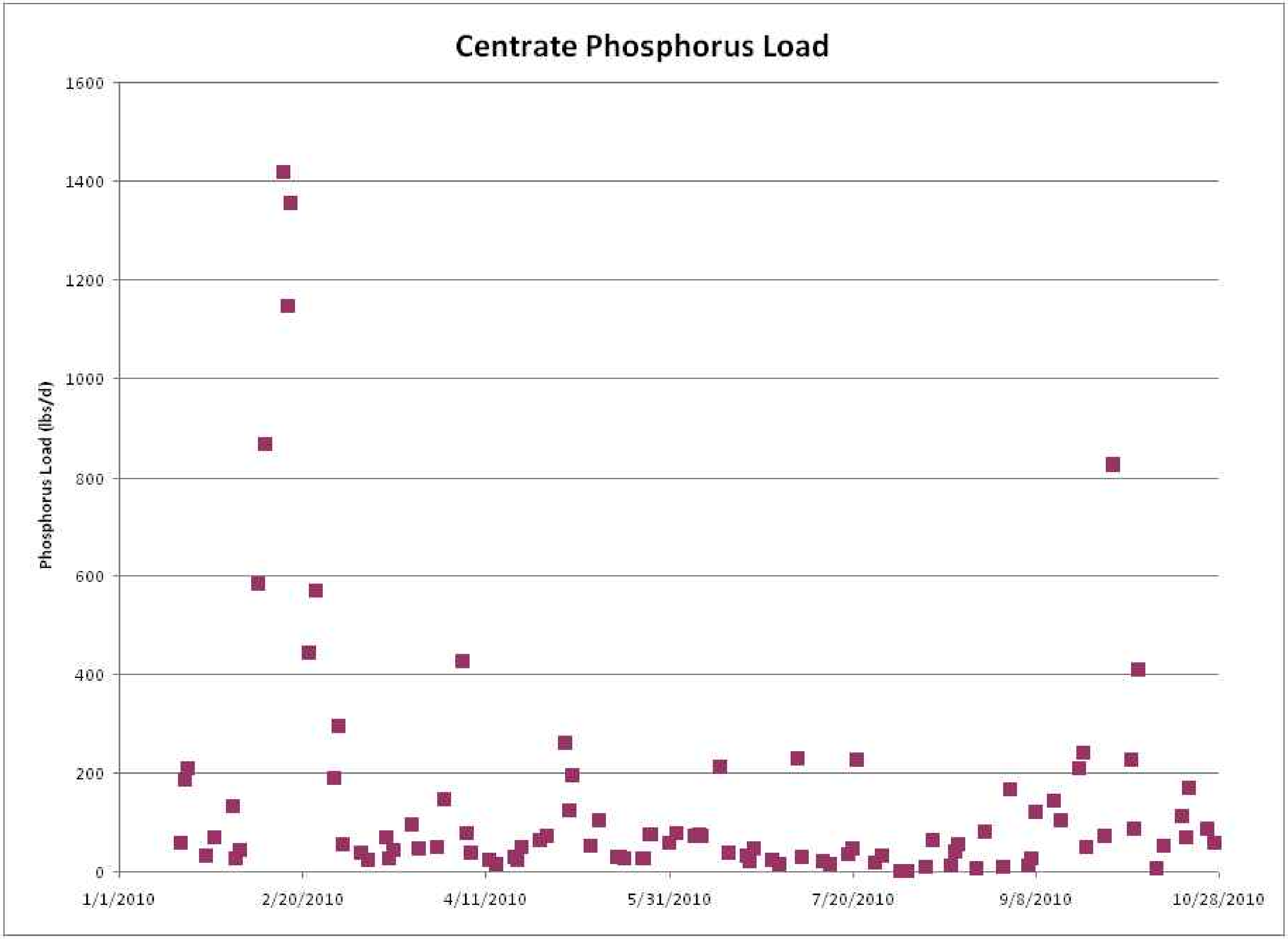


Figure 5-14

CENTRATE PHOSPHORUS LOAD
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

CRA

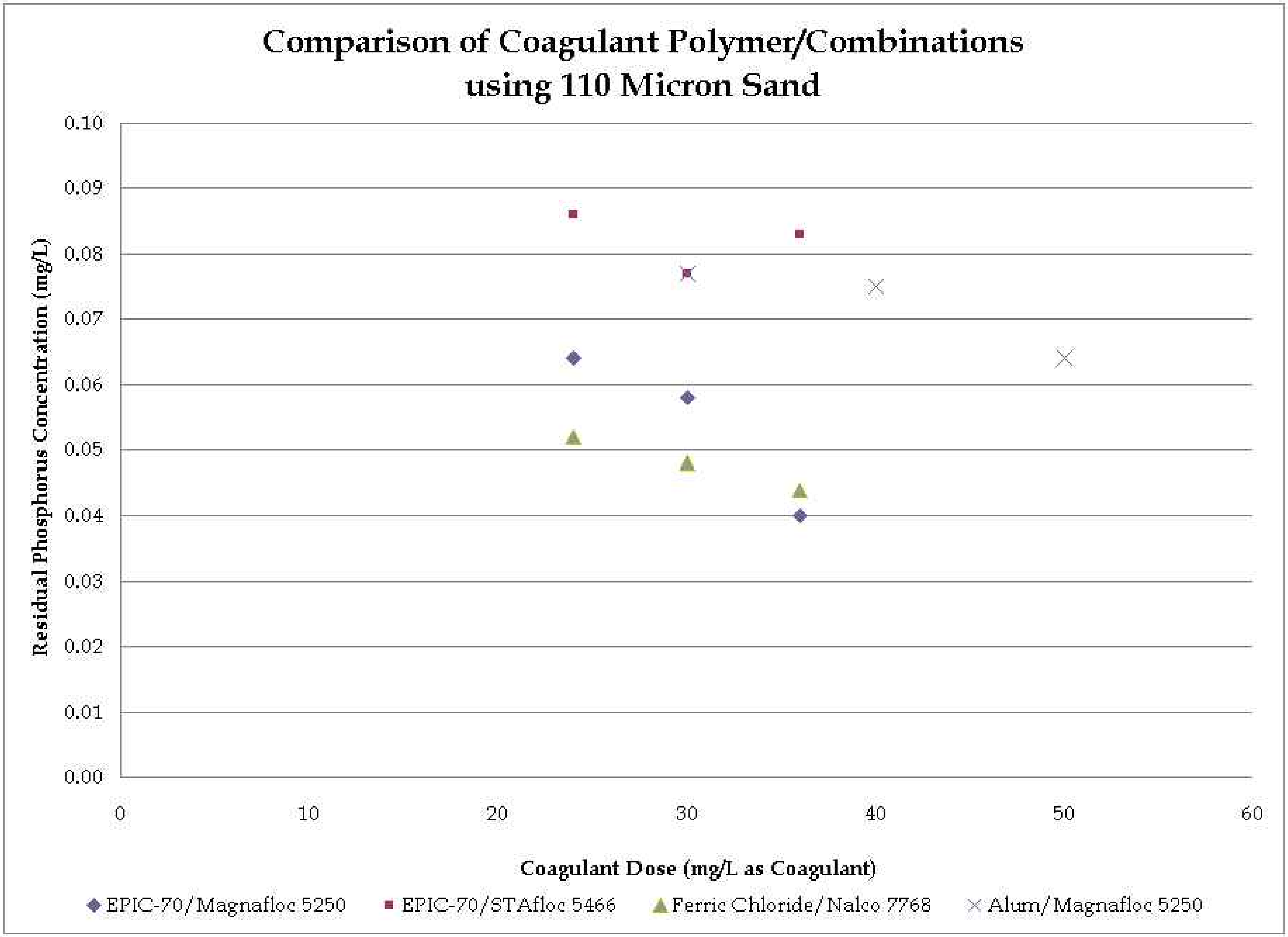


Figure 5-15

COMPARISON OF COAGULANT POLYMER/ COMBINATIONS USING 110 MICRON SAND
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

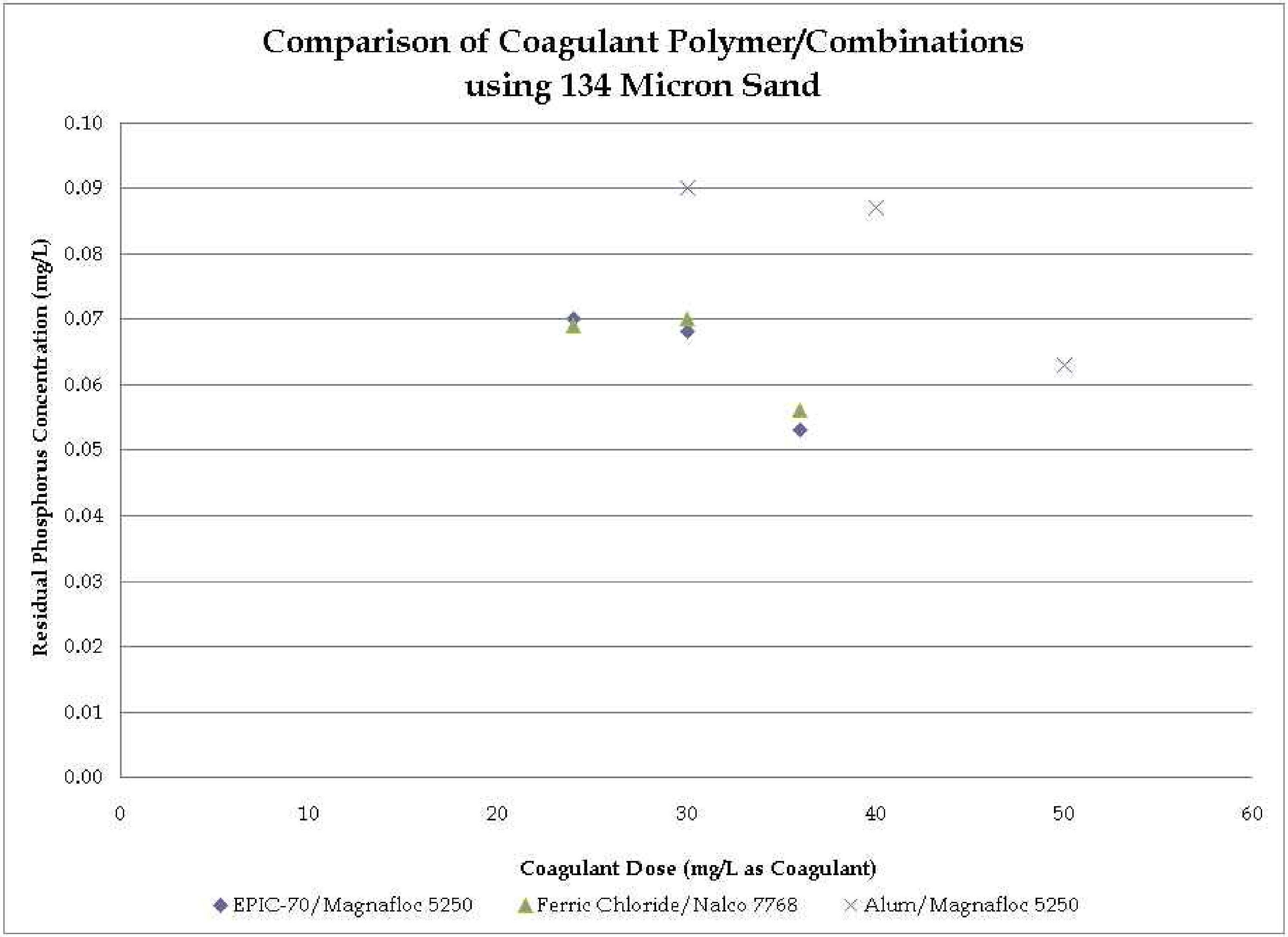
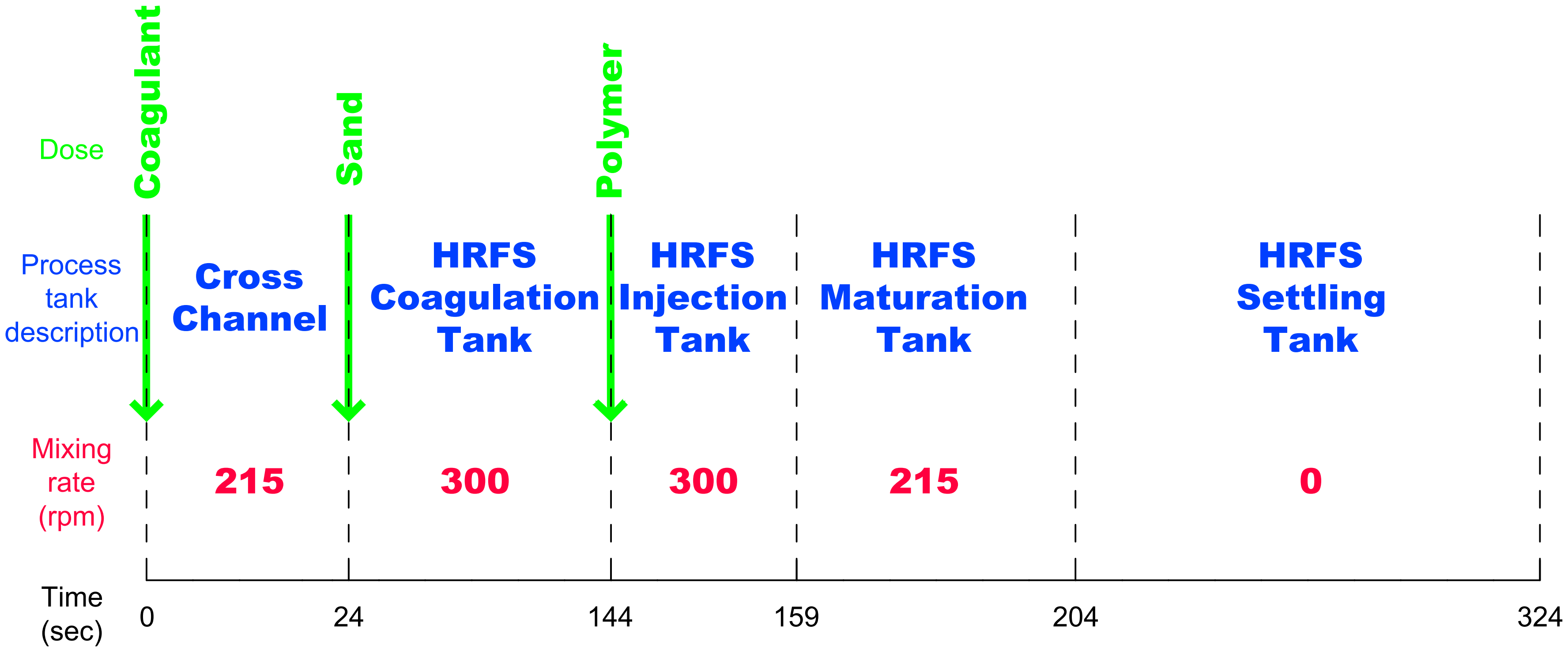


Figure 5-16

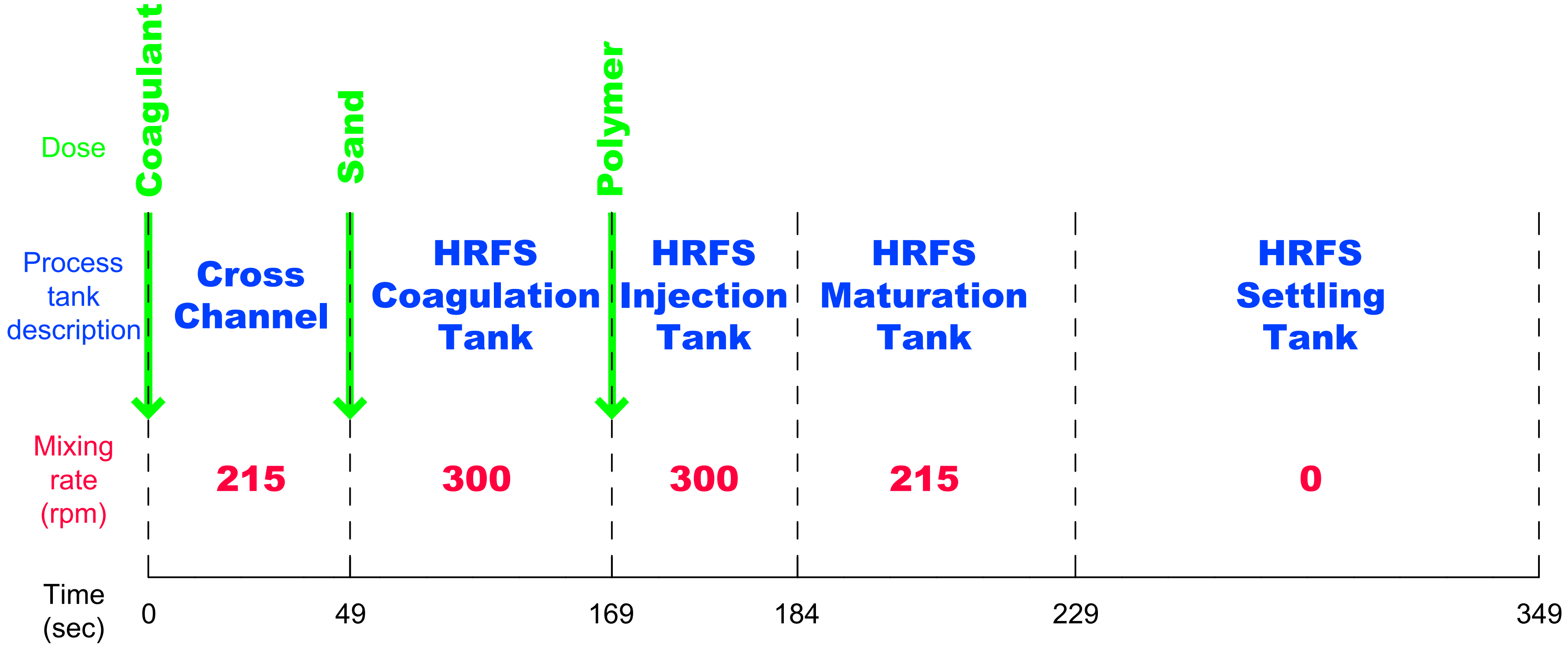
COMPARISON OF COAGULANT POLYMER/ COMBINATIONS USING 134 MICRON SAND
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



JAR TEST PROCEDURE

Figure 5-17

MIXING SCENARIO NO. 2
SIMULATES COAGULANT ADDITION AT THE
CROSS CHANNEL UNDER PEAK FLOW CONDITIONS
*Onondaga County WEP*



JAR TEST PROCEDURE

Figure 5-18

MIXING SCENARIO NO. 3
SIMULATES COAGULANT ADDITION AT THE
CROSS CHANNEL UNDER AVERAGE FLOW CONDITIONS
*Onondaga County WEP*

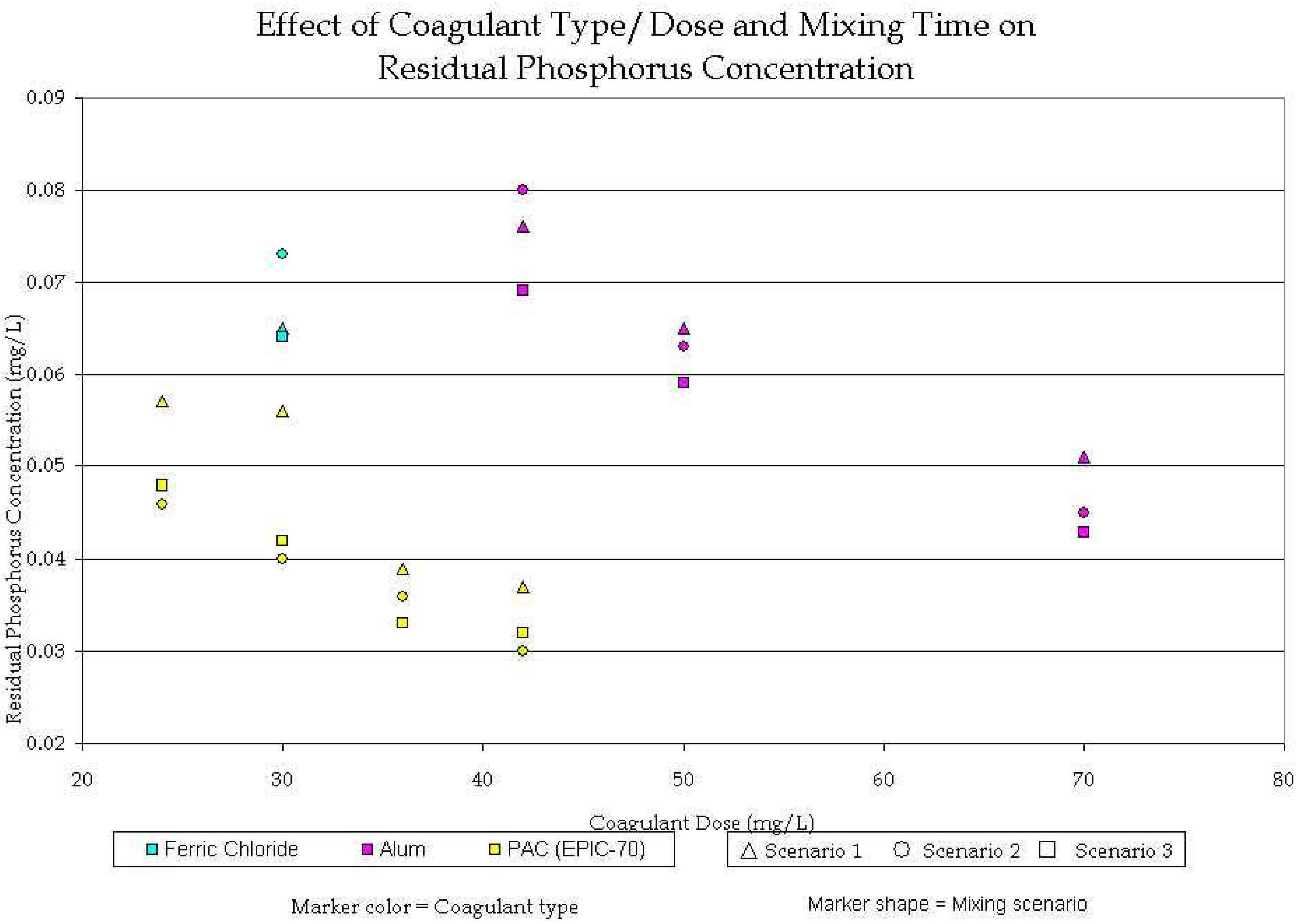


Figure 5-19

EFFECT OF COAGULANT TYPE/ DOSE AND MIXING LIME
ON RESIDUAL PHOSPHORUS CONCENTRATION
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

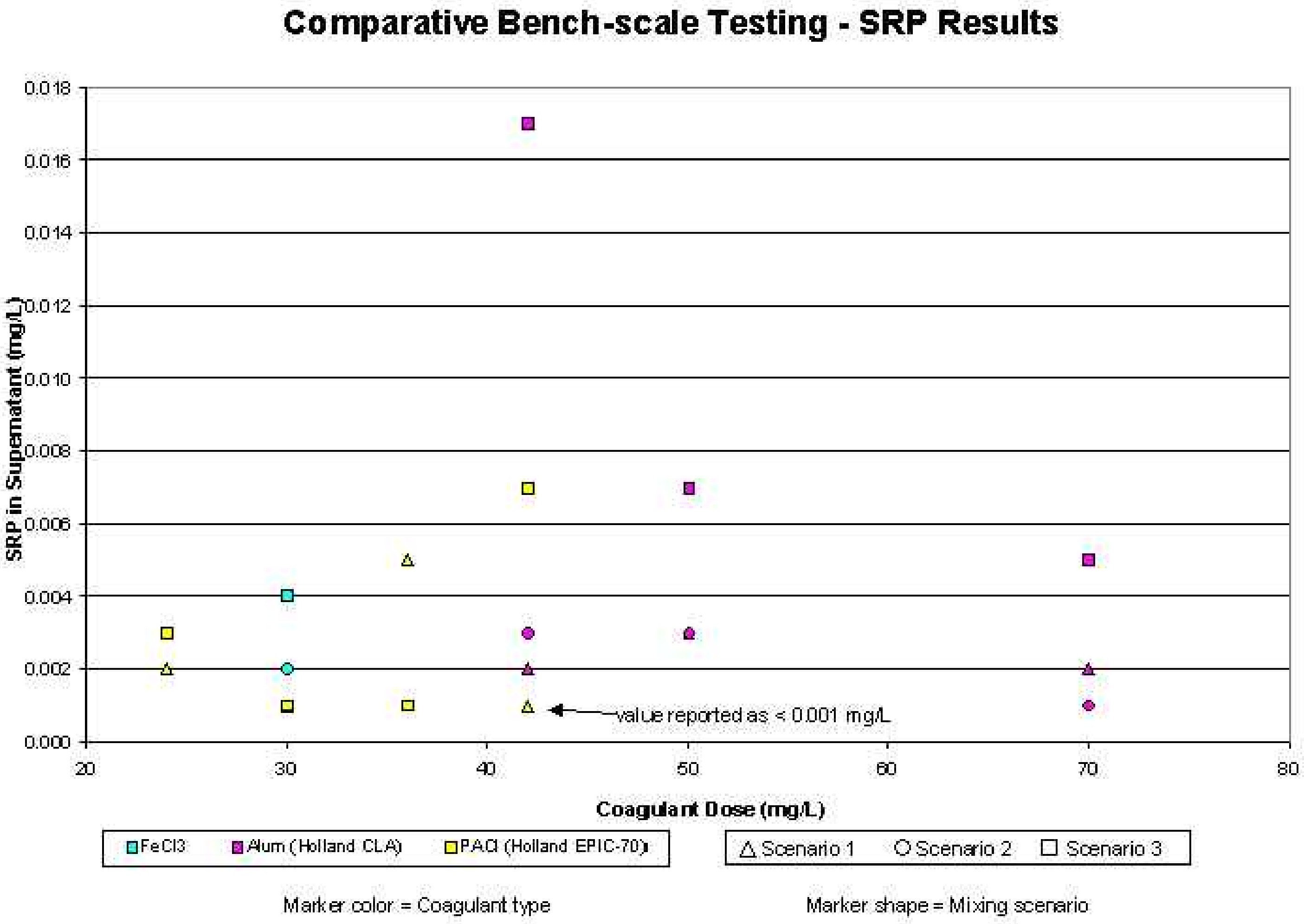


Figure 5-20

COMPARATIVE BENCH SCALE TESTING- SRP RESULTS
ON RESIDUAL PHOSPHORUS CONCENTRATION
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

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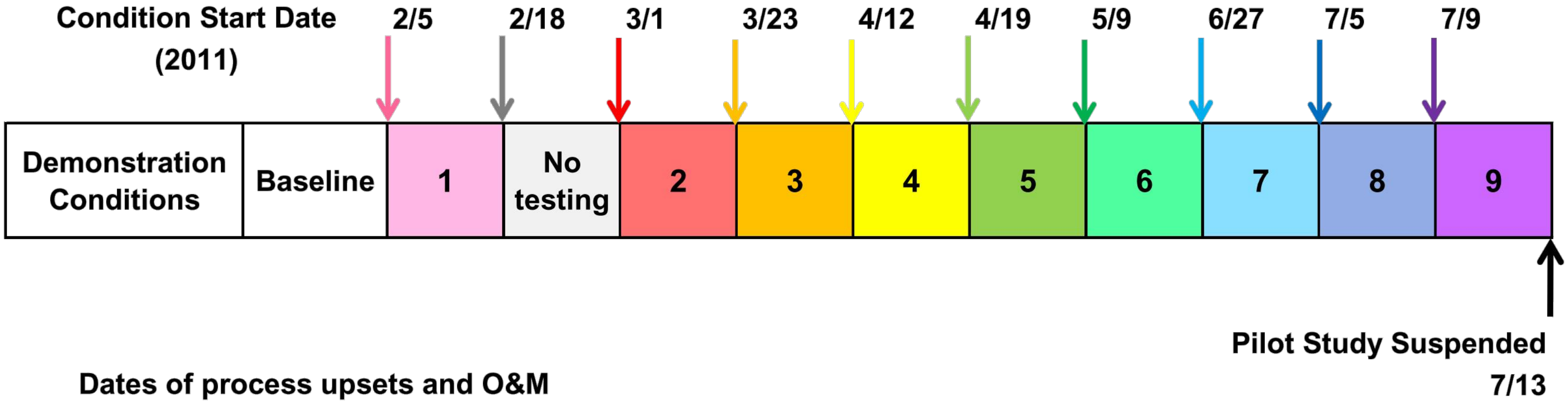


| Condition Start Date (2011) | | 2/5 | 2/18 | 3/1 | 3/23 | 4/12 | 4/19 | 5/9 | 6/27 | 7/5 | 7/9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Demonstration Conditions | Baseline | 1 | No testing | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

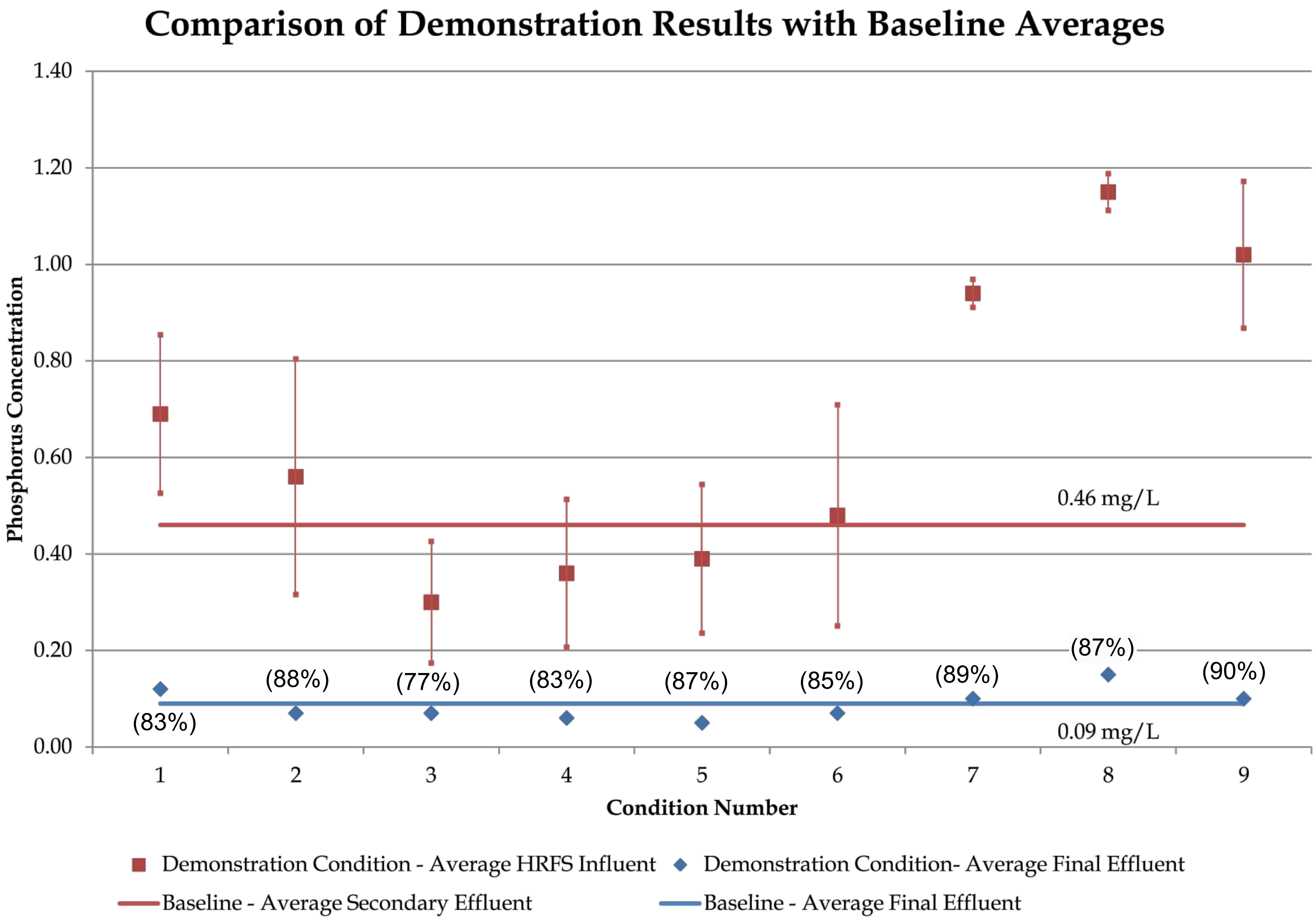
Pilot Study Suspended
7/13

**Dates of process upsets and O&M**

| Date | Description |
|---|---|
| 4/12 | HRFS Train 3 polymer addition modification |
| 4/13 | HRFS Train 4 polymer addition modification |
| 4/18 | HRFS Train 1 polymer addition modification |
| 4/19 | HRFS Train 2 polymer addition modification |
| 4/23 | Secondary Treatment System B-side Train 3 out of service |
| 5/4 | HRFS Train 3 sampling location moved |
| 5/11 | HRFS clarifier cleaning Train 1 |
| 5/12 | HRFS clarifier cleaning Train 2 |
| 5/13 | HRFS clarifier cleaning Trains 3 & 4 |
| 6/9 | Ferric chloride headers cleaned |
| 6/14 | Ferric chloride pump repair and HRFS Train 2 flow meter replacement |
| 6/22 | HRFS Trains 1 and 2 water hose break and HRFS Train 2 coagulant diffuser cleaned |
| 6/28 | HRFS Train 4 composite sample failure. Grab sample collected. |

Figure 5-21

FULL-SCALE DEMONSTRATION TIMELINE
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



NOTES:

1. AVERAGE PERCENT REMOVAL THROUGH THE HRFS SHOWN IN PARENTHESIS.
2. ERROR BARS REPRESENT ONE STANDARD DEVIATION.

Figure 5-22

COMPARISON OF DEMONSTRATION RESULTS WITH BASELINE AVERAGES
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

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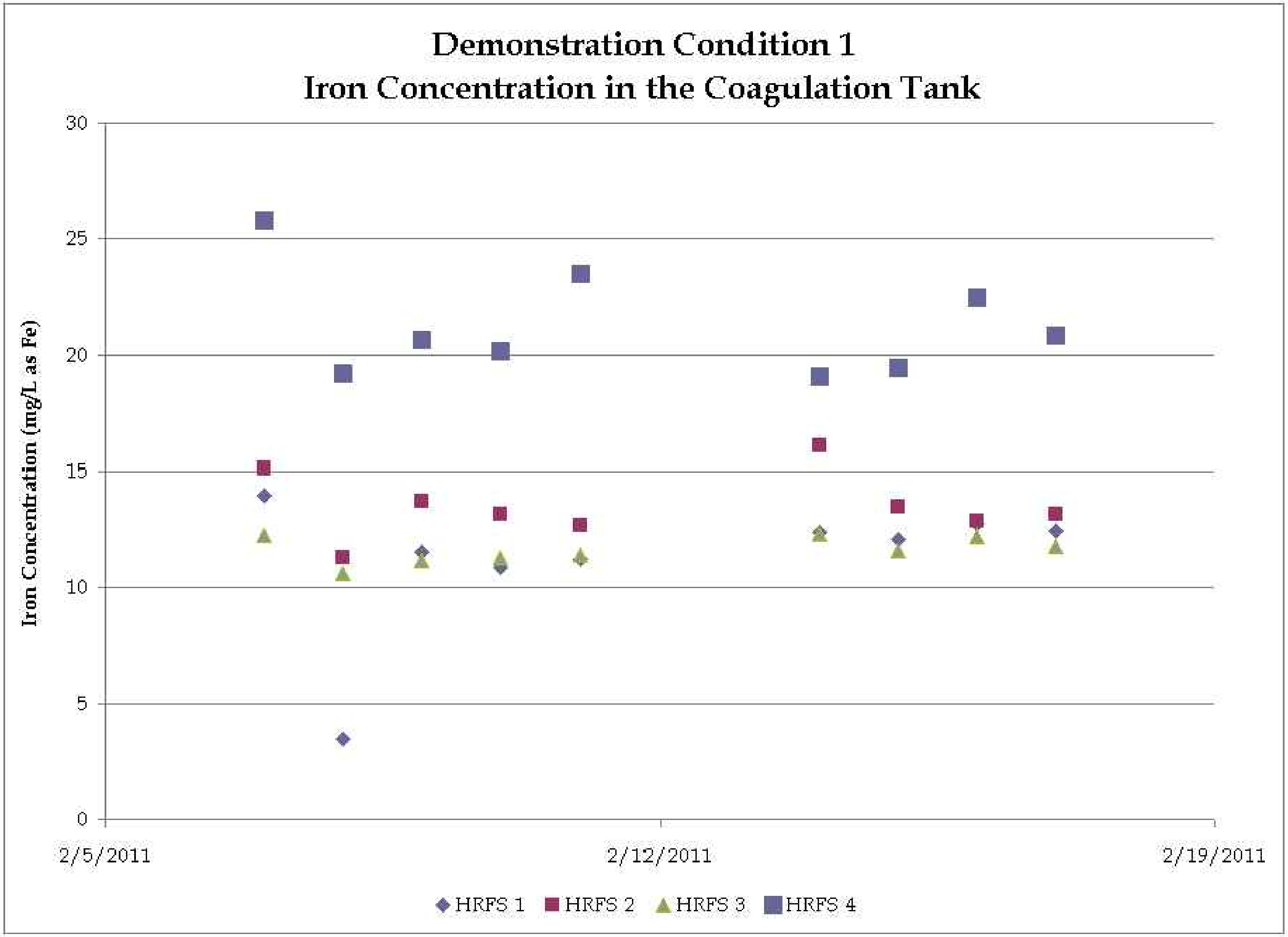


Figure 5-23

DEMONSTRATION CONDITION 1 IRON CONCENTRATION IN THE COAGULATION TANK
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

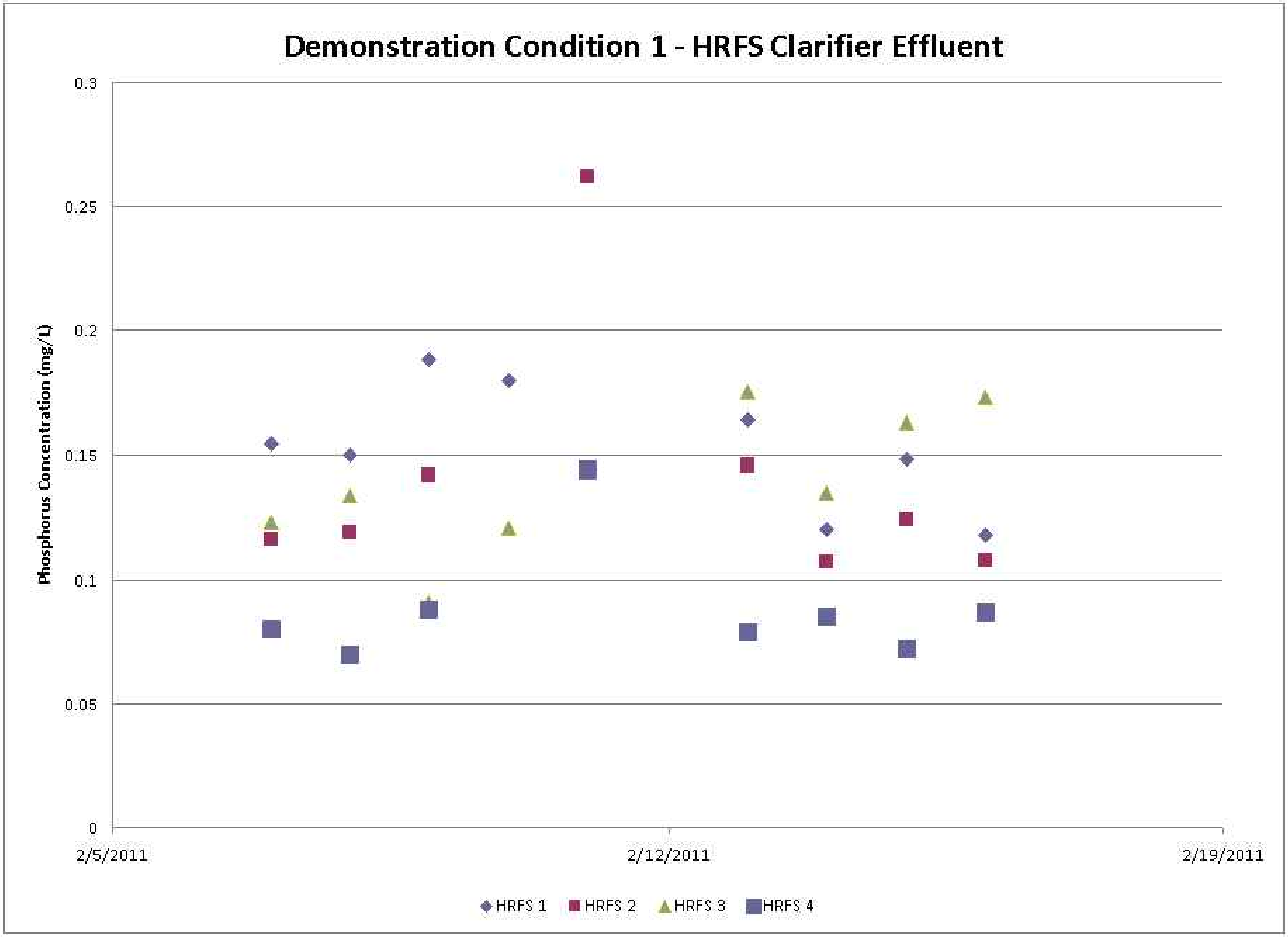


Figure 5-24

DEMONSTRATION CONDITION 1 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

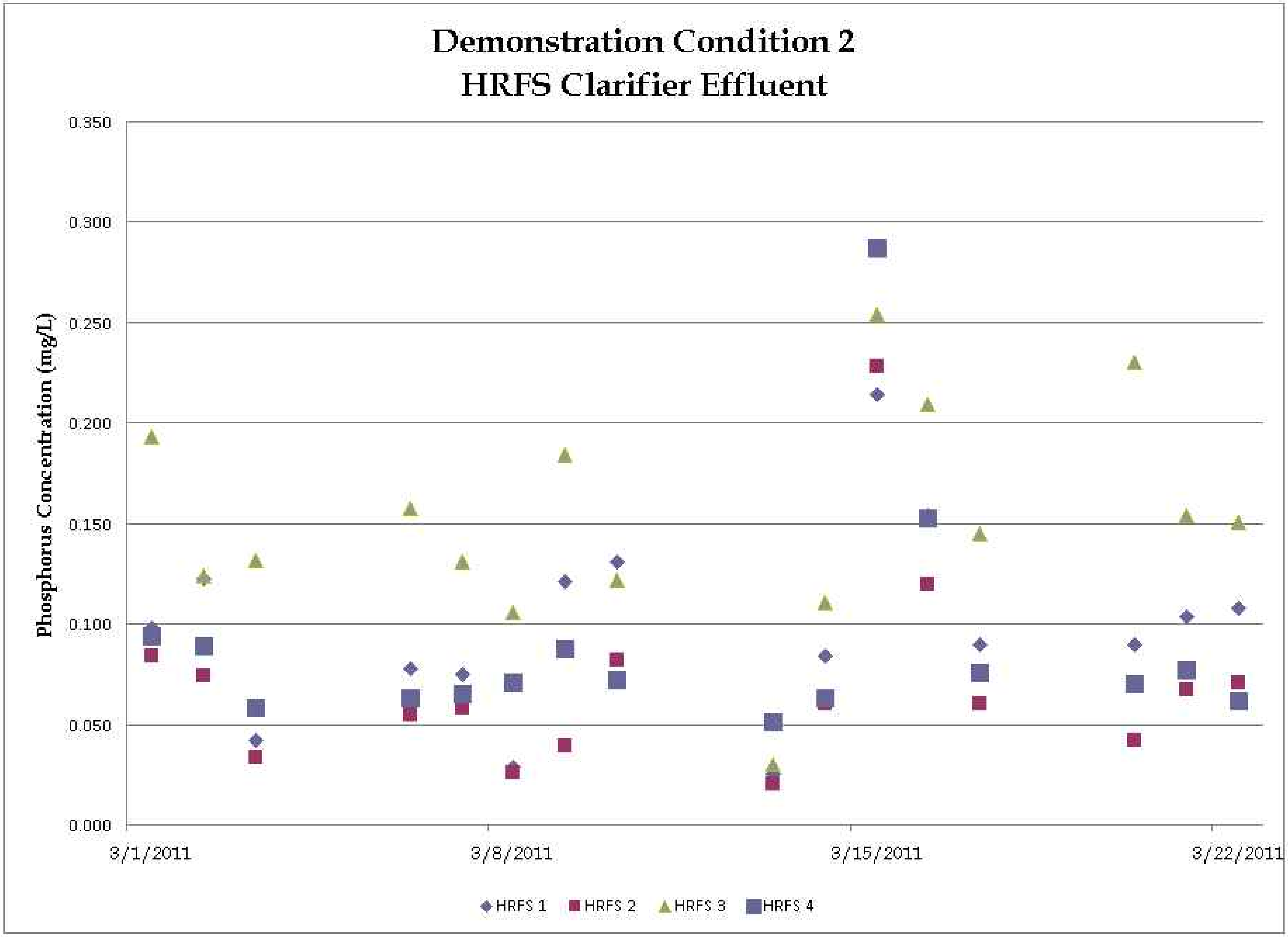


Figure 5-25

DEMONSTRATION CONDITION 2 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

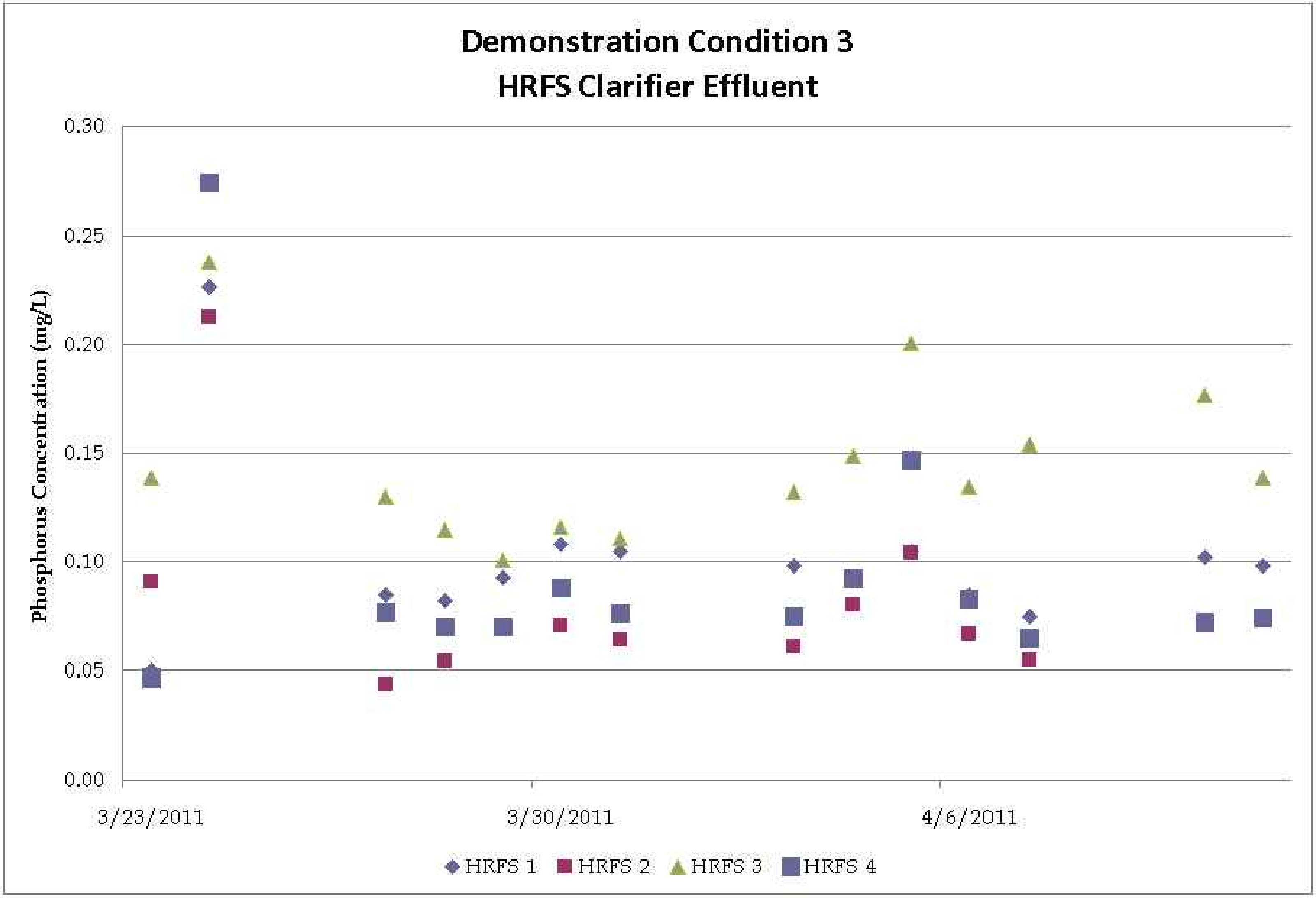


Figure 5-26

DEMONSTRATION CONDITION 3 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

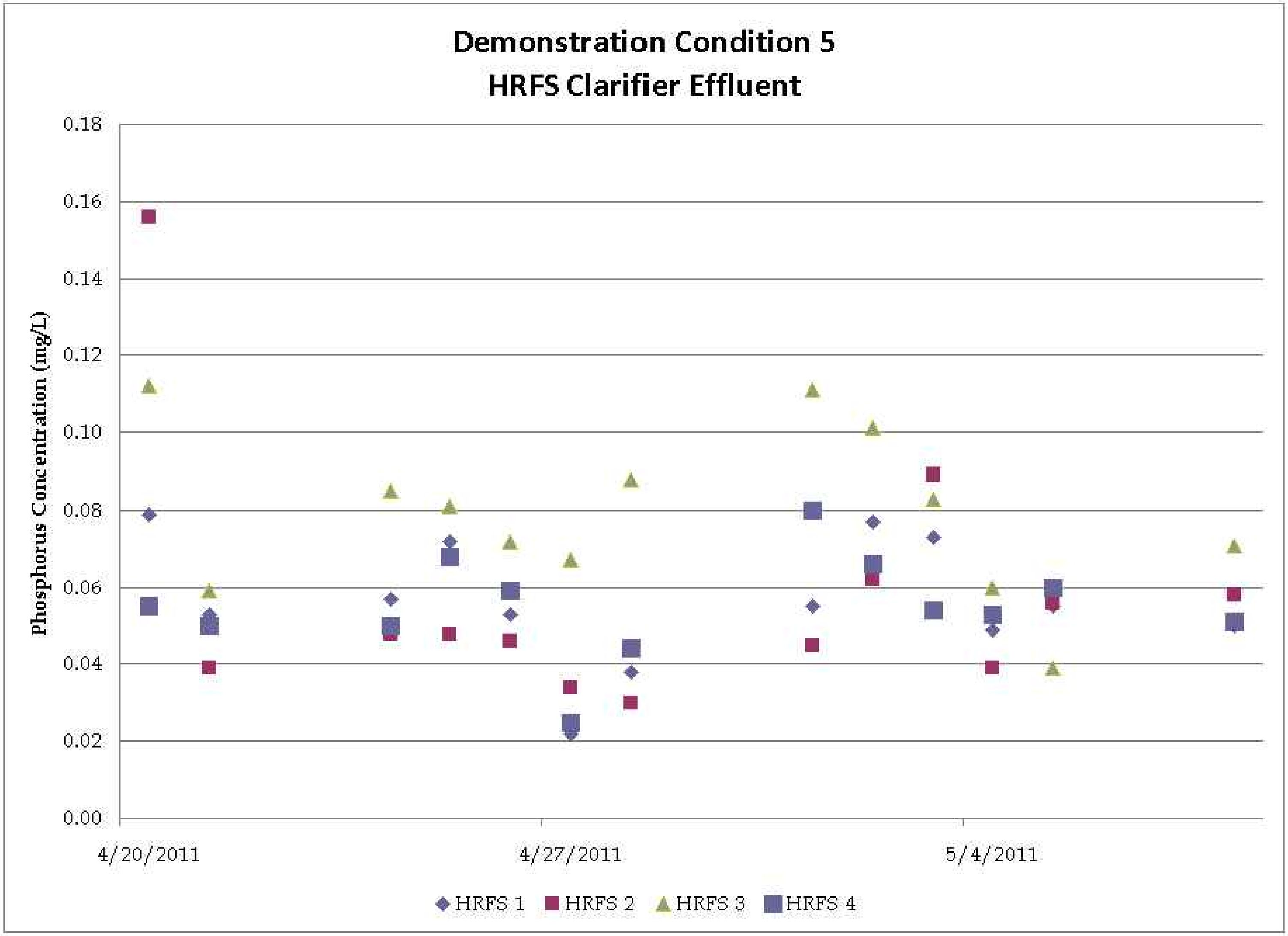


Figure 5-27

DEMONSTRATION CONDITION 5 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

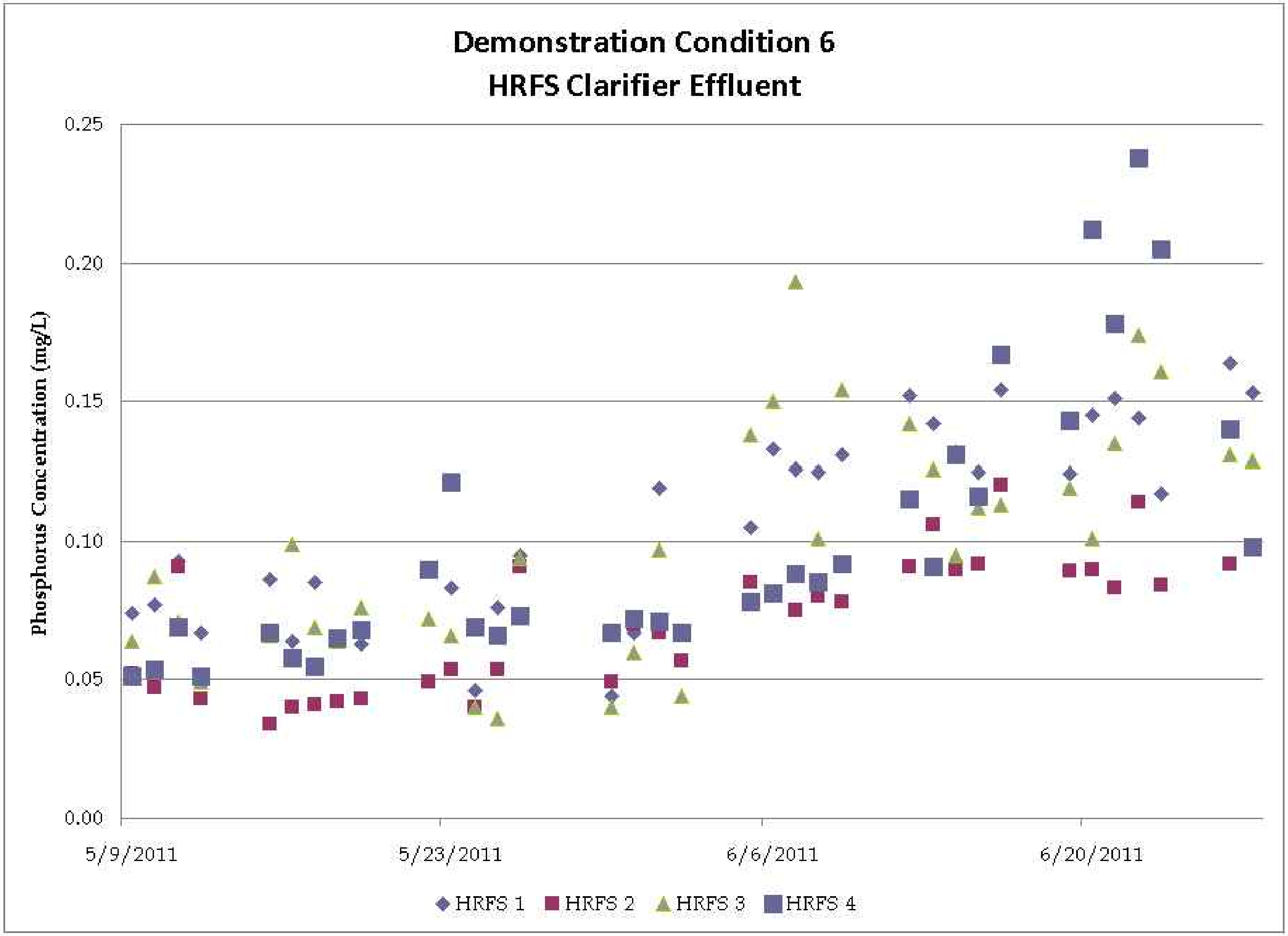


Figure 5-28

DEMONSTRATION CONDITION 6 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

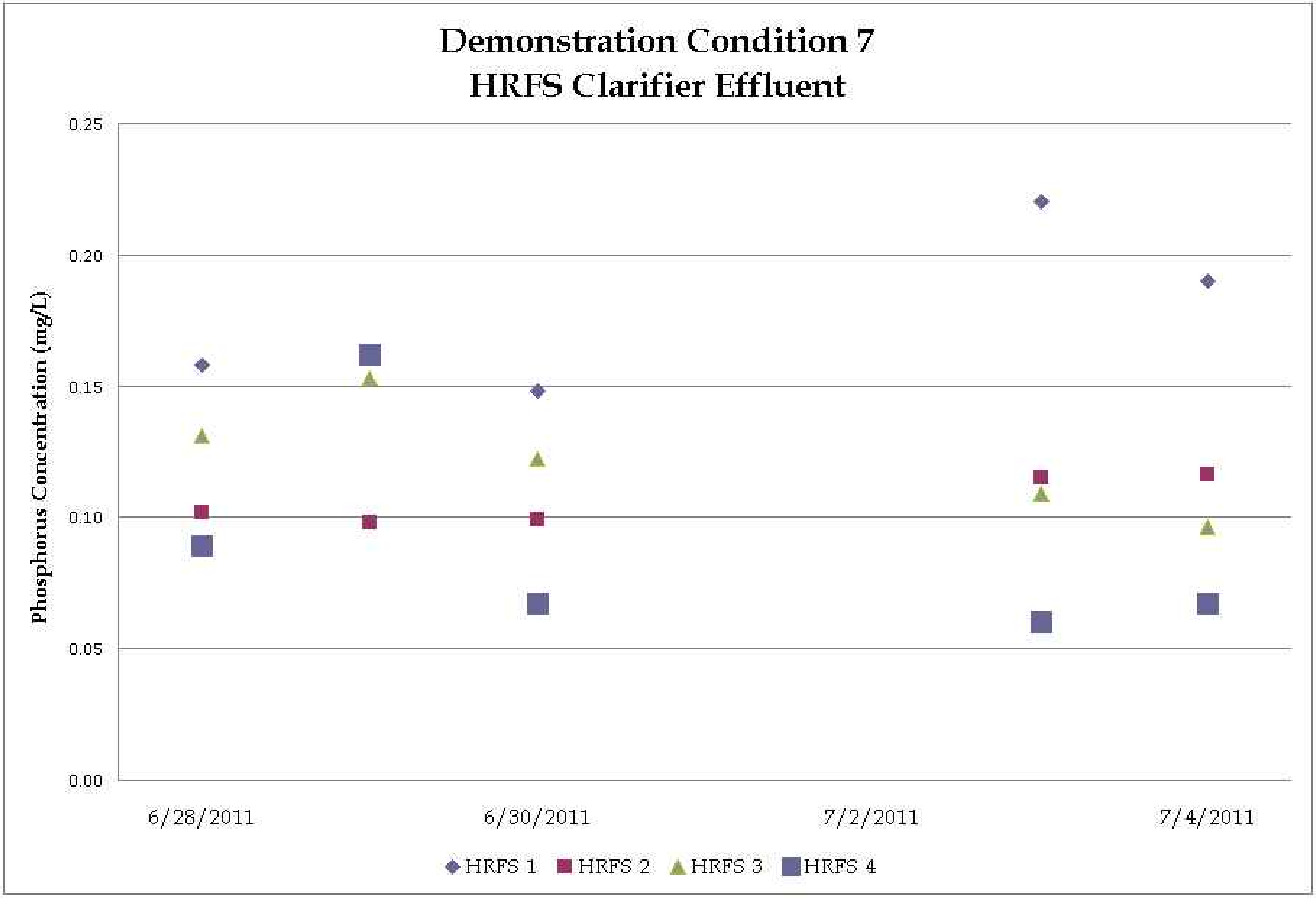


Figure 5-29

DEMONSTRATION CONDITION 7 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

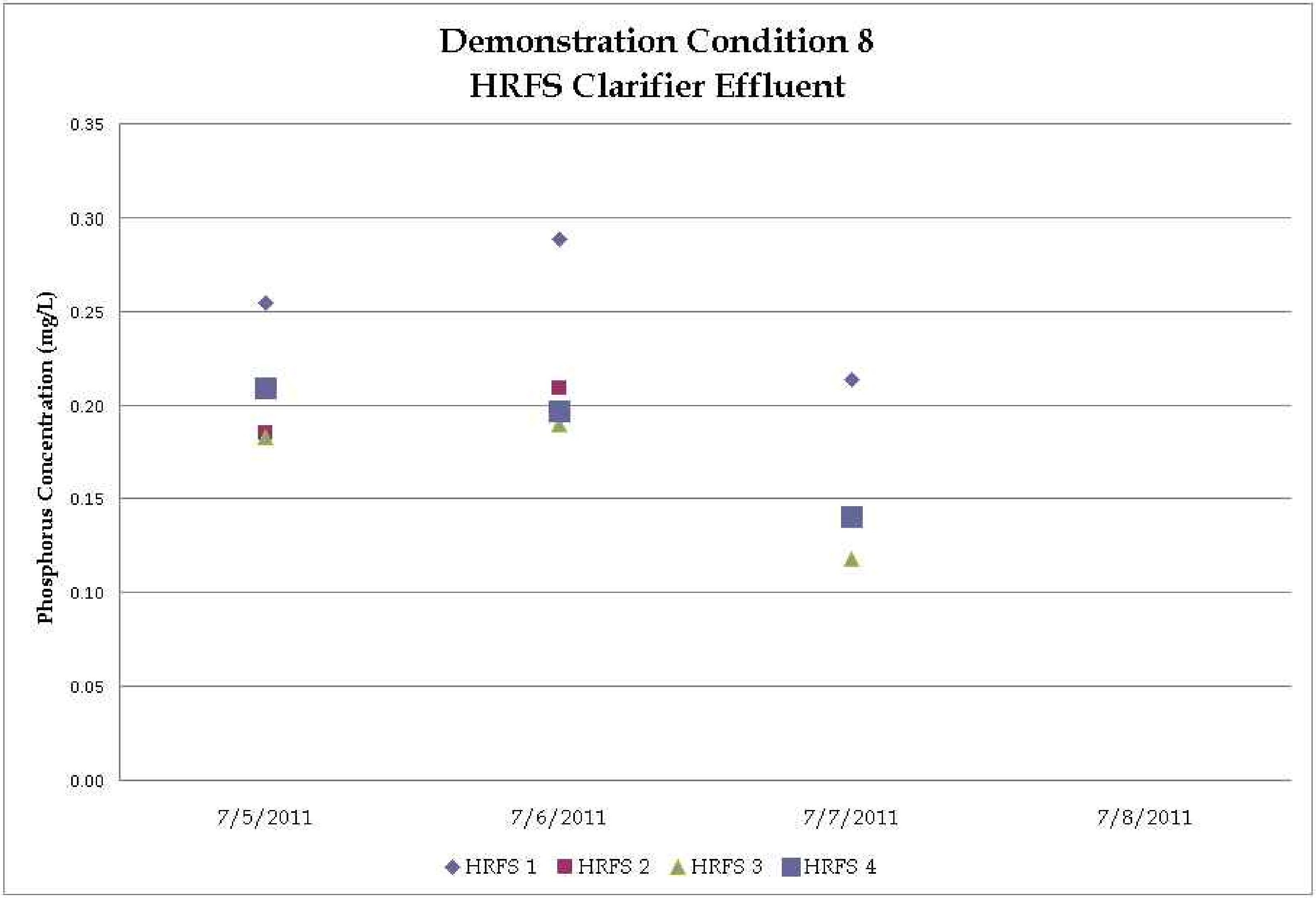


Figure 5-30

DEMONSTRATION CONDITION 8 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

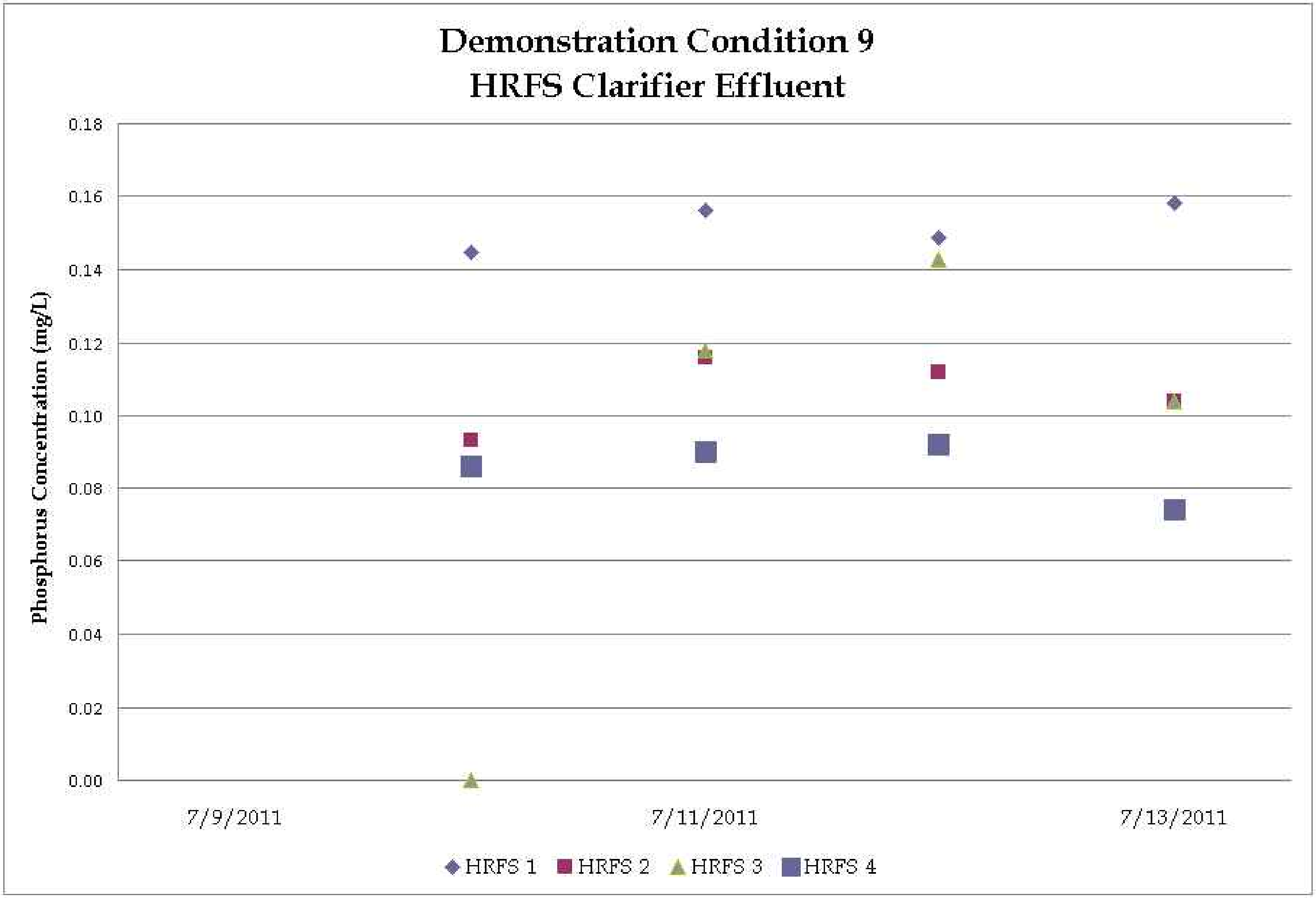
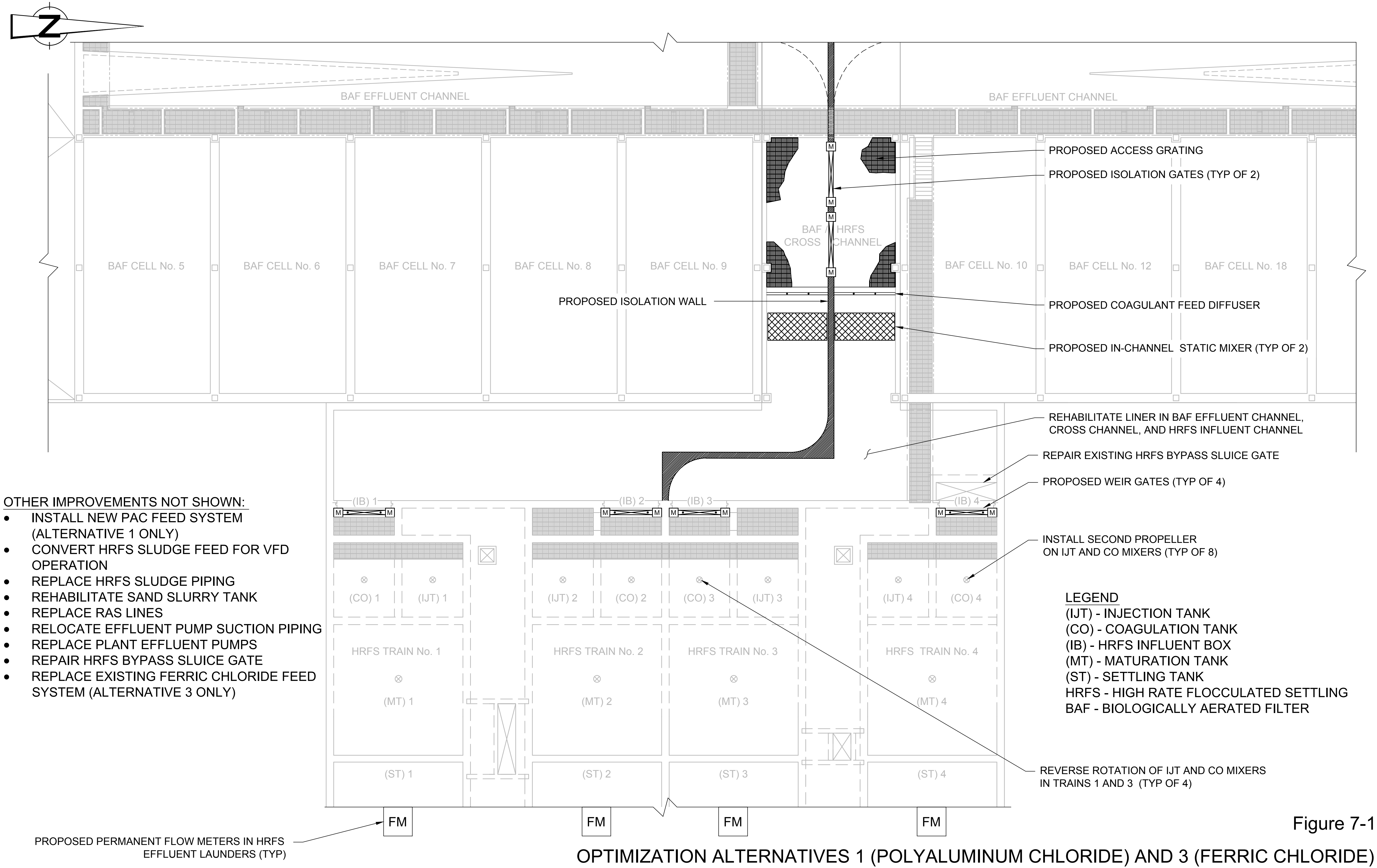


Figure 5-31

DEMONSTRATION CONDITION 9 - HRFS CLARIFIER EFFLUENT
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



OTHER IMPROVEMENTS NOT SHOWN:

- INSTALL NEW PAC FEED SYSTEM (ALTERNATIVE 1 ONLY)
- CONVERT HRFS SLUDGE FEED FOR VFD OPERATION
- REPLACE HRFS SLUDGE PIPING
- REHABILITATE SAND SLURRY TANK
- REPLACE RAS LINES
- RELOCATE EFFLUENT PUMP SUCTION PIPING
- REPLACE PLANT EFFLUENT PUMPS
- REPAIR HRFS BYPASS SLUICE GATE
- REPLACE EXISTING FERRIC CHLORIDE FEED SYSTEM (ALTERNATIVE 3 ONLY)

LEGEND

(IJT) - INJECTION TANK
(CO) - COAGULATION TANK
(IB) - HRFS INFLUENT BOX
(MT) - MATURATION TANK
(ST) - SETTLING TANK
HRFS - HIGH RATE FLOCCULATED SETTLING
BAF - BIOLOGICALLY AERATED FILTER

Figure 7-1

OPTIMIZATION ALTERNATIVES 1 (POLYALUMINUM CHLORIDE) AND 3 (FERRIC CHLORIDE)
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

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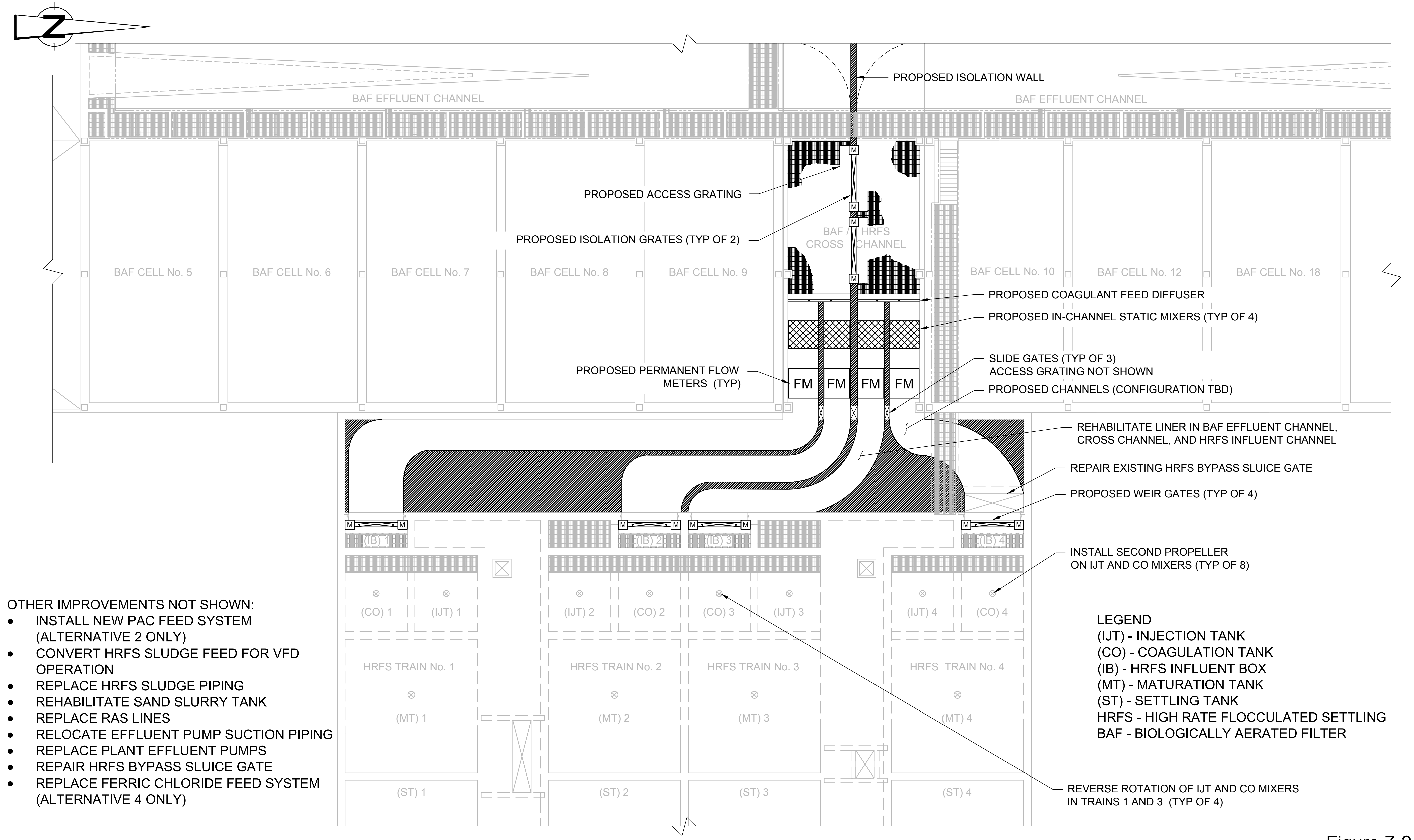


PROPOSED ISOLATION WALL

PROPOSED ACCESS GRATING

PROPOSED ISOLATION GRATES (TYP OF 2)

PROPOSED COAGULANT FEED DIFFUSER

PROPOSED IN-CHANNEL STATIC MIXERS (TYP OF 4)

PROPOSED PERMANENT FLOW METERS (TYP)

SLIDE GATES (TYP OF 3)
ACCESS GRATING NOT SHOWN

PROPOSED CHANNELS (CONFIGURATION TBD)

REHABILITATE LINER IN BAF EFFLUENT CHANNEL, CROSS CHANNEL, AND HRFS INFLUENT CHANNEL

REPAIR EXISTING HRFS BYPASS SLUICE GATE

PROPOSED WEIR GATES (TYP OF 4)

INSTALL SECOND PROPELLER ON IJT AND CO MIXERS (TYP OF 8)

REVERSE ROTATION OF IJT AND CO MIXERS IN TRAINS 1 AND 3 (TYP OF 4)

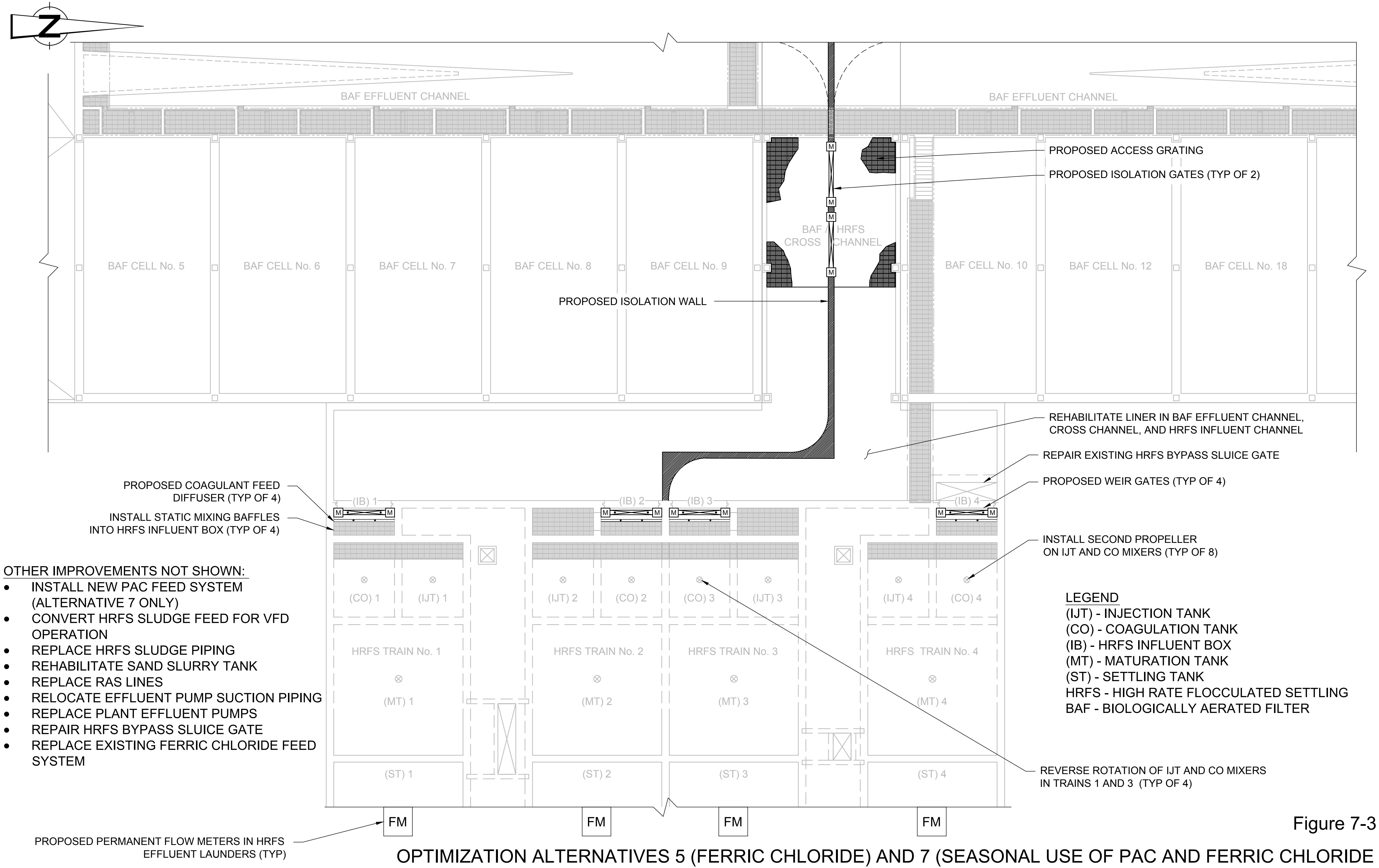
OTHER IMPROVEMENTS NOT SHOWN:

- INSTALL NEW PAC FEED SYSTEM (ALTERNATIVE 2 ONLY)
- CONVERT HRFS SLUDGE FEED FOR VFD OPERATION
- REPLACE HRFS SLUDGE PIPING
- REHABILITATE SAND SLURRY TANK
- REPLACE RAS LINES
- RELOCATE EFFLUENT PUMP SUCTION PIPING
- REPLACE PLANT EFFLUENT PUMPS
- REPAIR HRFS BYPASS SLUICE GATE
- REPLACE FERRIC CHLORIDE FEED SYSTEM (ALTERNATIVE 4 ONLY)

LEGEND
(IJT) - INJECTION TANK
(CO) - COAGULATION TANK
(IB) - HRFS INFLUENT BOX
(MT) - MATURATION TANK
(ST) - SETTLING TANK
HRFS - HIGH RATE FLOCCULATED SETTLING
BAF - BIOLOGICALLY AERATED FILTER

Figure 7-2

OPTIMIZATION ALTERNATIVE 2 (POLYALUMINUM CHLORIDE) AND 4 (FERRIC CHLORIDE)
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*



OTHER IMPROVEMENTS NOT SHOWN:

- INSTALL NEW PAC FEED SYSTEM (ALTERNATIVE 7 ONLY)
- CONVERT HRFS SLUDGE FEED FOR VFD OPERATION
- REPLACE HRFS SLUDGE PIPING
- REHABILITATE SAND SLURRY TANK
- REPLACE RAS LINES
- RELOCATE EFFLUENT PUMP SUCTION PIPING
- REPLACE PLANT EFFLUENT PUMPS
- REPAIR HRFS BYPASS SLUICE GATE
- REPLACE EXISTING FERRIC CHLORIDE FEED SYSTEM

LEGEND

(IJT) - INJECTION TANK
(CO) - COAGULATION TANK
(IB) - HRFS INFLUENT BOX
(MT) - MATURATION TANK
(ST) - SETTLING TANK
HRFS - HIGH RATE FLOCCULATED SETTLING
BAF - BIOLOGICALLY AERATED FILTER

Figure 7-3

OPTIMIZATION ALTERNATIVES 5 (FERRIC CHLORIDE) AND 7 (SEASONAL USE OF PAC AND FERRIC CHLORIDE
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

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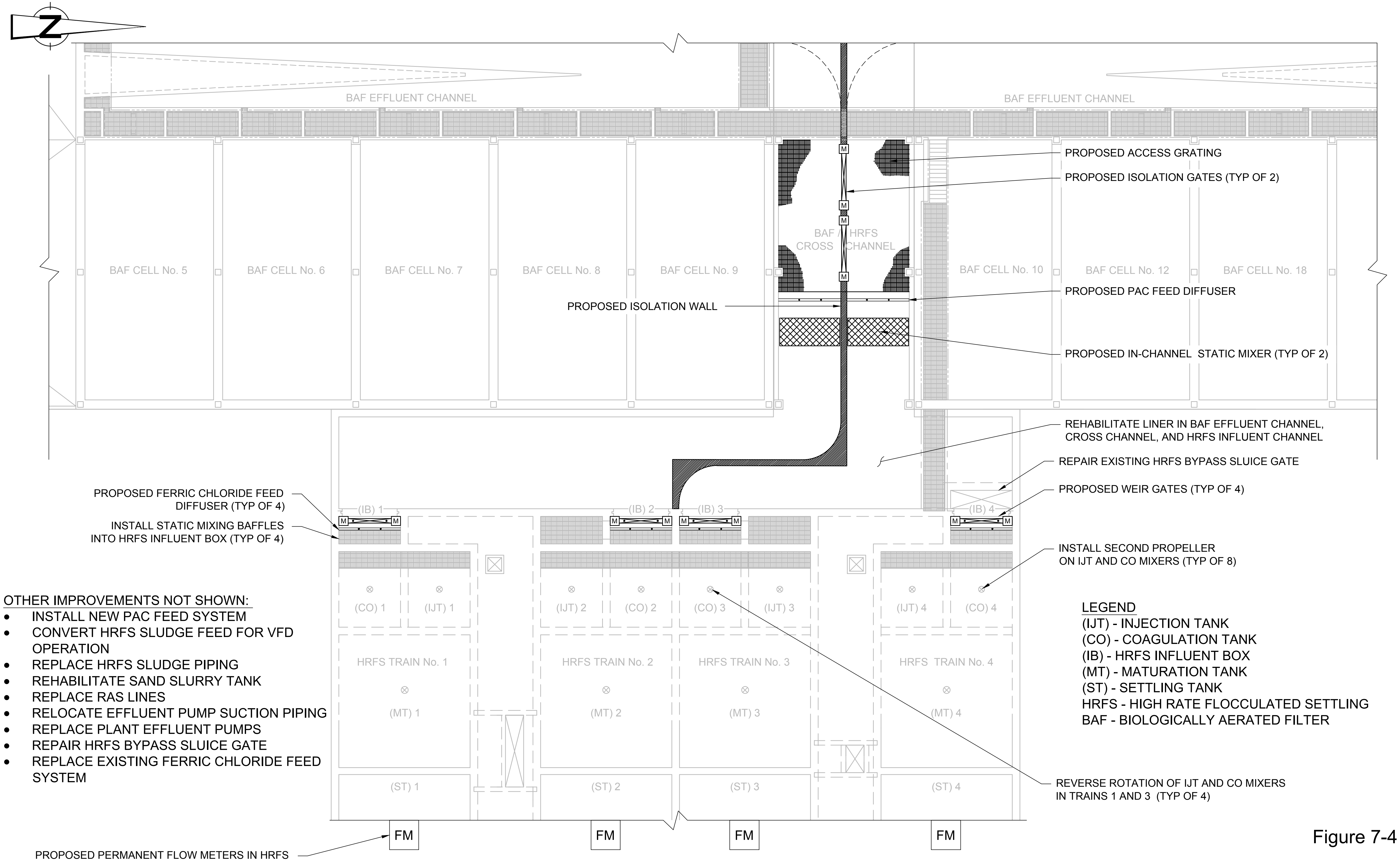

PROPOSED ACCESS GRATING

PROPOSED ISOLATION GATES (TYP OF 2)

PROPOSED PAC FEED DIFFUSER

PROPOSED ISOLATION WALL

PROPOSED IN-CHANNEL STATIC MIXER (TYP OF 2)

REHABILITATE LINER IN BAF EFFLUENT CHANNEL, CROSS CHANNEL, AND HRFS INFLUENT CHANNEL

REPAIR EXISTING HRFS BYPASS SLUICE GATE

PROPOSED WEIR GATES (TYP OF 4)

PROPOSED FERRIC CHLORIDE FEED DIFFUSER (TYP OF 4)

INSTALL STATIC MIXING BAFFLES INTO HRFS INFLUENT BOX (TYP OF 4)

INSTALL SECOND PROPELLER ON IJT AND CO MIXERS (TYP OF 8)

REVERSE ROTATION OF IJT AND CO MIXERS IN TRAINS 1 AND 3 (TYP OF 4)

PROPOSED PERMANENT FLOW METERS IN HRFS EFFLUENT LAUNDERS (TYP)

OTHER IMPROVEMENTS NOT SHOWN:
- INSTALL NEW PAC FEED SYSTEM
- CONVERT HRFS SLUDGE FEED FOR VFD OPERATION
- REPLACE HRFS SLUDGE PIPING
- REHABILITATE SAND SLURRY TANK
- REPLACE RAS LINES
- RELOCATE EFFLUENT PUMP SUCTION PIPING
- REPLACE PLANT EFFLUENT PUMPS
- REPAIR HRFS BYPASS SLUICE GATE
- REPLACE EXISTING FERRIC CHLORIDE FEED SYSTEM

LEGEND
(IJT) - INJECTION TANK
(CO) - COAGULATION TANK
(IB) - HRFS INFLUENT BOX
(MT) - MATURATION TANK
(ST) - SETTLING TANK
HRFS - HIGH RATE FLOCCULATED SETTLING
BAF - BIOLOGICALLY AERATED FILTER

Figure 7-4

OPTIMIZATION ALTERNATIVE 6 (SEASONAL USE OF PAC AND FERRIC CHLORIDE)
METRO WWTP OPTIMIZATION ANALYSIS OF TP TREATMENT
*Onondaga County WEP*

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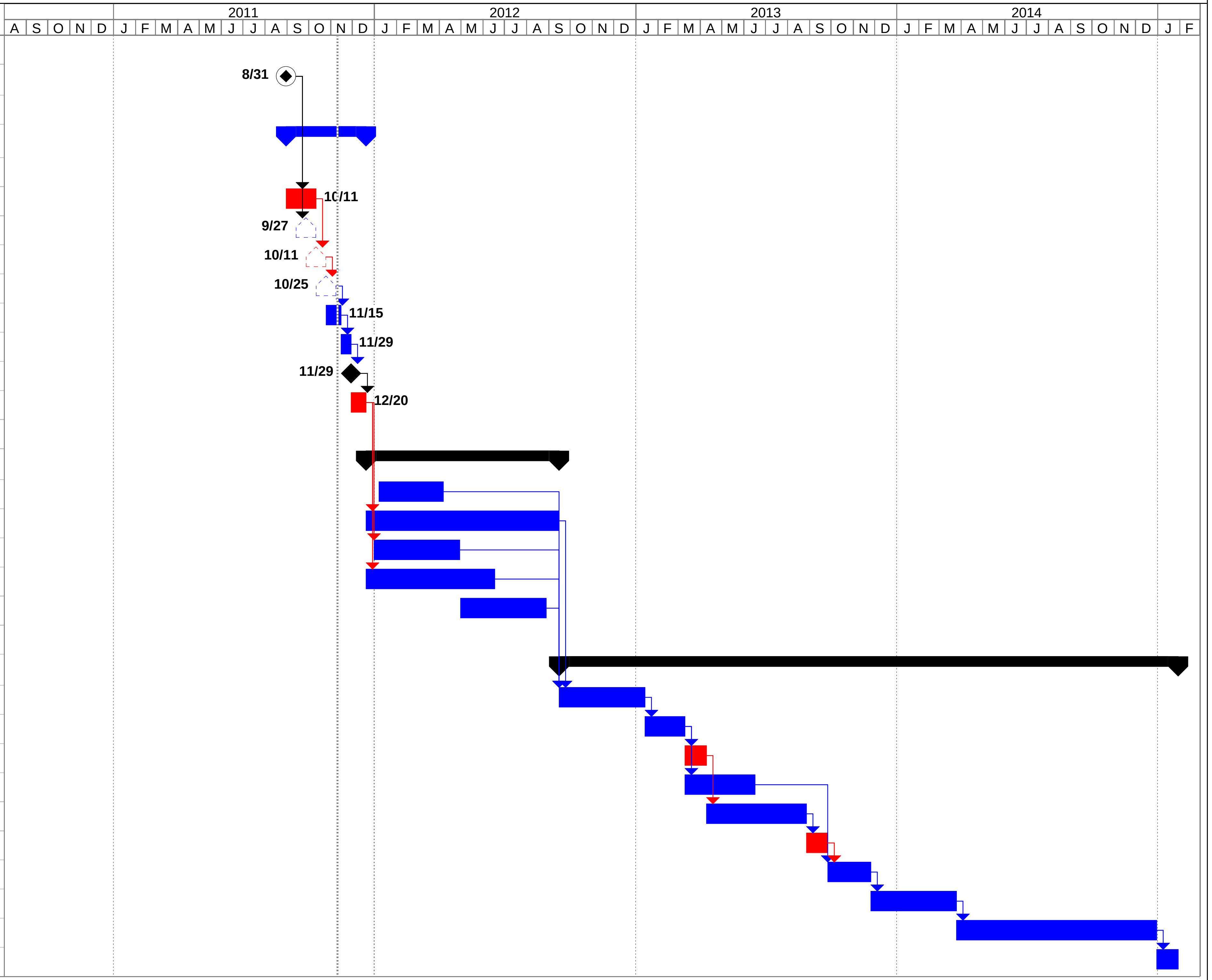
# Figure 8-1
# Onondaga County Department of Water Environment Protection
# Metro WWTP Phosphorus Treatment Optimization
# Preliminary Implementation Schedule (Dates are Approximate)

| ID | Task Name | Duration |
|---|---|---|
| 1 | | |
| 2 | **Submit Optimization Analysis Report to NYSDEC (MILESTONE)** | 0 days |
| 3 | | |
| 4 | **Finalizing Optimization Analysis Report** | **112 days** |
| 5 | | |
| 6 | NYSDEC Review | 42 days |
| 7 | Technical Coordination Meeting #1 (Tentative) | 0 days |
| 8 | Receive Optimization Analysis Report Comments from NYSDEC | 0 days |
| 9 | Technical Coordination Meeting #2 (Tentative) | 0 days |
| 10 | Response to Comments/Finalize Optimization Analysis Report | 21 days |
| 11 | Finalize Optimization Analysis Report | 14 days |
| 12 | **Submit Final Optimization Analysis Report to NYSDEC** | 0 days |
| 13 | NYSDEC Approval of Final Report | 21 days |
| 14 | | |
| 15 | **Pre Implementation Evaluations (need prior to start of design)** | **270 days** |
| 16 | Full-Scale Demonstration of Smaller Microsand | 90 days |
| 17 | PAC Temperature Dependency Testing | 270 days |
| 18 | CFD Modeling of BAF/HRFS Isolation Wall | 120 days |
| 19 | Full-Scale Mixer Evaluation | 180 days |
| 20 | PAC Bioavailability and Particle Content Analyses | 120 days |
| 21 | | |
| 22 | **Metro Phosphorus Treatment Optimization Implementation** | **866 days** |
| 23 | Consultant Procurement | 120 days |
| 24 | Prepare Preliminary Design Report | 56 days |
| 25 | NYSDEC Review Period | 30 days |
| 26 | Variance Application and Approval | 98 days |
| 27 | Prepare Detailed Design and Contract Documents | 140 days |
| 28 | NYSDEC Review Period | 30 days |
| 29 | Bid/Award Phase | 60 days |
| 30 | Construction of Isolation Wall (full tertiary bypass required) | 120 days |
| 31 | Complete Construction | 280 days |
| 32 | Start-Up and Commissioning | 30 days |



Project: Metro Optimization
Date: Thu 11/10/11

WEP Task 🟦
Progress ▬
ACJ Milestone ◈
Completed Milestone ◆
Summary ▬
Target Date ⬠
Rolled Up Progress ▬
NYSDEC Effort 🟥

**Note: All dates are subject to change based on submittal of NYSDEC comments and approval.**

# TABLES

## TABLE 3-1
## Metro Syracuse WWTP Optimization Analysis for Total Phosphorus Treatment
## Initial Evaluation Checklist

| Treatment System Issue/Goal | Potential Solution | Ancillary Benefits | Potential Unintended Consequences | Parameters to Evaluate |
|---|---|---|---|---|
| Continuously Maintain Phosphorus Limit <= 0.1 mg/L (or lower). | Change treatment scheme (coagulant, flocculants, dosages) | Alum and polyaluminum chloride generate the less sludge than ferric chloride, do not interfere with UV disinfection, do not coat UV system quartz sleeved, and do not corrode aluminum. Calcium may achieve best removals. | Coagulant or polymer may interfere with current solids handling ability. Ferric chloride interferes with UV disinfection, coats UV disinfection tubes, and corrodes aluminum and stainless steel. High pH needed for calcium could promote scaling. | Total phosphorus and turbidity of effluent<br>Modifications to existing chemical feed and storage<br>Settleability<br>Sludge volume and handling ability<br>Interference with UV frequency<br>UV quartz sleeve coating<br>Equipment corrosion |
| Optimize current coagulant, polymer, and microsand dosages | Promote thorough initial rapid mixing. Optimize mixing in HRFS coagulation, injection and maturation tanks. Install flow monitoring for flow paced dosing. | Reduced chemical costs. Reduced sludge volumes and disposal costs. Better clarifier performance and less carryover. Reduced clarifier maintenance. | Corrosion may continue. Impact to UV system from iron. Increased energy cost from rapid mixing. | Total phosphorus and turbidity of supernatant<br>Chemical and sludge disposal cost.<br>CFD Analysis of mixing regimes. |
| Reduce phosphorus load to HRFS system. | Increase removal of phosphorus in secondary treatment. | Reduced load to HRFS system and possible reduced chemical costs. Reduced sludge volumes. | Removal of phosphorus and carbon, which could inhibit BAF operation. Added complexity of operation. | Phosphorus concentrations in influent, primary effluent and return streams. |
| Control and balance flow to the HRFS process trains under all flow conditions. | Installation of variable weir gates. Modify weir width or elevation. Installation of baffle walls in cross channel and HRFS influent channel to channelize flow. Install open channel pumps. Use SCADA to control BAF backwash so that flow is more equalized. | All process trains will receive approximately equal flow and coagulant dosages. May improve mixing effectiveness and phosphorus removal. May mitigate entrainment of microsand. May reduce carryover of unreacted iron to UV lamps. | Flow control gates may require frequent adjustment or may jam depending on size of the units. Headloss may increase. | CFD Analysis<br>Headloss<br>Operability<br>Maintenance requirements |
| Adequately disperse coagulant under all flow conditions | Relocate mixing point to HRFS influent boxes, possibly with use of mixers, chemical eductors, and/or baffles in the cross channel. | Potentially smaller cost and reduced energy use.<br>Eliminate BAF backwash concerns.<br>Reduce corrosion issues. | Less time for chemical reactions.<br>More difficult construction and maintenance. | CFD Analysis<br>Headloss<br>Maintenance<br>Controls |
| Adequately disperse coagulant under all flow conditions | Add combination of mixers, baffles and/or chemical inductors, either in existing cross channel, or series of smaller channels. | Elimination of coagulant plumes. Improved phosphorus removal. Reduced chemical costs. | Excessive headloss. Increased energy use. Coagulant migrates into BAF backwash without stop gates. | Perform CFD Analysis. Mixer size and impeller direction. Baffling requirements. Headloss. Operability. Maintenance. |
| Optimize mixing in the HRFS coagulant, injection and maturation tanks. | Modify existing mixers (e.g., blade diameter or angle, shaft length, direction of rotation, speed, etc.), replace mixers, relocate mixers. | Reduced chemical costs. Reduced sludge volumes and disposal costs. Better clarifier performance and less carryover. Reduced clarifier maintenance. Lower phosphorus concentrations. | Modifications to tanks and mixers could be costly. Modification of mixers may cause added stress and vibration. Increase energy cost. | Perform CFD Analysis. Mixer size and impeller direction. Baffling requirements. Headloss. Operability. Maintenance. |
| Offset headlosses induced by mixing and channel modifications. | Lower weir at HRFS influent. Raise channel walls or BAF influent weirs. | Allows a higher headloss option that may be more effective in process control and mixing. | Hydraulic impact to upstream and downstream processes. | Hydraulic profile. |
| Backwash BAF without concern for ferric chloride being drawn into the filters. | Relocate coagulant to coagulant mixing tanks. Use SCADA system to correlate coagulant addition with backwash (turn off coagulant addition before and during a portion of backwash.). Install blocking baffles to reduce migration potential. | Elimination of migration into BAF backwash. | Relocating point many be more difficult to construct and maintain.<br>SCADA changes could be complex and lead to inconsistent treatment. Baffles may cause excessive headloss. | Coagulant addition location<br>SCADA Programming Analysis. CFD modeling. |
| Maintain low effluent turbidity out of clarifier | Prevent flow and solids overloading.<br>Adjust sludge withdrawal rate.<br>Establish routine maintenance plan | Reduce microsand carryover to the UV channel. Maintain disinfection efficiency. | Increased sludge wasting may increase water content at solids handling unit. | Flow and solids loading<br>Sludge withdrawal rate<br>Routine maintenance |
| Microsand in the effluent channel impacting the effluent water pumps | Provide flow balancing to reduce individual tank overloading. Relocate pump suction. Install filter on pump suction. | Reduce sand entrainment. Protect effluent water pumps from wear. Reduced sand loss. | New wall penetrations may cause leakage. Piping relocation can shut down entire disinfection system during construction. | Clarifier solids carryover |
| Maintain UV disinfection efficiency | Reduce ferric chloride dosage. Promote flow balancing to prevent tank overloading and carryover. Change coagulants. | Extended lamp life. Lower energy use. Less frequent cleaning. Reduce UV dose. | Changing coagulants could impact sludge handling effectiveness. | UV transmittance<br>Scaling of UV tubes, sludge characteristics |

Table 5-21
Full-Scale Demonstration Timeline
Note - Change is highlighted

| Condition | Period | Flow to HRFS Trains | Coagulant Diffuser Set-up | | | | | Coagulant added - reported as average measured metal concentration (mg metal /L) in coagulation tank | | | | | Polymer Set-up | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cross Channel | HRFS Train | | | | Cross Channel | HRFS Train | | | | HRFS Train | | | |
| | | | | 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Baseline | 4/1/2006 - 2/4/2011 | Unbalanced flow to all 4 HRFS trains | Diffuser with FeCl3 fed neat | Not used | Not used | Not used | Not used | Dosed at 33 mg/L | metal concentration not measured | | | | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser |
| 1 | 2/5 - 2/17/11 | Unbalanced flow to all 4 HRFS trains | Not used | Diffuser with FeCl3 fed neat | Diffuser with dilution | one water champ | three water champs | None | 11.2 mg Fe/L | 13.5 mg Fe/L | 11.6 mg Fe/L | 21.2 mg Fe/L | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser |
| Pilot-study suspended | 2/18 - 2/28/11 | Unbalanced flow to all 4 HRFS trains | Diffuser with FeCl3 fed neat | Not used | Not used | Not used | Not used | Dosed at 33 mg/L | metal concentration not measured | | | | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser |
| 2 | 3/1 - 3/22/11 | Balanced flow to all 4 HRFS trains | Not used | Diffuser with FeCl3 fed neat | Diffuser with dilution | One water champ | Three water champs | None | 10.7 mg Fe/L | 13.1 mg Fe/L | 12.6 mg Fe/L | 16.1 mg Fe/L | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser |
| 3 | 3/23 - 4/11/11 | Balanced flow to all 4 HRFS trains | Not used | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Three water champs | None | 11.1 mg Fe/L | 14.5 mg Fe/L | 13.4 mg Fe/L | 17.7 mg Fe/L | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser | Single outlet T diffuser |
| 4 | 4/12 - 4/19/2011 | Balanced flow to all 4 HRFS trains | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | None | 11.3 mg Fe/L | 13.8 mg Fe/L | 14.9 mg Fe/L | 18.5mg Fe/L | Polymer modifications period | | | |
| 5 | 4/20 - 5/8/2011 | Balanced flow to all 4 HRFS trains | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | None | 12.0 mg Fe/L | 13.9 mg Fe/L | 12.9 mg Fe/L | 14.4 mg Fe/L | Baffle drops | Baffle drops | Baffle drops | Baffle drops |
| 6 | 5/9 - 6/27/2011 | Balanced flow to all 4 HRFS trains | Not used | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | None | 11.4 mg Fe/L | 14.6 mg Fe/L | 12.8 mg Fe/L | 17.5 mg Fe/L | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank |
| 7 | 6/28 - 7/4/2011 | Balanced flow to all 4 HRFS trains | Not used | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | None | 12.0 mg Fe/L | 15.9 mg Fe/L | 12.3 mg Fe/L | 11.2 mg Al/L | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank |
| 8 | 7/5 - 7/8/2011 | Balanced flow to all 4 HRFS trains | Not used | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | None | 11.9mg Fe/L | 17.3 mg Fe/L | 13.3 mg Fe/L | 5.8 mg Al/L | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank |
| 9 | 7/9 - 7/13/2011 | Balanced flow, 3 trains used during low flow periods | Not used | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | Diffuser with dilution | None | 11.7 mg Fe/L | 15.6 mg Fe/L | 8.9 mg Fe/L | 5.2 mg Al/L | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank | T-header diffuser at maturation tank |

# APPENDIX A

# COMPARATIVE BENCH-SCALE TESTING RESULTS

## Onondaga 1st Round of Jar Testing Sample Key

| | | |
|---|---|---|
| **HRFS influent** | | 630742-Initial |
| **Total Phosphorus** | **mg/L** | **0.197** |

**Test #1: Test of multiple coagulants at dosage recommended by manufacturer.  Identifier 630742-1-1 serves as baseline conditions**

| | Units | 630742-1-1 | 630742-1-2 | 630742-1-3 | 630742-1-4 | 630742-1-5 | 630742-1-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 |
| Effective Sand Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 30 | 50 | 4.2 | 30 | 30 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.033** | **0.036** | **0.148** | **0.029** | **0.040** | **0.055** |

**Test #2: Same as Test #1 but polymer changed to Magnafloc 5250**

| | Units | 630742-2-1 | 630742-2-2 | 630742-2-3 | 630742-2-4 | 630742-2-5 | 630742-2-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 30 | 50 | 4.2 | 30 | 30 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.035** | **0.032** | **0.130** | **0.030** | **0.044** | **0.046** |

**Test #3: Same as Test # 2 but smaller effective size sand used**

| | Units | 630742-3-1 | 630742-3-2 | 630742-3-3 | 630742-3-4 | 630742-3-5 | 630742-3-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Effective Sand Size | microns | 110 | 110 | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 30 | 50 | 4.2 | 30 | 30 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.030** | **0.027** | **0.135** | **0.025** | **0.038** | **0.046** |

**Test #4: Same as Test 1 but polymer changed to STAFLOC 5466**

| | Units | 630742-4-1 | 630742-4-2 | 630742-4-3 | 630742-4-4 | 630742-4-5 | 630742-4-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 |
| Effective Sand Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 30 | 50 | 4.2 | 30 | 30 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.032** | **0.032** | **0.113** | **0.032** | **0.046** | **0.043** |

**Test #5: Same as Test 4 but coagulant dose was doubled**

| | Units | 630742-5-1 | 630742-5-2 | 630742-5-3 | 630742-5-4 | 630742-5-5 | 630742-5-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 | STAFLOC 5466 |
| Effective Sand Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 60 | 100 | 8.4 | 60 | 60 | 60 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.026** | **0.024** | **0.104** | **0.024** | **0.037** | **0.033** |

**Test #6: same as Test #2 but coagulant dose was doubled**

| | Units | 630742-6-1 | 630742-6-2 | 630742-6-3 | 630742-6-4 | 630742-6-5 | 630742-6-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Effective Sand Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 60 | 100 | 8.4 | 60 | 60 | 60 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.026** | **0.022** | **0.092** | **0.023** | **0.043** | **0.031** |

**Test #7: Same as Test # 1 but coagulant dose was doubled**

| | Units | 630742-7-1 | 630742-7-2 | 630742-7-3 | 630742-7-4 | 630742-7-5 | 630742-7-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Holland CLA | Nalco 2 | Holland EPIC-70 | Nalco 8187 | STERNPAC-50 |
| Polymer | NA | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 |
| Effective Sand Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 60 | 100 | 8.4 | 60 | 60 | 60 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.041** | **0.084** | **0.145** | **0.101** | **0.161** | **0.049** |

**Test #8: Coagulant dose test on Praestol K2001**

| | Units | 630742-8-1 | 630742-8-2 | 630742-8-3 |
|---|---|---|---|---|
| Coagulant | NA | Praestol K2001 | Praestol K2001 | Praestol K2001 |
| Polymer | NA | Praestol K2001 | Praestol K2001 | Praestol K2001 |
| Effective Sand Size | microns | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 15 | 30 | 60 |
| Polymer Dose | mg/L | 15 | 30 | 60 |
| Sand Dose | g/L | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.185** | **0.182** | **0.189** |

Test #9: Repeat Testing of 630742-2-1

| | Units | 630742-9-1 |
|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ |
| Polymer | NA | Magnafloc 5250 |
| Effective Sand Size | NA | Current |
| Coagulant Dose | mg/L | 30 |
| Polymer Dose | mg/L | 0.6 |
| Sand Dose | g/L | 5 |
| **Total Phosphorus** | **mg/L** | **0.044** |

## 630742 Comparative Bench-Scale Testing Round 2

**Source Water** **630742-20-Initial =** **0.172** **mg TP/L**

### Test #1 PAC dose, microsand dose

| | Units | 630742-21-1 | 630742-21-2 | 630742-21-3 | 630742-21-4 | 630742-21-5 | 630742-21-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 30 | 30 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 3 | 7 | 9 |
| **Total Phosphorus** | **mg/L** | **0.040** | **0.064** | **0.058** | **0.056** | **0.051** | **0.054** |

### Test #2 PAC with alternate polymer, alum

| | Units | 630742-22-1 | 630742-22-2 | 630742-22-3 | 630742-22-4 | 630742-22-5 | 630742-22-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland CLA | Holland CLA | Holland CLA |
| Polymer | NA | STAFloc 5466 | STAFloc 5466 | STAFloc5466 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 30 | 50 | 40 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.083** | **0.086** | **0.077** | **0.077** | **0.064** | **0.075** |

### Test #3 PAC and alum with larger size microsand

| | Units | 630742-23-1 | 630742-23-2 | 630742-23-3 | 630742-23-4 | 630742-23-5 | 630742-23-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland CLA | Holland CLA | Holland CLA |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 134 | 134 | 134 | 134 | 134 | 134 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 30 | 50 | 40 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.053** | **0.070** | **0.068** | **0.090** | **0.063** | **0.087** |

### Test #4 Ferric chloride, multiple dosages, two microsand effective sizes

| | Units | 630742-24-1 | 630742-24-2 | 630742-24-3 | 630742-24-4 | 630742-24-5 | 630742-24-6 |
|---|---|---|---|---|---|---|---|
| Coagulant | NA | Onondaga $FeCl_3$ | Onondaga $FeCl_3$ | Onondaga $FeCl_3$ | Onondaga $FeCl_3$ | Onondaga $FeCl_3$ | Onondaga $FeCl_3$ |
| Polymer | NA | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 | Nalco 7768 |
| Sand Effective Size | microns | 134 | 134 | 134 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 36 | 24 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.056** | **0.069** | **0.070** | **0.044** | **0.052** | **0.048** |

Onondaga 3rd Round of Jar Testing Sample Key

| | | |
|---|---|---|
| **Untreated** | | **630742-30-Initial** |
| **Total Phosphorus** | **mg/L** | **0.310** |

**Test #1** **Coagulant added at HRFS influent box (Mixing Scenario 1)**

| | Units | 630742-31-1 | 630742-31-2 | 630742-31-3 | 630742-31-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 42 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| Total Phosphorus | mg/L | 0.039 | 0.057 | 0.056 | 0.037 |

**Test #2 - Error** **Coagulant added at HRFS influent box (Mixing Scenario 1) - Error: sand added with coagulant**

| | Units | 630742-32-1 | 630742-32-2 | 630742-32-3 | 630742-32-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland CLA | Holland CLA | Holland CLA | Onondaga $FeCl_3$ |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Nalco 7768 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 70 | 50 | 60 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| Total Phosphorus | mg/L | 0.051 | 0.065 | 0.076 | 0.065 |

**Test #3** **Coagulant added in Cross Channel at peak flow (Mixing Scenario 2)**

| | Units | 630742-33-1 | 630742-33-2 | 630742-33-3 | 630742-33-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 42 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| Total Phosphorus | mg/L | 0.037 | 0.054 | 0.045 | 0.036 |

**Test #4** **Coagulant added in Cross Channel at peak flow (Mixing Scenario 2)**

| | Units | 630742-34-1 | 630742-34-2 | 630742-34-3 | 630742-34-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland CLA | Holland CLA | Holland CLA | Onondaga $FeCl_3$ |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Nalco 7768 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 70 | 50 | 60 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.045** | **0.063** | **0.080** | **0.073** |

**Test #5** **Coagulant added in Cross Channel at average flow (Mixing Scenario 3)**

| | Units | 630742-35-1 | 630742-35-2 | 630742-35-3 | 630742-35-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 42 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.033** | **0.048** | **0.042** | **0.032** |

**Test #6** **Coagulant added in Cross Channel at average flow (Mixing Scenario 3)**

| | Units | 630742-36-1 | 630742-36-2 | 630742-36-3 | 630742-36-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland CLA | Holland CLA | Holland CLA | Onondaga $FeCl_3$ |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Nalco 7768 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 70 | 50 | 60 | 30 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.043** | **0.059** | **0.069** | **0.064** |

**Test #7** **Coagulant added in Cross Channel at peak flow (Mixing Scenario 2)**

| | Units | 630742-37-1 | 630742-37-2 | 630742-37-3 | 630742-37-4 |
|---|---|---|---|---|---|
| Coagulant | NA | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 | Holland EPIC-70 |
| Polymer | NA | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 | Magnafloc 5250 |
| Sand Effective Size | microns | 110 | 110 | 110 | 110 |
| Coagulant Dose | mg/L | 36 | 24 | 30 | 42 |
| Polymer Dose | mg/L | 0.6 | 0.6 | 0.6 | 0.6 |
| Sand Dose | g/L | 5 | 5 | 5 | 5 |
| **Total Phosphorus** | **mg/L** | **0.036** | **0.046** | **0.040** | **0.030** |

# APPENDIX B

# PRELIMINARY CAPITAL AND O&M COST ESTIMATE SUMMARIES

# APPENDIX B

# PRELIMINARY CAPITAL AND O&M COST ESTIMATE SUMMARIES

# CONSTRUCTION COST ESTIMATE

## Onondaga County Department of Water Environment Protection
## Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus

*Project N0. 630742*

**ALTERNATIVE 1 COST ESTIMATE**

| *Description* | *Quantity* | *Units* | Materials | | Labor | | *Total Cost* |
|---|---|---|---|---|---|---|---|
| | | | *Unit Cost* | *Total* | *Unit Cost* | *Total* | |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| Effluent Launder Flow Meters | 4 | EA | 10,000 | 40,000 | 5,000 | 20,000 | 60,000 |
| Install PAC Feed System (Pumps and Piping) | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 200,000 | 200,000 | 200,000 |
| SCADA Modifications | 1 | LS | 25,000 | 25,000 | 50,000 | 50,000 | 75,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 32,000 | SF | 5 | 160,000 | 5 | 160,000 | 320,000 |
| In-Channel Static Mixer | 2 | EA | 100,000 | 200,000 | 20,000 | 40,000 | 240,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *2,769,250* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 221,540 |
| Electrical and Instrumentation | 20% | | | | | | 553,850 |
| Contractor Overhead/Profit | 10% | | | | | | 276,925 |
| Engineering/Legal/Administration | 18% | | | | | | 498,465 |
| Contingency and Allowances | 20% | | | | | | 553,850 |
| | | | | | **ESTIMATE** | | **4,874,000** |

# CONSTRUCTION COST ESTIMATE

**Onondaga County Department of Water Environment Protection**
**Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus**
*Project N0. 630742*

**ALTERNATIVE 2 COST ESTIMATE**

| | | | Materials | | Labor | | |
|---|---|---|---|---|---|---|---|
| *Description* | *Quantity* | *Units* | *Unit Cost* | *Total* | *Unit Cost* | *Total* | *Total Cost* |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| Channeling (Concrete) | 275 | CY | 750 | 206,250 | | | 206,250 |
| Channel Equalization Gates | 3 | EA | 25,000 | 75,000 | 7,000 | 21,000 | 96,000 |
| Influent Channel Flow Meters | 4 | EA | 20,000 | 80,000 | 10,000 | 40,000 | 120,000 |
| Install PAC Feed System (Pumps and Piping) | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 300,000 | 300,000 | 300,000 |
| SCADA Modifications | 1 | LS | 40,000 | 40,000 | 40,000 | 70,000 | 110,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 35,000 | SF | 5 | 175,000 | 5 | 175,000 | 350,000 |
| In-Channel Static Mixers | 4 | EA | 50,000 | 200,000 | 10,000 | 40,000 | 240,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *3,296,500* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 263,720 |
| Electrical and Instrumentation | 20% | | | | | | 659,300 |
| Contractor Overhead/Profit | 10% | | | | | | 329,650 |
| Engineering/Legal/Administration | 18% | | | | | | 593,370 |
| Contingency and Allowances | 20% | | | | | | 659,300 |
| **ESTIMATE** | | | | | | | **5,802,000** |

# CONSTRUCTION COST ESTIMATE

**Onondaga County Department of Water Environment Protection**

**Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus**

*Project N0. 630742*

**ALTERNATIVE 3 COST ESTIMATE**

| | | | Materials | | Labor | | |
|---|---|---|---|---|---|---|---|
| *Description* | *Quantity* | *Units* | *Unit Cost* | *Total* | *Unit Cost* | *Total* | *Total Cost* |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| Effluent Launder Flow Meters | 4 | EA | 10,000 | 40,000 | 5,000 | 20,000 | 60,000 |
| Replace Ferric Chloride Feed System | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 200,000 | 200,000 | 200,000 |
| SCADA Modifications | 1 | LS | 25,000 | 25,000 | 50,000 | 50,000 | 75,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 32,000 | SF | 5 | 160,000 | 5 | 160,000 | 320,000 |
| In-Channel Static Mixer | 2 | EA | 100,000 | 200,000 | 20,000 | 40,000 | 240,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *2,769,250* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 221,540 |
| Electrical and Instrumentation | 20% | | | | | | 553,850 |
| Contractor Overhead/Profit | 10% | | | | | | 276,925 |
| Engineering/Legal/Administration | 18% | | | | | | 498,465 |
| Contingency and Allowances | 20% | | | | | | 553,850 |
| **ESTIMATE** | | | | | | | **4,874,000** |

# CONSTRUCTION COST ESTIMATE

Onondaga County Department of Water Environment Protection
Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus
*Project N0. 630742*

**ALTERNATIVE 4 COST ESTIMATE**

| | | | Materials | | Labor | | |
|---|---|---|---|---|---|---|---|
| *Description* | *Quantity* | *Units* | *Unit Cost* | *Total* | *Unit Cost* | *Total* | *Total Cost* |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| Channeling (Concrete) | 275 | CY | 750 | 206,250 | | | 206,250 |
| Channel Equalization Gates | 3 | EA | 25,000 | 75,000 | 7,000 | 21,000 | 96,000 |
| Influent Channel Flow Meters | 4 | EA | 20,000 | 80,000 | 10,000 | 40,000 | 120,000 |
| Replace Ferric Chloride Feed System | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 300,000 | 300,000 | 300,000 |
| SCADA Modifications | 1 | LS | 40,000 | 40,000 | 40,000 | 70,000 | 110,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 35,000 | SF | 5 | 175,000 | 5 | 175,000 | 350,000 |
| In-Channel Static Mixers | 4 | EA | 50,000 | 200,000 | 10,000 | 40,000 | 240,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *3,296,500* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 263,720 |
| Electrical and Instrumentation | 20% | | | | | | 659,300 |
| Contractor Overhead/Profit | 10% | | | | | | 329,650 |
| Engineering/Legal/Administration | 18% | | | | | | 593,370 |
| Contingency and Allowances | 20% | | | | | | 659,300 |
| **ESTIMATE** | | | | | | | **5,802,000** |

# CONSTRUCTION COST ESTIMATE

## Onondaga County Department of Water Environment Protection
## Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus

*Project N0. 630742*

**ALTERNATIVE 5 COST ESTIMATE**

| | | | Materials | | Labor | | |
|---|---|---|---|---|---|---|---|
| *Description* | *Quantity* | *Units* | *Unit Cost* | *Total* | *Unit Cost* | *Total* | *Total Cost* |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| HRFS Drop Box Baffles | 4 | EA | 10,000 | 40,000 | 10,000 | 40,000 | 80,000 |
| Effluent Launder Flow Meters | 4 | EA | 10,000 | 40,000 | 5,000 | 20,000 | 60,000 |
| Replace Ferric Chloride Feed System | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 200,000 | 200,000 | 200,000 |
| SCADA Modifications | 1 | LS | 25,000 | 25,000 | 50,000 | 50,000 | 75,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 32,000 | SF | 5 | 160,000 | 5 | 160,000 | 320,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *2,609,250* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 208,740 |
| Electrical and Instrumentation | 20% | | | | | | 521,850 |
| Contractor Overhead/Profit | 10% | | | | | | 260,925 |
| Engineering/Legal/Administration | 18% | | | | | | 469,665 |
| Contingency and Allowances | 20% | | | | | | 521,850 |
| **ESTIMATE** | | | | | | | **4,593,000** |

## CONSTRUCTION COST ESTIMATE

**Onondaga County Department of Water Environment Protection**

**Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus**

*Project N0. 630742*

**ALTERNATIVE 6 COST ESTIMATE**

| | | | Materials | | Labor | | |
|---|---|---|---|---|---|---|---|
| *Description* | *Quantity* | *Units* | *Unit Cost* | *Total* | *Unit Cost* | *Total* | *Total Cost* |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| HRFS Drop Box Baffles | 4 | EA | 10,000 | 40,000 | 10,000 | 40,000 | 80,000 |
| Effluent Launder Flow Meters | 4 | EA | 10,000 | 40,000 | 5,000 | 20,000 | 60,000 |
| Replace Ferric Chloride Feed System | 6 | EA | 25,000 | 150,000 | 7,500 | 45,000 | 195,000 |
| Install PAC Feed System (Pumps and Piping) | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 200,000 | 200,000 | 200,000 |
| SCADA Modifications | 1 | LS | 40,000 | 40,000 | 40,000 | 70,000 | 110,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 32,000 | SF | 5 | 160,000 | 5 | 160,000 | 320,000 |
| In-Channel Static Mixer | 2 | EA | 100,000 | 200,000 | 20,000 | 40,000 | 240,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *3,079,250* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 246,340 |
| Electrical and Instrumentation | 20% | | | | | | 615,850 |
| Contractor Overhead/Profit | 10% | | | | | | 307,925 |
| Engineering/Legal/Administration | 18% | | | | | | 554,265 |
| Contingency and Allowances | 20% | | | | | | 615,850 |
| **ESTIMATE** | | | | | | | **5,420,000** |

# CONSTRUCTION COST ESTIMATE

**Onondaga County Department of Water Environment Protection**
**Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus**
*Project N0. 630742*

**ALTERNATIVE 7 COST ESTIMATE**

| | | | Materials | | Labor | | |
|---|---|---|---|---|---|---|---|
| *Description* | *Quantity* | *Units* | *Unit Cost* | *Total* | *Unit Cost* | *Total* | *Total Cost* |
| **Coagulant Feed System Modifications** | | | | | | | |
| HRFS Influent Upward Acting Weir Gates | 4 | EA | 35,000 | 140,000 | 15,000 | 60,000 | 200,000 |
| HRFS Drop Box Baffles | 4 | EA | 10,000 | 40,000 | 10,000 | 40,000 | 80,000 |
| Effluent Launder Flow Meters | 4 | EA | 10,000 | 40,000 | 5,000 | 20,000 | 60,000 |
| Replace Ferric Chloride Feed System | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Install PAC Feed System (Pumps and Piping) | 6 | EA | 35,000 | 210,000 | 17,500 | 105,000 | 315,000 |
| Miscellaneous Shutdown Provisions | 1 | LS | | | 200,000 | 200,000 | 200,000 |
| SCADA Modifications | 1 | LS | 40,000 | 40,000 | 40,000 | 70,000 | 110,000 |
| **Cross Channel Modifications** | | | | | | | |
| Cross Channel Isolation Gates | 2 | EA | 35,000 | 70,000 | 17,000 | 34,000 | 104,000 |
| Isolation Gate Access Platform | 950 | SF | 100 | 95,000 | 35 | 33,250 | 128,250 |
| Cross Channel Concrete Wall Construction | 60 | CY | 750 | 45,000 | | | 45,000 |
| Concrete Cross Channel Liner Rehabilitation | 32,000 | SF | 5 | 160,000 | 5 | 160,000 | 320,000 |
| **HRFS Chemical Mixing Modifications** | | | | | | | |
| Reverse Rotation of Train 1 & 3 Coag Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Reverse Rotation of Train 1 & 3 Injection Mixers | 2 | EA | 34,000 | 68,000 | 8,500 | 17,000 | 85,000 |
| Add Second Propeller to Coag Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| Add Second Propeller to Inj Mixers | 4 | EA | 25,000 | 100,000 | 7,000 | 28,000 | 128,000 |
| **Other Modifications** | | | | | | | |
| Sludge Pump Upgrades (VFD and Motor) | 4 | EA | 15,000 | 60,000 | 4,000 | 16,000 | 76,000 |
| Sand Slurry Tank Rehabilitation | 1 | LS | 15,000 | 15,000 | 15,000 | 15,000 | 30,000 |
| Replace RAS Lines Corroded by Ferric Chloride | 2 | EA | 110,000 | 220,000 | 55,000 | 110,000 | 330,000 |
| Effluent Pump Suction Piping and Pump Replacement | 1 | LS | 30,000 | 30,000 | 15,000 | 15,000 | 45,000 |
| HRFS By-Pass Gate Repairs | 1 | LS | 10,000 | 10,000 | 15,000 | 15,000 | 25,000 |
| Replace Stainless Steel Sludge Line | 1 | LS | 100,000 | 100,000 | 50,000 | 50,000 | 150,000 |
| **Subtotal** | | | | | | | *2,959,250* |
| Mobilization, Bonding, Insurance, Etc. | 8% | | | | | | 236,740 |
| Electrical and Instrumentation | 20% | | | | | | 591,850 |
| Contractor Overhead/Profit | 10% | | | | | | 295,925 |
| Engineering/Legal/Administration | 18% | | | | | | 532,665 |
| Contingency and Allowances | 20% | | | | | | 591,850 |
| **ESTIMATE** | | | | | | | **5,209,000** |

# OPERATIONS AND MAINTENANCE COST ESTIMATE

**Onondaga County Department of Water Environment Protection**
**Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus**
*Project N0. 630742*

| Cost Element | Unit | Alternative | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Coagulant Use** | | | | | | | | |
| Ferric Chloride Dose (as Fe) | mg/L | 0.00 | 0.00 | 10.37 | 10.37 | 10.37 | 10.37 | 10.37 |
| Ferric Chloride Use | lbs./day | 0 | 0 | 6054 | 6054 | 6054 | 6054 | 6054 |
| Annual Days Used | days/yr | 0 | 0 | 365 | 365 | 365 | 169 | 169 |
| Annual Ferric Chloride Use (af Fe) | lbs./yr. | 0 | 0 | 2209791 | 2209791 | 2209791 | 1023164 | 1023164 |
| Unit Cost of Ferric Chloride | $/lb. | $0.00 | $0.00 | $0.83 | $0.83 | $0.83 | $0.83 | $0.83 |
| Annual Cost | $/yr. | $0 | $0 | $1,834,127 | $1,834,127 | $1,834,127 | $849,226 | $849,226 |
| PAC Chloride Dose | mg/L | 30 | 30 | 0 | 0 | 0 | 30 | 30 |
| PAC Chloride Use | lbs./day | 17514 | 17514 | 0 | 0 | 0 | 17514 | 17514 |
| Annual Days Used | days/yr | 365 | 365 | 0 | 0 | 0 | 196 | 196 |
| Annual PAC Use | lbs./yr. | 6392610 | 6392610 | 0 | 0 | 0 | 3432744 | 3432744 |
| Unit Cost of PAC | $/lb. | $0.31 | $0.31 | $0.00 | $0.00 | $0.00 | $0.31 | $0.31 |
| Annual Cost | $/yr. | $1,981,709 | $1,981,709 | $0 | $0 | $0 | $1,064,151 | $1,064,151 |
| **Total Annual Coagulant Cos** | $/yr. | $1,981,709 | $1,981,709 | $1,834,127 | $1,834,127 | $1,834,127 | $1,913,376 | $1,913,376 |
| **UV System** | | | | | | | | |
| No. of Lamps | No. | 308 | 308 | 308 | 308 | 308 | 308 | 308 |
| Frequency of Replacement | Lamps/yr. | 154 | 154 | 308 | 308 | 308 | 154 | 154 |
| Cost per Lamp | $/lamp | $300 | $300 | $300 | $300 | $300 | $300 | $300 |
| Annual Replacement Cost | $/yr. | $46,200 | $46,200 | $92,400 | $92,400 | $92,400 | $46,200 | $46,200 |
| No. of Quartz Sleeves | No. | 308 | 308 | 308 | 308 | 308 | 308 | 308 |
| Frequency of Replacement | Lamps/yr. | 31 | 31 | 62 | 62 | 62 | 31 | 31 |
| Cost per Sleeve | $/lamp | $300 | $300 | $300 | $300 | $300 | $300 | $300 |
| Annual Replacement Cost | $/yr. | $9,240 | $9,240 | $18,480 | $18,480 | $18,480 | $9,240 | $9,240 |
| Power Use | | | | | | | | |
| No. of Lamps | No. | 308 | 308 | 308 | 308 | 308 | 308 | 308 |
| Low Power Demand | W/lamp | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 |
| Median Power Demand | W/lamp | 1,800 | 1,800 | 1,800 | 1,800 | 1,800 | 1,800 | 1,800 |
| Maximum Power Demand | W/lamp | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 |
| Days of Low Power Use | days | 56 | 56 | 28 | 28 | 28 | 56 | 56 |
| Days of Median Power Use | days | 84 | 84 | 63 | 63 | 63 | 84 | 84 |
| Days of Maximum Power Use | days | 56 | 56 | 105 | 105 | 105 | 56 | 56 |
| Annual Low Power Use | kwh/yr | 496,742 | 496,742 | 248,371 | 248,371 | 248,371 | 496,742 | 496,742 |
| Annual Median Power Use | kwh/yr | 1,117,670 | 1,117,670 | 838,253 | 838,253 | 838,253 | 1,117,670 | 1,117,670 |
| Annual Maximum Power Use | kwh/yr | 993,485 | 993,485 | 1,862,784 | 1,862,784 | 1,862,784 | 993,485 | 993,485 |
| Total Annual Power Use | kwh/yr | 2,607,898 | 2,607,898 | 2,949,408 | 2,949,408 | 2,949,408 | 2,607,898 | 2,607,898 |
| Unit Eletricity Cost | $/kWh | $0.12 | $0.12 | $0.12 | $0.12 | $0.12 | $0.12 | $0.12 |
| Annual Electrical Cost | $/yr. | $312,948 | $312,948 | $353,929 | $353,929 | $353,929 | $312,948 | $312,948 |
| Labor Cost to Replace Lamps | | | | | | | | |
| No. of Personnel Used | No. | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Hours per person | hrs./per | 20 | 20 | 40 | 40 | 40 | 20 | 20 |
| Total Hours | hrs/yr. | 40 | 40 | 80 | 80 | 80 | 40 | 40 |
| Hourly Cost | $/hr | $75 | $75 | $75 | $75 | $75 | $75 | $75 |
| Annual Labor Cost | $/yr. | $5,625 | $5,625 | $5,625 | $5,625 | $5,625 | $5,625 | $5,625 |
| Cleaning Chemical Use | | | | | | | | |
| Annual Use | gal/yr. | | | | | | | |
| Unit Cost | $/gal. | | | | | | | |
| Annual Chemical Cost | $/yr. | $2,500 | $2,500 | $5,000 | $5,000 | $5,000 | $2,500 | $2,500 |
| **Total Annual UV Cos** | | $376,513 | $376,513 | $475,434 | $475,434 | $475,434 | $376,513 | $376,513 |

## OPERATIONS AND MAINTENANCE COST ESTIMATE

Onondaga County Department of Water Environment Protection
Metropolitan Syracuse WWTP Optimization Analysis of Total Phosphorus
*Project N0. 630742*

| Cost Element | Unit | Alternative | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **Cross Channel Maintenance** | | | | | | | | |
| No. of Personnel Used | No. | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Hours per person | hrs./per | 40 | 40 | 40 | 40 | 16 | 16 | 16 |
| Total Hours | hrs/yr. | 160 | 160 | 160 | 160 | 64 | 64 | 64 |
| Hourly Cost | $/hr | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| **Annual Labor Cost** | $/yr. | 12000 | 12000 | 12000 | 12000 | 4800 | 4800 | 4800 |
| **Sludge Disposal Cost** | | | | | | | | |
| Ferric chloride dry solids production | lbs/day. | 0 | 0 | 12,225 | 12,225 | 12,225 | 12,225 | 12,225 |
| Ferric chloride use | days/yr | 0 | 0 | 365 | 365 | 365 | 169 | 169 |
| Annual Ferric Chloride dry solids | tons/yr. | 0 | 0 | 2,231 | 2,231 | 2,231 | 1,033 | 1,033 |
| PAC dry solids production | lbs/day. | 8,810 | 8,810 | 0 | 0 | 0 | 8,810 | 8,810 |
| PAC use | days/yr | 365 | 365 | 0 | 0 | 0 | 196 | 196 |
| Annual PAC dry solids | tons/yr. | 1,608 | 1,608 | 0 | 0 | 0 | 863 | 863 |
| Total annual dry solids production | tons/yr. | 1,608 | 1,608 | 2,231 | 2,231 | 2,231 | 1,896 | 1,896 |
| Final solids concentration | % | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| Total HRFS solids disposal | tons/yr. | 5,024 | 5,024 | 6,972 | 6,972 | 6,972 | 5,926 | 5,926 |
| Disposal cost | $/ton | $50 | $50 | $50 | $50 | $50 | $50 | $50 |
| **Annual Sludge Disposal Cost** | $/yr. | $251,223 | $251,223 | $348,604 | $348,604 | $348,604 | $296,311 | $296,311 |
| **TOTAL O&M COST** | **$/yr** | **$2,621,000** | **$2,621,000** | **$2,670,000** | **$2,670,000** | **$2,663,000** | **$2,591,000** | **$2,591,000** |