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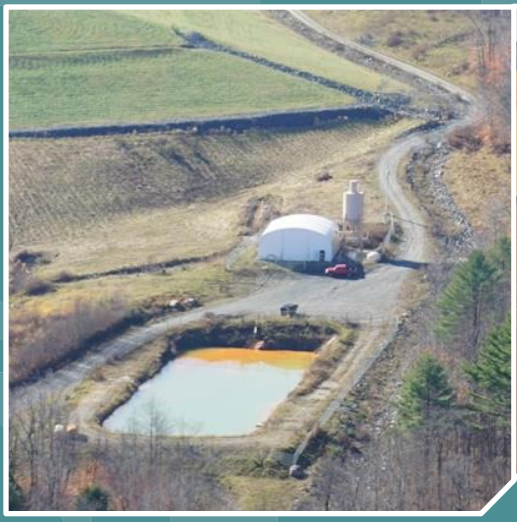
Evaluation of Rotating Cylinder Treatment System™ at Elizabeth Mine, Vermont



Office of Research and Development
Land Remediation and Technology Division

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Evaluation of the Rotating Cylinder System™ at Elizabeth Mine, Vermont

by

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NOTICE AND DISCLAIMER

The U.S. Environmental Protection Agency, through its Office of Research and Development, conducted the data analyses and interpretations described herein under an approved Quality Assurance Project Plan (Quality Assurance Identification Number G-LMMD-0031208-QP-1-2). Data were provided by EPA Region 1; therefore, no funding was required. The cover photo of the rotating cylinder was taken by Kevin Countryman (EPA) and the aerial cover photo of the site (tailings pile embankment, treatment plant, and sedimentation basin) was taken by Nobis Engineering, Inc.

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ABSTRACT

This report presents a case study of the rotating cylinder treatment system™ (RCTS™) operated at the Elizabeth Mine in Strafford, Vermont. Historical mining at the Elizabeth Mine resulted in mining wastes and mine drainage contaminating Copperas Brook, Lord Brook, and the West Branch of the Ompompanoosuc River, which led to the mine site being listed on the Superfund list in 2001. Lime treatment of mining-influenced water is a conventional and effective treatment; however, there are historical issues with high-volume lime treatment plants being energy-intensive, requiring constant monitoring, having low lime-efficiency rates due to less than ideal mixing, and presenting significant challenges for locations that are remote or have limited available space. The RCTS™ is an innovative system designed to address those issues. An RCTS™ system, followed by a sedimentation basin, was constructed to treat high concentrations of iron discharging from the tailing impoundment. For the Elizabeth Mine, the RCTS™ provided interim treatment during the time required for the source control measures (capping and surface water/groundwater diversion) to reduce the flow and concentration of iron to levels that would allow for the installation of a passive treatment system at the space limited site. Performance of the RCTS™ was evaluated from eight years of data (2009-2017). Over this eight-year period, the maximum annual total iron concentration treated was approximately 1,700 mg/l and the minimum annual total iron concentration treated was 50 mg/l. The system effectively removed iron to low concentrations, with generally less than the site-specific cleanup criteria of 1 mg/l in the effluent from the sedimentation basin. This report covers operation of the treatment system from May 2009 through November 2017 and data analysis was completed August 22, 2018.

FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Center's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. CESER collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. CESER's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

Documenting studies of treatment technologies at Superfund and other sites is important in providing an understanding of how these technologies remove contaminants and can aid a reader, such as a site manager, in determining if the technology would be effective under the conditions of their site of interest. This publication has been produced as part of the Center's long-term strategic research plan. It is published and made available by US EPA's Office of Research and Development to assist readers in the remediation community in understanding the capabilities and limitations of active lime treatment of water using the Rotating Cylinder Treatment System™ technology.

Gregory Sayles, Director
Center for Environmental Solutions and Emergency Response

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ACRONYMS AND ABBREVIATIONS

DO	Dissolved oxygen
ft	Feet
gpm	Gallons per minute
Inc	Incorporated
lb/day	Pound per day
kg/day	Kilogram per day
LLC	Limited liability company
m^3	Cubic meters
m^3/hr	Cubic meters per hour
mg/l	Milligram per liter
RCTS™	Rotating Cylinder Treatment System™
TM	Trademark
TP	Tailings Pile (Tailings Facility)
µm	Micrometer or micrometer
U.S. EPA	United States Environmental Protection Agency
VT	Vermont
yd	Yard

ACKNOWLEDGMENTS

System data and operations information used to develop this report were documented by several plant operators over time (Weston Solutions, Inc., Nobis Engineering, and Koman Government Solutions, LLC) under contract to the Army Corps of Engineers, New England District, and provided to the EPA Region 1 Remedial Project Manager, Ed Hathaway. The Army Corps of Engineers was managing the work pursuant to an inter-agency agreement with EPA. Discussions with Michele Mahoney of the EPA's Office of Land and Emergency Management prompted development of this report to add to the knowledge-base of treatment technologies for cleanup at Superfund sites. The following individuals are acknowledged for their technical reviews of an earlier draft of this report: Randy Parker and Dr. Robert Ford of U.S. EPA ORD, and Dr. Robert Seal of the U.S. Geological Survey.

1.0 INTRODUCTION

1.1 Study Site

The Elizabeth Mine is in Vermont's Orange County's historic Copper Belt near Strafford, VT (Figure 1). The mine was operated intermittently from 1809 to 1958 and began as a site where iron sulfide ore was mined, heaped, roasted, and leached to create an iron sulfate product known as copperas, which historically was an important industrial chemical (U.S. EPA, 2015). In the early 1880s, mining of the iron sulfide ceased due to low market prices, competition from other newer sources, and high production costs from use of older technology (U.S. EPA, 2015). In the early 1820's, copper mining began and by the 1880's had replaced iron sulfide mining at the Elizabeth Mine. The 149 years of mining resulted in mining wastes and mine drainage contaminating the Copperas Brook, Lord Brook, and the West Branch of the Ompompanoosuc River, which led to the site being listed as a Superfund site in 2001 (U.S. EPA, 2015). Much work has been conducted between 2003 and 2019 at the site to clean up the sources of metals and acidity to the environment, and remediation has resulted in recovery of the macroinvertebrate communities in Copperas Brook and the West Branch of the Ompompanoosuc River (U.S. EPA, 2015). Figure 2 shows the contrast between the pre-remediation iron precipitate load (October 2007) and the clearer water post-remediation (October 2013) at the confluence of Copperas Brook and the West Branch of the Ompompanoosuc River.

Figure 1. Location of the Elizabeth Mine in Strafford, VT 05070. Map data ©2018 Google.

Figure 2. Confluence of Copperas Brook and the West Branch of the Ompompanoosuc River before (October 2007; left side photo) and after (October 2013; right side photo) remediation efforts. Approximate location 43.83138889, -72.32666667.

One of the initial response actions at the Elizabeth Mine Superfund Site was to stabilize the tailings dam associated with Tailings Pile 1 (TP-1). This was implemented in 2004 and 2005 and involved installing a soil buttress against the dam, creating a surface channel to drain standing water from the top of the impoundment, and grading the side slopes to minimize erosion. To prevent water from becoming trapped behind the buttress, a toe drain was installed at the downgradient base of TP-1, with a series of eight lateral 20.32 cm (8-inch) diameter pipes running beneath the buttress to discharge the water from the toe drain. During construction of the toe drain and removal of tailings that had eroded from the face of the dam, four historical decant structures for the impoundment were uncovered. A 10.16 cm (4-inch) pipe was installed within each of these decant structures to allow them to function similarly to a horizontal drain.

The improved drainage at the toe of TP-1 resulted in an average of 12.3 m^3/hr (54 gpm) of leachate containing very high concentrations of ferrous iron, with releases of up to 362.9 kg/day (800 lb/day) of iron (peak month July 2007, Figure 9) into Copperas Brook and the West Branch of the Ompompanoosuc River. Other than iron and sulfur (as sulfate), elements generally found in mine-drainage and requiring treatment, such as cadmium, copper, and zinc, were either not present or present at trivial concentrations in the leachate. Vermont has an average allowable concentration – chronic criterion of 1 mg/l total iron for protection of aquatic biota (State of Vermont, 2016), which is the site-

specific cleanup criteria for iron.

The Elizabeth Mine cleanup plan included the construction of a passive treatment system for the drainage from TP-1 (U.S. EPA, 2006). Passively treating inorganic constituents requires enough space to accommodate retention times necessary for biological and chemical reactions to occur. The iron concentration and overall iron load in 2008 was determined to be too high to be effectively treated in the space available using a passive system. As a result, passive treatment was postponed until the concentration and flow would be decreased enough that a passive system could be sized sufficiently to treat the drainage. In the interim, an active water treatment system was designed and installed in 2008 to treat combined flows from the toe and horizontal drains. An aerial view of the treatment system and TP-1 is shown in Figure 3.

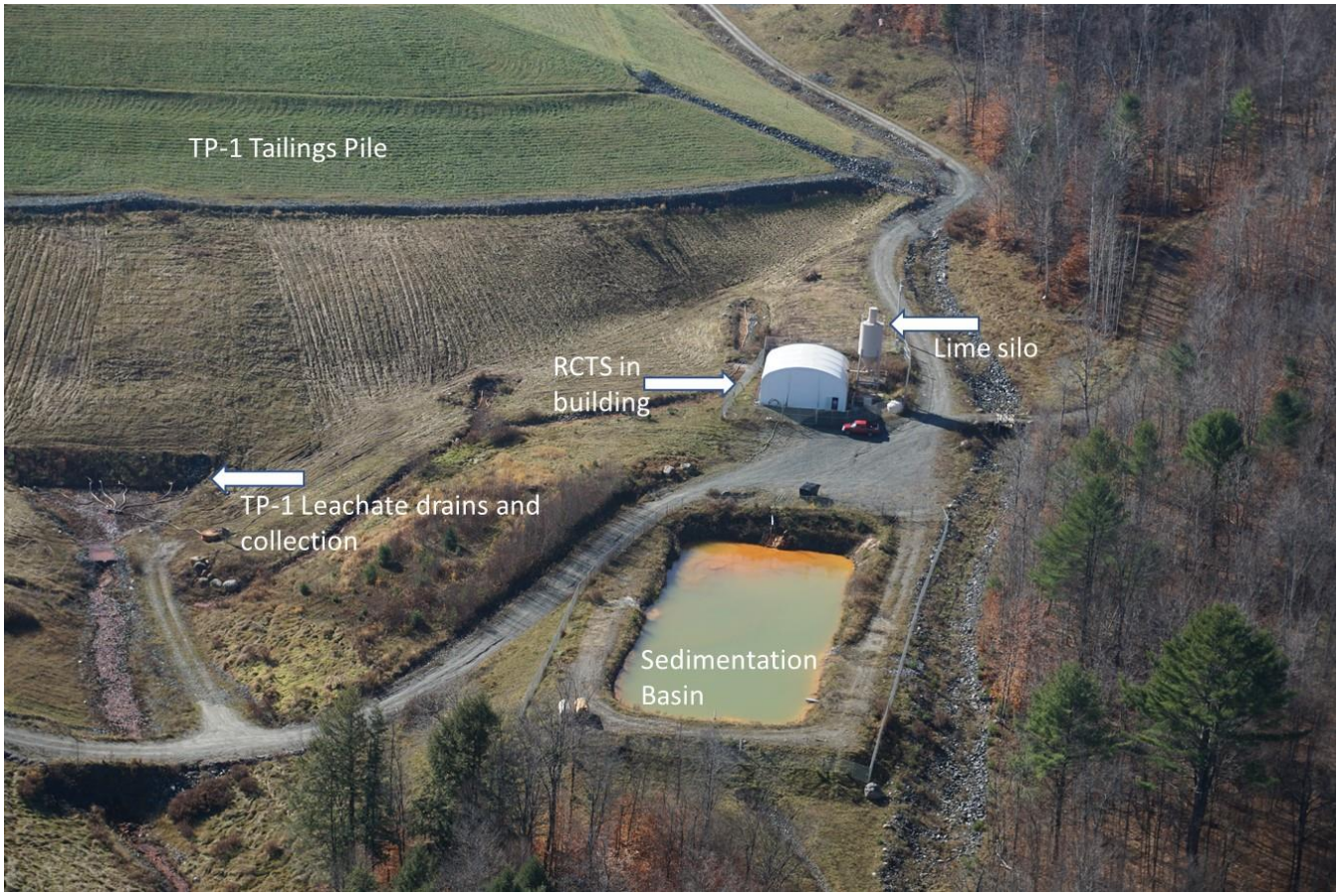

Figure 3. Aerial view of TP-1 and treatment system location (November 2015).

Prior to the treatment system's construction, four horizontal drains were installed in 2008 to facilitate drawdown of the water within TP-1. Between 2010 and 2012, a multi-layered low permeability cover system was constructed over TP-1 to limit infiltration and perimeter drainage channels were constructed to divert surface flow and shallow groundwater around TP-1. These measures led to further improved drawdown of water within the impoundment.

1.2 Water Treatment

The typical active treatment for ferrous iron involves adding oxygen to oxidize ferrous iron to ferric iron and increasing the pH above about 3.5, commonly with lime, to precipitate ferric hydroxide. Ferrous hydroxide also will precipitate with the addition of lime (pH > 8) but will oxidize to ferric hydroxide

when exposed to oxygen. The abiotic oxidation rate of ferrous to ferric iron depends on the dissolved oxygen concentration ([$O_{2(aq)}$]), ferrous iron concentration ([Fe^{2+}]), and the pH according to the Equation 1 (modified from Stumm and Lee, 1961), which is rearranged in terms of pH in Equation 2:

$$-\frac{d[Fe^{2+}]}{dt} = k_{Fe}[Fe^{2+}][O_{2_{(aq)}}][OH^{-}]^{2}$$

Equation 1

$$-\frac{d[Fe^{2+}]}{dt} = \frac{k_{Fe}[Fe^{2+}][O_{2_{aq}}][10^{-28}]}{10^{-(2\ x\ pH)}}$$

Equation 2

The rate of ferrous oxidation is first order in terms of ferrous iron concentration and dissolved oxygen concentration, and second order in terms of hydroxyl ion concentration. Therefore, an increase of one pH unit will increase the oxidation rate by 100 times and a doubling of the oxygen concentration will double the oxidation rate. Additionally, higher concentrations of ferrous iron are oxidized faster than lower concentrations at constant pH and dissolved oxygen concentration.

Conventional lime treatment plants use mixers in reaction tanks to form a lime slurry and compressors, diffusers, and agitators to provide oxygen to oxidize ferrous iron and other reduced ions. (Tsukamoto and Moulton, 2006). A more compact and mobilizable Rotating Cylinder Treatment System™ (RCTS™) technology for lime treatment was developed by Ionic Water Technologies, Inc. The technology replaces conventional agitators, compressors, diffusers, and reaction vessels with a perforated cylinder that rotates through a trough containing the lime slurry and water being treated (Tsukamoto and Moulton, 2006; Tsukamoto and Weems, 2010). A film of water adheres to the inner and outer surfaces of the cylinder as it rotates, where oxygen exchange occurs, and agitation created by the impact of the perforations with water in the trough enhances lime mixing and dissolution and oxygen transfer (Tsukamoto and Moulton, 2006). The RCTS™ technology has been successful at treating high concentrations of iron in mine drainage while using minimal space, power, and lime (Tsukamoto and Moulton, 2006), has been deployed as a portable unit (California Water Boards, 2019), and in direct comparison to conventional lime treatment in 2004 at the Leviathan Mine, the technology had lower lime consumption (105.7 kg/day vs. 180.5 kg/day), higher average DO concentration in the effluent (7.86 mg/l vs. 4.22 mg/l), a shorter hydraulic residence time (58.5 min vs. 131.7 min), and less energy consumption (2640 W vs. 8640 W) (Tsukamoto and Weems, 2009). Due to its smaller footprint, mobility, potential for decreased costs (versus a conventional treatment plant), and the anticipation that the treatment would be temporary, the RCTS™ was chosen to treat the drainage from TP-1.

1.3 Purpose

The purpose of this report is to describe the performance of the RCTS™ in removing high concentrations of iron from mining-influenced water (tailings pile leachate) over an 8-year (2009-2017), seasonal (spring through fall) operating time. The report includes an assessment of the treatment system's efficiency, using both field and laboratory data, and documents operating and maintenance requirements from lessons learned at the Elizabeth Mine site. This type of information is expected to be useful to project managers or other practitioners in evaluating the use of the RCTS™ technology for sites with similar issues.

2.0 MATERIALS AND METHODS

2.1 Treatment System

The treatment facility at Elizabeth Mine was designed to operate during non-winter months (April to November) with an average influent flow of 6.8 m^3/hr (30 gpm), a maximum influent flow of 9.1 m^3/hr (40 gpm), an average influent iron concentration of 900 mg/l, a maximum effluent iron concentration of < 50 mg/l, and an anticipated operating life of five years (Weston Solutions, 2016). Operation during only the non-winter months was determined to be more economical due to the location and climate of the site, where insulating and heating the building housing the treatment system would have been expensive and it would have been difficult to keep the water from freezing, both before and after being treated.

The water treatment system comprises several processes, which include collection, neutralization, aeration, precipitation, and settling of iron solids. Photos of system components are provided in Figures 4-6, the layout of components inside the building are shown in Figure 7, and a schematic of the process with sampling points is shown in Figure 8.

Figure 4. Neutralization/mixing tank with dark blue-green color of ferrous hydroxide particles.

Figure 5. Funnel and grinder pump for mixing water with quicklime and recirculating back to the neutralization/mixing tank (left-side of photo).

Figure 6. RCTS™ unit with orange/rust colored discharge water.

Figure 7. Layout inside building: RCTS™ unit on left hand side; funnel, grinder pump, and recirculation plumbing on right-hand side; neutralization tank right-hand side at back.

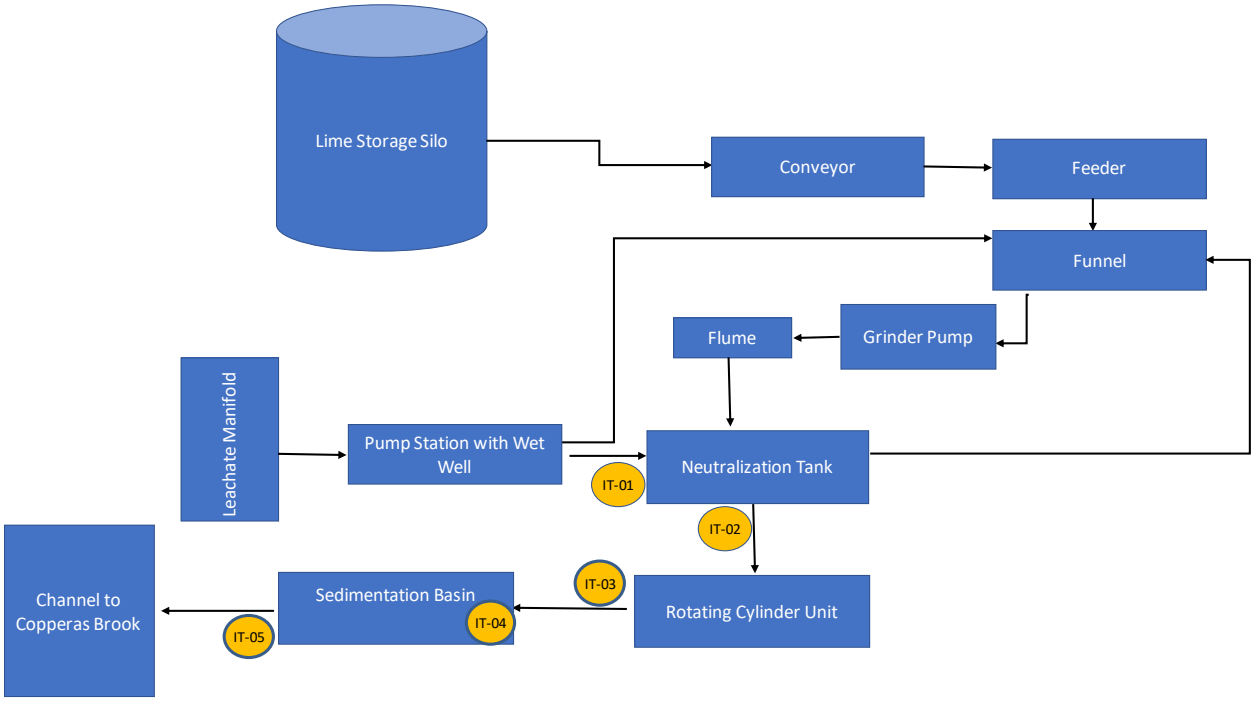

Figure 8. Treatment system components and water flow through the system with sampling locations.

Combined toe and horizontal drain leachate flows into a manifold that drains by gravity into a pump station wet well. The treatment system flow is controlled by floats in the pump station. The pumps operate at a higher rate than the leachate flow from TP-1 to maintain a wet well level, which results in

intermittent operation over the course of each day; since 2011, operation time typically is 9-10 hours per day. From the wet well, the leachate is pumped to a neutralization/mixing tank (Figure 4) to raise the pH, with some of the leachate going first into a funnel (Figure 5) where it is mixed with quicklime in a grinder pump and then that slurry is recirculated back into the neutralization/mixing tank, which increases residence time to allow neutralization of the water before exiting to the RCTS™ unit. The lime is stored in a silo (Figure 3) and fed to the grinder pump through the funnel system. A visual check on the neutralization step is observation of the color of the water in the neutralization tank, with the expected color being blue-green to indicate the presence of fine particles of ferrous hydroxide (Figure 4). From the neutralization/mixing tank, the water flows by gravity to the RCTS™ unit (on left in Figure 7) where it is aerated as a thin layer of water around the inside of two rotating cylinders to oxidize ferrous iron to ferric iron. A visual check of performance of the RCTS™ is observation of an orange/rust color in the effluent (Figure 6). The aerated alkaline water from the RCTS™ is then gravity fed to the sedimentation basin (Figure 3) where iron precipitates settle out. In troubleshooting the system in July 2011, Nobis Engineering, Inc. (2016a) conducted a red dye tracer test to assess the retention time of the RCTS™ and the sedimentation basin and found that the red dye appeared at the outlet of the RCTS™ in less than one minute and that the dye took approximately 1.5 hours to travel across the sedimentation basin, although there was no discussion of the depth of the water column containing the dye. The RCTS™ contained precipitates and wind caused some short-circuiting across the sedimentation basin; therefore, observed retention times were shorter than what would be expected under typical operating conditions. Overlying water from the sedimentation basin discharges to a channel that then feeds into Copperas Brook, and eventually feeds into the West Branch of the Ompompanoosuc River.

Operation and maintenance of the system includes maintaining equipment in accordance with manufacturer's instructions (including pumps and motors); maintaining accurate records of data from operations, process operation monitoring using field analytical methods, removing precipitates from system components; and troubleshooting and repairing/replacing faulty equipment. Additionally, since the treatment system was operated seasonally, commissioning and decommissioning of the system was required each year. Additional information on these activities is available in Nobis Engineering Inc. (2016b) and Weston Solutions (2012), among other publicly-available documents on EPA's Elizabeth Mine Superfund Site webpage.

Process operation monitoring included field testing for total (ferrous + ferric) and ferrous iron and pH at locations throughout the system: the combined influent (IT-01), the effluent from the neutralization tank (IT-02), the rotating cylinder effluent (IT-03), the water within the sedimentation basin (IT-04), and the sedimentation basin effluent (IT-05) (Figure 8). Process operation monitoring occurred at least once per week during months of operation (typically April to November), generally at each location.

2.2 Data Analysis

This study uses field data from the combined influent (IT-01), effluent from the rotating cylinder (IT-03), and effluent from the sedimentation basin (IT-05) from 2009-2017. The field sampling raw data are provided in Appendices A-I. In addition to operational field samples for pH and total (ferrous + ferric) and ferrous iron, several samples were collected from the combined influent, the rotating cylinder effluent (RCTS™), and sedimentation basin effluent over the course of time for laboratory analysis of total sulfate and total recoverable and dissolved (filtered, 0.45 µm) analytes. Laboratory raw data for alkalinity, total sulfate, and total and dissolved Al, Ca, Fe, K, Mg, Mn, Na, and Zn are provided in Appendix J. This study includes discussion of laboratory results for total recoverable iron and dissolved iron (field-filtered, 0.45 µm) in combination with field monitoring results for total iron (ferrous + ferric), ferrous iron, and pH.

2.4 Quality Assurance

Contractor-collected iron field data (total [ferrous + ferric], and ferrous) indicated that RCTS™ effluent (IT-03) samples were filtered (0.45 µm), but influent (IT-01) and sedimentation basin effluent (IT-05) samples were not indicated as such, so were assumed to be unfiltered. Influent samples were diluted 500:1 and RCTS™ effluent and sedimentation basin effluent samples were undiluted. Field samples were analyzed using a Hach 890 colorimeter. Ferrous iron was analyzed using Hach Method 8146 and total (ferrous + ferric) iron was analyzed using Hach Method 8008. EPA-collected laboratory samples were analyzed at the EPA Region 1 laboratory in North Chelmsford, MA for inorganic anions (EPA 300.0), total recoverable and dissolved (field-filtered at 0.45 µm) metals by ICP-OES (EPA 3010A or 3005A and 6010B), and alkalinity (EPA 310.1).

Both filtered and unfiltered field data are presented, but only unfiltered total (ferrous + ferric) iron and unfiltered ferrous iron concentrations were compared between the system influent and the sedimentation basin effluent for determining percentage removal by the treatment system. Field data excluded from processing and analysis included the following:

- those reported as suspect by the system operators,
- those appearing to be in error when compared to surrounding sampling dates or typical values (e.g., typographical errors),
- those with "> x" values, where "x" was an upper reporting limit,
- those where a corresponding pH was not reported,
- any sampling date where no concentrations were provided for the combined influent location or that had data for influent but no data for RCTS™ effluent or sedimentation basin effluent, and
- any sampling date where there was clear notation of the system not operating (e.g., October 2012, where there was data for only a single date due to a two-week downtime to replace the grinder pump in the early part of the month).

On several occasions (July 1 and 2, 2009, June 7, 2010, April 19 and 21, 2011, and September 16 and 19, 2013), the pH of the sedimentation basin effluent was 5-6 and effluent total iron (unfiltered, ferrous + ferric) concentrations were much higher than typical (23 to 178 mg/l versus 0 to < 10 mg/l), indicating that something in the system was not working properly, but data were not indicated as suspect in field notes. However, system shutdown notes indicated that there were various issues with the supply of lime on or around these dates. Therefore, data from those dates were excluded from monthly averages (and associated calculations) to not skew assessment of typical monthly operating capability, but they were included in graphs where concentration data were presented over time (Figures 10-12) to be inclusive of times when the system was not operating properly but was not completely shut down.

Ferrous iron concentrations often were higher than total (ferrous + ferric) iron concentrations in the RCTS™ effluent samples, and occasionally in the sedimentation basin effluent samples (see graphs in Section 3.1). This was evident for most samples in 2012, 2013, 2014, 2015, and 2016 (June through August), with all but 3 of 52 measurements in 2015 having ferrous iron concentrations higher than total iron concentrations in the RCTS™ effluent. Yearly average concentrations also show this trend for 2012-2014, although standard deviations suggest there is no difference between the means (Table 1). The grouping of total (filtered, ferrous + ferric) iron concentrations in RCTS™ effluent was higher in

2016 and 2017 than in previous years and this trend of increased concentration was also observed for filtered ferrous iron in 2016, and more visible in the 2017 data (see Section 3.1). In these years, several dates had reported ferrous and total (ferrous + ferric) iron concentrations that exceeded method ranges (0.02 to 3.00 mg/l Fe^{2+}, Hach Method 8146 and 0.02 to 3.00 mg/l Fe, Hach Method 8008, respectively), but no notes regarding whether samples had been diluted were provided. Most field sediment basin effluent samples contained less than 1 mg/l total iron, except for 2011 where all but one sample exceeded 1 mg/l. These observed anomalies in the data likely are due to differences in field analytical techniques between different system operators (three different contractors operated the system over the years covered in this report) or to other analytical issues. For some of the sampling dates where ferrous concentrations were higher than total (ferrous + ferric), field notes indicated the ferrous iron samples were cloudy, which may have influenced the measurement; however, an unambiguous reason for the anomalies cannot be given because notes were not provided for all sampling dates when they occurred.

3.0 RESULTS

Figure 9 presents field measured total iron load (unfiltered, ferrous + ferric) from all TP-1 drains and the corresponding total leachate flow. Figures 10-14 present treatment system field monitoring data, and Figures 15-18 present laboratory data from the treatment system.

3.1 Field Data Derived Figures

Unfiltered total (ferrous + ferric) iron loads and flows of leachate from TP-1 are provided in Figure 9, along with the annual average loads and flows. Figure 10 presents flows and concentrations of unfiltered (IT-01 and IT-05) and filtered (0.45 µm, IT-03) total (ferrous + ferric) iron; Figure 11 presents flows and concentrations of filtered (0.45 µm, IT-03) and unfiltered (IT-01 and IT-05) ferrous iron; and Figure 12 presents pH. The figures include each of the days sampled where field data were provided and the data were not stated as suspect in contractor reports or determined to be erroneous (e.g., typographical errors).

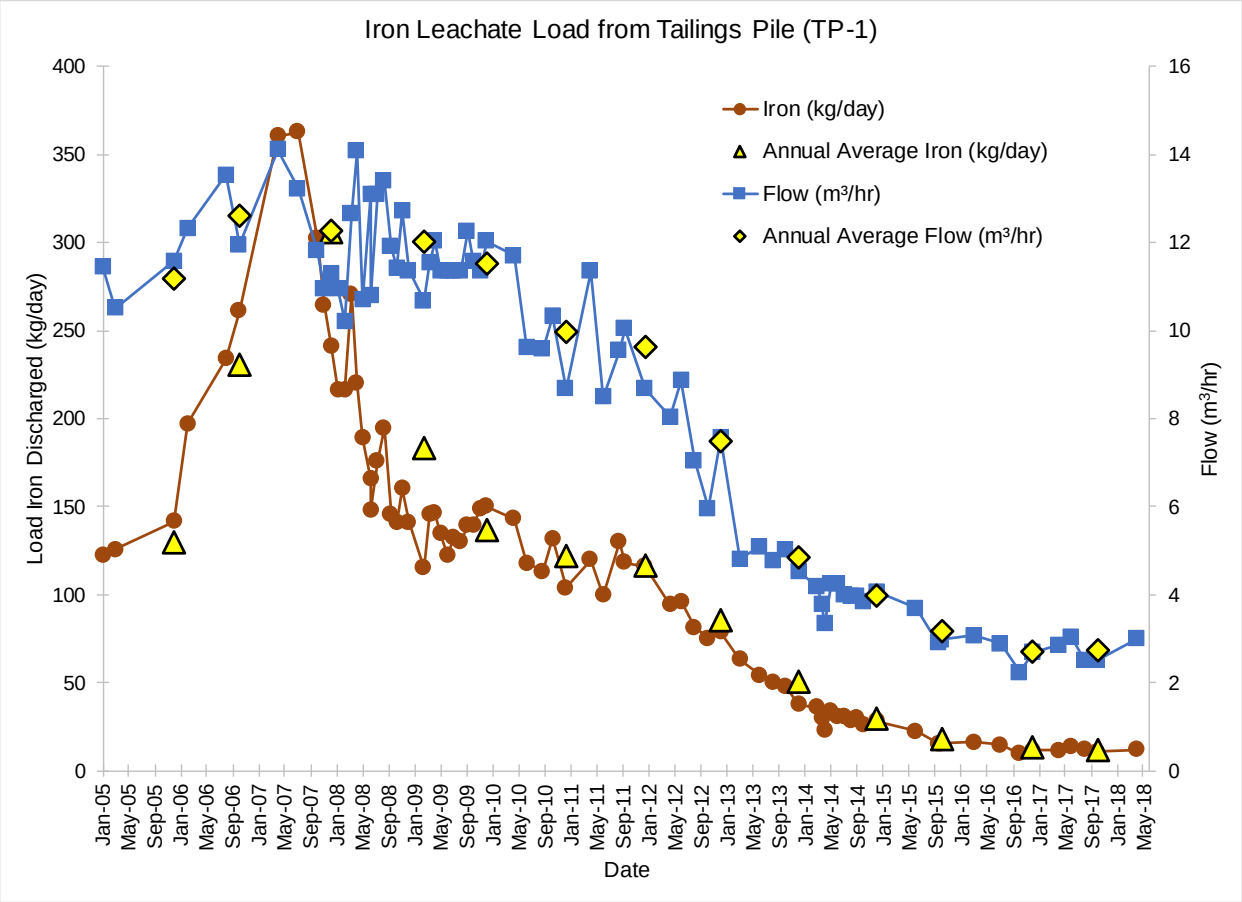

Figure 9. Field measured iron load (solid brown circles) and flow rates (solid blue squares) from tailings pile (TP-1) over time. Average annual iron loads are represented by yellow triangles and average annual flows are represented by yellow diamonds. To convert to pounds per day, multiply load values by 2.20462; to convert to gallons per minute, multiply flow values by 4.4029.

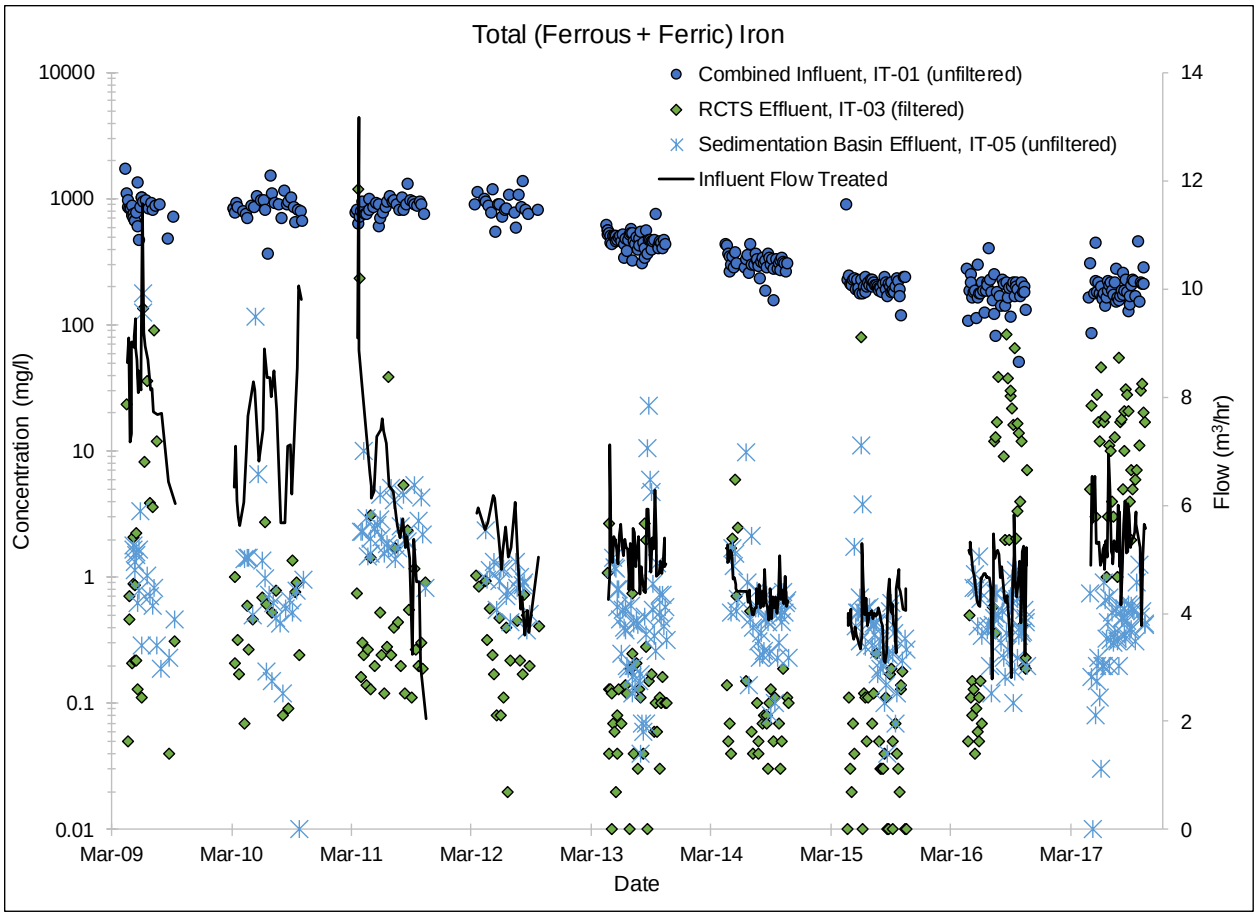

Figure 10. Field measured total (ferrous + ferric) iron concentration and flow over time. Solid blue circles represent the treatment system influent, solid green diamonds represent effluent from the RCTS™, blue asterisks represent effluent from the sedimentation basin, and the solid black lines represent flow. Concentrations are plotted on a log-scale for ease of viewing.

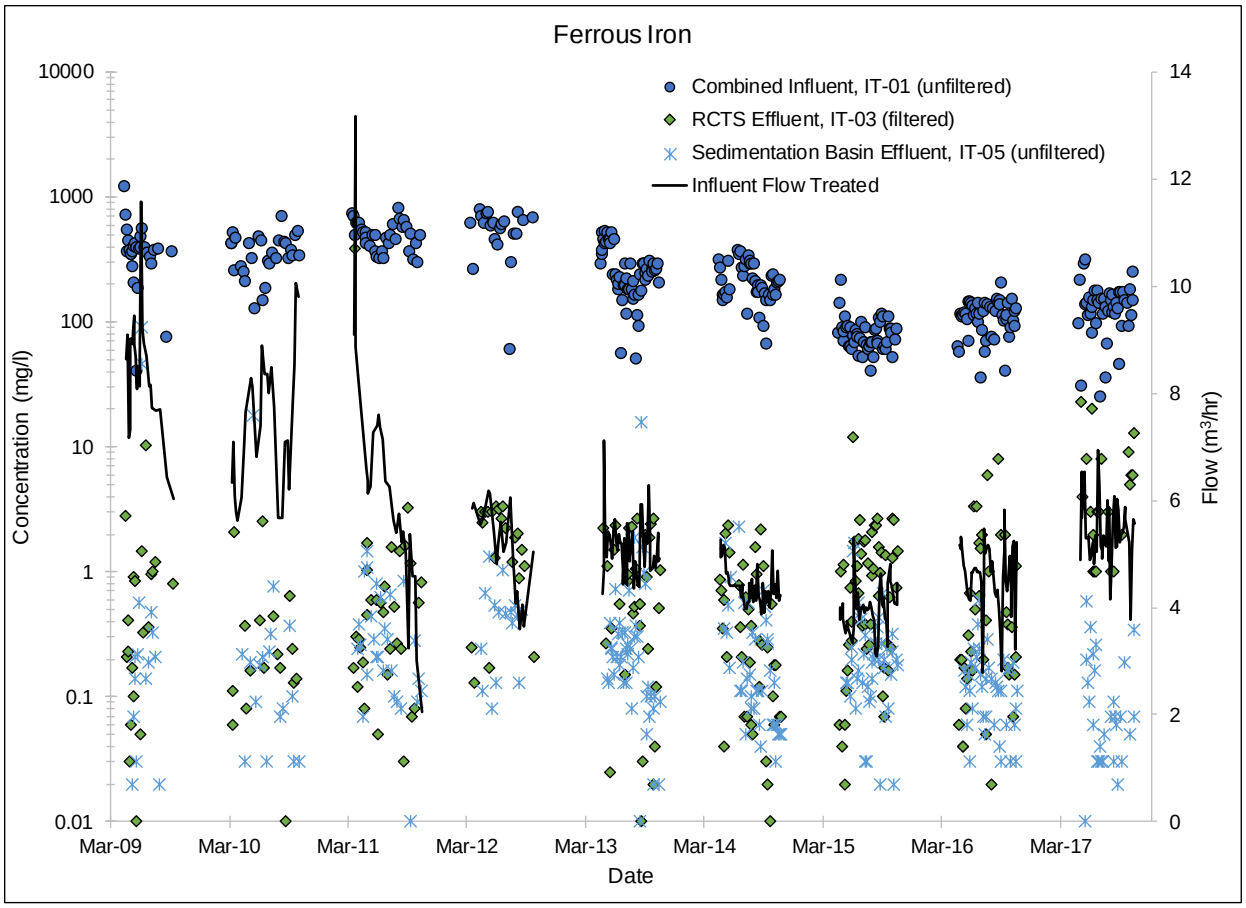

Figure 11. Field measured ferrous iron concentration and flow over time. Solid blue circles represent the treatment system influent, solid green diamonds represent effluent from the RCTS™, blue asterisks represent effluent from the sedimentation basin, and the solid black lines represent flow. Concentrations are plotted on a log-scale for ease of viewing.

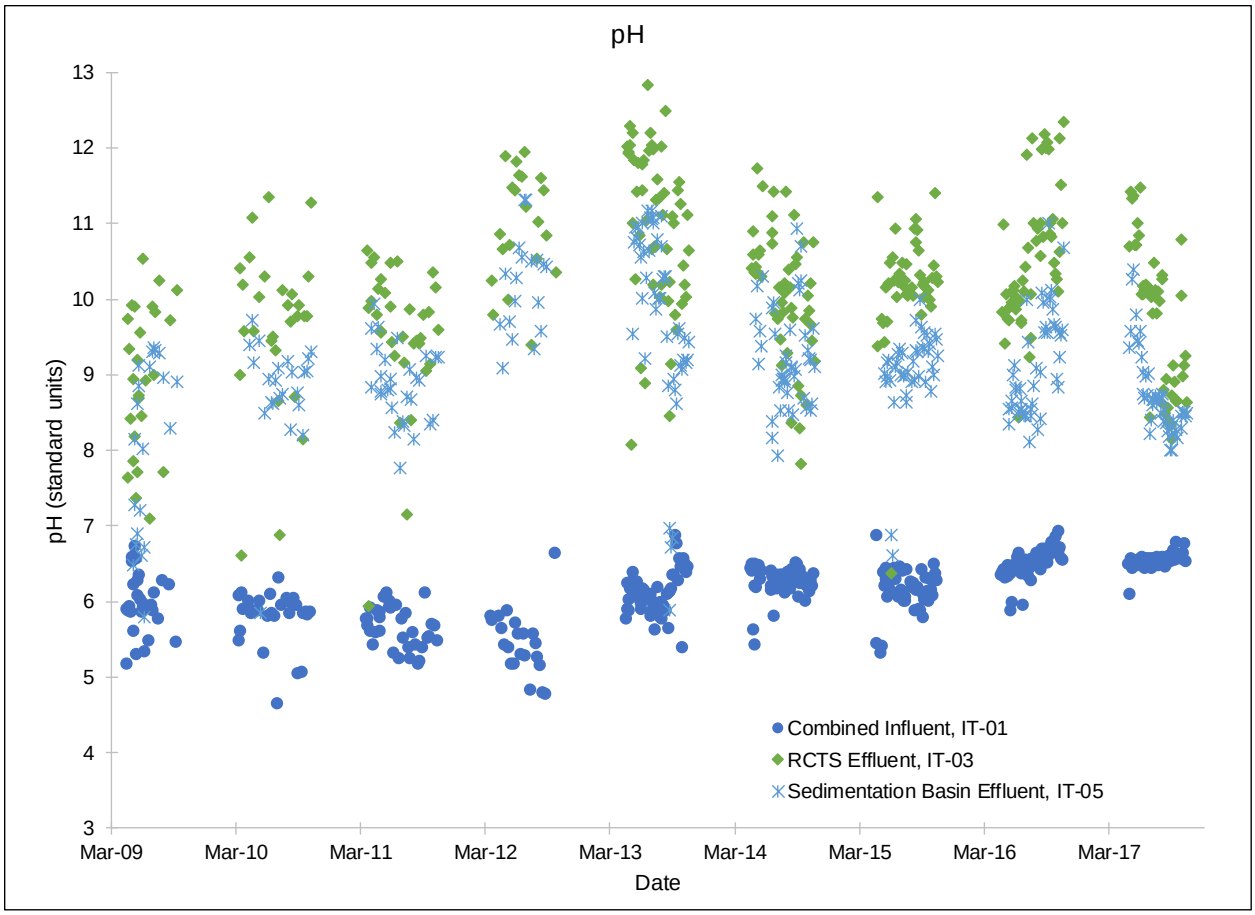

Figure 12. Field measured pH in the combined influent (solid blue circles), effluent from the RCTS™ (solid green diamond), and effluent from the sedimentation basin (blue asterisks) for each sampling date.

The percentages of the average monthly unfiltered ferrous iron concentrations removed by the overall system (i.e., between the influent and the sedimentation basin effluent) are plotted in Figure 13, along with monthly averages of the corresponding effluent pH values. The percentages of the average monthly total iron concentrations (ferrous + ferric, unfiltered) removed are plotted in Figure 14, along with the monthly averages of the corresponding effluent pH values. For each of these figures, only sampling dates having measurements for both iron concentrations and pH were used. Percentage removals were calculated using Equation 3.

$$\text{Removal } \% = 100 \times \frac{\left(influent\ concentration\ (IT{-}01) - sedimentation\ basin\ effluent\ concentration\ (IT{-}05)\right)}{influent\ concentration\ (IT{-}01)}$$

Equation 3

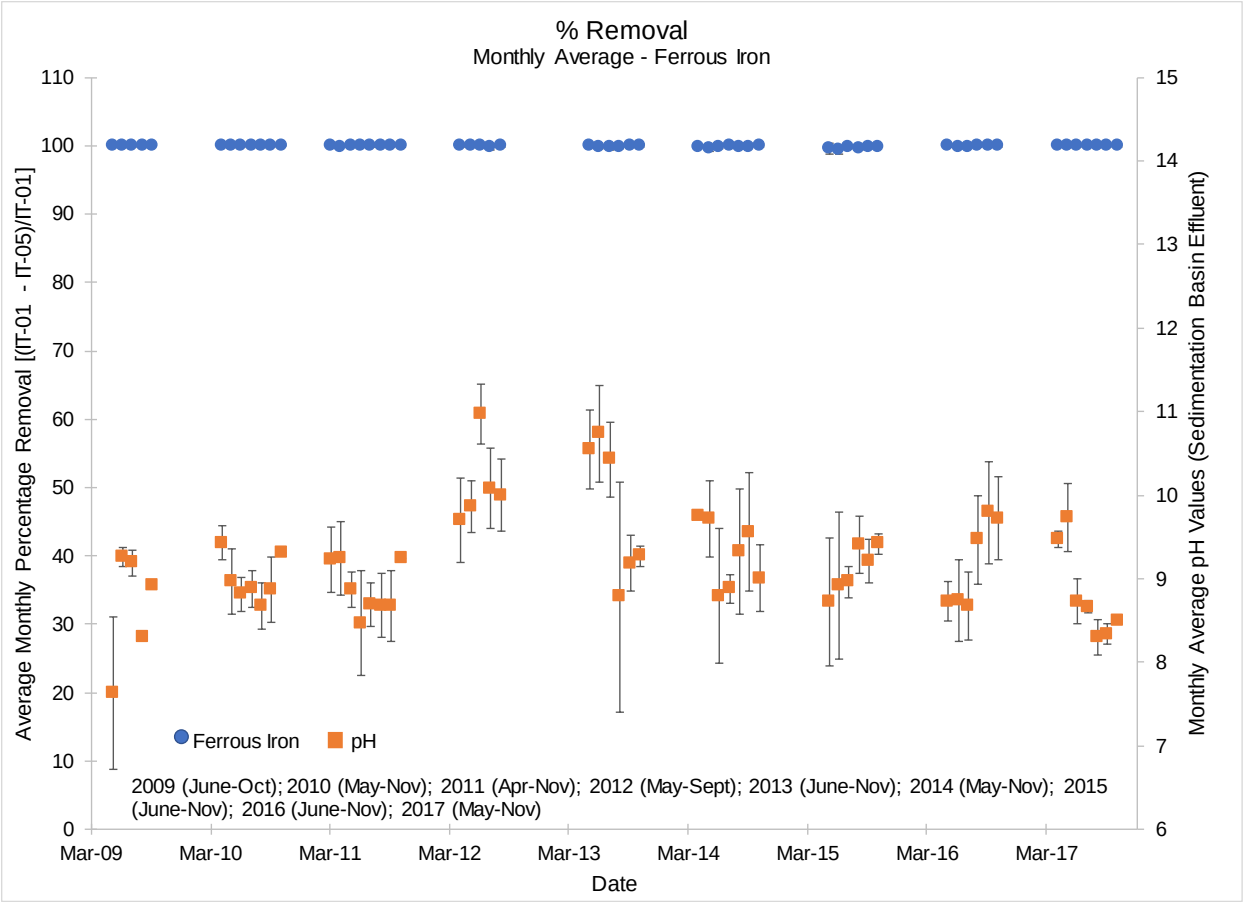

Figure 13. Monthly average percentage removals of field measured unfiltered ferrous iron (solid blue circles) between the influent and the sedimentation basin effluent and monthly average pH values (solid orange squares) in the sedimentation basin effluent. Error bars represent the standard deviations of the average values over the sampling dates within each month. Note: more variability is evident in pH measurements than in removal percentages; non-visible error bars for pH indicate those months where data for only a single sampling date was used for both iron and pH.

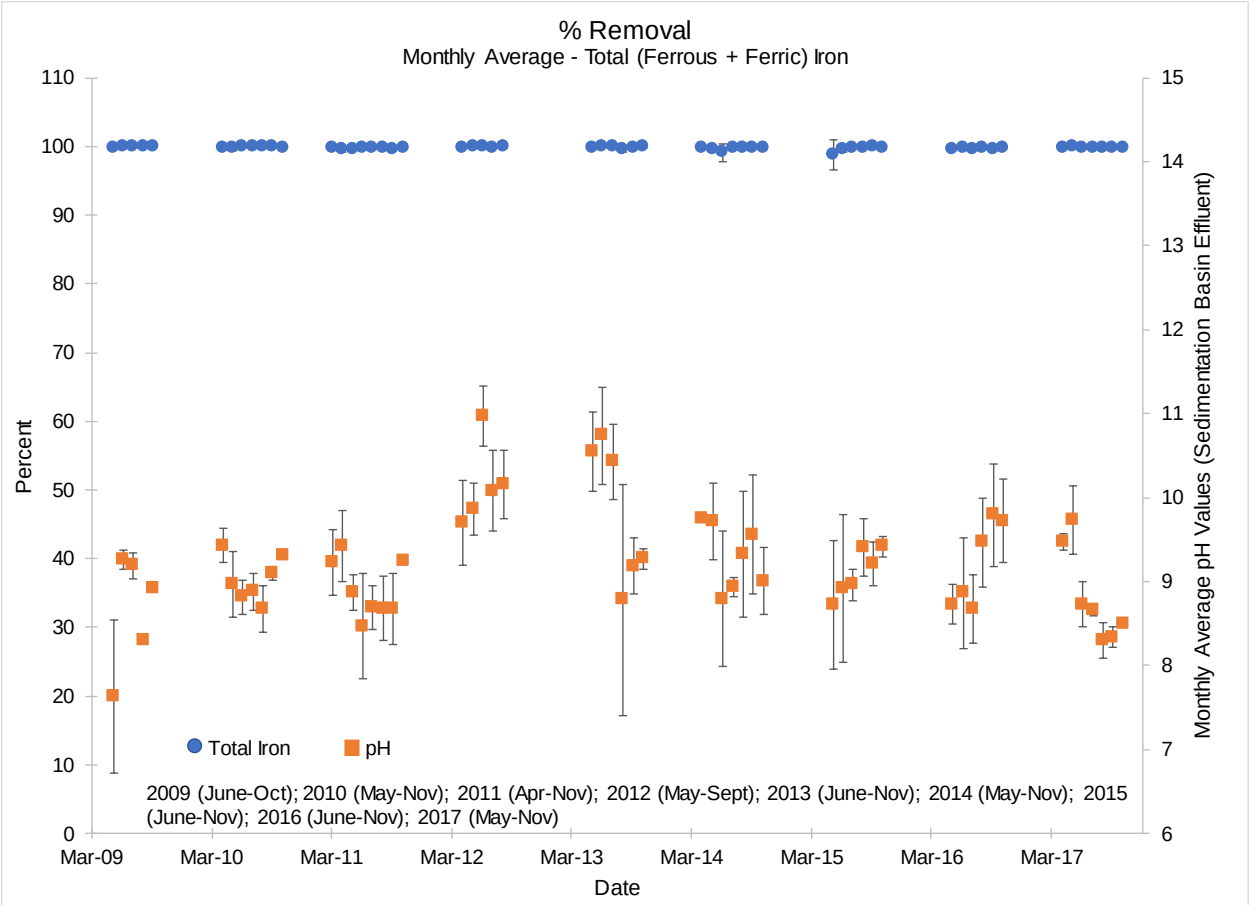

Figure 14. Monthly average percentage removals of field measured unfiltered total (ferrous + ferric) iron concentrations (solid blue circles) between the influent and the sedimentation basin effluent and monthly average pH values (solid orange squares) in the sedimentation basin effluent. Error bars represent the standard deviations of the average values over the sampling dates within each month. Note: more variability is evident in pH measurements than in removal percentages; non-visible error bars for pH indicate those months where data for only a single sampling date was used for both iron and pH.

3.2 Laboratory Data Derived Figures

Figure 15 presents total recoverable and dissolved iron (filtered, 0.45 µm) concentrations in the influent on multiple sampling dates between 2009 and 2016; Figure 16 presents data for RCTS™ effluent; and Figure 17 presents data for the sedimentation basin effluent. There were no laboratory samples run for RCTS™ effluent in 2010-2014 and only two dates were sampled in 2015 and one date in 2016. Figure 18 presents the percentages of both total recoverable and dissolved (filtered, 0.45 µm) iron concentrations removed due to neutralization and aeration steps (RCTS™ effluent), calculated using Equation 4 and for those steps plus settling (sedimentation basin effluent), calculated using Equation 3.

$$\text{Removal } \% = 100 \times \frac{\left(influent\ concentration\ (IT{-}01) - RCTS\ effluent\ concentration\ (IT{-}03)\right)}{influent\ concentration\ (IT{-}01)}$$

Equation 4

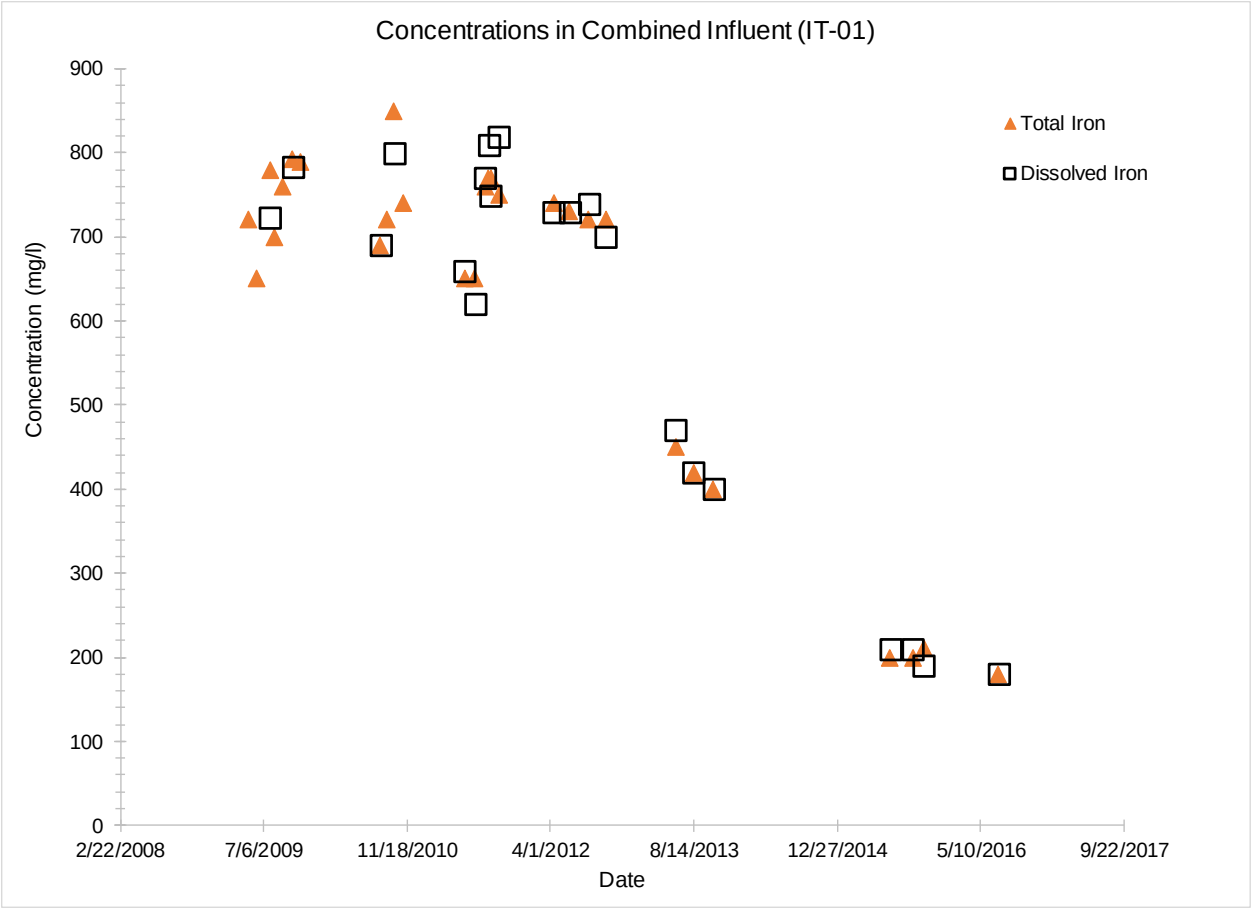

Figure 15. Laboratory results of total recoverable iron (solid orange triangles) and dissolved (filtered, 0.45 µm) iron (open black squares) concentrations in the combined influent over time.

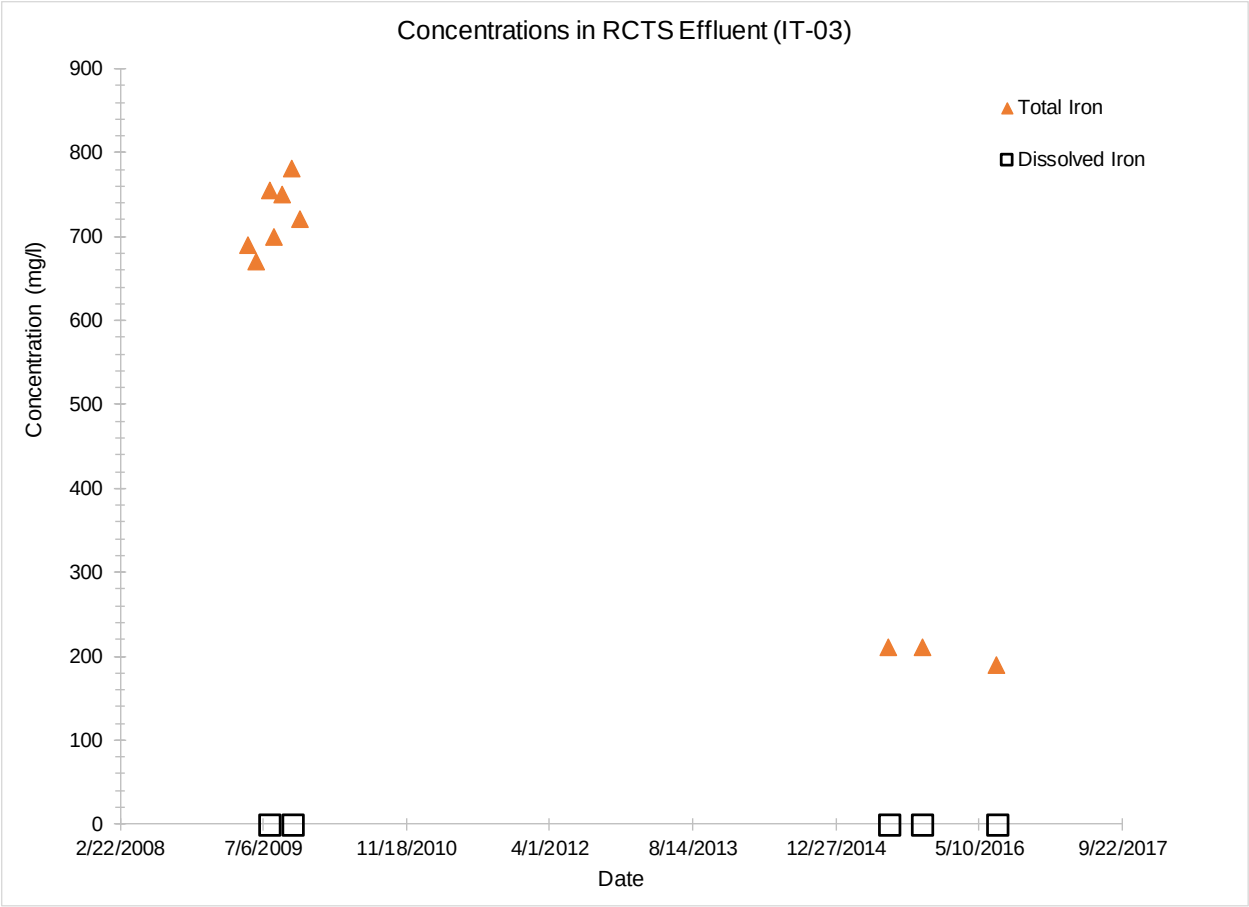

Figure 16. Laboratory results of total recoverable iron (solid orange triangles) and dissolved (filtered, 0.45 µm) iron (open black squares) concentrations in the RCTS™ effluent over time. Except for 10/14/2009 (value 0.293 mg/l), all dissolved iron data were qualified as being below the detection limit and reported at detection limit values ranging from 0.100 to 0.180 mg/l.

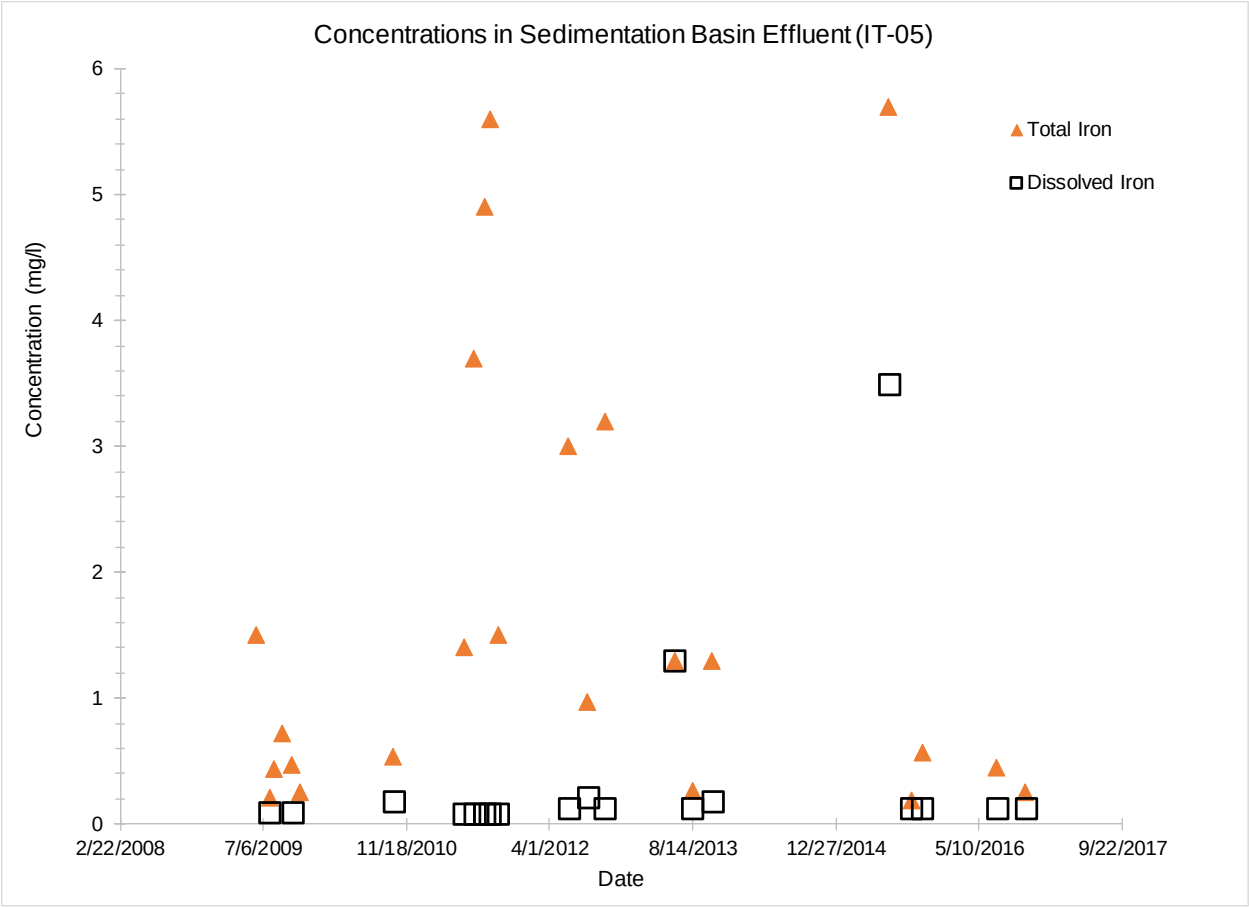

Figure 17. Laboratory results of total recoverable iron (solid orange triangles) and dissolved (filtered, 0.45 µm) iron (open black squares) concentrations in the sedimentation basin effluent over time. Only 6/11/2013 (1.3 mg/l) and 7/1/2015 (3.5 mg/l) dissolved iron data are above detection; all other samples were qualified as being below the detection limit and reported at detection limit values ranging from 0.090 to 0.220 mg/l.

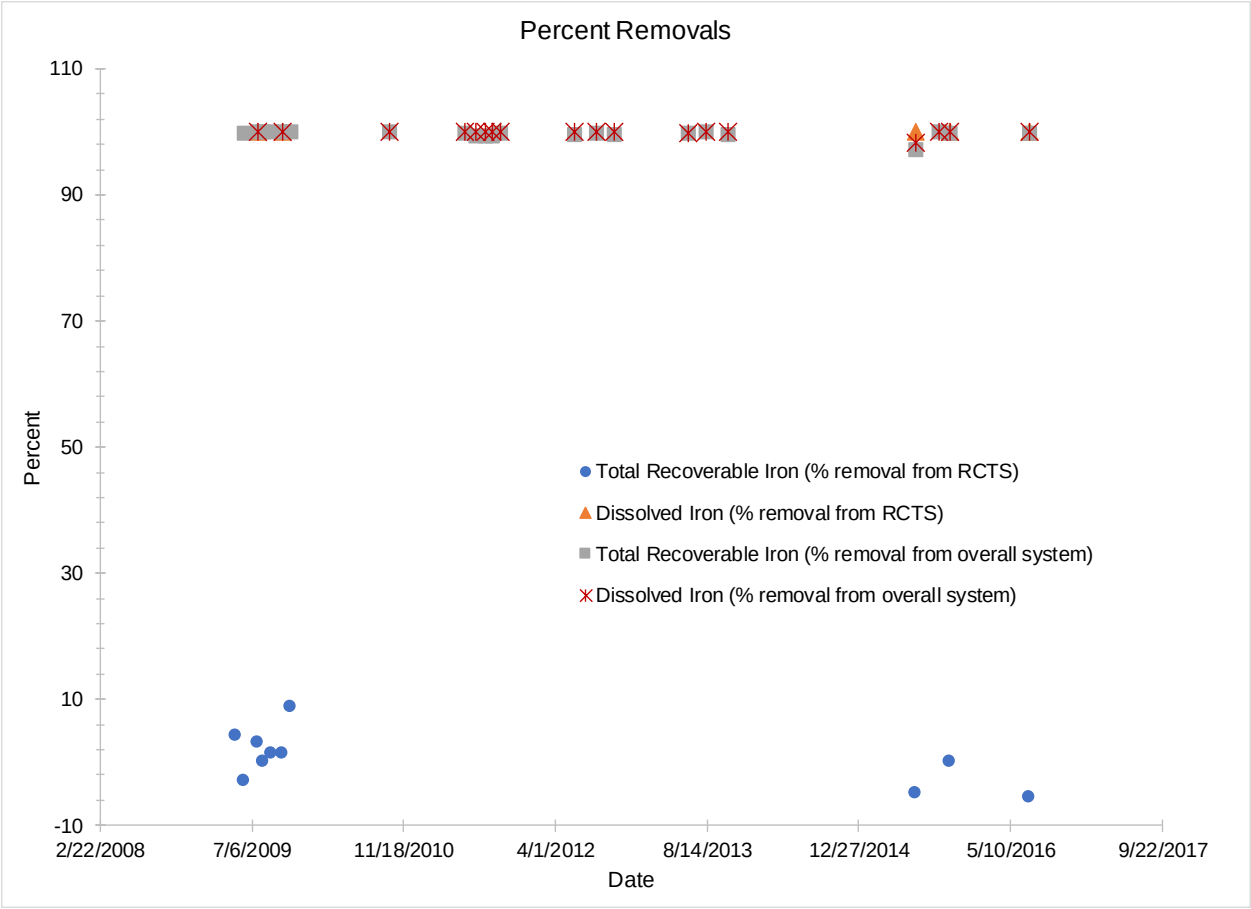

Figure 18. Percentage removals of total recoverable and dissolved (filtered, 0.45 µm) iron over time between the influent and the RCTS™ effluent (total recoverable iron: solid blue circles; dissolved iron: solid orange triangles) and between the influent and the sedimentation basin effluent (total recoverable iron: solid gray squares; dissolved iron: red asterisks) based on laboratory results.

3.3 Tables

Table 1 presents average annual concentrations and standard deviations for 2009-2017 and Table 2 presents average system influent flows and standard deviations for those years. Tables 3 and 4, respectively, present the maximum and minimum field measured treatment system influent concentrations for each year with their corresponding RCTS™ effluent and overall system (sedimentation basin) effluent concentrations.

Table 1: Average annual concentrations of total (ferrous + ferric) iron and ferrous iron (field data)

Year [a]	Analyte[b]	Combined Drainage Influent (mg/l) – unfiltered IT-01	RCTS™ Effluent (mg/l) – filtered IT-03	Sedimentation Basin Effluent (mg/l) – unfiltered IT-05
2009	Total Iron	850.57 ± 239.84	8.92 ± 20.41	1.05 ± 0.74
2009	Ferrous Iron	388.04 ± 204.33	0.95 ± 2.16	0.14 ± 0.16
2010	Total Iron	858.45 ±189.55	0.52 ± 0.59	0.94 ± 1.32
2010	Ferrous Iron	360.48 ± 121.03	0.34 ± 0.63	0.13 ± 0.17
2011	Total Iron	856.24 ± 126.83	1.98 ± 6.85	2.89 ± 1.81
2011	Ferrous Iron	492.63 ± 125.90	0.63 ± 0.69	0.37 ± 0.36
2012	Total Iron	879.55 ± 181.09	0.37 ± 0.29	0.96 ± 0.44
2012	Ferrous Iron	554.05 ± 175.39	1.81 ± 1.16	0.42 ± 0.34
2013	Total Iron	461.65 ± 74.47	0.24 ± 0.58	0.68 ± 1.07
2013	Ferrous Iron	266.02 ± 119.49	0.93 ± 0.90	0.27 ± 0.32
2014	Total Iron	309.32 ± 51.68	0.35 ± 1.01	0.81 ± 1.48
2014	Ferrous Iron	213.56 ± 72.83	0.47 ± 0.61	0.30 ± 0.44
2015	Total Iron	214.35 ± 96.21	1.61 ± 11.05	0.66 ± 1.68
2015	Ferrous Iron	79.94 ± 26.85	1.19 ± 1.73	0.26 ± 0.32
2016	Total Iron	183.62 ± 53.93	10.46 ± 17.95	0.52 ± 0.29
2016	Ferrous Iron	110.16 ± 31.59	0.78 ± 1.52	0.13 ± 0.11
2017	Total Iron	199.15 ± 64.75	12.28 ± 12.74	0.41 ± 0.25
2017	Ferrous Iron	136.26 ± 56.05	2.67 ± 4.98	0.07 ± 0.12

[a] Months included for RCTS™ effluent: May-Oct (2009); Apr-Oct (2010, 2012); Apr-Nov (2011); May-Nov (2013, 2014, 2015, 2016 [no total iron provided for July], 2017. Months included for sedimentation basin effluent: Apr-Nov (2011); May-Nov (2010, 2014, 2017); May-Sept (2012); June-Oct (2009); June-Nov (2013, 2015, 2016).

Table 2: Average of each year's influent flow rates

Year [a]	Influent Flow (m^3/hr) IT-01
2009	8.42 ± 1.01
2010	7.36 ± 1.24
2011	6.00 ± 1.64
2012	5.12 ± 0.79
2013	5.10 ± 0.51
2014	4.39 ± 0.34
2015	3.93 ± 0.43
2016	4.58 ± 0.60
2017	5.37 ± 0.57

[a] Months included: May-Oct (2009); Apr-Oct (2010); May-Oct (2012); May-Nov (2011, 2013-2017).

Table 3: Maximum annual influent concentrations of total and ferrous iron and their corresponding effluent concentrations from the RCTS™ and sedimentation basin (field data)

Year [a]	Analyte	Combined Drainage Influent (mg/l) – unfiltered IT-01	RCTS™ Effluent (mg/l) – filtered IT-03	Sedimentation Basin Effluent (mg/l) – unfiltered IT-05	Date of Occurrence
2009	Total Iron	1710	23.6	No data	05/13/2009
2009	Ferrous Iron	1208	2.77	No data	05/13/2009
2010	Total Iron	1480	0.52	0.15	07/28/2010
2010	Ferrous Iron	680	No data	0.23	09/08/2010
2011	Total Iron	1280	0.55	No data	09/21/2011
2011	Ferrous Iron	810	1.61	No data	09/01/2011
2012	Total Iron	1340	0.72	0.91	09/06/2012
2012	Ferrous Iron	790	0.88	0.13	05/09/2012
2013	Total Iron	745	0.06	1.29	10/14/2013
2013	Ferrous Iron	525	2.39	0.1	05/28/2013
2014	Total Iron	430	0.14	No data	05/16/2014
2014	Ferrous Iron	365	0.86	No data	07/14/2014
2015	Total Iron	875	0.01	No data	05/18/2015
2015	Ferrous Iron	215	0.06	No data	05/26/2015
2016	Total Iron	395	No data	0.2	07/26/2016
2016	Ferrous Iron	200	1.53	0.15	10/01/2016
2017	Total Iron	445	11	1.25	10/24/2017
2017	Ferrous Iron	310	9	0	06/16/2017

[a] Months included for RCTS™ effluent: May-Oct (2009); Apr-Oct (2010, 2012); Apr-Nov (2011); May-Nov (2013, 2014, 2015, 2016 [no total iron provided for July], 2017. Months included for sedimentation basin effluent: Apr-Nov (2011); May-Nov (2010, 2014, 2017); May-Sept (2012); June-Oct (2009); June-Nov (2013, 2015, 2016).

Table 4: Minimum annual influent concentrations of total and ferrous iron and their corresponding effluent concentrations from the RCTS™ and sedimentation basin (field data)

Year [a]	Analyte	Combined Drainage Influent (mg/l) – unfiltered IT-01	RCTS™ Effluent (mg/l) – filtered IT-03	Sedimentation Basin Effluent (mg/l) – unfiltered IT-05	Date of Occurrence
2009	Total Iron	460	No data	3.3	06/24/2009
2009	Ferrous Iron	40	No data	0.57	06/19/2009
2010	Total Iron	360	0	0.72	07/22/2010
2010	Ferrous Iron	125	0	0.03	06/18/2010
2011	Total Iron	600	No data	2.86	06/24/2011
2011	Ferrous Iron	295	0.3	No data	11/02/2011
2012	Total Iron	535	0.08	0.55	06/13/2012
2012	Ferrous Iron	60	3.02	0.08	08/08/2012
2013	Total Iron	300	0.04	0.06	09/03/2013
2013	Ferrous Iron	50	2.69	0.3	09/03/2013
2014	Total Iron	155	0.11	0.57	10/06/2014
2014	Ferrous Iron	65	0.25	0.27	10/06/2014
2015	Total Iron	118	0.18	0.22	11/02/2015
2015	Ferrous Iron	40	2.61	0.02	08/27/2015
2016	Total Iron	50	4	0.4	10/25/2016
2016	Ferrous Iron	35	0	0.03	07/29/2016
2017	Total Iron	85	0	0.01	06/02/2017
2017	Ferrous Iron	25	4	0	08/01/2017

[a] Months included for RCTS™ effluent: May-Oct (2009); Apr-Oct (2010, 2012); Apr-Nov (2011); May-Nov (2013, 2014, 2015, 2016 [no total iron provided for July], 2017. Months included for sedimentation basin effluent: Apr-Nov (2011); May-Nov (2010, 2014, 2017); May-Sept (2012); June-Oct (2009); June-Nov (2013, 2015, 2016).

4.0 DISCUSSION

4.1 Water Chemistry

4.1.1 Field Data

Improved drainage of TP-1 from initial response actions led to leachate containing very high concentrations of iron, with a peak load in July 2007 of 362.9 kg/day (800 lb/day) (Figure 9). Over time, there has been a 97 % decrease in observed average iron load to 10.9 kg/day (24 lb/day) in October 2017, as well as a 78 % decrease in discharge from an annual average of 12.3 m^3/hr (54 gpm) in 2007 to an annual average of 2.7 m^3/hr (12 gpm) in 2017.

The decrease in iron leached from TP-1 over time is reflected also in the decreasing combined treatment system influent concentrations shown in Figures 10 and 11 and in the average annual concentrations provided in Table 1. Table 2 provides the average annual treatment system inflow rates, which were highest in 2009-2011, and lower, but similar, for years 2012 through 2017. The differences between the values of average annual flows of leachate observed from TP-1 (Figure 9) and the average annual flows at IT-01 (Table 2) are because the flows used for Figure 9 were total drain flows and the flows for the treatment system were reported flows into the process (controlled by floats in the pump station), which may have been higher or lower than the total seepage flow for any given date.

The highest maximum total (unfiltered, ferrous + ferric) iron and ferrous iron leachate concentrations were treated in 2009-2012 (Figure 10 and Table 3). The decrease in leachate concentrations since 2012 is due to additional remedial activities that occurred at the site from 2010-2012 when the multi-layered low permeability cover system was constructed over the impoundment to minimize infiltration into the tailings pile, along with continued dewatering by the drains. A sample in 2015 had the highest maximum total (unfiltered, ferrous + ferric) influent iron concentration (875 mg/l) after 2012, but this is still quite a bit lower than the lowest maximum value of 1,280 mg/l in 2011 (Table 3) before the cover was completed. Minimum total (unfiltered, ferrous + ferric) iron concentrations treated also decreased over time (Figure 10 and Table 4).

The trend of decreased maximum and minimum concentrations over time is true also for influent ferrous iron (Figure 11 and Tables 3 and 4), although there are more exceptions than for total iron, possibly due to inconsistent changes in amounts of oxygen entering the drain openings over time. Dissolved oxygen (DO) from TP-1 drains ranged from < 1 mg/l to about 12 mg/l over 2007-2010. DO data collected in 2009 (Appendix K) indicate an average concentration of 4.3 mg/l, with a range of 2.7 to 5.5 mg/l in the combined influent, an average of 6.4 mg/l and range of 5.0 to 7.6 mg/l in the RCTS™ effluent, and an average of 6.3 mg/l and range of 4.3 to 9.1 mg/l in the sedimentation basin effluent. The average DO concentration achieved by the RCTS™ in 2009 (6.4 mg/l) was not as high as what was achieved in the Tsukamoto and Weems (2009) comparison of the RCTS™ with conventional lime treatment (7.86 mg/l, Section 1.2). The DO concentration of the influent was not provided in Tsukamoto and Weems (2009), but comparison of the RCTS™ effluent (IT-03) and the combined system influent (IT-01) in this study indicates an increase of 2 mg/l in the average DO concentration achieved by the RCTS™.

Combined field influent pH remained mostly within the range of about 4.5 to 6.8 over the nine years (Figure 12). There is more variability in pH values over time in both the RCTS™ effluent (IT-03) and sedimentation basin effluent (IT-05) within each year and over 2009-2017 (Figures 12-14), with maximum pH values occurring in the RCTS™ effluent. Generalized values based on field data from the

2015 operating season suggest that the optimal pH range for the RCTS™ is 8.5 to 11, 8.5 to 9.5 for the sedimentation basin, and 8.5 to 11 for the neutralization tank; although operational experience also demonstrated that system operation below pH 8.0 leads to high amounts of iron in the sedimentation basin effluent and operation at pH about 9.5 leads to an increase in gypsum formation and scaling on the rotating cylinder (Nobis Engineering Inc., 2016b). Issues with scaling were often observed and reported in monthly reports, and Figure 12 shows that the pH of the RCTS™ effluent generally exceeded 9.5. Total recoverable sulfate concentration was observed to decrease by 100 to 1800 mg/l following quicklime addition and aeration from the RCTS™ (see Appendix J); however, because calcium concentration increased (Appendix J) from dissolution of the lime, a correlation between loss of sulfate and formation of gypsum could not be determined. It is also possible that some sulfate loss is due to formation of iron oxyhydroxysulfate minerals, but mineralogical testing of the precipitates was not conducted.

The monthly average percentages of unfiltered ferrous iron and total (unfiltered, ferrous + ferric) iron removed by the overall treatment system (difference between the influent and the sedimentation basin effluent) exceeded 98% for all years of operation (Figures 13 and 14). Data in Tables 3 and 4 show that the neutralization plus RCTS™ can treat a wide range of influent ferrous iron concentrations to less than about 3 mg/l, except for the maximum treated in 2017, where the RCTS™ effluent concentration was 9 mg/l. However, the 9 mg/l ferrous iron was reduced to 0 mg/l by the overall system (neutralization + RCTS™ + sedimentation basin) from additional oxygen transfer occurring within the sedimentation basin. The overall treatment system could remove a wide range of total (ferrous + ferric) iron concentrations to below 1 mg/l with two exceptions previous to 2012, during startup of operations in 2009 and in 2011, where concentrations in the sedimentation basin effluent were close to 3 mg/l, and two exceptions in 2013 and 2017 where maximum influent concentrations were treated to about 1.3 mg/l (Tables 3 and 4).

4.1.2 Laboratory-Analyzed Data

System influent total recoverable and dissolved (filtered, 0.45 µm) iron concentrations each show a decreasing trend (Figure 15) beginning with the 2013 samples, as was observed in the field iron data (Table 1). The concentration of total recoverable iron is essentially the same in the RCTS™ effluent (IT-03) as in the combined influent (IT-01) and dissolved (filtered, 0.45 µm) iron concentration is much lower in the RCTS™ effluent as compared to the combined influent (compare Figures 15 and 16), with only one sample (October 2009, see Appendix J) identified as being above the laboratory's detection limit. The dissolved (filtered, 0.45 µm) iron results at IT-03 suggest that the aeration from the RCTS™ is effectively oxidizing dissolved and particulate ferrous iron in the alkaline water to ferric oxyhydroxides.

Comparison of Figure 17 with Figures 15 and 16 shows that total recoverable iron concentration is much lower in the sedimentation basin effluent (IT-05) than in the system influent and RCTS™ effluent, indicating effective settling of precipitated iron oxyhydroxides. Dissolved (filtered, 0.45 µm) iron concentrations in the sedimentation basin effluent were reported at below detection for all but two sampling dates (June 11, 2013 and July 1, 2015), where concentrations were 1.3 and 3.5 mg/l, respectively (Figure 17 and Appendix J). Field samples within a day or two of each of these sampling dates also showed > 1 mg/l ferrous iron. The 2013 sample was collected within about a week from the start of discharge from the system after starting up in May, which may be why ferrous iron was present above detection. The field pH in the sedimentation basin effluent was 6.88 on 6/29/2015 and it was 6.38 in the RCTS™ effluent and 6.62 in the effluent from the neutralization tank (data not shown) preceding the RCTS™. This suggests that there was an issue with lime dosing that resulted in a decrease in pH throughout the system, which could have resulted in dissolution of any precipitated unoxidized ferrous

iron (at typical pH of the sedimentation effluent, both ferrous and ferric oxyhydroxide would precipitate), although no field notes indicated a problem, so the reason is not known. The field sample collected on 7/2/15 still had ferrous iron at 1.17 mg/l (3.78 mg/l total iron) and a pH of 6.60 in the sedimentation basin effluent, but the sample obtained on 7/6/15 had only 0.52 mg/l total iron and 0.08 mg/l ferrous iron with a pH of 8.64, indicating the system was again operating effectively.

The percentage of total recoverable iron removed between the RCTS™ effluent and the treatment system influent was < 10% and sometimes was negative (Figure 18). This result is expected because the neutralization and aeration steps will change the oxidation state of the iron and its solubility, and it is expected that most of the settling of precipitates will occur in the sedimentation basin as the water velocity from the RCTS™ to the basin should keep the forming precipitates in suspension. The small amount removed indicates coating of the neutralization/mixing tank and/or the rotating cylinder, which did occur over time and was periodically cleaned off along with gypsum scale that formed. The laboratory samples also showed high removal percentages for the overall system (neutralization + RCTS™ + sedimentation basin) for both total recoverable and dissolved (filtered, 0.45 µm) iron (Figure 18), with the lowest removals of 97% for total recoverable iron and 98% for dissolved iron occurring on July 1, 2015.

4.2 Treatment System Costs

The water treatment system construction costs were reported as $1,446,100 by Weston Solutions (2012). These costs included preparation of the site for construction of the building to house the system, treatment plant and sedimentation basin construction, project management, quality assurance, health and safety considerations, and other administrative costs.

Major categories of operating costs are maintenance, labor, utilities (electric and phone/internet), process chemicals, equipment, and supplies. Labor includes operation, administration, and maintenance; chemicals are quicklime and field test supplies; and supplies are cleaning materials, maintenance equipment and supplies, tools, and other such expendable items. Operational costs are provided in Table 5.

Table 5: Operational Costs

Year	Costs	Reference
2008-2010	$537,200	Weston Solutions, 2012
2011-2012	$760,488	Nobis Engineering Inc., 2016b
2013	$261,923	Nobis Engineering Inc., 2016b
2014	$213,105	Nobis Engineering Inc., 2016b
2015-2016	$263,962	Nobis Engineering Inc., 2016b

Electricity usage was about 40,000 kilowatts during each 6-month operating period and costs varied from $0.11 to $0.16 per kilowatt over the years of operation. Maintenance included cleaning the RCTS™ drums to remove precipitated iron and gypsum scaling three to four times per year and yearly commissioning and decommissioning due to seasonal operation. Grinder pumps required frequent replacement (one to two per operating season) and accounted for the highest annual maintenance equipment cost of a little more than $4,000 each (Nobis Engineering Inc., 2016b).

Sludge management also contributes to operational costs. The sludge generated at the Elizabeth Mine was sampled and tested and did not contain any constituents that would require special handling. Approximately 764.6 m^3 (1,000 yd^3) of sludge accumulated in the sediment basin each year during the

early years of operation, which was excavated yearly and placed on the tailing impoundment until the cover system was completed in 2012. From 2012 onward, sludge was accumulated in the sedimentation basin and by 2018 the basin contained approximately 1,529 m^3 (2,000 yd^3) of soft, non-weight bearing sludge at a depth of up to 1.5 m (5 ft). Although the sedimentation basin is fenced to prevent access, onsite sludge disposal included adding Portland cement to stabilize the sludge and further minimize the safety hazard of someone sinking into it if walked upon. Stabilization and final closure of the sedimentation basin cost approximately $150,000 ($98.10 / m^3).

From data in Table 5, typical average annual operational costs (excluding the 2011-2012 costs and excluding sedimentation basin closure cost) for the system were about $232,000. Operational costs reported for 2011-2012 were higher than typical due to revisions made in 2012 to improve the system and running a 2-week pilot of a weir tank to evaluate its ability to minimize maintenance of the RCTS™. The revisions included installation of two new RCTS™ drums with larger perforations, installation of an overhead crane/lift system for the RCTS™ drums to decrease manpower and to improve efficiency and safety of conducting maintenance on the system, replacement of pump station plumbing, installation of a new sedimentation outlet, and installation of remote monitoring cameras (Nobis Engineering Inc., 2016b).

As of November 31, 2017, a total of 183,312 cubic meters (48,425,871 gallons) of leachate had been treated since the beginning of operation in late summer 2008. Using the estimated typical average annual operational costs and the system construction cost, the average annual cost of treating 3.785 liters (one gallon) of water was approximately $0.071 ([$1,446,100 + 8.5-yr * $232,000]/48,425,871).

4.3 Lessons Learned

Neutralization of acidity with a base (e.g., limestone, lime, sodium hydroxide) and subsequent precipitation of metals and metalloids is a conventional active treatment method for mining-influenced water. Generally, there is a preference to use lime over sodium hydroxide (also called caustic soda), based on the former creating a denser sludge and having a higher neutralization capacity (U.S. EPA, 1983). Sodium hydroxide in water treatment is a liquid and can cause serious chemical burns and therefore its use requires careful storage and handling. Control of pH is more difficult with sodium hydroxide than with lime, because small amounts can cause rapid and large changes in pH, whereas use of lime allows slower changes in pH with each incremental dose. In addition, there may be environmental concerns with discharging large quantities of sodium. At this site, lime was chosen as more suitable due to safety concerns and other disadvantages of sodium hydroxide (Nobis Engineering Inc., 2016b).

A disadvantage of using lime in treating mining-influenced water is that the calcium released will react with sulfate to form gypsum when sulfate is present in the mining-influenced water at concentrations of greater than about 1,500-2000 mg/l (Runtti et al., 2018; Bowell, 2004). Gypsum precipitation is a common cause of scaling and plugging in treating this type of water and results in increased monitoring and maintenance costs. At this site, gypsum buildup affected nearly all components of the treatment system, including clogging of pipes, chunks of gypsum falling off sides of tanks clogging outlets, cracking of seams of RCTS™ drums, failure of bearings due to drums being out of balance from scale buildup, and blocking of the sedimentation basin effluent pipe (Nobis Engineering Inc., 2016b). In one instance, a clogged plastic pipe melted from extended exposure to the lime as it reacted with water in an exothermic reaction. An additional cause of clogging was buildup of unground lime in pipes between the grinder pump and the neutralization tank and between the neutralization tank and the RCTS™, resulting from inefficient grinding of the lime after the first few months of grinder pump use (Nobis Engineering Inc., 2016b).

Several lessons learned are that system plumbing and equipment should be as accessible as possible to allow for easier maintenance, the design should consider potential future upgrades, and configuration of pumps should be designed to allow use of universal motors. Several factors need to be considered together in optimizing both treatment efficiency and costs for the lime RCTS™ treatment, including identifying and minimizing potential safety hazards of reagents, identifying and understanding any required specifications for piping and other system components contacting the lime, and identifying ways to minimize complications of gypsum formation. It is important to closely monitor pH to allow sufficient neutralization followed by effective aeration with minimal scaling of the RCTS™ unit, which allows conversion of the ferrous iron to ferric oxyhydroxides that will settle within the sedimentation basin. Monitoring ferrous iron concentration in the RCTS™ effluent allows assessment of the performance of the RCTS™ at oxidizing the ferrous iron to ferric iron. Although not done at this site, monitoring DO also may be beneficial in assuring oxidation in the RCTS™ is maximized to minimize the potential for any oxidation needing to occur in the sedimentation basin where efficiency of oxidation is dependent on the basin's surface area for oxygen transfer.

Disposal of sludge also can be a challenge. Factors needing to be considered are whether there are any hazardous constituents and whether it can be disposed on-site or if a dry cake needs to be created for transportation and disposal off-site. Safety hazards with respect to trespass need to be mitigated if sludge is disposed on-site, because the consistency does not support being walked upon.

Some other considerations for this type of treatment system, which are common to other active treatment systems, include that there is a need for access to power and a level space for construction of the pad, assembly may be difficult if the location is very remote with limited access, and economics of year-round operation in locations with cold winters should be considered as well as economics of long-term treatment. A final note is that the harsh environment within the treatment plant created challenges with power equipment. At the time of decommissioning in 2018, several treatment system components (neutralization tank) and the RTCS drums were approaching the end of their useful life and would have required replacement to continue treatment. For long-term operation, a replacement cost schedule would be appropriate to ensure capital funds were available acquire the equipment in time to avoid loss of treatment capability.

5.0 CONCLUDING REMARKS

The wide range of total (ferrous + ferric) iron and ferrous iron concentrations treated over the eight years of data analyzed is evident in Figures 10 and 11 and in Tables 3 and 4. Comparison of the field-measured influent maximum and minimum concentrations with their corresponding effluent concentrations (Tables 3 and 4) indicates that neutralization and aeration using the RCTS™ followed by settling is highly effective in removing high (and low) concentrations of iron to low levels, generally to less than 1 mg/l, which was a greater than 99% removal of the iron. Laboratory data also support this conclusion.

The Phase 3 Non-time-critical removal action at the site involves the construction of a passive treatment system to remove iron from the leachate originating from TP-1. Concentrations of total iron in the combined leachate from horizontal and toe drains averaged about 900 mg/l in 2007. High concentrations of iron are difficult to treat passively at sites that have limited land space to accommodate the retention times necessary to allow biological and/or chemical reactions to occur. Therefore, the choice of constructing an active system at Elizabeth Mine in 2008 was due to the very high loading of iron needing to be treated (362.9 kg/day (800 lb/day) at its highest in 2007, Figure 9) and limited space, and was intended to be a temporary system. The temporary system provided effective iron treatment for 10 years with sedimentation basin effluent concentrations that met the instream Vermont state aquatic biota water quality criterion (1 mg/l) for total iron. It successfully treated the leachate discharge from the tailing impoundment during the period when flows (and related loads) were reducing due to the cleanup actions. The treatment system along with the greater than 90% reduction in aluminum, copper, and zinc in Copperas Brook due to the mine waste consolidation and capping, resulted in the West Branch of the Ompompanoosuc River achieving the Vermont water quality standards for the first time since monitoring began in the 1960, and likely since the early 1800's. The West Branch of the Ompompanoosuc River was removed from the federal impaired waters list in 2014. Because loads are much lower (10.9 kg/d (24 lb/day) in October 2017) now than what they were in 2007, passive treatment is now a viable, long-term strategy for the site. EPA installed a passive treatment system to replace the RCTS™ treatment plant that became operational in summer 2019.

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7.0 APPENDICES

7.1 Appendix A: 2009 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
5/13/2009	1710	23.6		1208	2.77		5.88	7.64		38	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/15/2009	1080	0.05		710	0.21		5.16	9.74		38	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/20/2009	845	0.46		535	0.41		5.87	9.34		40	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/22/2009	950	0.71		355	0.23		5.92	8.42		31.58	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/26/2009	830	>3.3		440	0.03		5.84	9.92		32.2	Greater than values provided for total iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
5/29/2009	815	0.21		370	0.06		6.57	7.86		39.72	No data for IT-05, date not used for IT-01/IT-05 comparisons
6/1/2009	870	0.89	1.64	345	0	0.02	6.52	8.95	6.49	39.72	
6/3/2009	715	2.1	1.77	340	0.17	0	5.59	8.19	8.14	39.32	
6/5/2009	735	0.22	1.33	270	0.1	0	6.21	9.9	7.27	40.12	
6/8/2009	680	0.86	1.14	355	0.9	0.07	6.72	7.37	6.75	41.62	
6/10/2009	660	2.25	1.57	200	0.85	0.14	5.29	7.71	8.61	39.23	
6/12/2009	655	0.22	1.5	395	0	0.21	6.56	9.19	6.9	38.31	
6/15/2009	760	0.13	0.62	420	0.01	0.03	6.27	8.72	9.12	35.53	
6/17/2009	1315		0.79	385		0.22	6.07	8.69	8.85	37.4	No data for IT-03
6/19/2009	590		1.64	40		0	6.33	9.56	7.2	36.69	No data for IT-03
6/24/2009	460		3.3	185		0.57	6.01	8.46	6.6	35.8	No data for IT-03
6/26/2009	840	0.11	0.29	380	0.05	0	5.85	10.53	8.02	37.72	
7/1/2009	1000		178	475		46	5.9		5.8	51.04	pH values and concentrations at IT-05 suggest that the system was not operating properly as values are much higher than typical - operations log indicates system was down 5 hours for repairs - data excluded from comparisons and averages, but retained in plots of individual data over time
7/2/2009	990	135	125	385	1.48	90	5.95	8.83	6.72	40.54	pH values and concentrations at IT-05 suggest that the system was not operating properly as values are much higher than typical - operations log indicates system was down 2.5 hours for repairs - data excluded from comparisons and averages, but retained in plots of individual data over time
7/7/2009	930	8.21		550	0.33		5.32	8.93		39.4	No data for IT-05, date not used for IT-01/IT-05 comparisons
7/16/2009	943	36.4	1.04	390	10.4	0.14	5.47	7.09	9.11	38.3	
7/24/2009	823	3.9	0.7	349	0.36	0.19	5.94	9.91	9.3	35.8	
7/29/2009	897	3.6	0.6	322	0.95	0.47	5.86	9	9.37	35.9	
8/3/2009	796	91	0.82	289	1.01	0.33	6.1	9.84	9.32	34	
8/14/2009	871	12	0.29	364	1.2	0.21	5.76	10.24	9.28	33.78	
8/26/2009	881		0.19	378		0.02	6.26	7.72	8.97	33.94	No data for IT-03
9/17/2009	475	0.04	0.23	75	0	0	6.21	9.73	8.3	28.32	
10/7/2009	700	0.31	0.46	355	0.81	0	5.45	10.12	8.91	26.59	
Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 μm; IT-05 = sedimentation basin effluent, unfiltered											

7.2 Appendix B: 2010 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
4/7/2010	815	0.21		415	0.11		6.06	8.99		27.85	No data for IT-05, date not used for IT-01/IT-05 comparisons
4/8/2010	820	1		420	0.06		5.46	10.41		31.2	No data for IT-05, date not used for IT-01/IT-05 comparisons
4/12/2010	760	>3.3		510	2.06		5.6	6.6		26.71	Greater than values provided for total iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
4/16/2010	905	0.32		250	0		6.11	10.2		25.43	No data for IT-05, date not used for IT-01/IT-05 comparisons
4/21/2010	840	0.17		460	0		5.88	9.57		24.75	no data for IT-05, date not used for IT-01/IT-05 comparisons
5/5/2010	780	0.07	1.38	270	0	0.22	6	10.55	9.39	26.7	
5/14/2010	735	0.59	1.41	245	0.37	0.03	5.83	11.09	9.73	31.1	
5/19/2010	680	0.27	1.42	205	0.08	0	5.86	9.58	9.17	33.72	
6/2/2010	860	0.46	0.5	420	0.16	0.19	5.87	10.03	9.45	36.42	
6/7/2010	845		118	320		18	6		5.85	35.76	No data for IT-03,and appears suspect for IT-05 with low pH and very high iron concentrations; issue noted for feeder in shut down notes - data excluded from comparisons and averages, but retained in plots of individual data over time
6/18/2010	1030		6.49	125		0.09	5.3	10.3	8.5	29.99	No data for IT-03
6/30/2010	960	0.69	1.36	470	0.41	0.18	5.79	11.36	8.95	32.6	
7/8/2010	960	2.71	0.99	440	2.52	0.21	6.09	9.46	8.63	39.17	
7/14/2010	810	0.61	0.18	145	0.17	0	5.83	9.51	8.61	36.8	
7/22/2010	360	0	0.72	184	0	0.03	5.8	9.32	8.92	36.8	
7/28/2010	1480	0.52	0.15	305		0.23	4.63	8.65	9.09	35.3	No data for ferrous at IT-03
8/4/2010	1090		0.63	285		0.32	6.3	6.88	8.7	37.4	No data for IT-03
8/11/2010	905	0.79	0.47	350	0.44	0.76	5.93	10.12	8.75	34.1	
8/25/2010	885	0	0.43	315	0.22	0	6.03	9.93	9.18	24.98	
9/2/2010	695	0.08	0.12	435	0.17	0.07	5.83	9.71	8.28	24.98	
9/8/2010	1140	0	0.56	680	0	0.08	5.97	10.06	9.03	24.98	
9/15/2010	880	0.09		430	0.01		6.03	8.71		31.28	No data for IT-05, date not used for IT-01/IT-05 comparisons
9/22/2010	940	0	0.65	420	0	0	5.94	9.77	8.77	31.3	
9/28/2010	995	1.37	0.53	320	0.64	0.37	5.04	9.93	8.6	27.3	
10/8/2010	840	0.76	2.35	365	0.24	0.1	5.06	8.14	8.21	35.14	Total iron data for IT-05 stated as "suspect data", date not used for IT-01/IT-05 total iron comparison
10/13/2010	640	0.91	0.79	330	0.13	0.03	5.83	9.78	9.03	37.6	
10/20/2010	800	0.24	0.01	480	0.14	0	5.85	9.77	9.05	44.3	
10/27/2010	790	0.03	0	525	0.11	0.03	5.81	10.3	9.21	43.2	IT-03 data stated as "suspect data"
11/3/2010	655	0.2	0.95	335	0.05	0	5.85	11.28	9.3	no data	IT-03 data stated as "suspect data"

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.3 Appendix C: 2011 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
4/14/2011	755	0.74		725	0.17		5.76	10.65		40	No data for IT-05, date not used for IT-01/IT-05 comparisons
4/19/2011	800	1185		695	390		5.75	5.94		58	pH values and concentrations at IT-03 suggest that the system was not operating properly as values are much higher than typical - operations log indicates system was down many hours between 4/15 and 4/26 due to flume issues - data excluded from comparisons and averages, but retained in plots of individual data over time
4/21/2011	630	237		490	0.3		5.67	9.88		39	pH values and concentrations at IT-03 suggest that the system was not operating properly as values are much higher than typical - operations log indicates system was down many hours between 4/15 and 4/26 due to flume issues - data excluded from comparisons and averages, but retained in plots of individual data over time
4/27/2011	705	0.16	2.27	615	0.12	0.24	5.9	9.97	9.61	36.5	
4/29/2011	775	0.3	2.28	610	0.29	0.38	5.59	10.48	8.84	no data	No flow provided
5/4/2011	930	0.24	10	610	0.25	0.26	5.41	10.56	9.94	no data	No flow provided
5/12/2011	735	0.14	2.92	535	0.19	0.07	5.58	9.8	9.35	no data	No flow provided
5/18/2011	745	0.27	1.46	510	0.08	1.01	5.86	10.14	9.63	no data	No flow provided
5/25/2011	980	3.08	18	515	0.45	1.46	5.85	9.56	8.98	29	Total iron was flagged by contractor for IT-05, date not used for IT-01/IT-05 total iron comparisons
5/26/2011	805	0.13	2.04	465	1.04	1.08	5.6	9.58	8.79	28	
5/27/2011	8	1.44	1.52	420	1.7	0.15	5.78	10.26	8.75	27	Value for total iron at IT-01 appears suspect, date not used for total iron comparisons
6/7/2011	845	0.2	2.42	400	0.6	0.44	6.05	10.09	9.2	27.5	
6/15/2011	900		2.59	490		0.29	6.1		8.8	32	
6/22/2011	880	0.52	4.52	480	0.59	0.81	5.92	9.9	8.82	no data	No flow provided
6/24/2011	600		2.86	360		0.21	6	10.48	8.94	32.53	No data for IT-03
6/29/2011	685	0.24	2.1	325	0.05	0.21	5.91	9.43	8.56	33.5	
7/6/2011	765	0.12	1.53	315	0.57	0.63	5.31	9.25	8.24	32.5	
7/13/2011	850	0.28	1.84	355	0.47	0.16	5.93	10.5	9.48	31.5	
7/20/2011	935	39	1.72	320	0.76	0.35	5.24	8.37	7.77	28	
7/28/2011	1030	0.24	5.12	460	0.15	0.29	5.75	9.5	8.38	no data	No flow provided
8/3/2011	925	0.4	4.08	420	0.24	0.65	5.51	9.17	8.33	27.53	
8/10/2011	965	1.7	1.4	480	1.56	0.16	5.83	7.16	8.71	25.7	
8/17/2011	890	0.44	1.68	595	0.52	0.1	5.38	9.86	9.07	24.8	
8/24/2011	805	0.2	2.54	455	0.27	0.09	5.23	8.41	8.67	23.7	
9/1/2011	1010	5.4	4.56	810	1.46	0	5.57	9.42	8.14	25.3	
9/7/2011	800	0.12	1.97	655	0.24	0.08	5.42	9.46	8.97	23	
9/14/2011	890	2.35	1.91	560	0.03	0.85	5.16	9.42	8.92	23.9	
9/21/2011	1280	0.55		645	1.61		5.19	9.48		22.09	No data for IT-05, date not used for IT-01/IT-05 comparisons
9/29/2011	950	0.11		560	3.27		5.38	9.79		14.3	No data for IT-05, date not used for IT-01/IT-05 comparisons
10/5/2011	927	1.16	5.32	357	1.16	0.01	6.1	9.06	9.26	23.6	
10/12/2011	895	0.27		500	0.07		5.51	9.84		20.13	No data for IT-05, date not used for IT-01/IT-05 comparisons
10/19/2011	860	0.2	2.77	310	0.08	0.28	5.53	9.14	8.34	20.13	
10/27/2011	920	0.3	4.34	420	0	0.09	5.69	10.35	8.41	13.24	
11/2/2011	895	0.19	2.19	295	0.57	0.14	5.67	10.15	9.24	no data	No flow provided
11/10/2011	750	0.91	0.83	485	0.83	0.11	5.47	9.59	9.24	8.97	

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.4 Appendix D: 2012 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
4/13/2012	895	1.03		605	0.25		5.8	10.25		25.8	No data for IT-05, date not used for IT-01/IT-05 comparisons
4/18/2012	1100	0.84		260	0.13		5.74	9.79		26.2	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/9/2012	985	0.93	2.36	790	3.04	0.24	5.79	10.87	9.66	24.47	
5/16/2012	925	0.32	0.95	685	2.45	0.11	5.63	10.67	9.09	25	
5/24/2012	865	0.56	1.14	605	3	0.68	5.41	11.9	10.34	no data	No flow provided
6/1/2012	770	0.24		725	3		5.87	9.99		27.26	No data for IT-05, date not used for IT-01/IT-05 comparisons
6/6/2012	1165	0.17	1.34	740	0.17	1.34	5.38	10.72	9.71	27	
6/13/2012	535	0.08	0.55	585	3.02	0.08	5.16	11.48	9.47	no data	No flow provided
6/20/2012	895	0.47	0.94	615	1.28	0.54	5.16	11.45	9.97	23.73	
6/27/2012	895	0.08	1.16	450	3.3	0.13	5.7	11.82	10.29	21.24	
7/3/2012	710	0.11	1.17	405	3.18	0.48	5.55	11.65	10.69	22.8	
7/11/2012	805	0.4	0.71	545	2.69	0	5.29	11.63	10.55	24.6	
7/18/2012	830	0.02	0.78	600	3.3	1.02	5.55	11.95	11.32	22.2	
7/25/2012	1065	0.22	0.44	620	2.22	0.46	5.26	11.22	11.32	22.99	
8/8/2012	760	0	1.33	60	0	0.47	4.82	9.4	10.51	26.7	
8/15/2012	580	0.45	0.82	295	1.19	0.39	5.55	1.54	9.34	21.8	pH for IT-03 not used as suspect data
8/23/2012	1045	0.22	1.01	500	1.88	0.54	5.43	10.54	10.52	18	
8/29/2012	835	0.17	0.86	500	2.04	0.45	5.25	11.03	9.95	19	
9/6/2012	1340	0.72	0.91	745	0.88	0.13	5.14	11.6	9.57	15.8	
9/13/2012	805	0.5	0.38	0	1.51	0.5	4.78	11.44	10.46	17.88	No data for ferrous iron at IT-01, date not used for IT-01/IT-05 ferrous comparisons
9/20/2012	745	0.2	0.51	635	1.11	0	4.76	10.84	10.43	16	
10/18/2012	800	0.41	186	670	0.21	124	6.63	10.63	5.06	22.22	Notes on system shutdowns indicates system wasn't running 10/8-10/15; this appears to have created anomolous values at IT-05, date not used for IT-01/IT-05 comparisons, but retained in plots of individual data over time

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.5 Appendix E: 2013 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
5/17/2013	615	1.08		290			5.76	12.02		18.76	No data for ferrous iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
5/21/2013	550	2.65		345	2.26		6.23	11.95		20.72	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/22/2013	550	0.04		515			5.89	11.93		20.72	No data for ferrous iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
5/23/2013	510	0.13		365			5.86	12.05		23.22	No data for ferrous iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
5/24/2013	520	0.13		445			6.02	12.29		31.3	No data for ferrous iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
5/28/2013	499	0.12		525	0.27		6.15	8.08		22.68	No data for IT-05, date not used for IT-01/IT-05 comparisons
5/31/2013	435	0.01		420			6.24	12.2		21.69	No data for ferrous iron at IT-03; no data for IT-05, date not used for IT-01/IT-05 comparisons
6/3/2013	430	0.07	1.43	425	1.12	0.14	6.19	11.01	9.54	23.81	
6/7/2013	495	0.06	1.21	505		0.13	6.38	11.85	10.76	23.29	No data for ferrous iron at IT-03
6/10/2013	500	0.02	1.17	445	0.025	0.39	6.21	10.26	10.96	23.65	
6/14/2013	500	0.04	0.58	455	0.35	0.25	6.09	11.42	10.81	22.9	
6/17/2013	455	0.08	0.81	415	> 3.3	0.24	6.24	11.81	10.96	21.6	Greater than value provided for ferrous iron at IT-03
6/21/2013	465	0.13	0.81	515	0	0.21	6.06	10.84	10.72	23.97	
6/24/2013	480	0	0.46	235	1.5	0.15	6.02	9.09	10.56	24.9	
6/28/2013	495	0.07	0.25	450	2.33	0.73	5.96	11.44	10.02	23.24	
7/1/2013	455	0	0.55	235	>3.3	0.21	5.88	11.78	11.01	23.11	Greater than value provided for ferrous iron at IT-03
7/5/2013	505	0	0.4	210	>3.3	0.32	6.16	11.85	10.62	22.28	Greater than value provided for ferrous iron at IT-03
7/8/2013	425	0.14	0.57	180	0.55	0.18	6.14	8.89	9.21	23.69	
7/12/2013	335	>3.3	0.38	195	>3.3	0.39	6.05	11.04	10.29	22.95	Greater than value provided for total and ferrous at IT-03
7/15/2013	470	0.12	0.2	225	>3.3	0.21	6.02	12.83	11.18	22.83	Greater than value provided for ferrous iron at IT-03
7/19/2013	380	0	0.19	55	>3.3	0.33	6.01	11.96	10.64	20.73	Greater than value provided for ferrous iron at IT-03
7/22/2013	465	0.01	0	145	>3.3	0.13	6.06	12.2	11.08	19.51	Greater than value provided for ferrous iron at IT-03
7/26/2013	505	0.19	0.6	190	0.15	0.33	6.08	10.66	11.18	23.26	
7/29/2013	565	0.25	0.12	190	>3.3	0.24	5.8	12.05	11.06	19.75	Greater than value provided for ferrous iron at IT-03
7/31/2013	520	0.75	0.16	285	>3.3	0.13	5.86	11.99	11.08	19.54	Greater than value provided for ferrous iron at IT-03
8/2/2013	315	0	0.2	115	0.85	0.26	5.99	10.19	11	24.51	
8/5/2013	520	0.04	0.43	220	0.95	0.22	5.97	10.71	10.08	24.24	
8/9/2013	455	0	0.13	180	2.26	0.71	5.62	11.32	9.87	21.4	
8/12/2013	425	0.21	0.45	180	>3.3	0.24	5.87	11.58	10.79	21.7	Greater than value provided for ferrous iron at IT-03
8/16/2013	490	0.03	0.42	285	2.28	0.08	6.18	11.34	10.01	22.63	
8/19/2013	390	0.13	0.15	180	0.46	0.17	5.86	10.03	10.01	23.9	
8/23/2013	475	0	0.17	205	>3.3	1.9	5.97	12.02	10.71	19.15	Greater than value provided for ferrous iron at IT-03
8/26/2013	420	0.11	0.04	150	0.53	0.3	5.77	10.19	11.1	21.4	
8/29/2013	535	0	0.07	160	1.07	0.37	5.75	11.12	10.26	21.15	
9/3/2013	300	0.04	0.06	50	2.69	0.3	5.94	11.4	10.3	19.4	
9/5/2013	435	2.7	0.49	110	>3.3	0.21	5.91	12.5	10.31	19.54	Greater than value provided for ferrous iron at IT-03
9/9/2013	395	1.96	0.07	90	0.55	0	5.86	10.66	9.5	19.3	
9/12/2013	335	0.28	0.35	160	0.37	0.01	6.08	9.97	8.85	26.12	
9/16/2013	550	0.01	10.6	235	0.01	15.8	6.11	8.46	6.98	26.1	Contractor noted "no lime feed/surge" for IT-05 (or IT-04), date not used for any averages since lime feed would have affected all sampling locations, but data are retained for time graphs
9/19/2013	355	0.15	22.8	175	0.03	1.57	5.63	10.23	5.89	23.24	Contractor noted "no lime feed/surge" for IT-04 and IT-05 on 9/16, which appears to have carried over to issues with IT-05 on this date also based on pH; also noted issue with neutralization tank on the 19th - data excluded from comparisons and averages, but retained in plots of individual data over time
9/23/2013	465	0	6	285	0	0.98	6.12	9.15	6.71	23.04	
9/26/2013	465	0.17	4.7	290	1.99	0.8	6.16	11.1	6.84	20.91	
9/30/2013	455	0	0.55	240	0.91	0.1	6.33	11.01	8.95	23.7	
10/3/2013	390	0	0.89	215	0	0.05	6.33	9.8	8.8	22.9	
10/7/2013	445	0.06	0.34	260	0.24	0.12	6.87	9.6	8.61	27.62	
10/10/2013	460	0.1	0.26	230	1.89	0.07	6.76	11.44	9.55	23.4	
10/14/2013	745	0.06	1.29	300	2.39	0.1	6.26	11.55	9.61	20.65	
10/21/2013	415	0.03	0.73	260	2.7	0.02	6.55	11.27	9.12	20.9	
10/24/2013	400	0.11	0.53	245	0.02	0.08	6.45	9.94	9.07	21.8	
10/28/2013	445	0.1	0.47	290	0.04	0.1	5.38	10.44	9.19	20.8	
10/31/2013	435	0.16	0.72	250	0.12	0	6.55	10.19	9.49	21.88	
11/4/2013	400	0	0.41	260	0	0	6.49	10.04	9.17	23.8	
11/7/2013	465	0.1	0.58	285	0.51	0.02	6.38	11.11	9.2	21.4	
11/11/2013	425	0.1	0.32	200	1.04	0.09	6.44	10.64	9.44	21.58	

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.6 Appendix F: 2014 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
5/16/2014	430	0.14		310	0.86		6.42	10.42		23.14	No discharge at IT-05, date not used for IT-01/IT-05 comparisons
5/19/2014	415	0.05		265	0.71		6.48	10.6		21.7	No discharge at IT-05, date not used for IT-01/IT-05 comparisons
5/22/2014	360	0.07		215	0.35		6.4	10.9		21.9	No discharge at IT-05, date not used for IT-01/IT-05 comparisons
5/27/2014	340	0.04		160	0.04		6.48	10.43		22.7	No discharge at IT-05, date not used for IT-01/IT-05 comparisons
5/29/2014	260	1.71	0.52	145	0.59	0.35	6.19	10.38	9.74	22.5	
6/2/2014	295	2.03	1.7	160	2.03	1.7	6.18	11.74	10.18	20.43	
6/5/2014	345	0	1.22	170	0.21	0.33	6.43	10.6	9.15	20.51	
6/9/2014	280	5.98	1.53	155	2.33	0.54	6.47	10.64	9.57	19.91	
6/12/2014	365	0.7	0.54	305	1.43	0.17	6.28	10.31	9.38	19.61	
6/16/2014	300	2.48	0.67	180	0	0.91	6.39	11.49	10.31	19.41	
7/14/2014	280	0.15	9.7	365	0.78	2.3	6.2	10.73	8.17	19.39	
7/17/2014	325	0	0.92	345	0.36	0.11	6.13	10.89	8.38	18.52	
7/21/2014	350	0	0.14	355	0.21	0.11	6.32	11.42	9.95	19.49	
7/24/2014	255	0.54	0.46	265	1.13	0.19	5.79	9.81	9.54	18.89	
7/31/2014	425	0.06	2.12	230	0.07	0.56	6.16	9.75	7.93	17.53	
8/4/2014	295	0.04	0.4	270	0.63	0.05	6.34	10.15	8.83	17.5	
8/7/2014	1405	0.17	0.38	310	0.07	0.14	6.25	9.47	8.53	18.08	Total iron at IT-01 appears anomolous, contractor didn't include in their calculated averages, so excluded total iron comparisons
8/11/2014	295	0	0.57	115	0.5	0.57	6.24	9.96	8.99	18.03	
8/14/2014	355	0.1	0.79	330	0.19	0.15	6.34	9.13	8.92	19.63	
8/18/2014	320	0.04	0.56	290	0.06	0.08	6.34	9.83	8.94	18.4	
8/21/2014	325	0.05	0.31	305	0.37	0.1	6.24	10.09	8.9	19.91	
8/25/2014	290	0	0.23	290	0.05	0.33	6.23	10.17	9.17	18.11	
8/28/2014	230	0	0.36	220	0	0.08	6.22	9.28	8.77	19.35	
9/2/2014	310	0.07	0.24	285	1.59	0.29	6.38	10.4	8.53	18.78	
9/4/2014	335	0.08	0.26	205	0.95	0.11	6.2	10.15	9.59	18.22	
9/8/2014	305	0	0.46	170	0	0.11	6.16	8.36	9.09	21.24	
9/11/2014	320	0.08	0.49	190	0.28	0.06	6.24	9.89	9.1	18.5	
9/15/2014	185	0.07	0.72	170	0.12	0	6.41	9.76	8.48	18.14	
9/18/2014	280	0.03	0.44	105	2.18	0.04	6.24	11.12	8.98	17.03	
9/22/2014	355	0.1	0.25	190	0.26	0.11	6.35	10.46	9.07	18.07	
9/25/2014	335	0.13	0.08	185	1.11	0.7	6.5	10.56	10.93	19.58	
9/29/2014	295	0	0.53	90	0	0.52	6.48	8.86	10.21	17.22	
10/2/2014	325	0.05	0.58	165	0.03	0.41	6.05	8.3	10.13	18.93	
10/6/2014	155	0.11	0.57	65	0.25	0.27	6.41	8.72	10.71	18.05	
10/9/2014	275	0	0.1	145	0.02	0.29	6.22	7.82	10.25	18.9	
10/16/2014	325	0	0.23	160	0.01	0.16	6.32	10.75	8.7	17.65	
10/20/2014	275	0.07	0.3	145	0.55	0	6.26	9.75	9.53	18.78	
10/23/2014	305	0.03	0.5	230	0.1	0.06	5.99	8.6	8.57	22.34	
10/27/2014	320	0.05	0.44	235	0.18	0.06	6.19	10.05	9.33	18.73	
10/30/2014	265	0	0.55	160	0.06	0.13	6.28	9.85	9.22	19.54	
11/3/2014	330	0.19	0.76	180	0.18	0.03	6.22	10.22	9.19	18.34	
11/6/2014	310	0	0.53	160	0	0.06	6.12	9.66	8.52	18.78	
11/10/2014	305	0	0.63	200	0	0.05	6.26	9.46	8.61	20.65	
11/13/2014	260	0.11	0.66	205	0.07	0.05	6.19	10.76	9.61	18.15	
11/17/2014	305	0.1	0.23	215	0.07	0.05	6.36	9.18	9.1	18.65	

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.7 Appendix G: 2015 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
5/18/2015	875	0.01		80	0.06		5.44	9.38		17.62	Total iron at IT-01 appears anomolous, but contractor did include in their calculated averages, so did not exclude from comparisons; No data at IT-05, date not used for IT-01/IT-05 comparisons
5/21/2015	225	0.11		140	1.01		6.86	11.36		16.6	No data at IT-05, date not used for IT-01/IT-05 comparisons
5/26/2015	240	0.03		215	0.04		5.61	10.36		17.97	No data at IT-05, date not used for IT-01/IT-05 comparisons
5/28/2015	208	0.02		88	1.14		5.42	10.33		16.68	No data at IT-05, date not used for IT-01/IT-05 comparisons
6/1/2015	209	0.07		69	0.06		5.3	9.74		16.1	No data at IT-05, date not used for IT-01/IT-05 comparisons
6/4/2015	202	0		83	0.02		5.4	9.68		15.46	No data at IT-05, date not used for IT-01/IT-05 comparisons
6/8/2015	222	0.04	1.76	108	0.11	0.13	6.38	9.44	9.01	16.27	
6/11/2015	229	0	0.41	88	0.16	0.13	6.2	10.16	8.9	16.5	
6/15/2015	186	0	0.52	90	0.26	0	6.42	10.17	9.17	15.79	
6/18/2015	226	0	0.52	63	0.75	0.1	6.29	9.7	8.98	15.5	
6/22/2015	183	0	0.31	89	0.4	0.25	6.05	10.22	9.2	15	
6/25/2015	193	0	0.69	62	0.28	0.2	6.34	10.49	8.92	14.75	
6/29/2015	174	79.75	11.1	60	12.05	1.48	6.13	6.38	6.88	15.8	
7/2/2015	221	0.01	3.78	77	1.74	1.71	6.27	10.56	6.6	23.31	
7/6/2015	172	0.12	0.52	67	0.85	0.08	6.4	10.24	8.64	19.97	
7/9/2015	195	0.11	0.28	85	1.11	0.14	6.43	10.94	9.1	17.5	
7/13/2015	237	0.05	0.57	78	0.67	0.56	6.28	10.04	9.16	18.8	
7/16/2015	177	0	0.47	74	1.85	0.16	6.39	11.1	9.88	16.6	
7/20/2015	195	0.11	0.49	53	2.58	0.46	6.39	10.23	9.27	17.17	
7/23/2015	212	0	0.58	73	1.38	0.42	6.05	10.34	9.34	17.57	
7/27/2015	202	0	0.45	98	0.37	0.13	6.44	10.23	9	17.53	
7/30/2015	224	0.07	0.29	51	1.75	0.22	6.14	10.48	9.28	17.85	
8/3/2015	223	0.12	0.43	67	1.78	0.31	6.39	10.17	8.98	17.17	
8/6/2015	198	0	0.41	68	0.38	0.03	5.99	10.24	9	17.59	
8/10/2015	210	0	0.35	89	0.24	0.03	6.05	10.06	8.63	17.36	
8/13/2015	203	0.25	0.44	64	1.18	0.12	6	10.46	8.73	17.46	
8/17/2015	204	0	0.17	59	0.26	0.09	6.41	10.05	9.03	17.5	
8/20/2015	196	0.05	0.27	63	0.38	0.1	6.32	10.22	8.94	18.06	
8/24/2015	191	0	0.19	67	2.07	0.14	6.11	11.42	9.25	17.65	
8/27/2015	183	0.03	0.31	40	0.94	0.19	6.24	10.15	8.91	16.97	
8/31/2015	194	0.03	0.22	68	1.06	0.22	6.18	10.05	9.18	16.6	
9/3/2015	179	0.03	0.2	51	2.36	0.2	6.23	10.94	8.92	13.87	
9/8/2015	206	0.04	0.1	84	2.38	0.27	5.87	11.06	9.33	13.65	
9/10/2015	236	0.11	0.14	87	2.64	0.36	6.18	10.76	9.72	13.68	
9/14/2015	211	0.01	0.25	69	1.57	0.43	6.13	10.91	9.31	14.39	
9/17/2015	188	0	0.04	66	0.64	0.2	6.17	10.65	8.98	19.17	
9/21/2015	164	0.01	0.24	105	0.99	0.02	5.89	10.32	10	20.44	
9/24/2015	206	0.17	0.54	97	1.43	0.27	5.87	9.8	9.63	17.84	
9/28/2015	195	0.19	0.62	113	0.1	0.67	6.41	10.19	9.36	17.65	
10/1/2015	178	0.01	0.42	59	0.17	0.17	5.78	10.23	9.34	18.42	
10/4/2015	210	0.05	0.25	109	0.07	0.2	6.08	10.04	9.56	16.74	
10/8/2015	183	0	0.36	63	1.36	0.07	6.01	10.16	8.91	16.54	
10/12/2015	180	0.07	0.07	60	0.27	0.24	6.3	10.04	9.53	14.39	
10/14/2015	196	0.04	0.12	68	0.16	0.08	6.12	10.13	9.3	19.65	
10/19/2015	230	0.03	0	109	0.63	0	6	9.99	9.41	21.13	
10/22/2015	220	0.02	0	86	0.25	0.15	6.28	9.91	8.79	19.73	
10/26/2015	188	0.13	0	86	1.28	0.23	6.13	10.28	9.11	19.43	
10/29/2015	166	0.14	0	80	2.68	0.32	6.06	10.44	9	18.7	
11/2/2015	118	0.18	0.22	51	2.61	0.02	6.48	11.4	9.54	17.97	
11/9/2015	237	0.01	0.33	71	0.75	0.2	6.36	10.31	9.47	17.8	
11/12/2015	232	0.01	0.27	87	1.46	0.18	6.27	10.23	9.25	19.62	

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.8 Appendix H: 2016 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
5/20/2016	276	0.05		63	0.06		6.33	9.84		22.71	No data at IT-05, date not used for IT-01/IT-05 comparisons
5/23/2016	105	0.5		57	0.2		6.37	10.99		22.39	No data at IT-05, date not used for IT-01/IT-05 comparisons
5/26/2016	185	0.11		115	0.2		6.41	9.42		23.46	No data at IT-05, date not used for IT-01/IT-05 comparisons
5/31/2016	246	0.15		112	0.04		6.3	10.07		22.22	No data at IT-05, date not used for IT-01/IT-05 comparisons
6/2/2016	212	0.08		109	0.04		6.36	9.75		21.06	No data at IT-05, date not used for IT-01/IT-05 comparisons
6/6/2016	163	0.13	0.83	111	0.17	0.16	6.32	9.88	8.54	20.63	
6/9/2016	179	0.04	1.06	117	0.08	0.12	6.46	9.73	8.34	19.65	
6/14/2016	181	0.09	0.83	114	0.14	0.06	6.36	9.93	8.65	18.6	
6/16/2016	112	0.06	0.41	104	0.31	0.15	5.86	9.96	8.56	18.65	
6/20/2016	161	0.11	1.47	69	0.16	0.11	5.97	10.12	8.99	18.3	
6/22/2016	292	0.05	0.78	141	0.68	0.03	6.46	10.17	9.12	18.2	
6/27/2016	176	0.15	0.67	144	0.23	0.19	6.46	9.86	8.8	20.55	
6/29/2016	172	0.07	0.34	138	0.16	0.08	6.47	10.03	8.83	20.44	
7/5/2016	210			131	3.3	0.24	6.57	8.43	8.51	20.83	No data for total iron at IT-03 or IT-05, date not used for total iron IT-01/IT-05 comparisons
7/9/2016	185			111	0.5	0.17	6.63	9.97	8.82	20.83	No data for total iron at IT-03 or IT-05, date not used for total iron IT-01/IT-05 comparisons
7/12/2016	123			126	3.3	0.21	6.54	9.69	8.65	20.53	No data for total iron at IT-03 or IT-05, date not used for total iron IT-01/IT-05 comparisons
7/15/2016	182		0.38	113		0.38	6.42	9.72	8.54	20.58	No data for IT-03
7/19/2016	211			97	0.64	0.6	6.35	10.25	8.51	20.53	No data for total iron at IT-03 or IT-05, date not used for total iron IT-01/IT-05 comparisons
7/22/2016	200		0.41	140	1.68	0.24	5.93	10.1	8.45	20.5	No data for total iron at IT-03, date not used for IT-01/IT-03 total iron IT-01/IT-05 comparisons
7/26/2016	395		0.2	115	1.53	0.15	6.42	10.43	8.45	19.72	No data for total iron at IT-03, date not used for IT-01/IT-03 total iron IT-01/IT-05 comparisons
7/29/2016	225		0.12	35	2	0.12	6.53	11.92	10	12.29	No data for total iron at IT-03, date not used for IT-01/IT-03 total iron IT-01/IT-05 comparisons
8/2/2016	180	0.58	0.42	85	0.2	0.07	6.43	10.68	9.43	19.8	
8/5/2016	155	12	0.48	120	0	0.05	6.32	9.23	8.11	24.11	
8/9/2016	245	0.36	0.74	140	0.05	0.07	6.43	10.07	8.54	22.1	
8/12/2016	120	13	0.51	57	0.41	0.14	6.53	9.49	8.46	22.5	
8/16/2016	81	17	0.74	69	6	0.29	6.26	12.14	8.62	22.8	
8/19/2016	180	39	0.5	135	1	0.17	6.55	11	8.86	22.4	
8/26/2016	165	0	0.3	130	0.02	0.14	6.51	10.77	9.09	20.54	
8/30/2016	140	0	0.54	75	0	0	6.62	10.94	8.27	21.43	
9/6/2016	225	9	0.23	125	0	0.06	6.53	10.58	8.42	18.8	
9/9/2016	205	2	0.16	70	0	0.13	6.47	11	9.04	18.5	
9/13/2016	140	84	0.36	120	0	0.12	6.41	11.99	10.08	19.02	
9/16/2016	215	38	0.27	150	8	0.11	6.69	10.82	9.95	18.8	
9/20/2016	160	2	0.68	140	0	0.04	6.6	12.18	9.56	17.5	
9/23/2016	191	27	0.71	145	2	0.11	6.68	12.01	9.63	15.5	
9/27/2016	190	30	0.59	135	0	0.03	6.5	12.07	9.56	12.4	
10/1/2016	115	22	0.98	200	0	0	6.5	11.98	11.01	20.02	
10/4/2016	196	16	0.1	110	0	0.2	6.6	11.01	10.03	22.3	
10/7/2016	212	66	0.18	100	2	0	6.7	10.86	9.99	25.6	
10/11/2016	165	2.04	1.13	40	0.47	0.06	6.61	10.82	10.13	19.72	
10/14/2016	214	16.6	0.23	102	0.38	0	6.77	11.07	9.86	18.95	
10/18/2016	198	3.3	0.67	112	0.17	0.16	6.66	10.48	9.66	20.19	
10/21/2016	188	14	0.34	138	0.15	0.17	6.75	10.34	9.63	21.9	
10/25/2016	50	4	0.4	75	0	0.03	6.84	10.27	8.95	19.1	
10/28/2016	167	12	0.36	88	0.36	0	6.69	10.1	8.84	16.8	
11/1/2016	210	0.42	0.37	150	0.07	0.19	6.92	10.62	9.24	22.6	
11/4/2016	180	0.2	0.55	100	0.15	0.06	6.64	12.14	9.56	23.09	
11/8/2016	195	0.23	0.47	120	0.21	0.08	6.7	11.51	9.52	14.1	
11/11/2016	178	0.19	0.44	90	1.1	0.03	6.56	11	9.59	23	
11/14/2016	130	7	0.2	125	0	0.11	6.54	12.35	10.69	21.47	

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.9 Appendix I: 2017 Field Data from System Sampling Locations

Date	Total iron (mg/l)			Ferrous Iron (mg/l)			pH			Influent Flow (gpm)	Notes for data usage
	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05	IT-01	IT-03	IT-05		
5/26/2017	160	5	0.74	95	0	0	6.49	10.7	9.37	21.49	
5/30/2017	300	23	0.16	215	23	0	6.08	11.43	9.57	28.72	
6/2/2017	85	0	0.01	30	4	0	6.56	11.34	10.26	25.03	
6/9/2017	175	3	0.08	290	0	0.01	6.42	11.37	10.4	28.81	
6/13/2017	220	28	0.2	135	8	0.2	6.45	10.72		23.25	
6/16/2017	435	0	0.15	310	0	0.58	6.49	10.72	9.79	23.3	
6/20/2017	180	17	0.23	140	0	0.13	6.49	11	9.46	23.4	
6/23/2017	215	12	0.11	110	0	0.09	6.54	10.85	9.42	23.26	
6/27/2017	175	46	0.03	155	3	0.36	6.51	11.48	9.58	21.47	
6/30/2017	195	0	0.2	115	20	0	6.46	10.06	9.23	21.85	
7/4/2017	165	0	0.2	130	1	0.06	6.53	10.18	9.03	22.85	
7/7/2017	158	17	0.92	80	2	0.22	6.57	10.07	8.75	23.2	
7/10/2017	175	19	0.66	145	1	0.16	6.56	10.13	8.7	21.15	
7/14/2017	140	1	0.33	175	1	0.26	6.42	10.19	8.98	23.52	
7/18/2017	160	3	0.44	95	3	0.03	6.56	10.17	8.73	22.2	
7/21/2017	185	0	0.2	175	0	0.03	6.53	10.14	9.01	30.52	
7/24/2017	220	11	0.69	145	3	0	6.56	8.44	8.22	27.65	
7/28/2017	200	10	0.32	140	0	0.04	6.45	10.03	8.41	22.65	
8/1/2017	210	4	0.52	25	8	0.03	6.56	10.09	8.68	22.25	
8/4/2017	185	3	0.3	150	0	0.03	6.43	9.81	8.6	21.64	
8/8/2017	170	13	0.36	115	0	0.05	6.49	10.48	8.68	23.5	
8/11/2017	210	0	0.56	150	0	0	6.55	10.12	8.72	22.95	
8/15/2017	275	1	0.33	35	0	0	6.47	9.81	8.64	22.69	
8/18/2017	150	0	0.31	130	0	0	6.57	10.11	8.68	26.42	
8/22/2017	160	55	0.2	65	3	0	6.47	9.97	8.7	21.4	
8/25/2017	155	17	0.59	120	0	0	6.51	8.64	8.49	25.91	
8/29/2017	166	18	0.48	165	1	0.07	6.48	10.32	8.75	18.31	
9/1/2017	185	5	0.48	145	0	0	6.56	10.26	8.7	21.13	
9/5/2017	169	21	0.57	118	1	0.09	6.58	8.8	8.38	24.86	
9/8/2017	255	10	0.35	160	0	0.03	6.53	8.49	8.53	26.76	
9/12/2017	185	31	0.33	130	0	0.07	6.44	8.95	8.36	22.5	
9/15/2017	225	28	0.45	115	0	0.06	6.49	8.57	8.25	22.67	
9/19/2017	180	21	0.61	140	0	0.02	6.56	8.37	8.18	26.53	
9/22/2017	125	4	0.38	125	0	0	6.59	8.33	8.01	25.6	
9/26/2017	143	2	0.39	45	0	0.07	6.52	8.15	8.01	23	
9/29/2017	165	7	0.59	170	0	0	6.55	8.72	8.31	23.63	
10/3/2017	200	5	0.55	170	2	0.03	6.61	9.13	8.41	23.76	
10/6/2017	225	0	0.54	90	0	0	6.67	8.91	8.22	24.19	
10/10/2017	220	6	0.31	170	0	0.19	6.54	8.65	8.28	25.86	
10/13/2017	165	7	0.92	145	0	0	6.77	8.65	8.16	24.92	
10/24/2017	445	11	1.25	140	9	0	6.6	10.8	8.3	22.92	
10/27/2017	150	30	0.49	90	5	0.05	6.56	10.05	8.46	16.57	
10/31/2017	210	34	0.54	180	6	0	6.55	8.98	8.51	22.25	
11/3/2017	205	20	0	110	6	0	6.63	9.12	8.51	22.26	
11/7/2017	205	0	0.42	145	0	0.34	6.75	9.26	8.46	24.91	
11/10/2017	280	17	0.43	245	13	0.07	6.51	8.63	8.49	24.5	

Key for Table: total = ferrous + ferric; IT-01 = combined influent, unfiltered; IT-03 = RCTS effluent, filtered at 0.45 µm; IT-05 = sedimentation basin effluent, unfiltered

7.10 Appendix J: Laboratory Data from System Sampling Locations

Sample Date	Sample ID	Total Al (mg/l)	Dissolved Al (mg/l)	Total Ca (mg/l)	Dissolved Ca (mg/l)	Total Fe (mg/l)	Dissolved Fe (mg/l)	Total K (mg/l)	Dissolved K (mg/l)	Total Mg (mg/l)	Dissolved Mg (mg/l)	Total Mn (mg/l)	Dissolved Mn (mg/l)	Total Na (mg/l)	Dissolved Na (mg/l)	Total Zn (mg/l)	Dissolved Zn (mg/l)	Alkalinity (mg/l as $CaCO_3$)	Total Sulfate (mg/l)
5/12/2009	IT-01	0.77	ND	460	ND	720	ND	43	ND	200	ND	11	ND	15	ND	0.16	ND	ND	3500
	IT-03	1.4	ND	1200	ND	690	ND	43	ND	190	ND	10	ND	15	ND	0.2	ND	ND	3100
6/9/2009	IT-01	0.83	ND	420	ND	650	ND	40	ND	190	ND	9.9	ND	14	ND	0.12	ND	ND	3500
	IT-03	1.6	ND	1100	ND	670	ND	44	ND	180	ND	9.7	ND	15	ND	0.15	ND	ND	2800
	IT-05	0.220 U	ND	760	ND	1.5	ND	41	ND	140	ND	0.65	ND	14	ND	0.040 U	ND	ND	2800
7/27/2009	IT-01	0.768	0.200 U J	416	414	779	724	43.1	42.3	189	184	11.5	11.5	15.8	14.6	0.14	0.138	42	3700
	IT-03	1.39	0.200 U J	1350	1090	755	0.100 U J	43.6	43.7	187	73.7	11.2	8.2 J	15.6	15.7	0.146	1.3 J	1200	2400
	IT-05	0.200 U J	0.200 U J	972	978	0.213	0.100 U J	41.7	41.3	85.6	84.5	11.6 J	6.2 J	15	14.8	1.8 J	1.2 J	13	2800
8/11/2009	IT-01	0.84	ND	430	ND	700	ND	ND	ND	190	ND	11	ND	ND	ND	0.11	ND	ND	3600
	IT-03	1.7	ND	1400	ND	700	ND	ND	ND	180	ND	10	ND	ND	ND	0.12	ND	ND	1800
	IT-05	0.220 U	ND	860	ND	0.44	ND	ND	ND	73	ND	0.28	ND	ND	ND	0.040 U	ND	ND	2600
9/8/2009	IT-01	0.78	ND	450	ND	760	ND	ND	ND	200	ND	11	ND	ND	ND	0.14	ND	ND	3600
	IT-03	1.3	ND	1200	ND	750	ND	ND	ND	190	ND	11	ND	ND	ND	0.14	ND	ND	2800
	IT-05	0.330 U	ND	910	ND	0.72	ND	ND	ND	77	ND	0.060 U	ND	ND	ND	0.060 U	ND	ND	2800
10/14/2009	IT-01	0.603 U	0.200 U	442	435	792	784	44.6	44	206	201	10.8	10.7	15.8	15.5	0.148	0.156	5.300 J	3600
	IT-03	1.25	0.200 U	1350	1110	781	0.293	44.3	46.6	194	87	10.4	0.0075 J	15.3	16.2	0.148	0.0036 J	910	2200
	IT-05	0.200 U	0.200 U	1020	970	0.474	0.100 U	44.8	43.8	84.1	84.2	0.0088 J	0.0041 J	15.8	15.3	0.002 J	0.0027 J	11	2600
11/9/2009	IT-01	0.73	ND	470	ND	790	ND	49	ND	210	ND	11	ND	17	ND	0.12	ND	ND	3300
	IT-03	1.6	ND	1500	ND	720	ND	46	ND	190	ND	9.9	ND	16	ND	0.13	ND	ND	1600
	IT-05	0.550 U	ND	1000	ND	0.25	ND	45	ND	86	ND	0.14	ND	16	ND	0.100 U	ND	ND	2600
8/16/2010	IT-01	1.2	0.490 U	450	440	690	690	43	43	200	200	8.9	8.9	15	15	0.080 U	0.090 U	ND	3500
9/8/2010	IT-01	0.440 U	ND	480	ND	720	ND	47	ND	210	ND	9.4	ND	17	ND	0.080 U	ND	ND	3100
10/4/2010	IT-01	0.75	0.490 U	500	470	850	800	49	49	220	210	11	11	17	18	0.09	0.098	ND	3400
	IT-05	0.440 U	0.490 U	940	910	0.54	0.180 U	47	45	130	120	0.080 U	0.090 U	17	16	0.080 U	0.090 U	ND	2800
11/3/2010	IT-01	0.330 U	ND	500	ND	740	ND	50	ND	210	ND	10	ND	18	ND	0.088	ND	ND	4200
6/6/2011	IT-01	0.330 U	0.370 U	450	460	650	660	45	47	190	190	9.1	9.3	17	17	0.060 U	0.067 U	ND	3400
	IT-05	0.220 U	0.250 U	820	850	1.4	0.090 U	43	44	140	140	0.040 U	0.045 U	16	16	0.040 U	0.045 U	ND	2700
7/12/2011	IT-01	0.330 U	0.370 U	490	450	650	620	46	44	200	200	9.5	9.1	16	17	0.075	0.067 U	ND	1500
	IT-05	0.220 U	0.250 U	870	800	3.7	0.090 U	46	42	150	140	0.057	0.045 U	16	16	0.040 U	0.045 U	ND	530
8/16/2011	IT-01	0.7	0.490 U	450	460	760	770	46	47	200	210	10	10	17	17	0.1	0.11	ND	3300
	IT-05	0.220 U	0.250 U	810	790	4.9	0.090 U	44	44	150	150	0.08	0.045 U	16	16	0.040 U	0.045 U	ND	2700
8/29/2011	IT-01	0.45	0.1	410	440 B	770 B	810	40	43	180	190	9.800 B	9.700 B	15	15.000 B	0.090 B	0.100 B	ND	3500
9/6/2011	IT-01	1.3	0.370 U	450	460	770	750	49	47	210	210	10	10	18	17	0.33	0.1	ND	3500
	IT-05	0.220 U	0.250 U	740	760	5.6	0.090 U	39	38	140	140	0.1	0.045 U	15	14	0.040 U	0.045 U	ND	2700
10/3/2011	IT-01	0.51	0.370 U	460	510	750	820	47	53	200	220	11	12	17	19	0.11	0.12	ND	3400
	IT-05	0.220 U	0.250 U	800	800	1.5	0.090 U	41	40	100	100	0.058	0.045 U	15	15	0.040 U	0.045 U	ND	2500
4/11/2012	IT-01	0.91	0.990 U	480	480	740	730	48	45	210	200	10	9.9	18	17	0.160 U	0.180 U	ND	3600
6/5/2012	IT-01	1.2	1.200 U	450	450	730	730	43	44	190	190	10	10	17	17	0.100 U	0.110 U	ND	3600
	IT-05	0.660 U	0.370 U	900	920	3	0.130 U	44	42	26	26	0.060 U	0.067 U	17	17	0.060 U	0.067 U	ND	2600
8/13/2012	IT-01	0.68	0.490 U	470	470	720	740	46	46	200	210	9.8	10	18	18	0.092	0.096	ND	3600
	IT-05	0.550 U	0.620 U	900	890	0.97	0.220 U	42	41	11	11	0.100 U	0.110 U	16	16	0.100 U	0.110 U	ND	2600
10/10/2012	IT-01	1	0.740 U	480	470	720	700	48	47	200	200	9.7	9.6	18	18	0.1	0.097	ND	4000
	IT-05	0.660 U	0.740 U	960	950	3.2	0.130 U	42	42	7.5	7	0.067	0.067 U	16	17	0.060 U	0.067 U	ND	2900
6/11/2013	IT-01	0.43	0.370 U	470	470	450	470	ND	ND	170	180	7.1	7.3	ND	ND	0.044	0.067 U	ND	ND
	IT-05	0.330 U	0.370 U	860	830	1.3	1.3	ND	ND	2.3	2.3	0.060 U	0.067 U	ND	ND	0.060 U	0.067 U	ND	ND
8/12/2013	IT-01	0.220 U	0.250 U	460	450	420	420	ND	ND	170	170	6.8	6.7	ND	ND	0.042	0.045 U	ND	2400
	IT-05	0.330 U	0.370 U	850	830	0.26	0.130 U	ND	ND	7.8	7.7	0.060 U	0.067 U	ND	ND	0.060 U	0.067 U	ND	2000
10/22/2013	IT-01	0.330 U	0.370 U	440	470	400	400	ND	ND	170	160	6.5	6.5	ND	ND	0.060 U	0.067 U	ND	2600
	IT-05	0.330 U	0.490 U	800	850	1.3	0.180 U	3.000 U	4.500 U	23	24	0.060 U	0.090 U	3.000 U	4.500 U	0.060 U	0.090 U	ND	2400
7/1/2015	IT-01	0.330 U	0.370 U	490	470	200	210	49	ND	140	130	4.6	4.5	16	ND	0.060 U	0.067 U	ND	2200
	IT-03	1.100 U	0.370 U	1100	820	210	0.130 U	40	ND	130	0.340 U	4.8	0.067 U	15	ND	0.200 U	0.067 U	ND	2000
	IT-05	0.660 U	0.370 U	650	590	5.7	3.5	39	ND	58	55	0.64	0.61	15	ND	0.120 U	0.067 U	ND	1700
9/16/2015	IT-01	0.330 U	0.370 U	470	470	200	210	43	ND	140 J	140	4.6	4.8	17	ND	0.060 U	0.067 U	ND	2300
	IT-05	0.330 U	0.370 U	690	690	0.19	0.130 U	41	ND	20	20	0.060 U	0.067 U	16	ND	0.060 U	0.110 U	ND	1900
10/26/2015	IT-01	0.220 U	0.250 U	460	450	210	190	38	ND	140	140	4.7	4.4	16	ND	0.040 U	0.045 U	ND	2200
	IT-03	0.59	0.490 U	890	670	210	0.180 U	42	ND	130	52	4.5	0.090 U	16	ND	0.060 U	0.090 U	ND	2100
	IT-05	0.330 U	0.370 U	660	580	0.57	0.130 U	40	ND	69	65	0.060 U	0.067 U	15	ND	0.060 U	0.067 U	ND	1800
7/12/2016	IT-01	0.330 U	0.370 U	470	460	180	180	39	ND	130	130	4.1	4.2	16	ND	0.060 U	0.067 U	ND	2100
	IT-03	0.44	0.370 U	800	640	190	0.130 U	36	ND	130	67	4.2	0.067 U	16	ND	0.040 U	0.067 U	ND	2000
	IT-05	0.330 U	0.370 U	580	570	0.45	0.130 U	40	ND	72	71	0.060 U	0.067 U	15	ND	0.060 U	0.067 U	ND	1800
10/19/2016	IT-05	0.330 U	0.370 U	610	620	0.250 B	0.130 U	39	ND	30	30	0.060 U	0.067 U	15	ND	0.060 U	0.067 U	ND	1900

Dissolved = filtered at 0.45 µm; IT-01 = combined influent; IT-03 = RCTS effluent; IT-05 = sedimentation basin effluent. ND = No Data; B = detected in blank; J = quantitation is approximate due to limitations identified in quality control review; U = value is not detected and detection limit is reported; U J = value is not detected and detection limit is estimated. Total and dissolved Ag, As, Ba, Be, Cd, Cr, Co, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sr, Tl, and V were analyzed but all were below detection so not included in this table.

7.11 Appendix K: Dissolved Oxygen (DO) Concentrations in 2009 at Primary System Sampling Locations

Sample Date	Sample ID	Dissolved Oxygen (mg/l)	Temperature (°C)
5/12/2009	IT-01	2.72	11.9
	IT-03	6.93	13
6/9/2009	IT-01	5.53	10.5
	IT-03	6.53	11.4
	IT-05	6.04	16.4
7/27/2009	IT-01	5.13	14.8
	IT-03	6.22	14.9
	IT-05	6.02	22.9
8/11/2009	IT-01	4.5	15.2
	IT-03	7.01	15.2
	IT-05	5.3	21.7
9/8/2009	IT-01	4	12.7
	IT-03	5	12.8
	IT-05	4.27	18
10/14/2009	IT-01	5	12.5
	IT-03	7.61	12.1
	IT-05	9.1	10
11/9/2009	IT-01	3.3	12.3
	IT-03	5.8	11.9
	IT-05	7.06	9.2
Average	IT-01	4.3	12.8
	IT-03	6.4	13.0
	IT-05	6.3	16.4
Minimum	IT-01	2.7	10.5
	IT-03	5.0	11.4
	IT-05	4.3	9.2
Maximum	IT-01	5.5	15.2
	IT-03	7.6	15.2
	IT-05	9.1	22.9

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