# RARE EARTH TECHNOLOGY FOR LOW-LEVEL P REMOVAL AND ENHANCED SLUDGE PROPERTIES

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## Abstract

With environmental regulations continuing to restrict the discharge of phosphorus from wastewater treatment facilities across the globe, traditional methods of phosphorus removal are proving inadequate. Facilities have received new upcoming phosphorus discharge limits and must explore viable options to achieve these limits, some as low as 0.07 mg/L-P. Many facilities in the United States have chosen to use a new rare earth technology to meet their phosphorus discharge permit due to its unique and effective reactivity with phosphate and, in addition, its ability to reduce sludge volumes and prevent the formation of struvite. Case studies from wastewater treatment facilities in Wisconsin, Minnesota & Pennsylvania will be presented which review the performance of rare earth technology to meet each facility's upcoming phosphorus permit level below 0.1 mg/L-P as well as show the sludge reduction properties and dewatering benefits of rare earth technology in their facility.

## Keywords

Chemical coagulant, Dewatering, Nutrient removal, Phosphorus removal, Rare earth, Sludge reduction, Wastewater treatment, Water clarification

## Introduction

As clean water becomes scarce, the removal of contaminants from wastewater is becoming increasingly important. Nutrients such as phosphorus (P) as phosphate ($PO_4^{3-}$) serve as a food source for algae. Recently excessive amounts of P in natural waters have led to eutrophication or large algal blooms which release toxins into the water and deplete dissolved oxygen concentrations. These consequences result in the death of other fresh water species and the contamination of drinking water sources. As a result, new regulations in the United States are being put into place that greatly restrict the discharge of P into the environment. New wastewater treatment plant discharge permits are requiring ever lower P concentrations in the effluent. These lower permit limits can be difficult to reach with existing technology. Typical iron and aluminium based coagulants have difficulty reaching these limits and new capital equipment can be cost prohibitive. Rare Earth (RE) technology has emerged as a viable alternative technology which can help reduce the effluent P concentration through chemical addition alone. RE technology from Neo Chemicals & Oxides (Neo) is a liquid coagulant that contains the rare earth (RE) elements lanthanum (La) and cerium (Ce). RE technology has proven to be effective at removing P without the need for additional capital equipment. Described herein is the chemistry of RE elements in wastewater and three case studies where RE technology was used to remove P to very low limits. The benefits of RE technology such as lower dose rate, lower P levels achieved, less sludge produced, and improved sludge dewatering efficiency are also described.

## Rare Earth Chemistry in Wastewater

The rare earth elements are the set of 15 elements with atomic numbers 57-71 as well as Yttrium(Y, Atomic number: 39). They are located on the lower portion of the periodic table sometimes referred to as the f-block. Until about 60 years ago, not much was known about these elements. The term "rare earth" is actually a misnomer because the elements are not rare. For example, the two RE elements of interest to this paper, La and Ce, are the 26th and 28th most abundant elements in the Earth's crust, respectively (Greenwood, 2001). In nature, rare earth elements are found in over 100 minerals with major deposits in India, South Africa, Brazil, Australia, Malaysia, and the USA (Greenwood, 2001). The rare earths in general and particularly La and Ce form very strong bonds with oxyanions like phosphate and carbonate. The La and Ce bond with phosphate is so favoured that common rare earth containing minerals contain rare earth phosphate. This strong bonding is the basis for the use of rare earths as phosphate removal agents. Rare earth based products like those from Neo have been used for phosphate removal from water in multiple industries like aquarium water treatment (Zhang n.d., Yaiullo 2007, Knop 2009), pool and spa water treatment (Mills 2000, Kulperger 2002, Kulperger 2003, Lowry 2003, Mills 2005), and lake remediation (Phoslock n.d., Peterson 1974). In wastewater treatment several patents were published circa 1970 describing the use of rare earth salts for precipitation and removal of phosphate (Daniels 1971, Kleber 1976). All of this demonstrates rare earth based products are effective at removing P in a variety of water treatment applications.

The typical coagulants used in wastewater treatment are iron (Fe) and aluminum (Al) based. Fe based coagulants include ferric chloride, ferrous sulfate, and ferrous chloride among others. Al based coagulants include aluminum sulfate (alum), sodium aluminate, and polyaluminum chloride (PAC). RE technology has emerged as a viable alternative technology for P removal. The principle difference between Fe, Al and RE based products is the mechanism by which phosphate is removed, as shown in Figure 1. There has been some debate about the mechanism of Fe and Al based products. Originally it was thought that Fe and Al formed $FePO_4$ or $AlPO_4$, but recent studies have shown that the mechanism is more complicated. Smith has reported that the mechanism actually consists of a two-step process. A metal oxide such as $Al_2O_3$ or $Fe_2O_3$ initially forms which is followed by adsorption of phosphate onto the metal oxide surface (Hanlon 2015). This mechanism is consistent with the observed need for increasing amounts of Fe or Al at low phosphate concentrations, i.e. the adsorption process is less efficient when there is little phosphate present.

**Figure 1. Depiction of phosphate removal reaction mechanism of RE vs. Fe**

In contrast, the mechanism for rare earth removal of phosphate is a straightforward metal phosphate precipitation resulting in the formation of the mineral rhabdophane, which is a stable form of RE found in nature. The precipitation reaction can be described by the equation

$RE^{3+} + PO_4^{3-} \rightarrow REPO_4 \cdot H_2O$

While RE can react in a similar mechanism to that of Fe and Al via the formation of a $RE(OH)_3$ which can adsorb phosphate, the precipitation reaction with phosphate to form rhabdophane is greatly favoured.

Another difference between Fe, Al, and RE based coagulants is the molar ratio of the coagulant metal to P that is needed to remove P to the desired level. The phosphate removal performance of various Fe, Al, and RE based coagulants vs the molar ratio of coagulant to P is shown in Figures 2 and 3. This data was collected using standard jar testing techniques. Regardless of starting P concentration, addition of the RE resulted in a RE:P ratio of 1:1. By comparison, Fe and Al based coagulants need to be dosed at higher mole ratios (at least 2.5:1 (Fe or Al):P) in order to achieve similar P concentrations.

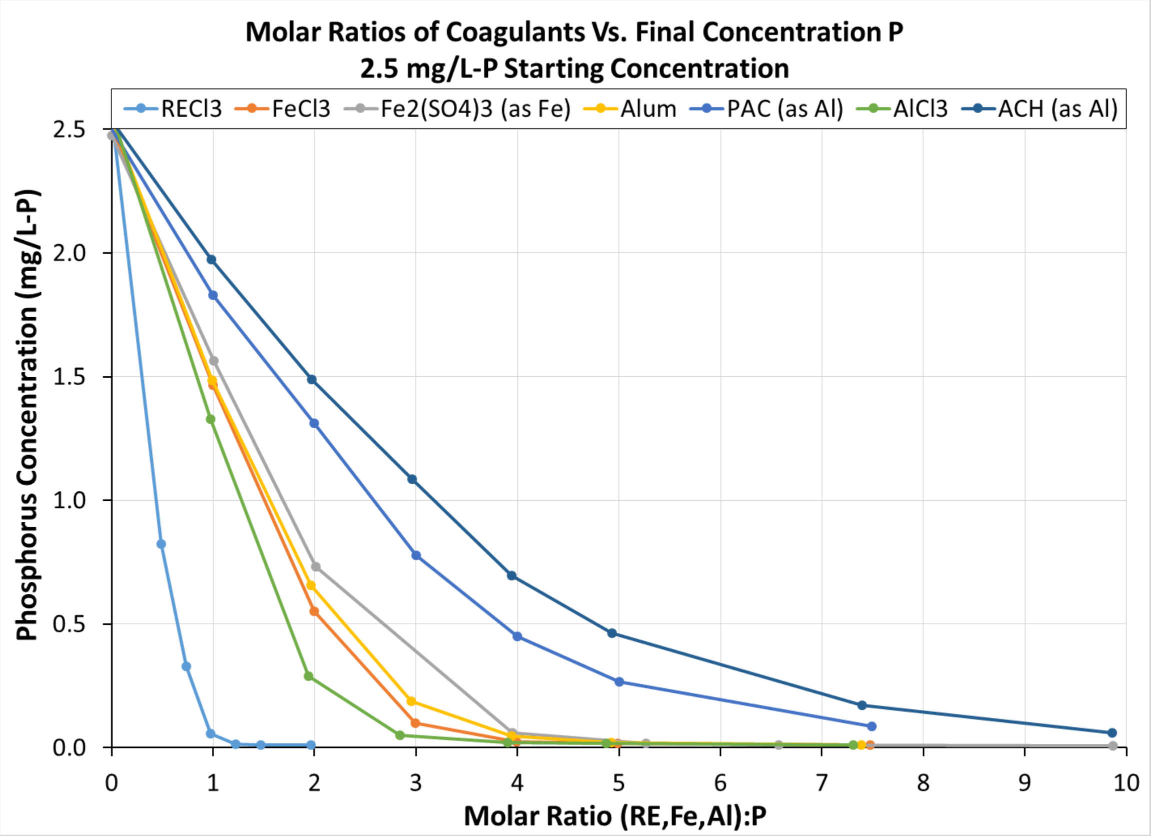

**Figure 2. P removal vs. molar ratio for various coagulants. Beginning P concentration of 2.5 mg/L.**

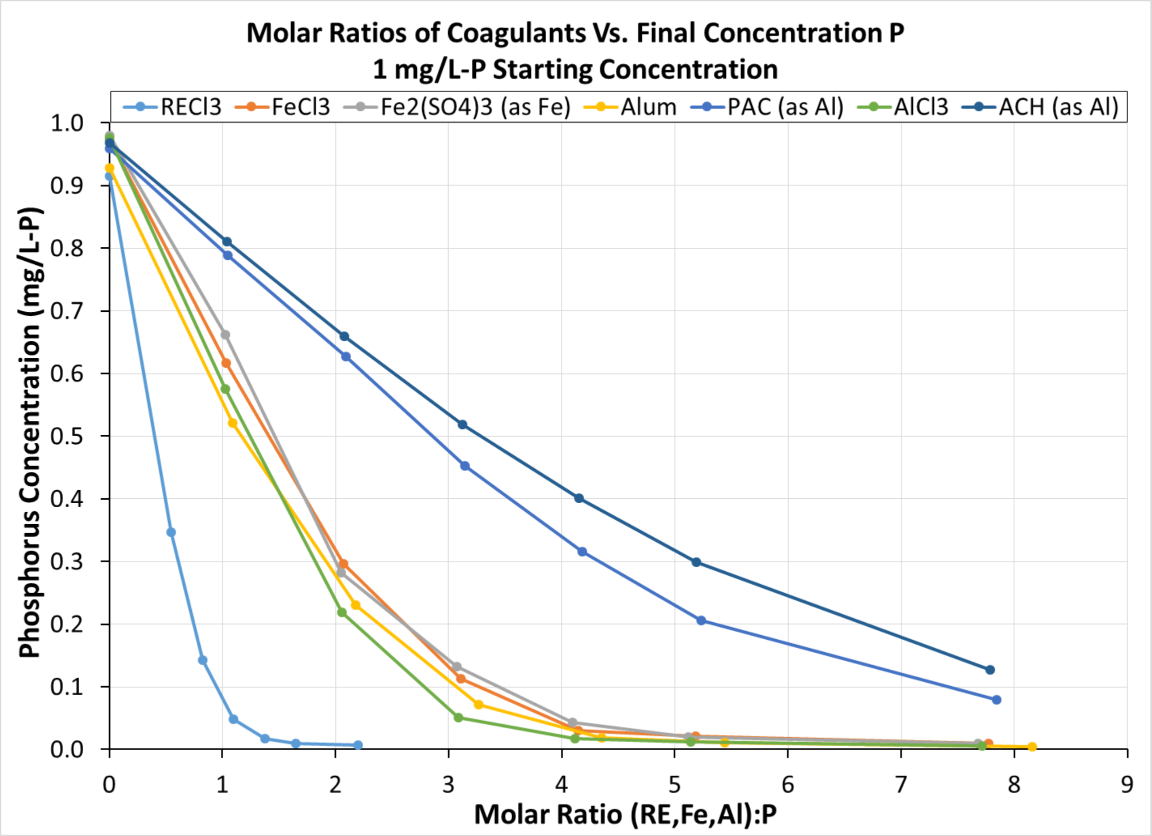

**Figure 3. P removal vs. molar ratio for various coagulants. Beginning P concentration of 1.0 mg/L.**

The RE to P reaction mechanism accounts for the near 1:1 RE:P molar ratio observed for P removal. In this way RE technology is unique among coagulants.

When comparing the amount of sludge generated from these coagulants it is clear that RE technology will produce less sludge. As a theoretical example, if RE is compared with Fe and Al on an influent stream that has 0.8 mg/L-P and a desired effluent P of 0.06 mg/L the data in Table 1 is generated.

In this example, the P concentration is reduced from 0.8 to 0.06 mg/L. The dose of coagulant is based on the molar ratio of the metal (M) to the influent P concentration. Fe and Al are multiplied by 4 due to the data in Figure 3 indicating a molar ratio of 4:1 is needed to achieve an effluent concentration of 0.06 mg/L-P. The amount of $MPO_4$ produced is calculated based on a 1:1 $M:PO_4$ ratio. The excess M added is assumed to be converted to $M(OH)_3$. Thus the total sludge produced is the sum of the $MPO_4$ and $M(OH)_3$ masses. In this example, the addition of RE will produce 6.00 mg of sludge per liter of solution. This is 51% less than the sludge produced by Fe and 34% less than the amount produced by Al addition. Dividing the amount of sludge produce by the amount of P removed yields a general estimate of the amount of sludge produced per mg/L of P removed. Based on this example, RE will produce 8.10 mg sludge/L of solution per mg/L of P removed.

RE technology also improves coagulation. This is accomplished by forming denser solids and removing the phosphates ability to disperse the solids. When comparing the solids formed in the precipitation of phosphate, the solids formed with iron or aluminum coagulants have a lower density than the solids formed with RE. See Table 2 which lists the potential species formed, the molecular weights of the metal coagulants and the density of the precipitates.

**Table 1:** **Estimation of sludge generated from coagulant addition**

| | RE | Fe | Al |
|---|---|---|---|
| Influent P (mg/L) | 0.8 | 0.8 | 0.8 |
| Effluent P (mg/L) | 0.06 | 0.06 | 0.06 |
| M:P Molar Ratio | 1 | 4 | 4 |
| MW of M (g/mol) | 140 | 56 | 27 |
| MW of $MPO_4$ (g/mol) | 235 | 151 | 122 |
| MW of $M(OH)_3$ (g/mol) | 191 | 107 | 78 |
| M dosed (mg/L) | 3.62 | 5.80 | 2.80 |
| $MPO_4$ sludge produced (mg/L) | 5.63 | 3.61 | 2.92 |
| $M(OH)_3$ sludge produced (mg/L) | 0.37 | 8.52 | 6.21 |
| Total chemical sludge produced (mg/L) | 6.00 | 12.13 | 9.13 |
| Sludge produced per mg P removed (mg/L) | 8.10 | 16.40 | 12.34 |
| %Reduction using RE | - | 51% | 34% |

**Table 2:** **Molecular weights and density of solids generated from coagulant addition**

| Precipitate formed | Molecular Weight of Metal (g/mol) | Density of Solids (g/ml) |
|---|---|---|
| Aluminum hydroxide $Al(OH)_3$ | 27 | 2.42 |
| Aluminum phosphate $AlPO_4$ | 27 | 2.57 |
| Iron phosphate dehydrate $FePO_4{\cdot}2H_2O$ | 55.85 | 2.87 |
| Iron hydroxide oxide Fe(O)OH | 55.85 | 3.4-3.9 |
| Rare Earth phosphate $REPO_4{\cdot}H_2O$ | 138-175 | 4 |
| Rare Earth hydroxide $RE(OH)_3$ | 138-175 | ~4.3 |

The mechanism of precipitations described previously indicates that when Fe or Al salts are used a metal hydroxide is formed and phosphate binds to the surface. Phosphate is a known dispersion agent which means it will help keep particles suspended. Trisodium phosphate along with tetrasodium pyrophosphate have been shown to effectively suspend laterite type soils which contain high concentrations of iron and aluminum oxide (Wintermyer 1955). Thus, when Fe or Al salts are added, iron or aluminum hydroxide forms, phosphate binds to the surface and as a result the particles are suspended. Thus coagulant added to remove phosphate ends up being a solid dispersed by phosphate. In contrast, the dominant mechanism for phosphate removal with RE is by formation of $REPO_4{\cdot}H_2O$ which effectively binds the phosphate rendering it incapable of suspending solids. This leads to the formation of a more compact solid which can be more easily dewatered.

The addition of RE technology to wastewater has the potential to remove multiple different anions. In addition to P as phosphate, the rare earth elements in RE technology can form insoluble complexes with carbonate ($CO_3^{2-}$), hydroxide ($OH^-$), and fluoride ($F^-$). Examples of these reactions are shown in Table 3. Also listed in Table 3 is the precipitation pH range, the solubility product ($K_{sp}$) and concentration of RE calculated from the $K_{sp}$. The $K_{sp}$ is a measurement of the solubility of a solid and is calculated by multiplying the equilibrium concentrations of the cation and anion with each raised to the power of its stoichiometric equivalent. For example, for $CePO_4$

$K_{sp} = [Ce^{3+}][PO_4^{3-}]$

while for $CeF_3$

$K_{sp} = [Ce^{3+}][F^-]^3$

The lower the equilibrium concentration, the smaller the $K_{sp}$, and thus the more insoluble the solid. For practical purposes, the smaller the $K_{sp}$ is the less soluble the reaction product. As a comparative example, the $K_{sp}$ of table salt (NaCl) is $3.73x10^1$. This $K_{sp}$ is 26 orders of magnitude greater than that of cerium phosphate and thus NaCl is very soluble and cerium phosphate is very insoluble.

**Table 3: Common reactions between rare earths and anions**

| Anion | Reaction than forms an inert solid | Precipitation pH range | $K_{sp}$ | Equilibrium Free RE in Solution, mg/L (pH 7) |
|---|---|---|---|---|
| Phosphate | $La^{+3}_{(aq)} + PO_4^{-3}_{(aq)} \rightarrow LaPO_4 \cdot H_2O_{(s)}$<br>$Ce^{+3}_{(aq)} + PO_4^{-3}_{(aq)} \rightarrow CePO_4 \cdot H_2O_{(s)}$ | >2 | $5.0x10^{-25}$ | $9.9x10^{-8}$ |
| Carbonate or Bicarbonate | $2La^{+3}_{(aq)} + 3HCO_3^-_{(aq)} \rightarrow La_2(CO_3)_{3(s)} + 3H^+_{(aq)}$<br>$2La^{+3}_{(aq)} + 3CO_3^{-2}_{(aq)} \rightarrow La_2(CO_3)_{3(s)}$<br>$2Ce^{+3}_{(aq)} + 3HCO_3^-_{(aq)} \rightarrow Ce_2(CO_3)_{3(s)} + 3H^+_{(aq)}$<br>$2Ce^{+3}_{(aq)} + 3CO_3^{-2}_{(aq)} \rightarrow Ce_2(CO_3)_{3(s)}$ | >3.5 | $\sim 8x10^{-36}$ | 0.01 |
| Hydroxide Alkalinity | $La^{+3}_{(aq)} + 3OH^-_{(aq)} \rightarrow La(OH)_{3(s)}$<br>$2La(OH)_3 + 6OH^- \rightarrow La_2O_{3(s)} + 6H_2O$<br>$Ce^{+3}_{(aq)} + 3OH^-_{(aq)} \rightarrow Ce(OH)_{3(s)}$<br>$2Ce(OH)_3 + 6OH^- \rightarrow Ce_2O_{3(s)} + 6H_2O$ | >4 | $1.0x10^{-22}$ | 0.19 |
| Fluoride | $La^{+3}_{(aq)} + 3F^-_{(aq)} \rightarrow LaF_{3(s)}$<br>$Ce^{+3}_{(aq)} + 3F^-_{(aq)} \rightarrow CeF_{3(s)}$ | 3-8 | $1.8x10^{-19}$ | 1.26 |

Typical wastewater effluent needs to be in the pH range of 6-9 and as seen in Table 3 the pH range where RE will precipitate these anions is well within this range. Also the lowest equilibrium free ion concentration calculated from the $K_{sp}$ in Table 3 is for the reaction with phosphate. This is further evidence that RE will favour precipitation of P.

RE technology is a RE based solution which is added into wastewater to remove P and/or to improve solids settling. Compared to other coagulants it is less corrosive and easier to handle. RE technology has a pH of 3-4 and a freezing point of -40°C. This pH means it is non-hazardous for transportation. It can be stored outside in most locations and heat tracing additions lines is not necessary. It is also less corrosive than coagulants like ferric chloride.

## Case Studies in Wastewater Treatment Plants

### Hartford Wisconsin

For the last twenty years, the Wisconsin Department of Natural Resources (WDNR) has limited total phosphorus (TP) in municipal wastewater treatment plant effluents to 0.6 to 1.0 mg/L-P as a means of preventing eutrophication of Wisconsin's surface waters. Wisconsin's watersheds flow into the Mississippi River Basin and Lake Michigan, and in 2010 the State accepted its share of overall nutrient reduction targets set forth under the Gulf Hypoxia Action Plan and the Great Lakes Restoration Initiative.

To meet its targets, WDNR implemented numeric nutrient-related water quality standards for all of its watersheds. As a result, four hundred Wisconsin municipal wastewater treatment plants will receive new TP discharge permits between 0.5 mg/L-P and 0.04 mg/L-P in the next few years. The majority of the affected plants cannot meet their new discharge permits with their current plant layouts and will need to install or upgrade their biological and/or chemical phosphorus removal systems. To reach a permit of 0.1 mg/L-P, for example, the WDNR estimated that plants would need to install enhanced biological phosphorus removal, rapid mix and flocculation chemical addition, sand filtration and enhanced biosolids handling (William 2012).

One of these affected plants is the City of Hartford Water Pollution Control Facility (WPCF), a 12,870 $m^3$/day municipal wastewater treatment plant which discharges directly into the Rubicon River. Hartford was one of the first municipalities in Wisconsin to receive a new TP permit for a final water quality based effluent limit (WQBEL) of 0.075 mg/L-P. The permit will go into effect in 2017. The plant has no dedicated biological phosphorus removal system, and relied on ferrous chloride for chemical phosphorus removal. Attempts to reach 0.075 mg/L-P with ferrous chloride were unsuccessful. Increasing the ferrous chloride dose to 30–60 $ppm_v$ only reduced TP to an average of 0.5 mg/L-P. Even with ferrous chloride doses of 100–120 $ppm_v$, phosphorus in the final effluent could only be reduced to 0.3 mg/L-P.

Capital costs for installation of new nutrient removal equipment were estimated at $2.8M (USD) (William 2012), with accompanying higher maintenance and operating costs for years to come. When plant management became aware of the targeted phosphorus removal efficiency of RE technology, they were interested to see whether RE chemical phosphorus removal alone could achieve the 0.075 mg/L-P TP permit limit.

The Hartford WPCF plant process (Figure 4) includes screening, primary clarification, biological treatment in an oxidation ditch, final clarification, anthracite sand filtration and ultraviolet light disinfection. Ferrous chloride had been added in the inner channel of the oxidation ditch and the same dose location was used for RE technology when the trial began in August 2014.

Figure 5 shows ferrous dosing prior to the trial, RE technology dosing during the trial, and final effluent TP during the trial to achieve 0.075 mg/L-P. Influent P averages around 6 mg/L-P. The plant turned off the ferrous chloride for nine days prior to dosing RE technology. This approach minimized the chance that RE technology would remove phosphorus from iron flocs already present in the activated sludge. RE has been observed to remove adsorbed P from Fe and Al flocs. Right before the trial, after nine days of no chemical phosphorus removal, TP in the final effluent was 2.2 mg/L-P. After 16–18 hours at a dose of 363 L/day, orthophosphorus in the final effluent went down from 2.1 mg/L to 0.6 mg/L. The dose was increased to reach the lower limit and after an equilibration time of approximately three weeks, the total phosphorus in the effluent could be maintained to an average of less than 0.075 mg/L-P with 715 L/day of RE technology.

The plant did not need to meet its new 0.075 mg/L-P TP permit until 2017, but decided to switch over to RE technology to meet its interim 0.60 mg/L-P limit. The RE technology dosage was reduced to allow the effluent phosphorus levels to rise. The dose was reduced to an average of 324 L/day and the final effluent TP subsequently rose to an average of 0.11 mg/L-P total phosphorus, which is still far below the 0.60 mg/L-P permit limit. Compared to ferrous, this is a significantly lower dose as ferrous was added at ~600 L/day to reach 0.45 mg/L-P.

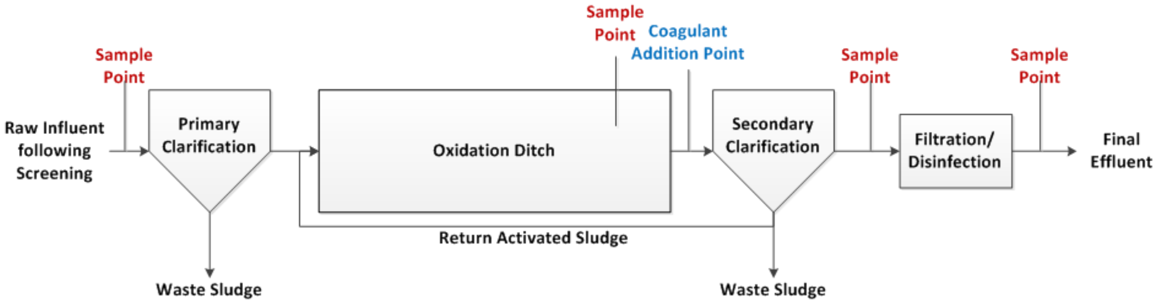

**Figure 4. Hartford plant process.**

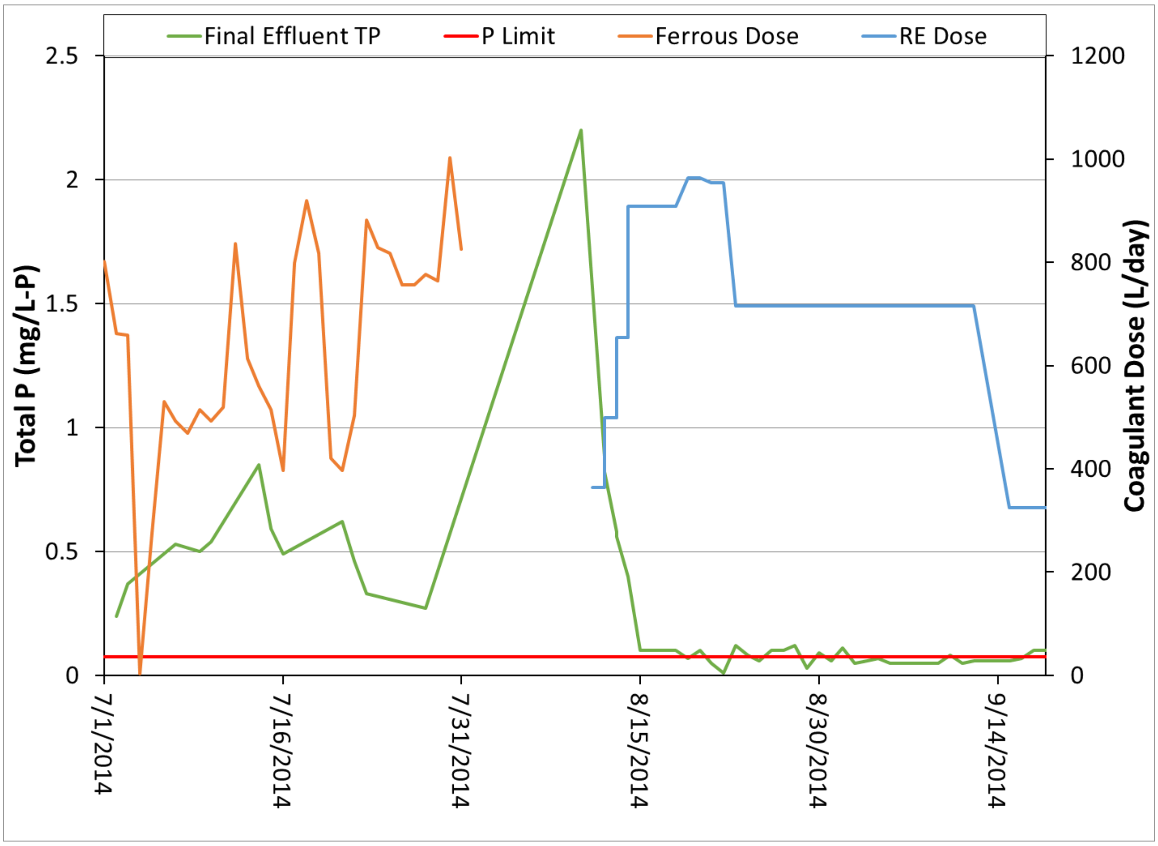

**Figure 5. Coagulant Dose and Effluent TP at Hartford**

From the reduction in dose and the trial data, a dosage curve, figure 6, was generated. This data represents the average effluent P for a specific dose. The initial dose necessary to achieve <0.075 mg/L-P was 715 L/day. However, as RE builds up in the return activated sludge, the dose was lowered over time. A dose of 460 L/day was needed to maintain the limit but after continued use the required dose in 2016 was 208 L/day which is an 80% decrease from the initial trial dose and a 54% reduction from the sustained trial dose.

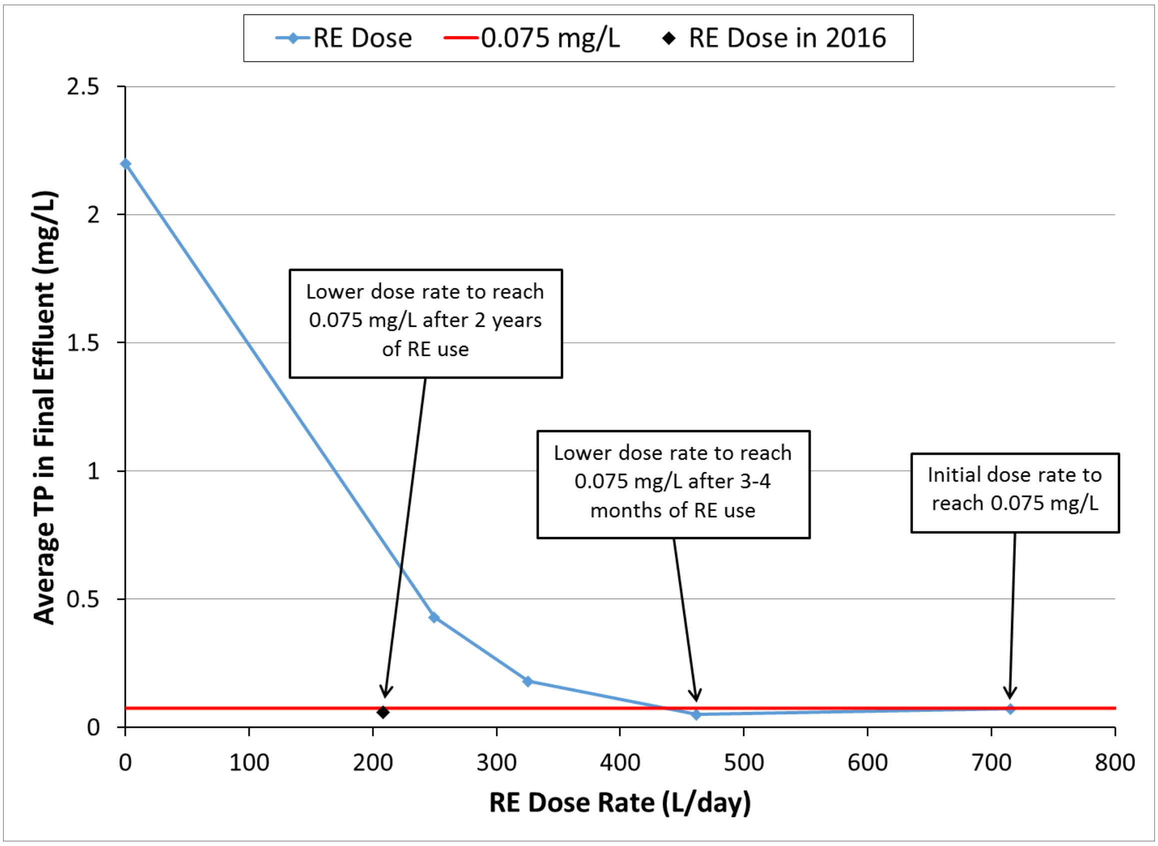

**Figure 6. Effluent P vs. RE Dose Curve at Hartford**

Harford also observed a reduction in sludge. This plant's sludge is not digested but stored in a 7,570 $m^3$ tank where farmers can pick up the sludge for land application. In years prior to RE usage, when ferrous was used, the tank has nearly reached capacity in winter. This has not been the case in years since RE has been implemented. In 2013, when ferrous chloride was used exclusively, the plant produced 22,712 $m^3$ of sludge and met a 1 mg/L-P discharge limit. This is quite large when compared to 2016 when RE was used and the plant produced only 14,006 $m^3$ of sludge (a 38% decrease) and met a 0.075 mg/L-P discharge limit. The most striking difference is the P discharge achieved was 0.075 mg/L with RE and 1 mg/L with ferrous. Thus a sludge reduction was observed even with the achievement of a significantly lower P discharge.

This trial shows RE technology can meet P discharge limits down to 0.075 mg/L-P with a lower dose than competing coagulants. Furthermore RE produced less sludge to achieve a lower P limit than the Fe coagulant used previously.

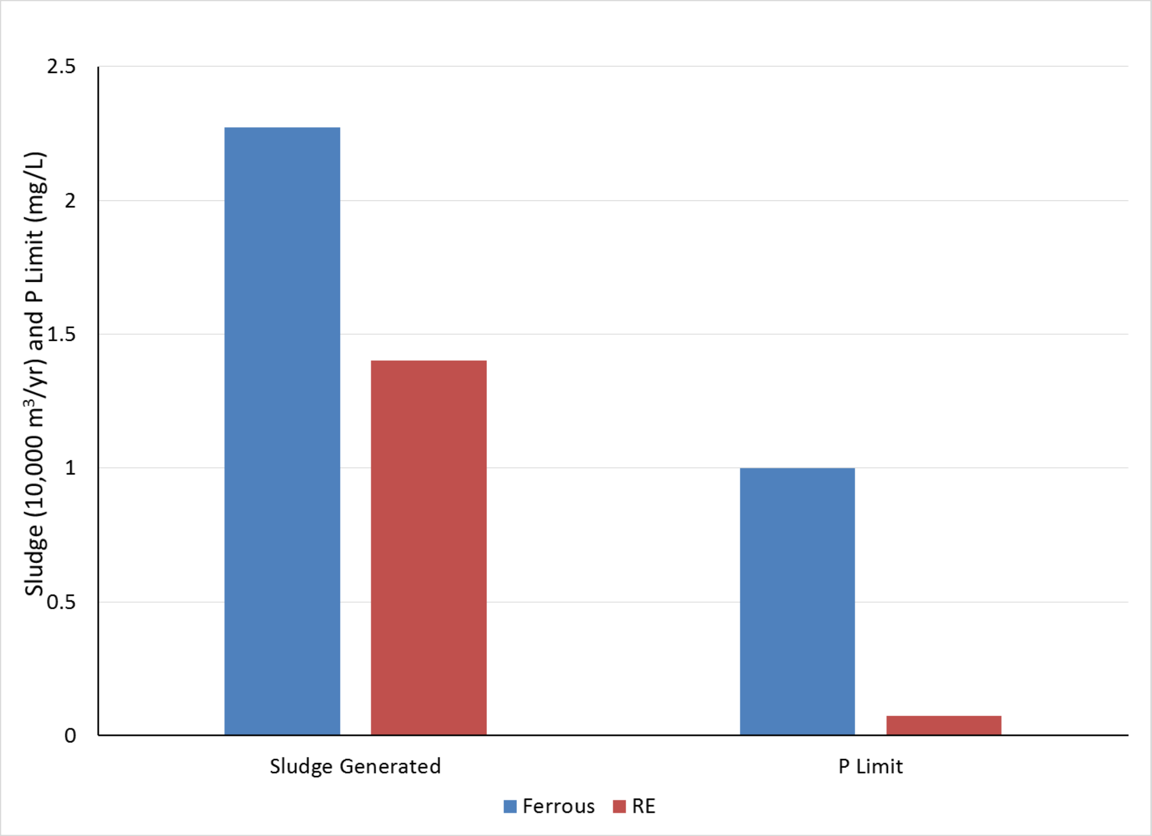

**Figure 7. Sludge generated in 10,000 m$^3$ per year using Ferrous or RE. P limit in mg/L met with each is included**

**City of Virginia Minnesota**

Virginia, MN has a 7,570 m$^3$/day municipal wastewater treatment plant, which discharges into a eutrophication impaired lake, and has been ordered by the Minnesota Pollution Control Agency to achieve a 0.075 mg/L-P monthly average total phosphorus discharge. The plant uses ferric chloride to reach a limit of 0.5 mg/L-P. With the pending lower limit, the plant has been evaluating P removal technologies. Thus, a full-scale trial with RE technology was conducted. The influent P averages around 2 mg/L-P but can range from 1-4 mg/L-P. Figure 8 shows the overall plant layout and coagulant dose point.

Prior to dosing RE technology, baseline information was collected for 1 month where ferric chloride was used to meet the 0.5 mg/L-P limit. Ferric was then turned off for 1 week. RE technology was then dosed at the head of the aeration basins at a rate of 368.7 L/day for 2 weeks, then 262 L/day for 2 weeks, then 121 L/day for 2 weeks and finally 65.5 L/day until no more remained. Samples were taken regularly. The samples were measured daily for total phosphorus. When RE technology was evaluated, the effluent TP dropped rapidly and within 7 days was below the target limit of 0.075 mg/L-P. The initially high dose rate rapidly gets the RE into the system and can then be lowered while maintaining the TP discharge limit. This method is effective for rapidly lowering the P and optimizing the dose to meet the P demand.

Figure 9 shows the influent and effluent total P and figure 10 shows the effluent P and the dosage during the RE trial. During the entire time influent P levels were around 3 mg/L-P. Since coagulant dosing was turned off for 5 days prior to dosing, the effluent P level increased to approximately 1.2 mg/L-P. After addition of RE began the effluent P level rapidly reduced to below the target limit of

0.075 mg/L-P. This was achieved within 7 days of dosing. The effluent P level continued to decrease for another 7 days. Around this point the dosage was reduced, but the effluent P level remained the same. For the next 2 weeks the effluent P remained at a somewhat constant level after which the RE dose was reduced again. At this point a slight increase in effluent P is seen but it still remains below the 0.075 mg/L-P limit. After the final reduction in RE dose, the effluent P is briefly above the limit. From this data it is clear that RE technology was capable of reaching the effluent P limit of 0.075 mg/L-P with a moderate dose of 121 L/day.

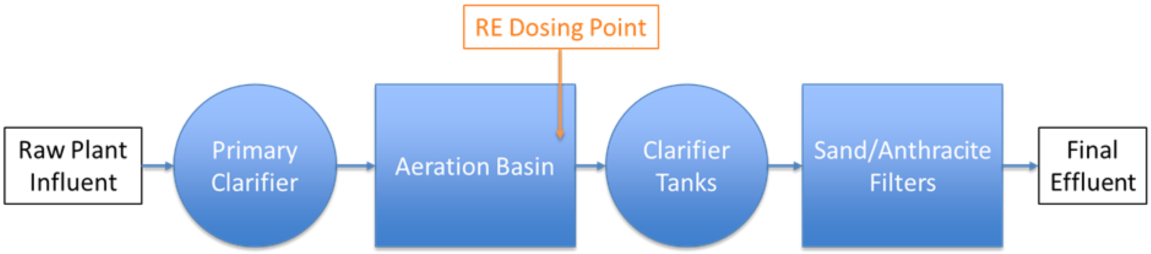

**Figure 8. Virginia, MN plant layout.**

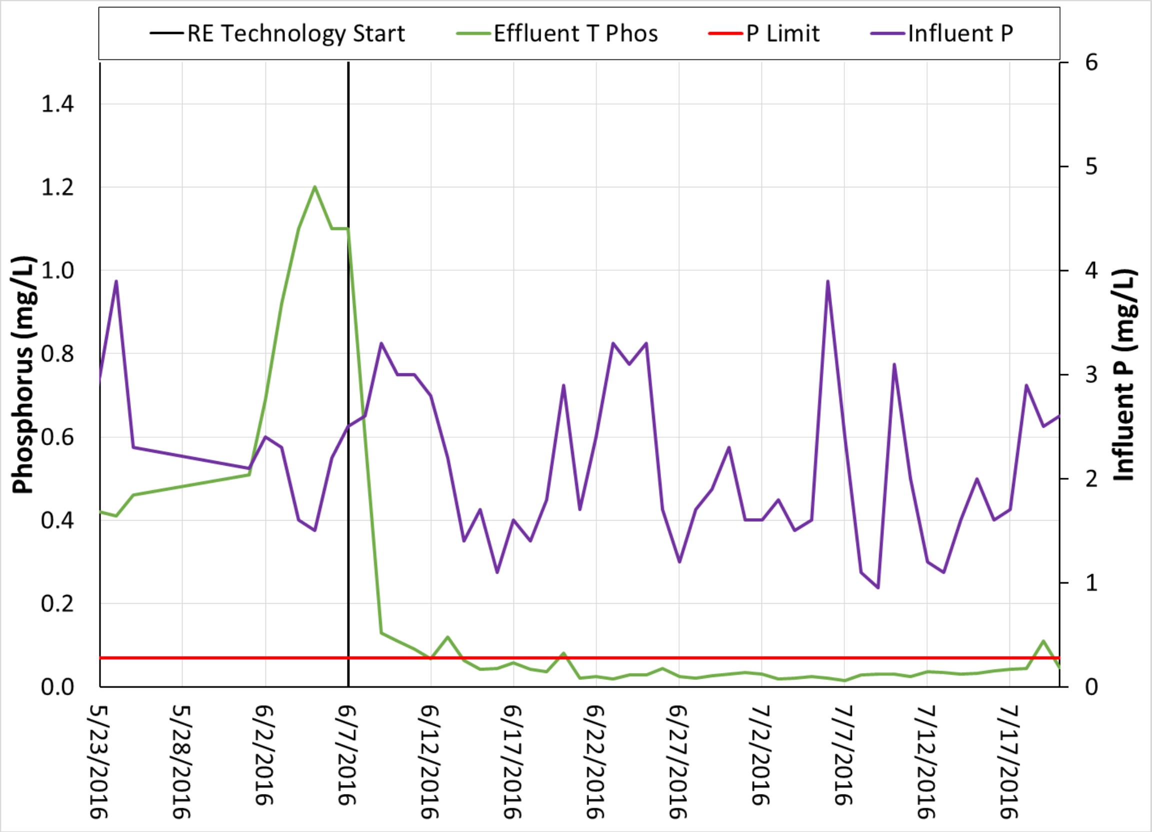

**Figure 9. TP discharge at City of Virginia, MN using RE Technology**

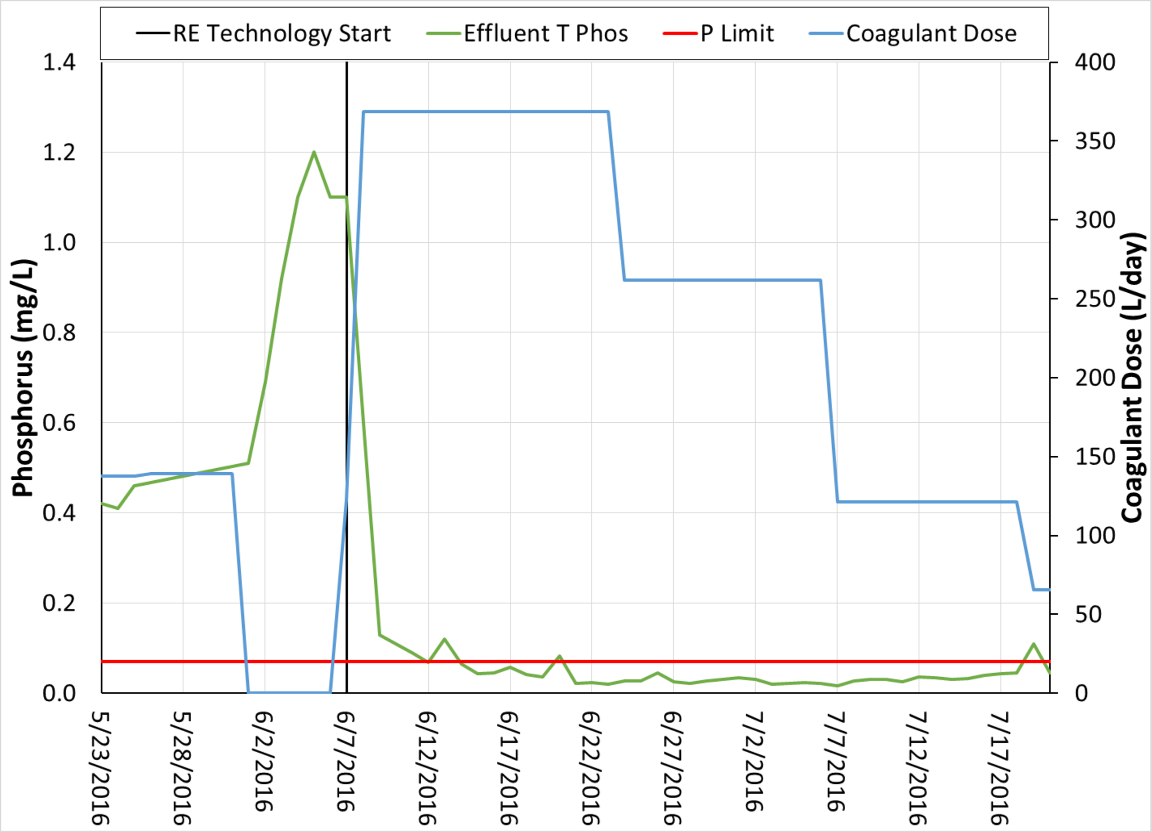

**Figure 10. Coagulant dose and TP discharge at City of Virginia, MN using RE Technology**

This plant quantifies the sludge benefits by measuring the dewatering efficiency each month. What is measured is the total volume of water separated from the solids, the average volume per hour and the maximum volume per hour. Table 4 and 5 contain the measured data for the 5 month prior and 3 months after RE technology was implemented.

**Table 4: Virginia, MN Dewatering Efficiency per month Pre RE Technology (Ferric Chloride Used)**

| Month | Total m$^3$ | Average m$^3$/hr | Max m$^3$/hr | Target P Limit (mg/L) |
|---|---|---|---|---|
| January | 728 | 35.5 | 37.6 | 1 |
| February | 923 | 28.1 | 31.5 | 1 |
| March | 826 | 29.5 | 30.9 | 1 |
| April | 267 | 13.6 | 14.8 | 1 |
| May | 755 | 28.1 | 39.7 | 1 |
| Average | 700 | 27.0 | 30.9 | |
| Average without April | 808 | 30.3 | 34.9 | |

It is important to note that there is significant variability and many factors involved when assessing biosolids dewatering efficiency; however, based on this data (excluding April because the plant had some issues during April which skew the numbers lower) it appears that dewatering efficiency was improved by 3.70 more m$^3$ removed per hour (12.2% increase) and 29.5 m$^3$ more removed per month on average (3.65% increase) when RE technology is used. While this is a small increase in efficiency it is important to consider that the performance improvement occurred after only one month. Additional improvement may be evident over longer periods of time. RE technology was initially trialed to achieve P discharge limits of 0.075 mg/L-P. During the time period of this data, not only did RE technology improve the biosolids dewatering efficiency, but it kept the P discharge below 0.07 mg/L-P. Thus at this facility two major benefits were observed 1) an increase in dewatering efficiency and 2) a low P discharge.

**Table 5: Virginia, MN Dewatering Efficiency per month Post RE Technology**

| Month | Total $m^3$ | Average $m^3$/hr | Max $m^3$/hr | Target P Limit (mg/L) |
|---|---|---|---|---|
| June | 1009 | 32.3 | 33.0 | 0.075 |
| July | 853 | 34.1 | 39.4 | 0.075 |
| August | 651 | 35.6 | 37.2 | 0.075 |
| Average | 838 | 34.0 | 36.5 | |
| Average Difference without April | 29.5 | 3.70 | 1.57 | |
| % increase with RE | 3.65% | 12.2% | 4.49% | |

Previously in 2015 a trial was done to evaluate the use of a combination of PAC and ferric chloride (Dayton 2016). While this trial was successful in meeting the discharge limit of 0.075 mg/L-P, numerous other issues arose related to filtration from the increased dosage of coagulant. In this trial, the coagulant dose was as high as 541 L/day. This led to recirculating lines clogging with solids. At this point coagulant dosing had to be suspended until the clogging could be remedied. The PAC trial also concluded an additional digester would be necessary to handle the increased sludge volume. Comparatively, RE technology provided advantages such as improved settling, lack of filtration issues, improved dewatering efficiency, no additional equipment and a much lower dose rate to achieve the P limit.

### Albion Pennsylvania

Albion, PA has a 2915 $m^3$/day plant that discharges to a stream leading to Lake Erie and has been using RE technology since October 2014. Figure 11 details the plant layout. The plant is set up to waste solids from the primary and secondary clarifier into an anaerobic digester. After the digester a gravity thickener is in place to thicken the solids prior to being separated by a belt filter press. The filtrate returns to the primary clarifier and the biosolids are hauled away in 15 $m^3$ dumpsters and disposed of in a landfill.

Initially the use RE technology was to help meet the total aluminum (1.1 mg/L) and total phosphorus (1 mg/L) discharge limits. Figures 14 and 15 show the influent and effluent P, influent and effluent Al and coagulant dose for the time preceding the trial and during the trial. This data shows that the use of RE technology quickly lowered the effluent TP and since Al based coagulants were no longer needed the Al limit was met as well. Based on this Albion has continued to use RE technology.

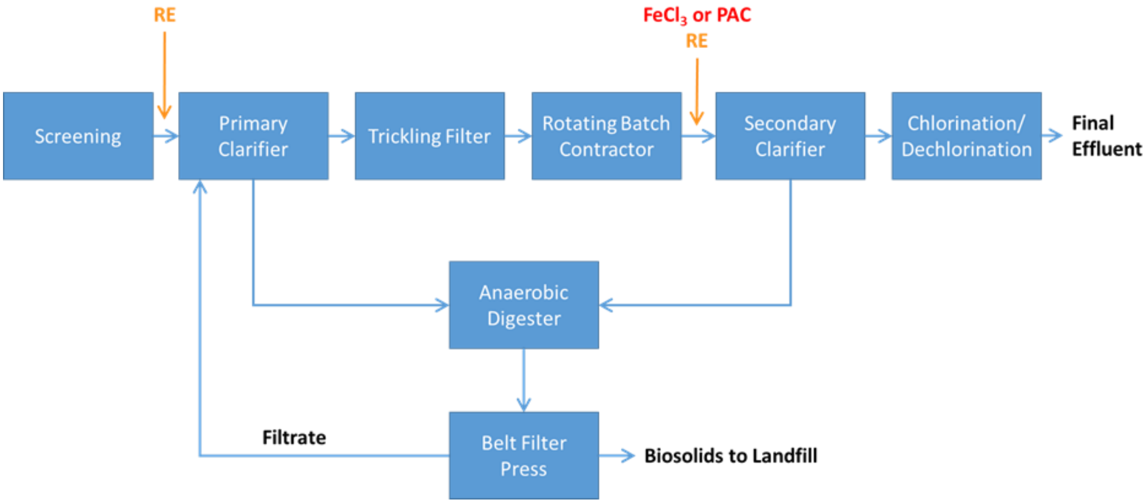

**Figure 11. Albion plant layout.**

**Figure 12. RE technology totes awaiting use (Temp -32°C)**

**Figure 13. Secondary clarifier before (left) and after (right) introduction of RE technology**

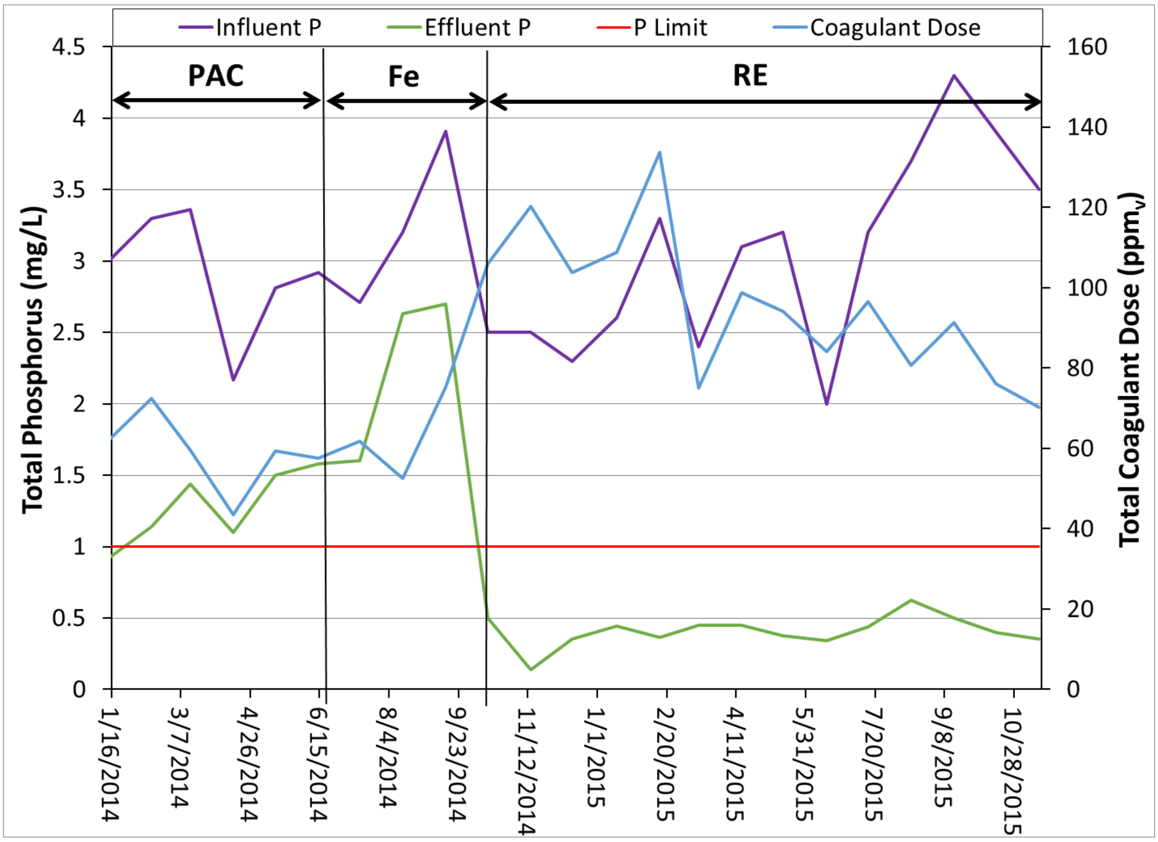

**Figure 14. Total Phosphorus before and after RE Technology**

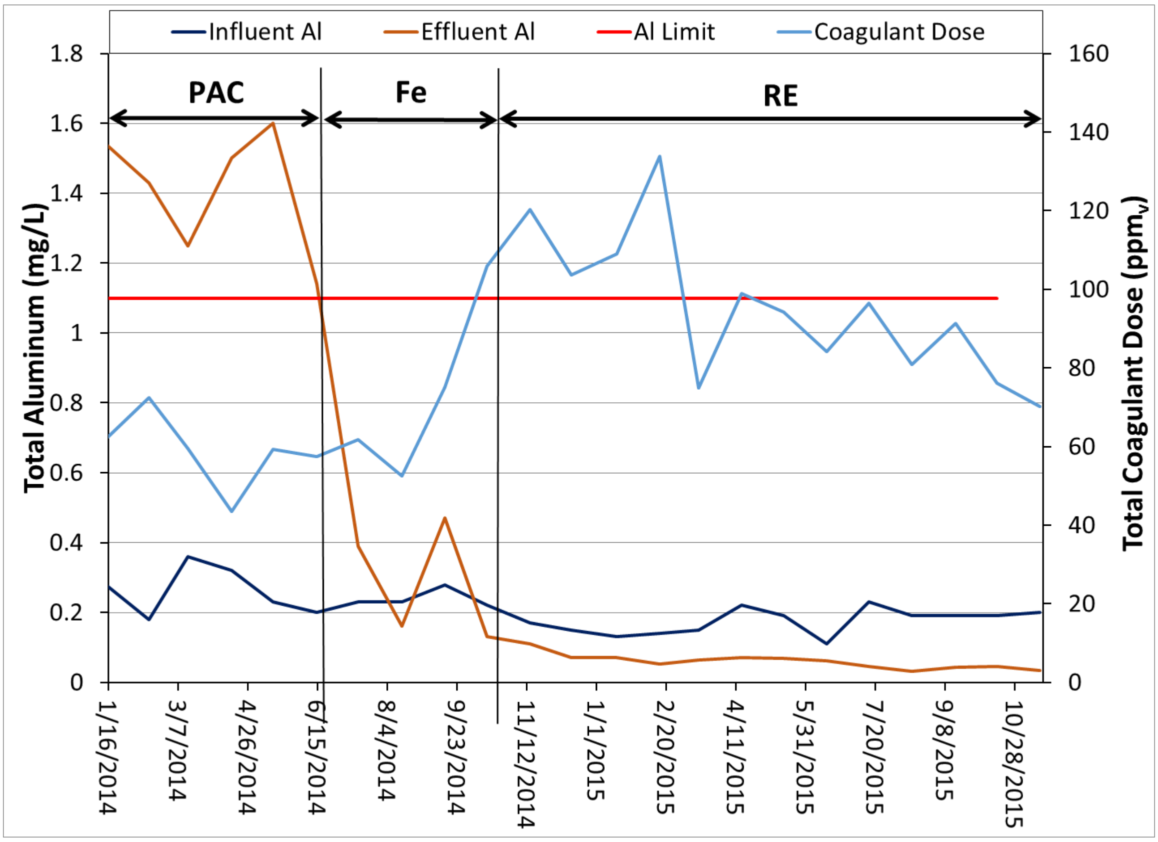

**Figure 15. Total Aluminum before and after RE Technology**

Prior to RE technology, the sludge had the appearance of dirty water and the belt filter press was run 8 hrs/day for 5 days/week. This is consistent with the Filter Press Cake Solids having a % Solids averaging ~15% (see Figure 16). After RE technology was adapted, the sludge increased in density, the % Solids of the Filter Press Cake Solids increased to an average of ~21%, and the gravity thickener prior to the belt filter press was no longer necessary. Furthermore the belt filter press run time was reduced to 8 hrs/day for 1 day/week. This translated into a reduction in power usage as the belt filter press is now run only 20% of the time (see Figure 17). However the clearest savings has been in the amount of 15 m$^3$ sludge containers hauled to the landfill. Prior to RE technology 75 containers were removed annually and after RE technology was implemented that number dropped with only 31 containers being hauled to the landfill in 2016. This represents a 58.7% reduction in the number of containers and a $70,000 savings per year in sludge hauling alone (see Table 6). Thus the use of RE technology has reduced cost in electricity, man power, and sludge hauling.

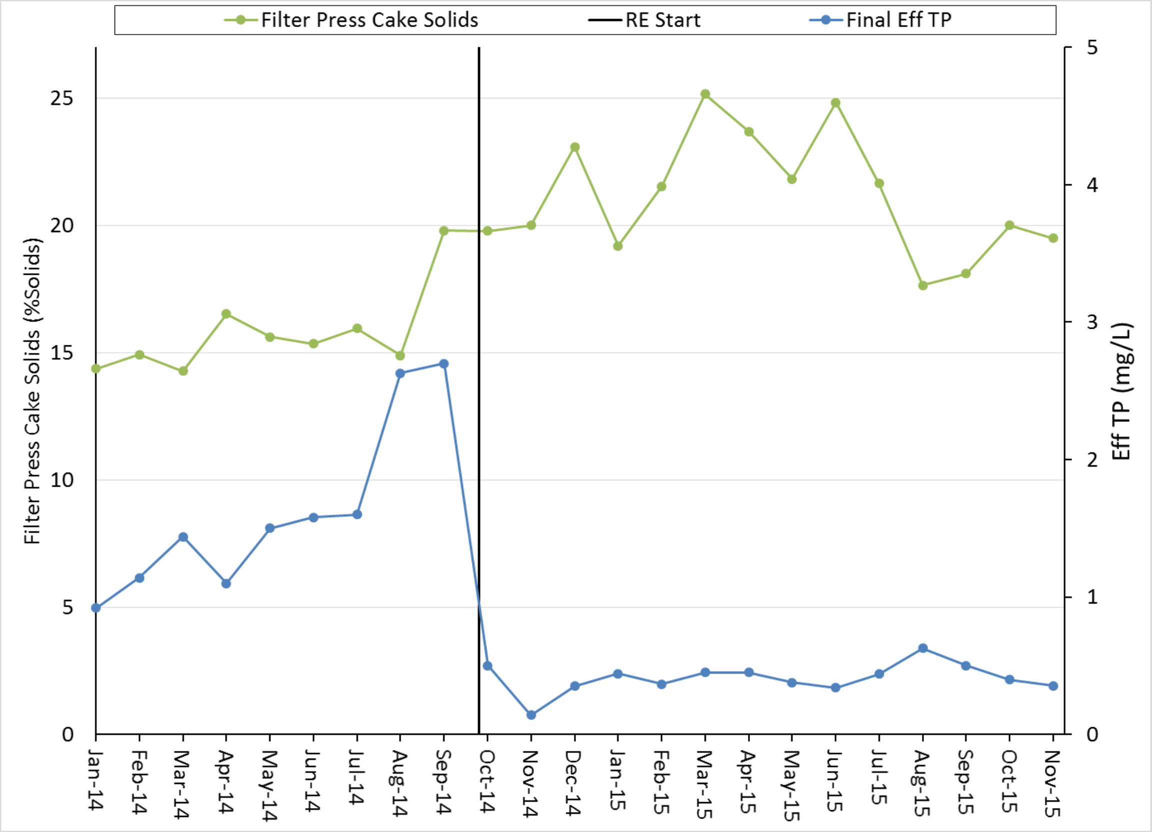

**Figure 16. %Solids of Filter Press Cake Solids and Effluent TP with and without RE**

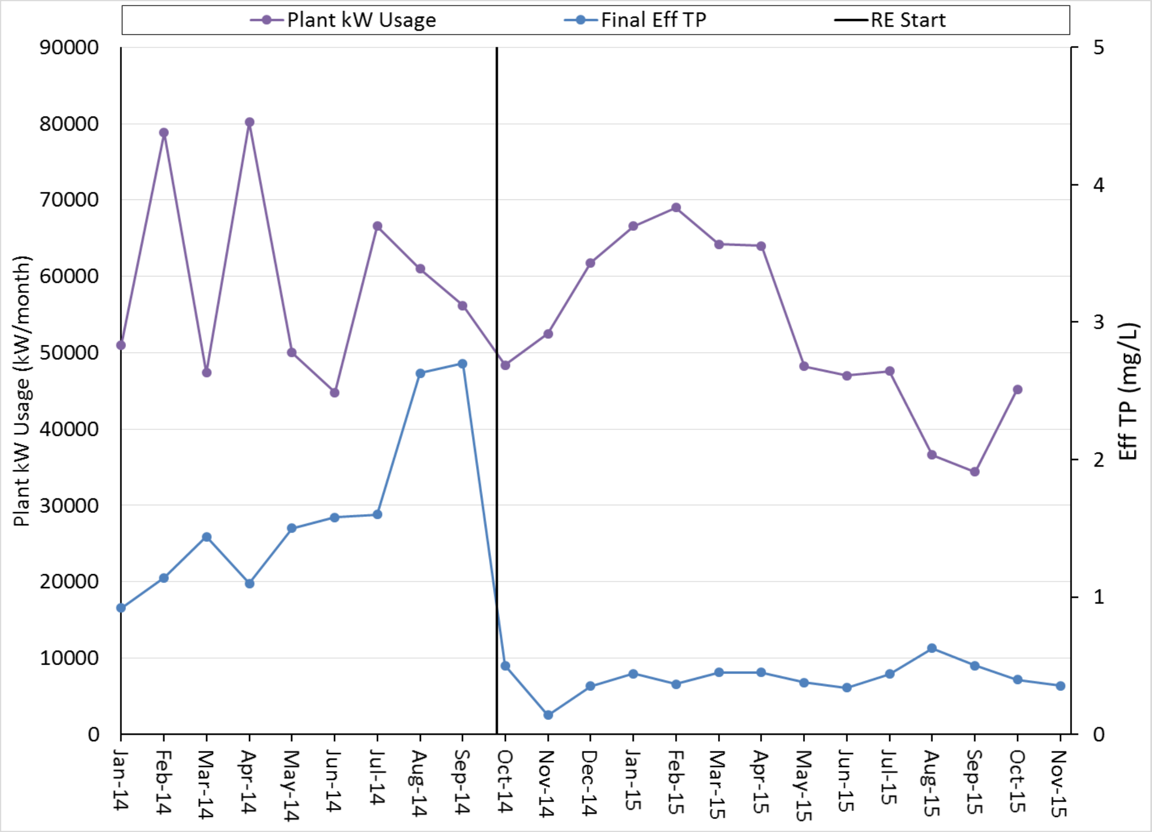

**Figure 17. Albion Plant kW Usage and Effluent TP with and without RE**

**Table 6: Sludge Hauling Pre and Post RE Technology**

| Year | Containers of Sludge Hauled | Container Reduction |
|---|---|---|
| 2013 (All Ferric) | 75 | - |
| 2015 (All RE) | 50 | 33.4% |
| 2016 (All RE) | 31 | 58.7% |

## Conclusions

1. Able to achieve very low TP discharge limits without capital equipment
2. Significant reduction in sludge volumes
3. Less coagulant volume required to reach low phosphorus limits
4. Compatible with existing dosing and filtration equipment
5. Reduction in maintenance costs vs. ferric-based coagulants
6. Faster coagulation and noticeable water clarification
7. Will not stain or discolor facility structures or equipment
8. Rated non-hazardous for US DOT regulations

## Acknowledgements

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