Brown AND Caldwell

201 N. Civic Drive, #115
Walnut Creek, CA 94596-3864
tel: 925.937.9010
fax: 925-937-9026

Technical Memorandum 4.6

Struvite Formation and Control Evaluation

Prepared for: San Jose/Santa Clara Water Pollution Control Plant

Project Title: FOG Evaluation, Digester Rehabilitation and Gas Line Replacement

Project No: 136242-003

Technical Memorandum No. 4.6

Subject: Struvite Formation and Control Evaluation

Date: September 7, 2010 (Revised February 4, 2011)

To: Ravi Kachhapati, Project Manager

From: Steve Krugel, Senior Vice President, Project Manager

Prepared by: Rion P. Merlo
Rion Merlo, Ph.D., P.E., Project Engineer
Professional Civil Engineer, CA License No. C69030
Engineer in Responsible Charge

RION P. MERLO
69030
Exp. 06/30/12

Reviewed by: Henryk Melcer, Ph.D., Vice President, NW Regional Process Engineer

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. EXECUTIVE SUMMARY

Struvite formation has been observed to occur at several points in the solids processing units at the San Jose/Santa Clara Water Pollution Control Plant (WPCP). As a result, struvite formation presents several serious issues including:

- Struvite deposition in the digesters reduces the digester active volume, which impacts digester performance
- Accumulation of struvite in the digester could pose a safety hazard to workers during a digester cleaning due to falling debris
- Formation in the digesters could impede floating cover operation, which could result in a cover failure
- Struvite in the intake bell of the digested sludge export pump station (DSEPS) pumps and in the digested sludge export line, elbows and fittings increase pumping costs due to an increase in total dynamic head (TDH)
- Plugging of the digested sludge export line with struvite would prevent the removal of digested sludge from the digesters, which would prevent further solids processing and require costly and immediate remedial actions
- Formation in the sludge lagoon supernatant line could reduce the rate that water can be withdrawn from the lagoons

1.1 Purpose of TM 4.6

The purpose of this TM is to provide an overview of existing struvite formation in the WPCP solids processing facilities and to evaluate and recommend measures for prevention and controlled precipitation to help mitigate the historical problems the plant has experienced in and around the digester complex.

1.2 Summary of Findings

Water chemistry modeling was performed using data from two separate sampling events. Data collected during the sampling events indicate high levels of magnesium, phosphorus and ammonia in the digester feed, digested sludge and lagoon supernatant. The average magnesium concentration in plant influent wastewater was more than twice the concentration of the drinking water concentration. Plant influent phosphorus concentration was also higher than average for municipal wastewater.

Several alternatives that could be implemented to mitigate struvite formation were evaluated using the water chemistry model. An alternative analysis was performed which involved a preliminary screening of viable alternatives. A cost estimate was performed on the alternatives that were identified to be viable solutions for full-scale implementation. In terms of present worth, addition of anti-scaling chemicals is the lowest cost alternative and has a comparable present worth to current costs associated with struvite. However, anti-scaling chemicals are not commonly added directly to anaerobic digesters, and may not work. Bench-scale and full-scale trials would be necessary to confirm anti-scaling chemicals as a viable solution. The other alternatives were significantly more expensive in terms of present worth value. Ferric chloride ($FeCl_3$) addition upstream of the primary clarifiers is the only alternative that would increase liquid stream secondary capacity and would reduce hydrogen sulfide (H_2S) in the digester gas. If anti-scaling chemicals are concluded to be inadequate for struvite prevention, we recommend that $FeCl_3$ is considered for full-scale implementation. However, continuous $FeCl_3$ could form excessive vivianite formation in the digester recirculation system and heat exchangers. If $FeCl_3$ is implemented, we recommend frequent inspection of digester recirculation piping and heat exchangers.

2. INTRODUCTION

This technical memorandum (TM) is provided under Service Order Number (No.) 1 for the San Jose/Santa Clara WPCP Fats, Oils, and Grease (FOG) Program Evaluation and Enhancement Study, Pre-Design Study of Digester Rehabilitation, Modifications and Gas Line Replacement, and Implementation Plan. The objective of Service Order No. 1 is to evaluate the existing digesters and develop an implementation plan for digester modifications through the 2030 planning period.

2.1 Purpose and Content of TM 4.6

This TM serves as the project deliverable for Task 4.6 of Service Order No. 1, Evaluate Struvite Formation and Control. The purpose of this TM is to provide an overview of existing struvite formation in the WPCP solids processing facilities and to evaluate and recommend measures for prevention and controlled precipitation to help mitigate the historical problems the plant has experienced in and around the digester complex. A water chemistry model (MINTEQA2) was used in conjunction with field data collected by City staff to determine struvite formation potential at three different locations at the WPCP. Alternatives were identified for struvite prevention and/or mitigation and the most promising were evaluated using the water chemistry model.

2.2 TM Organization

The general organization of this TM is as follows:

SECTION 1: EXECUTIVE SUMMARY

SECTION 2: INTRODUCTION

SECTION 3: BACKGROUND ON STRUVITE FORMATION AND CONTROL MEASURES

SECTION 4: EXISTING CONDITIONS AT SAN JOSE/SANTA CLARA WPCP

SECTION 5: ANALYSIS OF PREVENTION AND CONTROL MEASURES

SECTION 6: ALTERNATIVES ANALYSIS

SECTION 7: RECOMMENDATIONS

SECTION 8: REFERENCES

2.3 Scope of Work (Task 4.6)

The scope of work for this task (Task 4.6) consists of the following elements:

- Evaluate the historical formation of struvite in the WPCP digesters, and struvite control options that may be implemented in conjunction with modifications to the sixteen existing digesters.
- Evaluate measures to counter the effects of struvite precipitation and the impact to O&M. These measures shall include:
  - Preventative measures
    - pH reduction
    - construction of systems that minimize or preclude uncontrolled carbon dioxide (CO_2) release
    - dilution of digester feed stock materials that are low in phosphorus and/or magnesium
    - use of anti-scaling chemicals
    - addition of chemicals to form phosphate precipitates that are softer and easier to clean away than struvite
  - Controlled stimulation of struvite formation outside of the digesters (i.e. Ostara process)
- Practicality of alternatives will be evaluated using the chemical equilibrium model MINTEQA2. Data collected by City staff will be used in the analyses.
- Evaluate the impact of struvite formation on digester heat exchangers.

2.4 Acknowledgements

We wish to express our gratitude to the project team members from the WPCP staff who provided valuable assistance in completing this evaluation, including providing operating data, collecting and analyzing supplemental data, and providing review and comments. In particular, we wish to thank Ravi Kachhapti, Dr. Alex Ekster, Dr. Issayas Lemma, Steve Contreras, Carlos Musquiz, Ken Rock, and Noel Enoki. In addition, we would like to thank Dr. David Jenkins, who provided input on struvite formation modeling and reviewed the technical aspects of the TM.

3. BACKGROUND ON STRUVITE FORMATION AND CONTROL MEASURES

This section provides an overview of struvite formation chemistry and computer modeling to predict formation potential. The suite of practices used in the wastewater treatment industry for struvite prevention is also presented.

3.1 Struvite Formation Chemistry

Struvite is formed by the reaction of magnesium, ammonium and orthophosphate as shown in Equation 3-1.

$$Mg^{2+} + NH_4^{\ +} + PO_4^{\ 3-} + 6H_2O = MgNH_4PO_4 \cdot 6H_2O \quad (3\text{-}1)$$

Struvite can precipitate whenever the product of the activities of magnesium, ammonium and phosphate exceeds the struvite solubility constant (K_{SP}) as shown in equation 3-2.

$$\{Mg^{2+}\}\{NH_4^{\ +}\}\{PO_4^{\ 3-}\} > K_{SP} \quad (3\text{-}2)$$

Several values have been proposed for K_{SP} in the literature. The most common value used in the industry is $10^{-12.6}$ (Snoeyink and Jenkins, 1980). Ohlinger et al. (1998) determined the K_{SP} value for struvite to be $10^{-13.26}$, which agreed with observations at a full-scale wastewater plant where the $10^{-12.6}$ value did not. As a result of Ohlinger's analysis, struvite was shown to be less soluble than predicted by previous work.

As indicated in equations 3-1 and 3-2, struvite formation potential is a function of the activities of magnesium, ammonium and orthophosphate. The concentrations, and therefore the activities, of ammonium and phosphate will also be determined by pH of the solution, with higher pH values increasing the formation of struvite. Struvite solubility reaches its minimum at a pH value of 10.7 (Snoeyink and Jenkins, 1980). Temperature will also determine the formation potential.

It is important to note that even if the conditions in equation 3-2 are met, struvite may not form. This is because the kinetics of precipitation (or the time it takes for precipitation to occur) and the competing reactions are not considered in the equations. Therefore, equations 3-1 and 3-2 can be used to determine if the potential for struvite formation exists, but cannot predict struvite formation because of small changes in the physical/chemical regimes within mechanical systems that can modify the kinetic characteristics of precipitation.

3.2 Equilibrium Chemistry Modeling

Several models are available to perform struvite formation calculations. This section explores the different existent models, with their advantages and limitations, to select the most appropriate for this project.

Mineql+ is an equilibrium-based model which features the US EPA's MINTEQA2 thermodynamic database. This database has been found to contain errors in its organic ligand section, causing errors related to expressing reactions in Mineql+ components and to ionic strength and temperature correction of log K (Serkiz et al., 1996). Additionally, Mineql+ does not allow the user to fix a value for ionic strength (Ohlinger et al., 1998), but this has been corrected in the newer model Visual Minteq (vMinteq). Currently, vMinteq is the most widely used model for chemical speciation, due to both its stability and accessibility (Gustafsson, 2005). It has been established as an industry standard, to which most new models being developed are compared for validation. The model's biggest limitation is its inability to predict time-dependant data, since it is equilibrium-based and does not consider the kinetics of chemical reactions. Ignoring kinetics also prevents the model from being able to predict the final equilibrium state when multiple minerals compete for the same species to precipitate (Musvoto et al., 2000a). Since this model also uses thermodynamic data from MINTEQA2, earlier versions experienced the same problems due to errors in the organic ligand section. However, the model's newest version, vMinteq 2.61, addresses some issues found for surface and organic complexation (Gustafsson, 2005).

R.E. Loewenthal and I. Morrison from the University of Cape Town, South Africa, have developed the commercially available Struvite version 3.1 model to predict struvite precipitation (Britton, 2002). This model is very simple to use, and provides very fast results – in less than one second (Musvoto et al., 2000a). However, it has been observed to predict somewhat inaccurate outcomes, since it has a limited understanding of calcium species formation – mainly phosphates and carbonate, which precipitate around a pH value of 8.5 (Doyle et al., 2000). This causes the model to generally under-predict struvite formation at high pH values (approximately over 8.5) and to over-predict at low pH values (<8.5) (Doyle et al., 2000). Additionally, this model does not consider thermodynamic and growth kinetics, and also ignores ion pairing effects (Musvoto et al., 2000b). The model's handling of ionic strength and its algorithm for estimating the equilibrium pH also reduce the program's accuracy (Musvoto et al., 2000a).

Musvoto et al. (2000b) have developed a kinetic-based model that includes biological, chemical and physical processes. Its unique characteristics are that it includes ion pairing effects (Musvoto et al. 2000b), lists hydrogen ions as a compound, and uses kinetic constants to calculate new equilibria (Doyle and Parsons, 2002). These features allow it to predict time-dependant data and the final equilibrium state when multiple minerals compete for the same ions to precipitate (Musvoto et al. 2000a). However, this model is only valid for precipitation processes when the ionic product is greater than the solubility product, and it does not work correctly in situations when dissolution is significant. Moreover, it is not commercially available, and needs to be programmed manually from scratch, being significantly more complex and requiring time to be mastered.

A few mathematical models have been developed to describe struvite formation. Wild et al. (1997) developed a model to predict results from a laboratory-scale sludge digestion under different conditions. However, the model does not consider the influence of pH variations on precipitation reactions, and it is not valid for dissolved phosphorous concentrations smaller than 30-40 mg-P/L. Ali (2005) also developed a mathematical model to predict struvite formation, integrating solution chemistry and thermodynamics with reaction kinetics. For simplicity, the model makes several assumptions which slightly decrease its accuracy, including spherical struvite crystals, perfect mixing, constant number of crystals in the reactor, and a point-size crystal distribution (Ali, 2005). The model's overall results were very close to vMinteq. However, neither of these two mathematical models is commercially available at present.

Battistoni et al. have developed a model to predict struvite, calcium carbonate and hydroxiapatite recovery based on pH and contact time (Britton, 2002). However, as Britton (2002) explains, the model has limited equilibrium chemistry and relates supersaturation only to pH, not being very applicable to different situations since it does not take into account liquor variability.

A simpler tool to predict struvite precipitation is the equilibrium curve used by Ohlinger, but since it is not based on a thermodynamic equilibrium, it will likely need calibration for each wastewater (Britton, 2002). The equilibrium curve does not take competing reactions or reaction kinetics into account, producing less accurate data.

Harada et al. (2006) developed an equilibrium model to predict struvite formation for the recovery of phosphorous in human urine. However, due to its purpose, it only considers species present in urine and precipitates likely to be formed under those conditions, ignoring several other compounds that would be found in wastewater. This model also ignores reaction kinetics. In the past, Diaz et al. (1993) have used the model SOILCHEM. However, this model is less than ideal for wastewater applications since it was designed for chemical speciation in soils.

All models listed above ignore the magnitude of pressure drop at valves and fittings, which slightly reduces their accuracy. A possible way to fix that would be to measure localized pH at elbows and fittings to estimate the pressure drop.

Based on these findings, Musvoto's model seems particularly promising because it is the only one to include reaction kinetics. However, since it is not commercially available, vMinteq was preferred and chosen for this project. vMinteq is widely available, has been in use for over a decade, and has been proven effective for struvite calculations (Gustafsson, 2005).

3.3 Equilibrium Chemistry Modeling for the WPCP

Based on the review of current modeling approaches vMinteq was used to examine the formation potential of struvite. By itself, the vMinteq model does not include thermodynamic information for struvite. We added struvite to the database using the K_{SP} value of $10^{-13.26}$ (Ohlinger et al., 1998), and a ΔH value of 23.6 kJ/mol (Ronteltapa et al., 2007). The vMinteq model is an industry accepted model and in our judgment is the best model for struvite modeling because it contains an extensive library of thermodynamic data and considers the gas phase as well as the liquid phase.

The results of field testing performed by City staff were used as inputs to vMinteq. City staff performed sampling of the primary sludge, thickened waste activated sludge, digested sludge and lagoon supernatant. Samples were analyzed for particulate and soluble species. The results of the sampling effort were used as model inputs. For the digested sludge export line and the lagoon supernatant line, the results of each day were analyzed to determine which day had the highest struvite formation potential and these data were used for modeling.[1] For the digester modeling, the average of the sludge streams was used because sludge resides in the digester for 15 days or more, and daily variation does not have as much of an impact as cumulative loading.

Both chemical and complex biochemical reactions occur simultaneously in the anaerobic digestion process. It is not possible to know which specific species will be available for reaction in the digester. Therefore, for this analysis, we assumed that particulate species that passed through the digesters were not available for reaction inside the digester.[2] For the digested sludge export line and the lagoon supernatant line, the modeling took account of only the soluble species since biological activity is expected to be minimal in these lines.

It is also important to note that inside the digester, the headspace consists of approximately 60 percent methane (CH_4) and 40 percent CO_2. This means that when digested sludge samples are analyzed for pH, the measurement occurs in atmospheric conditions where CO_2 has a partial pressure of $10^{-3.5}$ atmospheres (atm). In the headspace of a digester that contains 40 percent CO_2, the partial pressure for CO_2 would be $10^{-0.42}$, which is 3 orders of magnitude higher than the atmosphere, or more than a 1,000 times.[3] This means that the pH inside the digester will be lower than the pH values of sludge measured outside the digester. Since the

---

[1] Data were analyzed to determine the solubility product of the magnesium, phosphate and ammonium content and comparing these data to the K value for struvite. The data that had the largest solubility product (or lowest –logK) was used for analysis.

[2] For instance, if the particulate calcium concentration (i.e. the difference between total and soluble calcium) were the same in the digester influent as the digester effluent, it was assumed that this solid was tied up in sludge and not available for reaction.

[3] The partial pressure for CO_2 was determined assuming the digester was operating at 1.01 atm and had 40 percent CO_2. The vapor pressure of water at 35 degrees C (0.056 atm) was subtracted from the total pressure, which assumes the digester gas is saturated with water.

chemistry of struvite formation is pH dependent (where struvite forms at higher pH conditions), it is critical to account for the CO_2 content of the digester gas (Jenkins, 2010a). For the digester, DSEPS and digested sludge export line, the system was modeled as an open system with a CO_2 partial pressure of $10^{-0.42}$. For the supernatant return line, the system was modeled as an open system using a CO_2 partial pressure of $10^{-1.08}$ and $10^{-1.19}$ for the first and second sampling event, respectively.[4]

To account for the effects of kinetics, several components were not allowed to precipitate in the model. If these species are allowed to precipitate, it could underestimate or preclude the precipitation of other species. The compounds are summarized in Table 3-1 and are based on assumptions reported in the literature.

Table 3-1. Summary of species not allowed to precipitate in the vMinteq model due to slow kinetics

Compound	Reference
Dolomite ($CaMg(CO_3)_{2(s)}$)	Sen et al., 1988
Bobierrite ($Mg_3(PO_4)_2 \cdot 8H_2O_{(s)}$)	Sen et al., 1988
Hydroxyapatite ($Ca_5(PO_4)_3OH_{(s)}$)	Sen et al., 1988
Whitlockite ($Ca_3(PO_4)_{2(s)}$)	Musvoto et al., 2000b
Octocalcium phosphate ($Ca_8(HPO_4)_2(PO_4)_{2(s)}$)	Salimi et al., 1985

It is important to note the limitations of the model predictions. The results of the vMinteq modeling only present the potential for formation of struvite and, in general, do not account for the kinetics, or the time required for precipitation to occur, (aside from the species listed in Table 3-1 that were prevented from precipitating in the model runs). This means that even though struvite may be predicted to form, it may not actually form because the reaction kinetics are limiting. Conversely, if struvite is not predicted to form by the model, it will not form. Therefore, eliminating struvite formation potential will guarantee that struvite formation will not occur and is a prudent approach for both alternatives evaluation and solution implementation. For this analysis, the value of the equilibrium model is its application to explore potential solutions to the existing struvite problems as the WPCP by exploring ways to reduce or eliminate formation potential. The modeling results were used to determine the relative level of impact associated with process modifications. The results of the modeling can prove or disprove a potential solution before any money (either research money or capital money) is spent.

3.4 Struvite Formation in Solids Processing Equipment

Struvite formation has been shown to occur in solids processing facilities (i.e., anaerobic digesters, digester piping and return streams from dewatering equipment) at many municipal wastewater treatment plants. Formation can be more prevalent at wastewater plants that use biological nutrient removal (BNR) for phosphorus removal due to the increased phosphorus content in the secondary waste sludge. The secondary process at the WPCP was converted to a BNR system in the late 1990s.

Struvite has been commonly observed to form in anaerobic digester recycle lines, especially at elbows and the suction side of pumps. The cause of the localized precipitation is the result of an increase in pH caused by the release of CO_2. For the case of pipe elbows and the suction side of pumps, a reduction in pressure occurs, which causes a portion of CO_2 to be released from solution. For the case of the centrate lines, the exposure of the sludge to atmospheric conditions, as opposed to the inside of the digester where the partial pressure of

---

[4] The lagoon supernatant will have elevated levels of CO_2 due to the CO_2 that has not gassed out. (Jenkins, 2010b) Values used for modeling were calculated from measure alkalinity and pH.

gas-phase CO_2 is higher, causes a portion of CO_2 to be released from solution and the pH to increase. It is interesting to note that struvite formed at the Southeast Water Pollution Control Plant (SEP) in San Francisco (Mamais, et al., 1994) even when BNR for phosphorus removal was not conducted.[5] In this case, the struvite formation was attributed to high levels of magnesium in the influent due to seawater intrusion into portions of the collection system.

3.5 Struvite Prevention in Solids Processing Equipment

Control of struvite in solids processing equipment typically involves making modifications to the water chemistry so that struvite is not supersaturated. Some of the most common prevention measures where chemical addition is used are:

- Ferric chloride ($FeCl_3$) or ferrous chloride ($FeCl_2$) addition, which results in the preferential formation of vivianite [$Fe_3(PO_4)_2 \cdot 8H_20$] rather than struvite. Precipitation will still occur, however the precipitate (vivianite) is a softer material that is can be easier to clean away than struvite. However, vivianite commonly forms in heat exchangers, causing degradation of performance and in this case becoming difficult to clean.
- Use of proprietary chemicals that act as crystal growth inhibitors.
- Acid addition to reduce pH. Hydrochloric acid (HCl) typically is a better choice than sulfuric acid due to the potential to form H_2S gas under anaerobic conditions with sulfuric acid use.

The City has experience with iron salt addition at the WPCP. $FeCl_2$ was metered into the WPCP digester recirculation piping upstream of the heat exchangers for sulfide control, approximately 20 years ago. From 1986 to 1996, $FeCl_2$ was added to the plant influent for H_2S control in digester gas; it has also been used in the collection system. More recently, full-scale testing has been performed at $FeCl_3$ doses from 5 to 20 mg/L to determine if chemically enhanced primary treatment (CEPT) could provide additional TSS and BOD removal in the primary clarifiers. A discussion of the results of these activities with respect to struvite formation is included in Section 5.7.

Accomplishing pH control can also be performed without chemical addition by minimizing low pressure zones and turbulence where CO_2 can come out of solution and increase pH. This solution is viable where struvite precipitates only in these low pressure and turbulent regions. An example is the use of long radius elbows to reduce sudden pressure drops that can result in selective precipitation at and downstream of sharper elbows.

Dilution of the sludge to reduce the concentration of magnesium, phosphate and ammonia can be performed, where practical. For instance, the Hyperion Treatment Plant in Los Angeles, California used to dilute digested sludge with secondary effluent to prevent struvite formation before final discharge to the ocean (Snoeyink and Jenkins, 1980). This practice is no longer performed, since ocean disposal of sludge is no longer allowed.

3.6 Struvite Prevention with the Proprietary Struvite Precipitation Processes

Another technique to control struvite formation is the use of designed struvite precipitation processes such as the Ostara process (Ostara Nutrient Recovery Technologies, Inc., Vancouver, British Columbia, Canada).

---

[5] The SEP currently operates an anaerobic selector in their secondary system which does result in phosphorus removal. At the time of the Mamais et al. (1994) work, the anaerobic selector was not in operation.

The Ostara process is principally designed for struvite recovery from dewatering side streams as a fertilizer resource.

Other drivers behind this process are to reduce nitrogen and phosphorus loadings in the solids processing return streams (to meet effluent nutrient requirements) and to prevent struvite formation in dewatering recycle return lines. The system is effective at removal of side stream phosphorus, but is not applicable to full sludge stream phosphorus removal.

Another process called the WASSTRIP process (waste activated sludge stripping to remove internal phosphorus, patent pending) that works in conjunction with Ostara was developed by Clean Water Services of Tigard, Oregon. The WASSTRIP process is designed to remove phosphorus and magnesium before it enters the digester, which can reduce struvite formation in the digesters. The process is only used for phosphorus removal from WAS resulting from liquid process biological phosphorus removal and can be up to 70 percent efficient in removal of bound phosphorus in this stream. The process consists of an anaerobic tank that is fed with secondary sludge and supplemental volatile fatty acids (VFAs) are added to encourage phosphorus and magnesium release by the microorganisms (like in the anaerobic portion of a BNR system). The sludge stream is then thickened, the thickened sludge is sent to the digesters, and the excess water (which contains higher levels of soluble phosphorus and magnesium) is sent to the Ostara process along with dewatering return streams. The WASSTRIP and Ostara processes are further discussed in Section 5 of this TM.

4. EXISTING CONDITIONS AT SAN JOSE/SANTA CLARA WPCP

A review of the historical occurrence of struvite at the WPCP is presented. The results of the field sampling were used as inputs to the water chemistry model and model predicted results were compared with historical occurrence of struvite at the WPCP.

4.1 Historical Occurrence of Struvite at San Jose

Figure 4-1 presents a process flow diagram of solids processing at the WPCP. Primary sludge is thickened in the primary clarifiers and secondary sludge is thickened using dissolved air flotation thickeners (DAFT). The thickened sludge is combined and pumped to the anaerobic digesters. Solids stabilization is performed in the digesters. The digesters are gas-mixed, and digested sludge is pumped through heat exchangers to maintain mesophilic temperatures.

Sludge flows from each digester to the DSEPS wet well, where it is pumped to the sludge lagoons. The DSEPS is a wet well/dry well pumping station with two wet wells and three centrifugal pumps. There are two buried digested sludge transfer pipes: a 14-inch diameter ductile iron pipe (DIP) and a 12-inch DIP. Currently, the 14-inch pipe is in service. These pipes are buried between DSEPS and the lagoons. At the sludge lagoons, the majority of the piping is above ground (digested sludge feed lines to lagoons #28-35 are partially buried, above ground for lagoons #59-56 & 36-46 and buried for lagoon #50-55).

WPCP staff have indicated a number of locations where struvite formation has been observed. These locations are shown in red in Figure 3-1 and listed below.

- On the underside of the digester floating covers, near the liquid-gas interface
- On the inside walls of the digesters
- At digester recirculation line valves (and approximately 1 ft before and after the valves)
- In the digester sampling lines
- On the intake bell to the DSEPS pumps
- In the transfer pipe between the DSEPS wet wells
- In the digested sludge transfer piping
- At the lagoon supernatant return line

Struvite formation has **not** been observed:

- In digester heat exchangers (The heat exchanger that services digester 5 was recently taken down. Visual inspection showed no scaling from struvite or any other deposit as shown in Figure 4-2.)
- In the lagoon supernatant channel

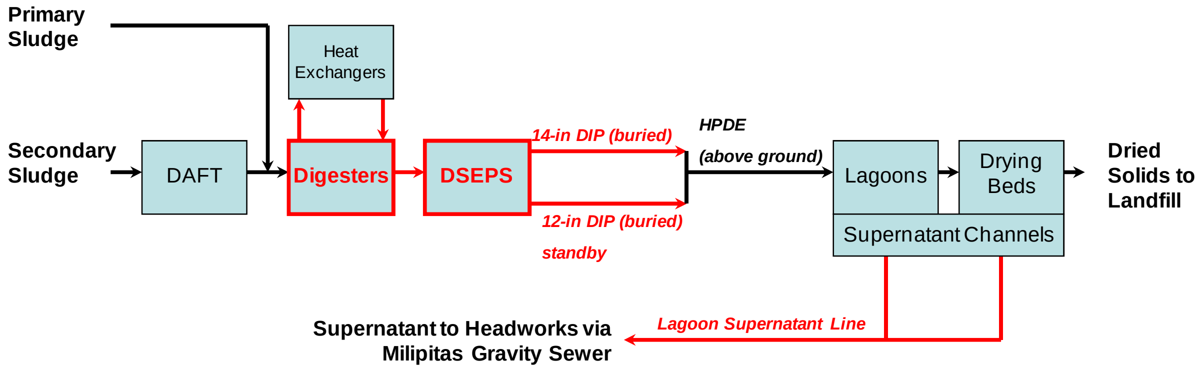

Figure 4-1. Process flow diagram of solids processing at the WPCP (items shown in red indicate historical occurrence of struvite).

Figure 4-2. Heat exchanger that serves digester 5 showing no sign of scaling.

As of 2004, the digesters are routinely taken down for cleaning by a contractor every four years. Plant staff analyzed a sample of digester debris removed from a recent cleaning. The analysis showed that struvite can make up between 20 and 30 percent of the debris that is removed during a digester cleaning. The remaining fractions consist of grit and organic material. During cleaning, the contractor enters the digester cover headspace and bangs on the cover base to dislodge struvite. This has proven to be very effective; most of the struvite that forms on the roof of the digester falls off. The sides of the digesters are cleaned using high-pressure water. For some struvite pieces, a crowbar and sledgehammer is used. Struvite formation in the digesters can pose a safety hazard during digester cleaning due to falling debris. In addition, the struvite formation that occurs in the recirculation lines, principally at valves and elbows, can cause pipes to plug and valves to stick, requiring time consuming maintenance to unclog or replace them. Figure 4-3 shows a photograph of struvite formation in an elbow on the digester recirculation piping at the WPCP. Digester recirculation piping has never been cleaned; only valves and elbows have been replaced. Acid cleaning the recirculation pipes has been considered by operations staff but this has not been done to date.

Figure 4-3. Struvite formation in the digester recirculation piping at the WPCP.

Struvite formation in the digested sludge export line results in an increase in TDH and, under extreme cases, could make it impossible to pump required sludge volume to the lagoons. Under normal operation without struvite accumulation, the DSEPS pumps should be capable of 1,500 gallons per minute (gpm) at 60 pounds per square inch (psi). Currently, the pumps pump 1,200 gpm at 70 psi with declining pump capacity in response to increasing struvite deposition in the DSEPS piping.

In 2002, acid cleaning (using a proprietary chemical) of the digested sludge export pipe was performed by a contractor for an estimated cost of $300,000. This was the first time cleaning had been performed since the pipe was installed. WPCP staff believe (Discussion of Struvite Occurrence, May 2, 2009) that only the 14-inch pipe was cleaned. The digested sludge export pipe was cleaned again in 2010 using a proprietary chemical. The contractor cost for the cleaning was $119,500.

The lagoon supernatant line has accumulated both struvite and grit. Figure 4-4 shows a schematic provided by WPCP staff that illustrates that struvite has been observed on ammonia and TSS probes, as well as in the lagoon supernatant pipe. The lagoon supernatant pipe was hydro-jetted in 2007, but has never been acid washed. The contractor cost for the cleaning was $125,000. This was the first time the lagoon supernatant line had been cleaned. Plant staff have recently converted a portion of the lagoon to a sedimentation zone prior to the lagoon supernatant return line to remove grit and debris. For purposes of the cost estimate, the cost of hydro-jetting the supernatant line is not included because the frequency of the cleaning is rare, and grit accumulation is the major driver to clean the line (WPCP staff. Meeting Discussion of Struvite Costs, August 13, 2010).

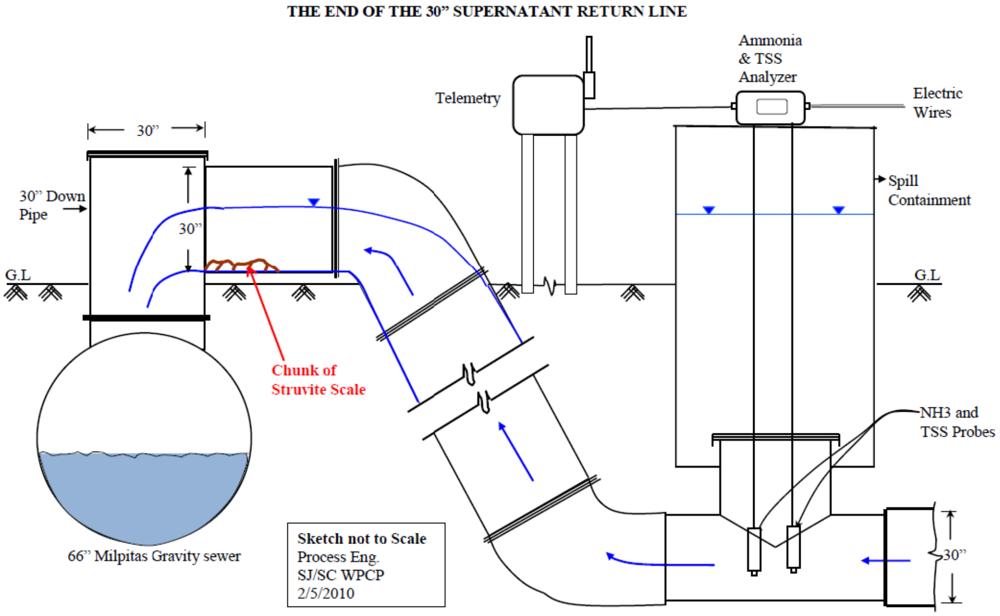

Figure 4-4. Struvite formation in the lagoon supernatant return line at the WPCP. Figure provided by WPCP Process Engineering staff.

The above-ground portion of the digested sludge export line consists mostly of laterals that feed the sludge lagoons. The buried portion of the pipe is ductile iron; the above ground portion was replaced with high-density polyethylene (HDPE) pipe approximately 3 years ago. At the sludge lagoons, we inspected several pieces of HDPE pipe that had been recently cut out. The inside of the pipe had no struvite formation on the smooth portions. However, at pipe seams and at lateral tees, struvite was observed (Figure 4-5). This indicates that struvite is less likely to adhere on the smooth portions of the HDPE pipe, even though the formation potential exists.

Figure 4-5. Inside of HDPE pipe found at the sludge lagoons where struvite has formed at the intake portion of a tee.

4.2 Results of Data Collection

San Jose WPCP staff collected data specific to struvite formation potential analysis. They conducted two sampling events: 1) from January 25 through 28, 2009 and 2) from March 15 through 17, 2009. The first data collection event was without any $FeCl_2$ addition to the treatment process; the second data collection event was conducted while a 5-mg/L dose (approximate) of $FeCl_2$ was added to the headworks. A complete list of data collected is presented in Attachment A; Table 4-1 presents selected data for primary sludge A&B, primary sludge C&D, TWAS, lagoon sludge (digested sludge), and lagoon supernatant. The average values from each sampling event are presented. The digester feed values were calculated using flows provided by WPCP staff for the days of sampling. Both untreated samples (representing total concentration) and filtered samples (representing soluble concentration) were analyzed for several of the key constituents (i.e. magnesium, ammonia, phosphate).

Analysis of Table 4-1 shows that there is an increase in alkalinity across the digesters, which is expected due to the release of CO_2 from biological degradation. There is a significant difference between total and soluble alkalinity for the sludge samples; there was no difference in supernatant lagoon samples. This difference is attributed to the presence of high concentration of solids that are presumed to have acid neutralizing capacity. The pH is higher in the lagoon supernatant than the digested sludge. The increase in pH could be due to the release of CO_2 to the atmosphere and/or algal activity in the lagoons (algae consume CO_2 and increase pH).

There is a decrease in both total and soluble magnesium across the digester, which could be due to struvite formation and retention within the digesters. The total phosphate levels in the TWAS are significantly higher than the primary sludges and are attributed to phosphorus uptake that occurs in the secondary system. There is a reduction in phosphate across the digesters, and even more significant reduction in the lagoon supernatant. The lagoon supernatant had low levels of magnesium and significantly lower levels of nitrogen and phosphorus than the digested sludge. The iron levels during the second round of testing were higher than during the first round of testing and are attributed to the $FeCl_2$ addition.

Table 4-2 presents data collected during the same time period for the influent wastewater, which includes the lagoon supernatant flow. Typical values for some of the constituents in San Jose drinking water are also presented. As expected, each constituent increases as drinking water becomes wastewater. It is important to note that the magnesium concentration more than doubles; wastewater is expected to have 4-10 mg/L more magnesium in the wastewater compared with the drinking water (Tchobanoglous et. al., 2003). Figure 4-6 presents historical WPCP influent and effluent magnesium concentrations. The average influent value was 34.5 mg/L and ranged from 27.0 mg/L to 41.3 mg/L. The average WPCP effluent value was 31.7 mg/L and ranged from 26.4 mg/L to 46.4 mg/L. The influent total phosphate is also much higher, as expected. The measured influent total phosphate (12.2 mg-P/L) is significantly higher than a typical value for medium strength wastewater (7 mg-P/L, Tchobanoglous et. al., 2003). These elevated levels of phosphorus and magnesium increase the potential for struvite formation. The increased phosphate concentration is partially attributed to the high concentration in the lagoon supernatant returned to the plant. However, the average magnesium concentration in the lagoon supernatant ranged from 6.1 mg/L to 12.7 mg/L (Attachment A), and does not explain the elevated concentration in the influent wastewater. The higher magnesium levels could be due to industrial contributions in the collection system. Magnesium hydroxide is typically used for pH neutralization of acidic waste streams. In addition, brine from reverse osmosis (RO) systems could also increase magnesium concentration.

Table 4-1. Summary of select data collected for struvite formation potential analysis. Results for the first sampling event (without ferric chloride addition) and second sampling event (with ferric chloride addition at the headworks) are presented.

Parameter	Primary Sludge A&B		Primary Sludge C&D		Thickened Waste Activated Sludge		Calculated Digester Feed[a]		Lagoon Sludge (Digested Sludge)		Lagoon Supernatant	
	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event	1st Event	2nd Event
Alkalinity												
Total, mg $CaCO_3$/L	1,097	1,365	1,110	1,410	2,533	1,975	1,533	1,551	2,640	3,870	2,110	2,055
Soluble, mg $CaCO_3$/L	499	526	582	547	468	506	1,036	529	2,373	2.570	1,850	2,060
pH	5.60	6.20	5.73	6.35	6.80	6.70	---	---	7.03	7.50	7.80	7.55
Magnesium												
Total, mg/L	137	136	124	160	418	502	216	246	190	197	6.11	12.7
Soluble, mg/L	55	54	56	54	102	103	70	67	22	20	4.54	1.70
Nitrogen												
Total TKN, mg/L	1,315	1,150	1,160	1,100	1,677	2,650	1,362	1,537	1,675	1,650	711	755
Soluble TKN, mg/L	223	<300	245	400	193	<300	223	259	955	950	680	705
Ammonia, mg/L	79	93	82	98	66	93	76	95	919	1,040	637	855
Phosphorus												
Total, mg-P/L	1,152	391	1,195	391	3,695	1,956	1,932	818	1,358	717	239	163
Soluble, mg-P/L	98	52	88	52	478	196	1,083	91	261	114	133	114
Orthophosphate, mg-P/L	29	3.3	30	37	<0.2	<0.2	---	---	0.08	<0.2	<0.2	<0.2
Iron												
Total, mg/L	374	456	347	533	512	1,190	404	690	406	549	3.3	7.0
Soluble, mg/L	6.7	8.5	6.5	7.1	2.4	3.7	5.4	6.6	2.4	0.3	0.1	0.2

[a] *Calculated using sludge flows during sampling events provided by WPCP staff*

Table 4-2. Summary of average annual selected data for influent wastewater compared with drinking water

Parameter	Influent Wastewater	Drinking Water[a]
Alkalinity, mg $CaCO_3$/L	310	84
TKN, mg/L	47.9	---
TSS, mg/L	357	---
Magnesium, mg/L	30.8	15
Iron, mg/L	5.1	<0.1
Total Phosphate, mg-P/L	12.2	---
Ortho-Phosphate, mg-P/L	3.3	0.3

[a] *Annual average value reported in 2008 Annual Water Quality Summary for the Santa Clara Valley Water District*

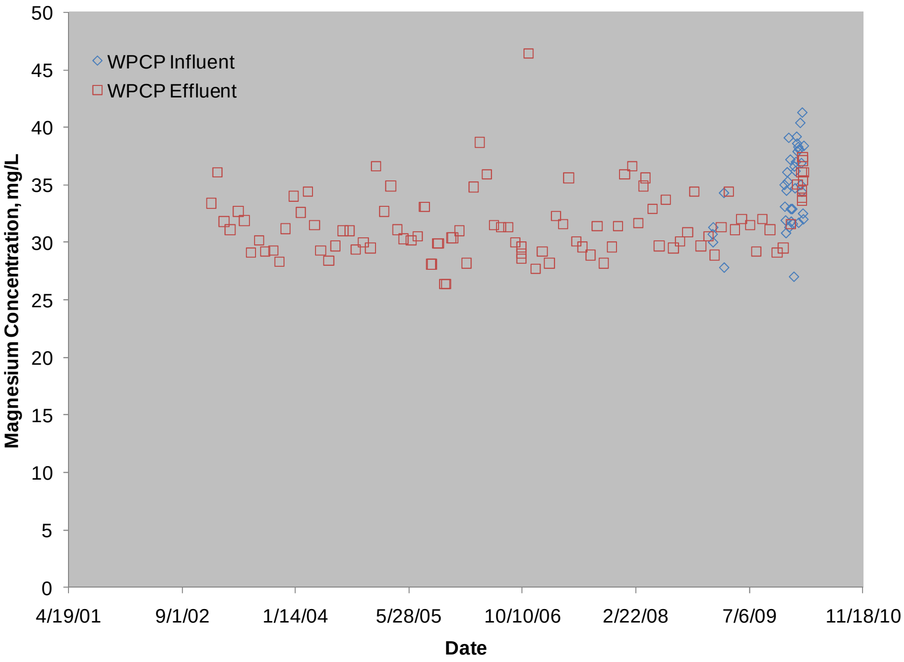

Figure 4-6. Historical WPCP influent and effluent magnesium concentrations.

4.3 Model Results for Digesters

The collected data presented in Table 4-1 show that the digester feed has substantial levels of the components necessary to form struvite. As a first step in the evaluation process, these data and further data presented in Attachment A were used to model the anaerobic digesters using vMinteq. Table 4-3 presents the results of the anaerobic digester simulation using the two sets of data. Both the field measured and model predicted pH values are presented. The model predicted pH is lower than the field measured value because of the impact of gas phase in the digester. The model shows that the potential exists for four species to precipitate: struvite, vivianite, diaspore and octacalcium phosphate. Struvite formation, as predicted by the model, agrees with field observations of struvite in the digesters and in the digester recirculation piping. The data from the second sampling event was collected while $FeCl_2$ was being added at the headworks at a dosage rate of 5 mg/L. As a result, there is an increase in vivianite formation with the second set of data. However, the model predicts that struvite will form with either set of data. This means that there was not enough $FeCl_2$ added to the digester influent to precipitate all of the phosphate and that the remaining phosphate is available for precipitation as struvite. The model predicts more struvite forming with the second set of data, even with $FeCl_2$ addition. The higher formation with the second set of data is due to the higher pH value (7.50 versus 7.03) and the higher concentration of magnesium (246 mg/L versus 216 mg/L).

It is interesting to note that the model predicts a significant amount of calcium phosphate formation. This is in agreement with recent work by Pastor et al. (2007) who showed that the presence of calcium can prevent struvite formation. They found that as calcium concentration increased, an amorphous calcium phosphate precipitate was measured. The amorphous nature of the compound was confirmed with x-ray diffraction. Although the model predicts that octacalcium phosphate forms, in reality amorphous calcium phosphate is expected. Calcium phosphate precipitates are expected to pose the same challenges to solids processing equipment as struvite.

Table 4-3. Model-predicted precipitated solids species for the anaerobic digesters

Parameter	1st Event Data, mg/L	2nd Event Data, mg/L
Field Measured pH	7.03	7.50
Model Predicted pH	6.74	6.93
Vivianite [$Fe_3(PO_4)_2 \cdot 8H_20$]	16	424
Diaspore [AlO(OH)]	38	72
Octacalcium Phosphate [$Ca_4H(PO_4)_3 \cdot 3H_2O$]	320	650
Struvite [$MgNH_4PO_4 \cdot 6H_20$]	400	633

4.4 Model Results for Digested Sludge Transfer Piping

Modeling using vMinteq was performed using the digested sludge as an input to determine the potential for struvite formation in the digested sludge transfer piping. Table 4-4 indicates that struvite does not have the potential to form using data from either sampling event. During the first sampling event, the predominant precipitate was octacalcium phosphate. As mentioned previously, it is expected that an amorphous calcium phosphate precipitate would form instead of octacalcium phosphate based on the findings of Pastor et al. (2007). The second sampling event consisted mostly of calcite. Although both of these compounds could result in scaling, struvite formation potential is not predicted. It is important to note that for both conditions, the lab-measured pH and the model predicted pH are different due to the impact of the CO_2 content in the gas phase. When samples are removed from the digested sludge piping, excess CO_2 off gases which results in a pH increase.

Historically, struvite has been reported to form in pipe bends and in the DSEPS wet well. Formation will be exacerbated at localized increases in pH resulting from areas of turbulence or reduced pressure, such as in pipe bends and pump intakes. These areas of turbulence can result in release of CO_2 gas and an increase in pH. This is shown in Figure 4-7 where the model was run at varying levels of CO_2 content in the gas phase using the second set of data. This represents conditions existing due to a pressure drop that occurs in pipe bends and fittings. Figure 4-7 shows that when the CO_2 partial pressure is reduced by approximately half, from 0.36 atmospheres (atm) at pH 7.1 to 0.2 atm, struvite formation potential occurs. This is because the pH increases due to off-gassing of CO_2. These results indicate that struvite has the potential to form at bends and other areas of sudden pressure loss where CO_2 partial pressure drops and pH rises. Table 4-5 presents the data shown in Figure 4-7. At a pH of 7.4, struvite is predicted to form. This is only 0.3 pH units higher than the model-predicted pH during the second sampling event, and it is very likely that this localized pH increase is occurring at export pipe valves and fittings. Therefore, interpretation of the modeling results indicate that struvite is likely to form in the DSEPS wet well and export pipe. This is in agreement with plant observations.

Table 4-4. Model-predicted precipitated solids for the digested sludge transport line

Parameter	1st Event Data, mg/L	2nd Event Data, mg/L
Field Measured pH [1]	7.0	7.7
Model Predicted pH	6.9	7.1
Vivianite $[Fe_3(PO_4)_2 \cdot 8H_20]$	0.7	1.1
Diaspore $[AlO(OH)]$	1.1	0.6
OctaCalcium Phosphate $[Ca_4H(PO_4)_3{:}3H_20]$	70.3	---
Calcite $[CaCO_3]$	---	49.8
Struvite $[MgNH_4PO_4 \cdot 6H_20]$	---	---

[1] pH values are taken from the specific sampling days where struvite formation potential was highest (i.e. the largest calculated $\{Mg^{2+}\}*(NH_4^{+}\}\{PO_4^{3-}\}$ of all sampling days)

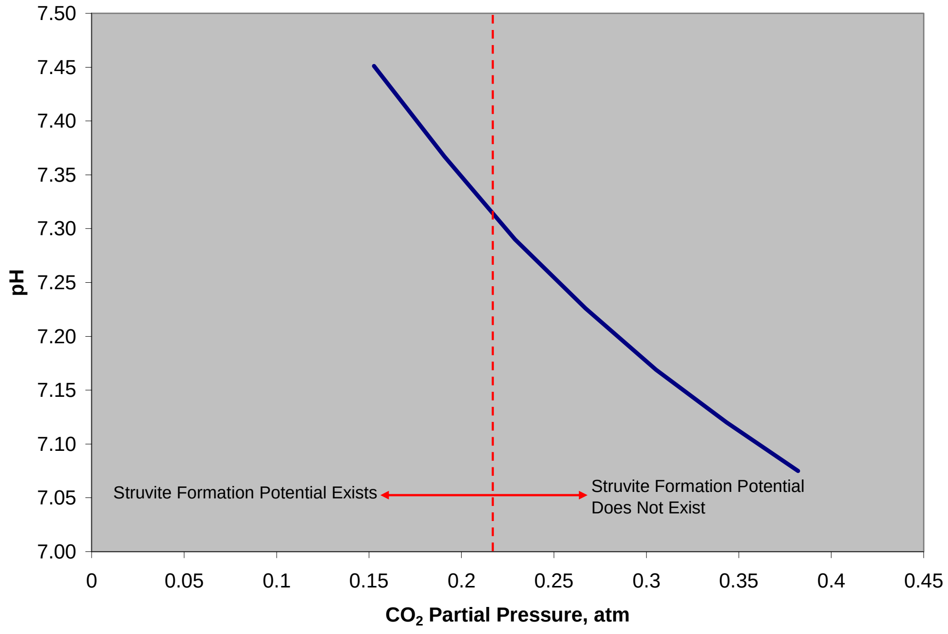

Figure 4-7. Relationship between CO_2 partial pressure, digested sludge pH and struvite formation potential. Second set of data were used for modeling in digested sludge transfer pipe. Note that atmospheric CO_2 partial pressure is 0.0003 atm.

Table 4-5. Model-predicted precipitated solids for the digested sludge transport line using second sampling event

Parameter	pH = 7.3	pH = 7.4	pH = 7.5
Struvite [$MgNH_4PO_4 \cdot 6H_20$]	---	32.4	63.0

4.5 Model Results for Lagoon Supernatant Line

Modeling results for the lagoon supernatant line (Table 4-6) show that struvite does not have the potential to form. Plant staff (Discussion of Struvite Occurrence, May 2, 2009) reported that struvite has formed in the return pipe; not the channel. However, they reported this has not been a major issue. We expect there are times when struvite can form with minor increases in pH at points of turbulence, however formation potential is expected to be relatively low compared to the digesters and digested sludge export lines. In addition, minor changes in ionic strength will impact formation, as discussed in section 4.6.

Table 4-6. Model-predicted precipitated solids for the lagoon supernatant line

Parameter	1st Event Data, mg/L	2nd Event Data, mg/L
Field Measured pH [1]	7.60	7.60
Model Predicted pH	7.60	7.60
Vivianite [$Fe_3(PO_4)_2 \cdot 8H_20$]	0.3	0.4
Diaspore [AlO(OH)]	1.1	1.1
Calcite [$CaCO_3$]	50.3	45.6
Struvite [$MgNH_4PO_4 \cdot 6H_20$]	---	---

[1] pH values are taken from the specific sampling days where struvite formation potential was highest (i.e. the largest calculated {Mg^{2+}}(NH_4^+}{PO_4^{3-}} of all sampling days)*

4.6 Comparison of Model Results with Solubility Curve

Plant reported values for magnesium, ammonia, phosphate and pH were used to generate Figure 4-8. Figure 4-8 presents two solubility curves for struvite using the Ksp value proposed by Ohlinger. The two curves represent an ionic strength of 0.0, which would represent a fluid completely free of ions, and 0.1, which represents a fluid more typical of municipal wastewater in ionic content. Using the plant reported conductivity and total dissolved solids data, the ionic strength is estimated to range between 0.05 and 0.1, calculated using relationships presented in Snoeyink and Jenkins, 1980.

If data points fall above the solubility curve, the sample is saturated with respect to struvite. If a data point falls below the solubility curve, the sample is not saturated with respect to struvite and struvite formation should not occur. Using a solubility curve, such as the one presented in Figure 4-8, does not account for competing precipitation reactions. For instance, Figure 4-8 does not consider the presence of iron, which could remove phosphate and form vivianite and prevent struvite precipitation.

The data points represent the data collected for the struvite modeling, as well as other samples that were collected subsequent to the struvite modeling data collection. All data points have been temperature corrected using the van't Hoff equation. Figure 4-8 shows that that the data falls between the two curves. At a 0.0 ionic strength, the samples are oversaturated (formation), and at 0.1 ionic strength the samples are undersaturated (no formation). Realizing that digested sludge and the lagoon supernatant will have an ionic strength closer to 0.1 than 0.0, Figure 4-8 shows that the digested sludge is very close to saturation, and minor changes in pH can result in struvite formation. For instance, a pipe bend, where a localized pressure drop would occur and increase pH, is very likely to have struvite. This is in agreement with the vMinteq predictions and plant observation.

For the lagoon supernatant, the data in Figure 4-8 show that it has less struvite formation potential than digested sludge, but that at times, it is supersaturated. These results, as well as the results presented from the vMinteq modeling (Table 4-6), suggest that struvite formation in the lagoon supernatant line can occur, but that it may not occur continuously. In addition, any localized pH changes, which could be caused by pipe elbows, are likely to result in struvite saturation. This is in agreement with plant staff observations of struvite occurring on submerged probes and in small amounts in the return pipe (cleaned only once for grit deposition).

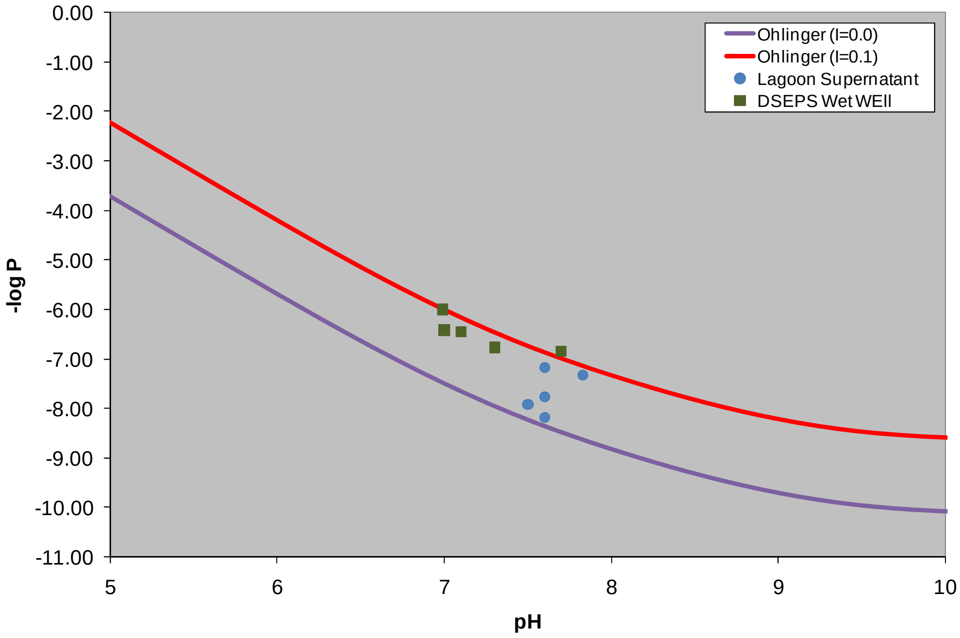

Figure 4-8. Comparison of temperature corrected plant data and solubility curve at ionic strength values of 0.0 and 0.1

5. ANALYSIS OF PREVENTION AND CONTROL MEASURES

Relevant alternatives were identified that could be used to mitigate struvite formation in each of the cases discussed above. When possible, the vMinteq model was used to determine which alternatives had potential for being effective if implemented at the WPCP.

5.1 pH Reduction

The reduction in pH with acid addition can reduce the formation potential of struvite. For San Jose, it was assumed that HCl would be added; sulfuric acid could be used, but would increase H_2S production in the digester gas. The vMinteq model was used to test the level of reduction required to eliminate formation potential. Table 5-1 summarizes the results of the vMinteq modeling. The model predicts that pH adjustment to approximately 6.5 would be required to eliminate the potential to form struvite in the digesters. This level of acid addition would destroy digester alkalinity, making the digester biology less stable. Operation at a pH of 6.5 with reduced alkalinity is not recommended for anaerobic digestion. In addition, the large quantity of acid poses significant cost and chemical handling risk. For these reasons, we do not recommend acid addition as a solution for struvite control within the digesters for the WPCP.

Table 5-1. Model results for the case where hydrochloric acid were added to the digester

Parameter	Model Prediction at pH = 7.03 (mg/L)	Model Prediction at pH = 6.75 (mg/L)	Model Prediction at pH = 6.50 (mg/L)
Concentration of HCl Added, mg/L	---	118	850
HCl Addition, lb/d[a]		905	6,500
Pre0cipitated Solids			
Vivianite $[Fe_3(PO_4)_2 \cdot 8H_20]$	16	16	16
Diaspore [AlO(OH)]	38	38	38
Octacalcium Phosphate $[Ca_4H(PO_4)_3 \cdot 3H_2O]$	320	320	---
Calcium Phosphate $[CaH(PO_4)]$	---	---	332
Struvite $[MgNH_4PO_4 \cdot 6H_20]$	400	370	---

[a] *Assuming annual average digester flow of 0.92 mgd (2007 average value)*

Acid addition could be performed downstream of the digesters to prevent formation in the digested sludge export piping and DSEPS wet well. Adjusting the pH to 6.0 could be performed on a continuous basis to prevent struvite formation. A pH value of 6.0 would provide was selected over the model-predicted value of 6.5, because there would be localized pH increases at elbows and fittings. Adjusting to pH 6.0 would reduce formation at these locations. However, acid addition could result in corrosion of the export piping and an overdose could negatively impact the sludge lagoons. A pH controller would need to be installed with feedback to ensure that a drastic decrease in pH does not occur. Using the second set of data, adjusting the pH to 6.0 would require approximately 1,670 mg/L of HCl, again a large quantity of acid posing higher costs and risks. Periodic cleaning with weak acid in a controlled maintenance procedure, as is currently done, is a less costly, more reasonable approach. If acid addition for pH adjustment were implemented, bench-scale analyses would be recommended to refine acid requirements. To test the cost of this option, acid addition for pH adjustment to the DSEPS line was retained for costing evaluation.

5.2 Physical Modifications to Minimize Carbon Dioxide Release

As discussed above, struvite formation can occur in regions of turbulence that cause CO_2 release. As a result, the pH increases, which raises the possibility of struvite formation. Minimizing CO_2 release would help control struvite formation in the DSEPS wet well, the digested sludge export line, and the digester recirculation lines. In the DSEPS, struvite is forming on the intake bell of the pumps. Struvite is expected to form in the pump intake regardless of the type of pump installed. Therefore, replacing the DSEPS pumps will not stop struvite formation. In the digested sludge recirculation line, headloss could be reduced by eliminating some of the pipe bends. However, struvite is still expected to form in this line regardless, because of headloss caused by isolation valves. For the digested sludge export line, a larger diameter pipe could result in reduced turbulence; however turbulence would still exist at pipe bends and struvite formation would probably still occur. Modifications to reduce CO_2 release are not practical solutions and are not recommended.

Another physical modification to reduce struvite formation in the digested sludge export line could be to replace the existing pipe with a new pipe that minimizes struvite accumulation (such as HDPE, see Section 2). In addition to HDPE, Baur (2008) showed that replacing ductile iron pipe for centrate with pipe lined with polyvinylidene fluoride (PVDF), specifically Kynar®, significantly reduced (but did not prevent) struvite accumulation over a 3-week testing period (Figure 5-1). Other materials that were tested included butyl rubber, polypropylene and teflon. We contacted Mr. Baur who informed us that Kynar® coated pipes for centrate have been in service for 5 years and have not shown any struvite accumulation. Use of PVDF lining could also be applied to the sludge recirculation piping to minimize formation. However, replacing the pipes would not reduce struvite formation inside the digester.

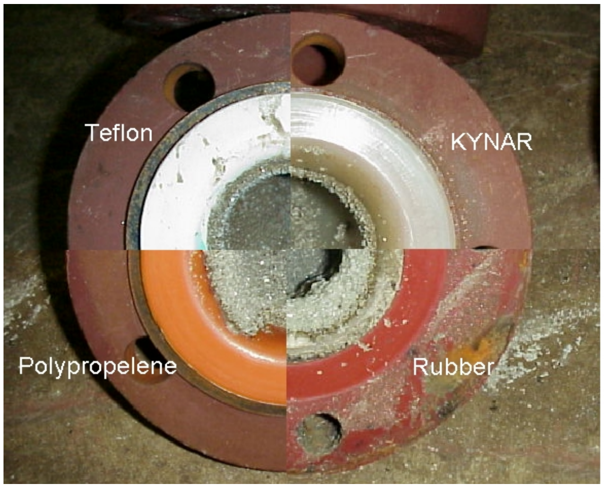

Figure 5-1. Picture of four types of pipe tested for struvite accumulation at the Durham AWWTP. (Photo courtesy of Rob Baur, Clean Water Services, Tigard, Oregon)

5.3 Digester Feedstock Dilution

Dilution of the digester feedstock to reduce magnesium, ammonia and phosphate concentrations with secondary effluent, for example, is not a viable alternative because it significantly reduces the digester hydraulic capacity.

5.4 Digester Feedstock Phosphorus Reduction through Liquid Stream Process Modification – Modified Ludzack-Ettinger Process

It has been commonly observed in the industry that with the advent of more biological phosphorus removal in liquid stream treatment, the incidence and severity of struvite problems have increased. Increased phosphorus being carried by waste activated sludge gets released during digestion and significantly increases formation potential. The secondary process at the WPCP was converted to a BNR system in the late 1990s. The conversion to a BNR facility was not the cause of struvite formation at the plant since, according to plant staff (Discussion of Struvite Occurrence, May 2, 2009); struvite was observed before the BNR conversion. However, it can be predicted that the conversion to BNR increased the rate of struvite formation due to higher phosphorus content in the secondary sludge. Conversion of the secondary process to a modified Ludzack-Ettinger (MLE) process[6] would reduce the phosphorus loading to the digester, but would not completely eliminate phosphorous load. To investigate the impact of this phenomenon on the WPCP, we investigated the impact of reducing the phosphorus content in the TWAS by operating without biological phosphorus removal.

Analysis of Table 4-1 shows that the total phosphate concentration in the TWAS is 3,695 mg-P/L and that the dissolved content is 478 mg-P/L. The particulate concentration is therefore 3,217 mg-P/L. During the testing, the volatile solids (VS) content of the TWAS was 2.63 percent VS. These values equate to 12 percent of the VS being phosphorus, on a dry weight basis. This fraction is typical for an activated sludge process that removes phosphorus, as is the case at the WPCP. Phosphorus removal is not required under WPCP's discharge permit; it is performed along with nitrogen removal as a means of reducing operating costs by saving aeration energy.

The modeling of the digester was repeated assuming the particulate phosphorus content of the VS was 2 percent, which is typical for an activated sludge that does not accumulate phosphorus. This results in a digester feed concentration of 1,124 mg-P/L, assuming that the dissolved phosphorus concentration is unchanged.[7] Table 5-2 presents the results of the modeling with and without phosphorus removal in the secondary system. Results indicate an approximately 25 percent reduction in potential. However, the results indicate a strong potential for struvite to precipitate, even if phosphorus removal were stopped. Conversion of the secondary process to the MLE process would reduce the phosphorus loading to the digester, but would not completely eliminate struvite formation potential. The conversion to MLE would need to be driven by regulations (i.e. total nitrogen limit), rather than struvite and is not considered further. Eliminating

---

[6] In the MLE process, the aeration basin is segregated into anoxic and aerobic zones for the purpose of nitrogen removal. There is an internal mixed liquor recycle (IMLR) that returns sludge from the aerobic zone to the anoxic zone. This internal recycle results in nitrate return to the anoxic zone, which is subsequently used for denitrification. Because nitrate is present in the anoxic zone, biological phosphorus uptake does not occur.

[7] 1. **Calculate TWAS PO_4^{3-}content**
VS = 2.63% = 26, 300 mg/L *assume 1% is approximately equal to 10,000 mg/L*
P content = 0.02*26,300 mg/L = 526 mg-P/L *assume 2% of VS is P*
Total P Content = 478 mg-P/L + 526 mg-P/L *add particulate and soluble PO_4^{3-}*
Total P Content = 1,004 mg/L
2. **Calculate Digester Feed PO_4^{3-}content**
Primary A&B PO_4^{3-}- content = 1,152 mg-P/L
Primary C&D PO_4^{3-}- content = 1,195 mg-P/L
Digester Feed PO_4^{3-} content = 0.3*1,152 mg-P/L+0.4*1,195 mg-P/L+0.3*1,004 mg-P/L *using relative digester flowrates*
Digester Feed PO_4^{3-} content = 1,124 mg-P/L

BNR in the future could potentially reduce, but would not eliminate struvite formation in the digesters. The phosphorus concentration would still be high enough for it to precipitate.

Table 5-2. Model results comparing precipitation in the digesters under existing conditions and if BNR were stopped in the secondary system

Parameter	Model Prediction Under Current Conditions (mg/L)	Model Prediction without BNR in Secondary (mg/L)
Vivianite $[Fe_3(PO_4)_2 \cdot 8H_20]$	16	16
Diaspore $[AlO(OH)]$	38	38
Octacalcium Phosphate $[Ca_4H(PO_4)_3 \cdot 3H_2O]$	320	315
Struvite $[MgNH_4PO_4 \cdot 6H_20]$	400	302

5.5 Digester Feedstock Phosphorus Reduction through Liquid Stream Process Modification – Modified Step Feed BNR

Conversion to the MLE process, as discussed in section 5.4, would have a 25-percent reduction in struvite formation potention. However, this would represent a significant capital cost for the conversion. An alternative to the MLE process would be to retain the current step feed configuration and provide for internal recycle from the rear of the aeration basin to the front of the aeration basin. A comparison of the MLE and modified step feed configurations is show in Figure 5-2. Conversion to the modified step feed could be achieved by installing an IMLR pump. However, the process could be optimized by adjusting the unaerated zones so that they account for only 20 percent of the total volume, rather than 50 percent which is the case currently.

The impact of the IMLR pumping ratio was compared to the phosphorus content in the secondary sludge. The BioWin model that was used for the master plan was reconfigured to represent the modified step feed using unaerated volume of 50 percent and 20 percent. Figure 5-2 shows that at an IMLR of 300 percent of the influent flow, there is a significant decrease in phosphorus loading to the digesters for the condition where 20 percent of the tank is unaerated. However, in the current condition of 50 percent unaerated, even an IMLR of 500 percent does not reduce phosphorus to the digester significantly. This is because the unaerated zones are too large to suppress biological phosphorus removal. There is not enough nitrate returned to the unaerated zones to suppress phosphorus release. Therefore, conversion to the modified step feed using the existing 50 percent unaerated configuration is not recommended as a struvite control measure. However, as stated above, the process could be optimized by adjusting the unaerated zones so that they account for only 20 percent of the total volume, rather than 50 percent.

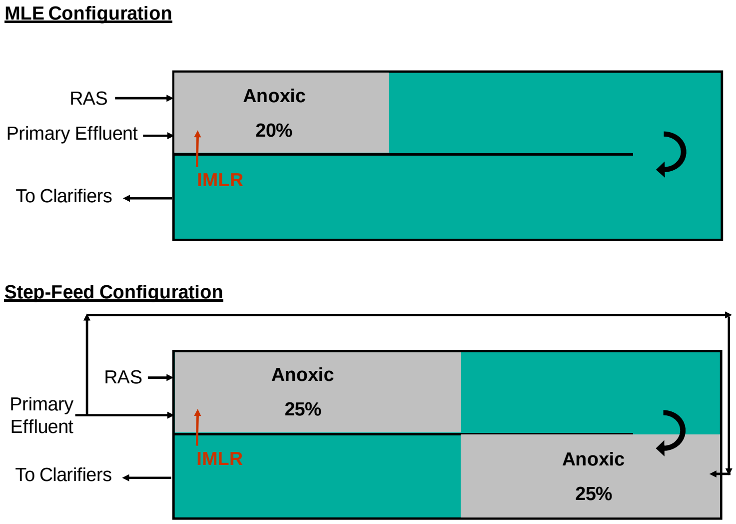

Figure 5-2. MLE and modified step feed configurations

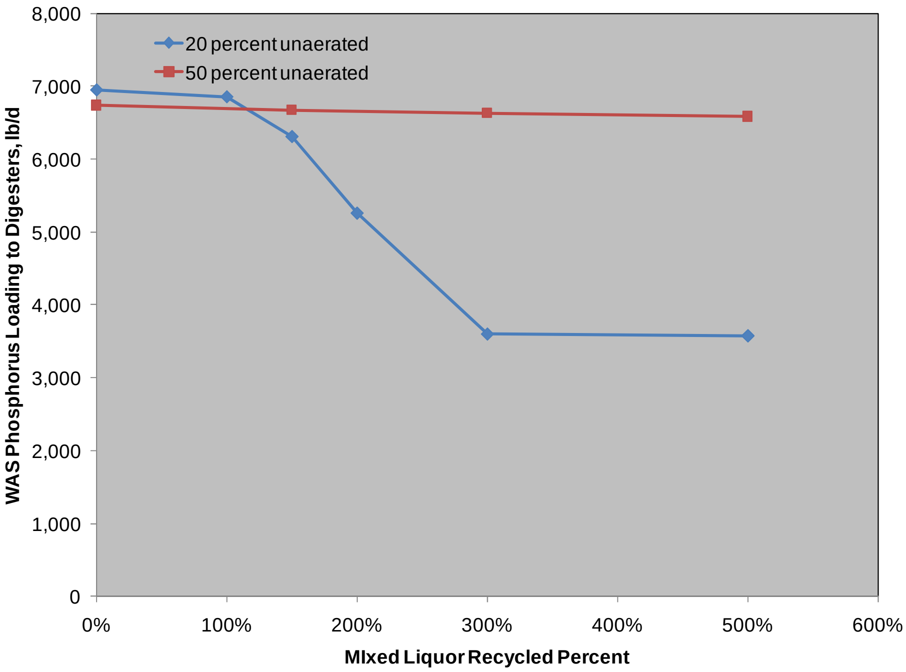

Figure 5-3. Comparison of phosphorus loading to the digesters over a range of IMLR value.

5.6 Anti-Scaling Chemicals

In recent years, commercial chemicals have become available that are purported to reduce or prevent struvite formation. Three chemical suppliers were contacted: Carus Phosphates, Inc. (Peru, Illinois), Schaner's Wastewater Products Inc. (Fulton, Texas) and SNF/Polydyne. (Riceboro, Georgia). These chemicals are designed to inhibit crystal formation. Of the vendors contacted, none had an example of a facility that added chemical to the digesters; all referenced projects had the chemical added downstream of the digesters. Bench-scale testing would need to be performed to determine if anti-scaling chemicals would work at the WPCP. If successful at bench-scale, full-scale trials could be performed.

Carus Phosphates, Inc. provided additional information on their product, Struvout™. The Struvout™ product contains a dispersant and sequestrant to prevent struvite formation. Dosages range from 30 to 50 mg/L. The vendor recommended dosing 15.6 gallons per day of product for struvite control at the WPCP. At a cost of $10 per barrel, this would equate to an annual cost of $57,000 for the chemical. Before applying the Struvout™ product, the vendor recommended that the pipes are cleaned to remove struvite to improve future struvite control. Carus Phosphates, Inc. provided contact information for two of their customers: Joint Meeting of Essex and Union Counties (New Jersey) and Rahway Valley Sewage Authority (New Jersey).

- The Joint Meeting wastewater facility treats an average flow of 85 mgd. Struvite had been observed to form in centrifuge feed lines and centrate lines; minimal struvite formation has been observed in the digesters. Currently, the plant uses the Struvout™ product, as well as several other products by other suppliers, interchangeably. This is due to limitations on product bidding. Anti-scaling chemicals have been used over the past 5 years and have significantly reduced struvite formation; however, struvite does still form.
- The Rahway wastewater facility stated that they have not used the product yet.

Schaner's Wastewater Products, Inc. did not provide any information after several requests. Polydyne recommended their Flosperse 30s product, priced at 0.89/lb. Flosperse 30s is an organic dispersant that is an effective anti-scalant. They estimated an annual chemical cost of $168,000 assuming a dose of 100 mg/L.

It should be reiterated that these dosage rates and product effectiveness cannot be relied upon without first testing for the desired application at the WPCP.

5.7 Iron Salt Addition

A common technique to prevent struvite formation is the addition of iron-based chemicals (i.e., $FeCl_3$ or $FeCl_2$) to preferentially precipitate vivianite. Mamais et al. (1994) performed anaerobic digestion experiments and determined that a $FeCl_3$ dose of 100 kg/ton TS was sufficient to prevent struvite formation at the Southeast Water Pollution Control Plant in San Francisco, California. However, the authors noted that in reality, only 47 kg $FeCl_3$/ton TS was being fed to the SEP digesters and prevented struvite formation in the centrate lines. The authors concluded that at supersaturated conditions, struvite precipitates can be removed with the digester effluent at a similar rate that it is formed so that there is no accumulation. There are other factors that could contribute to this difference such as degree of supersaturation, hydrodynamics of the digester and interior digester material.

Modeling was performed to determine the $FeCl_3$ dose to prevent the formation of struvite so that only vivianite were formed in the digester. As noted by Mamais et al. (1994), it may not be necessary to achieve undersaturated conditions to prevent struvite formation. Table 5-3 shows that using 47 kg $FeCl_3$/ton TS would still result in struvite formation, but that 100 kg $FeCl_3$/ton TS would be sufficient to prevent formation. It is important to note that as the $FeCl_3$ dose increases, the pH in the digester decreases. If $FeCl_3$ addition were performed, caustic soda addition may be necessary to prevent pH suppression, which could impact process performance. A subsequent model run was performed assuming a dose of 100 kg $FeCl_3$/ton TS and keeping the pH at 6.74 (the value where no $FeCl_3$ was added). At this condition, struvite is still predicted to form, but at 75 percent reduction than if no chemical were added. This modeling condition represents pH adjustment using caustic soda.

According to WPCP staff (Discussion of Struvite Occurrence, May 2, 2009), $FeCl_2$ was metered into the WPCP digester recirculation piping upstream of the heat exchangers for sulfide control, approximately 20 years ago. As a result, excessive vivianite formation occurred, which required an entire heat exchanger replacement. Dezham et al. (1988) documented the addition of $FeCl_2$ to the digester sludge recirculation lines downstream of the heat exchangers at the WPCP, which resulted in excessive vivianite formation that reduced the pipe diameter from 8 inches to 2 inches in 6 months. According to City staff, $FeCl_2$ was added to the plant influent from 1986 to 1996 for H_2S control in digester gas; Dezham et al. (1988) presents the original study. It has also been used in the collection system.

Recently, jar testing has been performed at $FeCl_3$ doses from 5 to 20 mg/L to determine if chemically enhanced primary treatment (CEPT) could provide additional TSS and BOD removal in the primary clarifiers. Full-scale testing was conducted and demonstrated a 27 percent reduction in BOD loading and 20 percent reduction in TSS loading to the secondary system.

At a dose of 15 mg/L, the $FeCl_3$ addition is estimated at 112 kg/ton TS at the current condition,[8] which may suppress struvite formation based on the results in Table 5-3. Addition of $FeCl_3$ would reduce H_2S content in the digester gas. However, this could result in excessive vivianite formation as reported by Dezham et al. (1988). If $FeCl_3$ addition is performed in the future, we recommend that it is performed at the headworks and not directly to the digesters. Chemical addition at the headworks would provide the added benefit of improved primary clarifier removal, which would reduce secondary aeration requirements. Also, digester recirculation lines and heat exchangers should be inspected routinely to determine if excessive vivianite accumulation is occurring.

Table 5-3. Precipitation potential from modeling at varying ferric chloride target dosages and at current loadings

Parameter	No FeCl3 Addition, mg/L	47 kg FeCl3/ton TS[a], mg/L	70 kg FeCl3/ton TS, mg/L	100 kg FeCl3/ton TS[b], mg/L	100 kg FeCl3/ton TS[b] (fixed pH), mg/L
Field Measured pH	7.03	---		---	---
Model Predicted pH	6.74	6.69	6.63	6.44	6.74
Vivianite [Fe3(PO4)2·8H20]	16	833	1,234	3,550	3,550
Diaspore [AlO(OH)]	38	38	38	38	38
Octacalcium Phosphate [Ca4H(PO4)3·3H2O]	320	317	314	285	305
Struvite [MgNH4PO4·6H20]	400	321	269	---	100

[a] *Existing dose presented in Mamais et al, (1994)*

[b] *Dose determined from pilot testing where struvite is not supersaturated (Mamais et al., 1994)*

5.8 Digested Sludge Dilution

Several model runs were performed to determine if struvite formation potential could be prevented by diluting digested sludge on its way to the lagoons with secondary effluent. Adding secondary effluent to the DSEPS would dilute the phosphate and ammonia. Phosphate and ammonia concentrations in secondary

---

[8] $FeCl_3$ = 15 mg/L * 110 mgd * 8.34 = 13,800 lb $FeCl_3$/d
Digested Sludge = 0.9 mgd * 15,000 mg/L * 8.34 = 112,600 lb/d
Ratio of $FeCl_3$ to Sludge = (13,800 lb/d)/(112,600 lb/d) = 0.123 lb $FeCl_3$/lb TS
= 0.123 lb/lb * 0.454 kg/lb * 2,000 lb/ton = 112 lb $FeCl_3$/ton TS

effluent will be significantly lower than values found in digested sludge. However, we assumed that the magnesium concentration would be unchanged. Table 5-4 summarizes the results of the modeling. The digested sludge export line modeling (Table 5-4) showed that struvite was not predicted to form unless there was an increase of pH to 7.3 (Figure 5-1) caused by off-gassing of CO_2 due to turbulence. The results in Table 5-4 show that a dilution with 33 percent secondary effluent would increase the pH of struvite formation to 7.80 and that a dilution with 50 percent secondary effluent would require a pH in excess of 8.0. Clearly in this case, dilution could be an effective control measure.

Table 5-4. Summary of model runs to predict struvite formation potential using secondary effluent dilution using data from second sampling event

Parameter	No Dilution (Existing Condition)	33 Percent Secondary Effluent	50 percent Secondary Effluent
Model Predicted pH for Struvite Formation	7.30	7.80	>8.0

5.9 Controlled Precipitation with the Ostara Process

Rather than preventing struvite from forming in the digesters and digested sludge transport line, another potential solution is to preferentially precipitate it out in a different location. This is the idea behind the Ostara process (Ostara Nutrient Recovery Technologies, Inc., Vancouver, British Columbia, Canada), where struvite is preferentially formed and sold as fertilizer as discussed in Section 3.5. Ostara Nutrient Recovery Technologies, Inc. will typically only consider the Ostara process for plants that have biological phosphorus removal so that the amount of struvite formation is maximized to make the system more economical. The system is effective at removal of side stream phosphorus, but is not applicable to full sludge stream phosphorus removal.

The Ostara process preferentially precipitates struvite in an upflow fluidized reactor, rather than in solids processing facilities. The reactor is fed with dewatering return streams that are high in phosphorus and ammonia. The TSS concentration in the feed is required to be less than 1,000 mg/L. The pH in the reactor is increased, using caustic soda, and magnesium (e.g. magnesium chloride) is added, as needed, to maximize struvite formation. The struvite is preferentially formed in fertilizer-sized particles, called prills. The larger prills fall to the bottom of the reactor and are removed. The reaction time for prill formation is estimated at 10 minutes (Baur et al., 2008). The prills are typically hauled off site and sold as fertilizer.

There are currently two full-scale Ostara installations: one in Edmonton, Canada that has been in operation since May, 2007 and a second in Tigard, Oregon that has been in operation since the end of April, 2009. The Ostara process has been pilot tested at wastewater plants in Suffolk, Virginia (Prasad et al., 2007); Tigard, Oregon (Baur et al., 2008); three facilities in Canada; and most recently in San Francisco, California. Pilot testing conducted a the wastewater plant in Oregon (Durham AWWTP, Clean Water Services) demonstrated a 95-percent recovery of phosphate and a 19-percent recovery of ammonia from the centrate (Baur et al., 2008). The drivers behind this full-scale application are to reduce nitrogen and phosphorus loadings in the solids processing return streams (to meet stringent effluent nutrient requirements) and to prevent struvite formation in the centrate lines.

For the WPCP, the Ostara process could be fed with lagoon supernatant to precipitate struvite. Although removing phosphorus from the lagoon supernatant is expected to reduce phosphorus loading to the digesters, it is not expected to eliminate struvite formation. If the Ostara process were fed with subnatant from the DAFT, most of the phosphorus is bound in the thickened sludge and would still result in struvite formation. It should be noted that if mechanical dewatering is added in the future, the recycled phosphorus could increase exacerbating the struvite precipitation.

Another approach would be to install the WASSTRIP process in conjunction with Ostara where the secondary sludge is held in a mixed reactor and fed with VFAs to encourage soluble phosphorus release prior to sludge thickening. As a result of the pilot testing at the Durham AWWTP, the WASSTRIP process (waste activated sludge stripping to remove internal phosphorus, patent pending) was developed by Clean Water Services. The WASSTRIP process is designed to remove phosphorus and magnesium before it enters the digester, which can reduce struvite formation in the digesters. The process is only used for phosphorus removal from WAS resulting from liquid process biological phosphorus removal and can be up to 70 percent efficient in removal of bound phosphorus in this stream. The process consists of an anaerobic tank that is fed with secondary sludge and supplemental volatile fatty acids (VFAs) are added to encourage phosphorus and magnesium release by the microorganisms (like in the anaerobic portion of a BNR system). This process has been successfully demonstrated at the Durham AWWTP in Oregon, where, VFAs are supplied by an existing fermentation process. The sludge stream is then thickened, and the thickened sludge is sent to the digesters, and the excess water (the thickening recycle which contains higher levels of soluble phosphorus and magnesium) is sent to the Ostara process along with dewatering return streams.

This process combined with Ostara has the potential of removing up to 70 percent of the phosphorus from the digester feed. This process would require the construction of a new reactor and an additional source of VFAs. Although potentially costly, this process has the potential for controlling struvite formation throughout the sludge system. However, as demonstrated in Section 6.4 where eliminating biological phosphorus content did not prevent struvite formation potential, the WASSTRIP process in conjunction with Ostara would not completely eliminate struvite formation potential, but could reduce the rate of formation.

5.10 Pipe Cleanouts

Another limited option for struvite control is to include pipe cleanouts in the digester recirculation piping and in the digested sludge export line. The pipe cleanouts for the digester recirculation piping could be designed so that an acid cleaning could be performed. This would require the addition of valves to isolate the recirculation piping from the digester contents to keep acid out of the digester. Unlike the other alternatives discussed above, this action would not prevent struvite formation, but it would provide easier access for regular pipe cleaning to minimize severe accumulation. This solution would only work if the struvite could be easily removed by frequent mechanical cleaning. The digested sludge export line is currently periodically cleaned by acid addition for struvite removal. This does not address struvite formation in the DSEPS wet well or inside the digesters. Therefore, installation of pipe cleanouts is not recommended specifically as a struvite control measure at WPCP; pipe cleanouts still would provide benefit for routine maintenance and would be recommended if regular pipe cleaning was effective in conjunction with other struvite control methods.

5.11 Maintaining Existing Struvite Control Measures

Implementing any new struvite control measures needs to be done recognizing the cost and risks of current practices. Although allowing struvite to form is traditionally not considered a control measure, cleaning of digesters; replacement of pipes, valves, and elbows; and acid cleaning of pipes have all been reasonably effective (albeit an operational headache) at keeping the plant operating. These measures have costs associated with them that must be weighed against alternative control measures.

6. ALTERNATIVES ANALYSIS

This section provides an analysis of the alternatives that were identified for struvite prevention. Alternatives that were identified to be potential solutions were further evaluated using a cost estimate.

6.1 Estimate of Existing Annual Costs Associated with Struvite

The existing annual operations and maintenance (O&M) costs associated with controlling struvite formation at the WPCP are summarized in Table 6-1. These costs were developed with costs provided by City staff (WPCP staff. Meeting Discussion of Struvite Costs, August 13, 2010). It is important to note that the costs presented in Table 6-1 may not accurately reflect the actual cost of struvite and could be lower than actual costs. For instance, the digester recirculation piping may have significant struvite accumulation unbeknownst to maintenance staff.

The digester cleaning and digester recirculation maintenance represent the highest costs. It is important to note that the digester cleaning costs have been reduced to 30 percent of the total cost since struvite only represents 30 percent of the digester debris. The DSEPS cleaning represents a significant cost ($119,500 every 5 years) and is necessary in order to pump sludge to the lagoons.

Currently, the plant hires a contractor to clean from 3 to 4 digesters per year at an average annual cleaning cost of approximately $30,000 per year per digester. During the recent cleaning, the contractor noted significant amount of rags and other recognizable debris in the digesters. In addition, the grit and other debris removed from the digesters are currently stored on site. In the future, this grit and debris may require disposal offsite at a significantly higher cost. The annual digester cleaning cost is expected to increase significantly if off site disposal were necessary.

Table 6-1. Selected O&M costs associated with struvite formation

Parameter	Cost Description	Annualized Cost
Chemical Cleaning of Export Pipe [a]	$119,500 every 5 years	$ 23,900
DSEPS Inspection and Maintenance [b]	60 man hours every 2 years	$ 1,440
Digester Cleaning [b,c]	4 digesters cleaned every 5 years; 160 man hours per year	$ 38,310
Recirculation System Maintenance [b,d]	17 valves per digester (4 digesters per year) are replaced every 5 years. Estimate includes 20 ft of pipe per digester, 130 man hours per digester	$ 162,600
Pumping Costs [e]	Total power over 5 years due to struvite accumulation	$ 5,190
Total		$ 231,400

[a] Annualized cost assuming 5-year cleaning cycle at $119,500 per cleaning
[b] Assume one FTE is $100,000/yr
[c] Assume 4 digesters are cleaned per year ($30,000/digester) and struvite accounts for 30% of debris
[d] Equipment costs and labor provided by City staff, 150 man hours per year per digester
[e] DSEPS pumping pressure increased by 4.8 psi per year, based on City provided acid cleaning data

6.2 Relationship between Struvite Control and Mixing Upgrades

Table 6-2 presents a sensitivity analysis that demonstrates the impact of reducing struvite formation potential and implementing mixing improvements. These same assumptions are used in the digester mixing TM (4.2). Based on the struvite sampling results, approximately 20 to 30 percent of the digester debris is struvite. Based on this relationship, cleaning costs per digester were assigned to mobilization (8.3 percent), struvite dislodging from covers and walls (8.3 percent), struvite removal (25 percent) and grit removal (58.3 percent). Both eliminating struvite formation and upgrading the digester mixing system would reduce the cleaning costs by 75 percent per digester and reduce the accumulation of debris by 80 percent. If only mixing upgrades were installed, the annual cost would be reduced by 63 percent and the debris accumulation would be reduced by 75 percent. This analysis demonstrates that mixing improvements will have a more significant impact on digester cleaning costs than struvite mitigation measures. A similar approach was used to determine the cleaning costs for each of the subsequent alternatives.

Table 6-2. Digester cleaning and struvite removal impact matrix

Struvite Control in Digester	Digester Mixing Upgrade	Digester Cleaning Frequency, Years	Unit Digester Cleaning Cost, percent				Annual Cleaning Cost per Digester, percent of current cost	Reduction in Debris Accumulation [b]
			Struvite Dislodging [a]	Struvite Removal	Grit Removal	Cleaning Mobilization		
no	no	4	8.3	25.0 [b]	58.3 [b]	8.3	100%	0
yes	no	4	0	0	58.3	8.3	66.6%	30%
yes	yes	8	0	0	16.7	8.3	25.0%	80%
no	yes	4	8.3	8.3	12.5	8.3	37.4%	75%
no	yes	8	16.7	7.2	16.7	8.3	48.9%	71%
no	no	2	8.3	12.5	29.2	8.3	58.3%	50%

[a] *Entering cover headspace, banging floor to dislodge struvite, cleaning walls, hand removal of large struvite pieces.*

[b] *Currently, 30 percent of removed material (grit plus struvite) is struvite from March 2010 sampling of stockpiled material*

6.3 Alternatives Analysis

Table 6-3 presents a summary of the alternatives that were evaluated that could potentially prevent struvite formation. Of the 12 alternatives identified in Table 6-3, six were identified to be appropriate for full-scale implementation. The alternatives that involved acid addition to the digesters and modifying piping to reduce CO_2 off gassing were concluded to not be feasible. Conversion of the secondary process to a MLE process would reduce the phosphorus loading to the digester, but would not completely eliminate struvite formation potential. The conversion to MLE would need to be driven by regulations (i.e. total nitrogen limit), rather than struvite and is not considered further. Equipping the existing step feed configuration with an IMLR was shown to not reduce the phosphorus loading to the digester, and it is not recommended unless the unaerated zones of the aeration basins are optimized to reduce biological phosphorus uptake. Optimizing the aeration basins could reduce the total phosphorus content in the secondary sludge by half. Although installation of pipe cleanouts is not expected to be an alternative to prevent struvite formation, they are still recommended as a benefit for routine maintenance and inspection.

Table 6-3. Summary of alternatives to prevent struvite formation

Alternative	Description	Recommendation
pH Reduction in the Digesters	Using acid addition in the anaerobic digesters to reduce the pH would require a pH of 6.5, which is not recommended because of potential adverse impacts on methanogenic bacteria and, potentially, corrosion. Reduced pH in an anaerobic digester could severely impact process performance.	Not Recommended
pH Reduction in the Export Line	Acid addition could be performed continuously in the digested sludge export line and in the DSEPS wet well. However this is a limited option as it would not eliminate struvite formation in the digesters and associated recirculation lines.	Recommended for Cost Analysis
Physical Modifications that Minimize CO_2 Release	Minimizing CO_2 release in the sludge recirculation lines would be difficult to achieve with piping modifications. In addition, this would not address the formation in the digester. Minimizing CO_2 release in the DSEPS intake bells is not possible. Installation of new pumps is not expected to prevent struvite formation. For the digested sludge export line, a larger diameter pipe could result in reduced turbulence; however turbulence would still exist at pipe bends and struvite formation would probably still occur. This alternative would have limited effect on overall struvite prevention and is not recommended as a directed program for struvite control. However, any new designs or future pipe replacements driven by maintenance or capacity upgrades should utilize long radius elbows and other gradual flow transition arrangements to minimize formation in susceptible lines.	Not Recommended
Modifications to Reduce the Attachment of Struvite	The digested sludge export line could be replaced with a new HDPE pipe since struvite formation appears minimal on existing HDPE pipe. Digested sludge recirculation lines could be replaced with pipe lined with PVDF to reduce struvite attachment and accumulation. However, this modification would not address struvite formation in the digesters or in the DSEPS wet well. This alternative is recommended for cost analysis as a directed program for struvite control. This will test whether or not struvite control alone can justify pipe replacement. Whether or not struvite-driven pipe replacement is cost effective, any new designs or future pipe replacements driven by maintenance or capacity upgrades should consider use of HDPE pipe or PVDF liners to minimize formation in susceptible lines.	Recommended for Cost Analysis
Digester Feed Stock Dilution	Dilution of the digester feedstock to reduce magnesium, ammonia and phosphate concentrations with secondary effluent, for example, is not a viable alternative because it significantly reduces the digester hydraulic capacity.	Not Recommended
Digester Feedstock Phosphorus Reduction through Liquid Stream Process Modification - MLE	The impact of preventing biological phosphorus removal from occurring in the activated sludge process was modeled. Even if biological phosphorus removal were no longer occurring, struvite formation potential still exists. It is expected that the rate of struvite formation would decrease with the activated sludge conversion.	Not Recommended
Digester Feedstock Phosphorus Reduction through Liquid Stream Process Modification – Modified Step Feed	Installing an IMLR in the current step feed configuration would return nitrate to the unaerated zones to compete with biological phosphorus removal. The current configuration where half of the aeration basin volume is unaerated would not reduce the phosphorus content in the secondary sludge due to biological phosphorus removal activity. The aeration basins would need to be reconfigured to reduce the total unaerated volume to suppress biological phosphorus uptake.	Not Recommended

Table 6-3. Summary of alternatives to prevent struvite formation

Alternative	Description	Recommendation
Anti-Scaling Chemicals	Proprietary anti-scaling chemicals that inhibit crystal growth could be a feasible alternative for struvite control in the digesters. This would also prevent formation in the DSEPS wet well and in the digested sludge export line. However, anti-scaling chemicals are not typically added to digesters and efficacy is unknown. Bench-scale analyses followed by full-scale trials would be required to confirm performance.	Recommended for Cost Analysis
Iron Addition	Modeling showed that high doses of iron would be required to prevent supersaturation of struvite. Performing CEPT (at $FeCl_3$ dose in primary sedimentation of approximately 15 mg/L) could reduce the rate of struvite formation. If CEPT is implemented continuously, we recommend frequent inspection of digester recirculation piping and heat exchangers for vivianite accumulation.	Recommended for Cost Analysis
Controlled Precipitation	Implementation of the Ostara system would require the WASSTRIP process to minimize struvite formation in the digesters.	Recommended for Cost Analysis
Digested Sludge Dilution	Diluting digested sludge with secondary effluent at the DSEPS could prevent struvite formation in the DSEPS and digested sludge export line. Approximately 50 percent of the total flow would need to be secondary effluent to prevent struvite formation potential.	Recommended for Cost Analysis
Pipe Cleanouts	Installation of pipe cleanouts would not address struvite formation in the DSEPS wet well or inside the digesters. This alternative would have limited effect on overall struvite prevention and is not recommended as a directed program for struvite control. However, any new designs or future pipe replacements driven by maintenance or capacity upgrades should utilize cleanouts at strategic locations to minimize cleaning costs in susceptible lines. The digester recirculation piping could be designed with a cleaning loop to allow acid cleanings without impacting the digester contents.	Not Recommended

Table 6-4 presents the costs associated with alternatives that were identified to be potential solutions. The existing cost associated with struvite issues at the WPCP is estimated to have a present worth value of $5.4 million. Alternatives had present worth values ranging from $2.2 million to $54 million. The lowest cost alternative based on initial manufacturer dosing information would be to add anti-scaling chemicals, but this is based on manufacturer claims and would require preliminary testing to confirm success. We have assumed that the existing costs due to struvite accumulation would be reduced by 90 percent, but this would require full-scale testing to confirm. As mentioned previously, anti-scaling chemicals are typically not added to anaerobic digesters. Adding secondary effluent to the digested sludge export line or pH adjusting the export line would not address struvite formation in the digesters.

$FeCl_3$ addition has a present worth value of $18 million, but could result in excessive vivianite formation in the digesters (this cost has not been considered since it is speculative). However, $FeCl_3$ addition would increase secondary capacity as well as increase digester gas production; the additional primary clarifier solids removal would mean that the digesters would generate more gas. The value of the gas has also been included in the cost analysis. The chemical addition would provide the added benefit of reducing H_2S in the digester gas. City staff report that H_2S content in the digester gas has been increasing and at times can even be high enough to violate the WPCP air permit. Currently, plant staff control H_2S by strategic $FeCl_3$ addition only when the H_2S concentration approaches permit limits.

Replacing the export line with HDPE and replacing the digester recirculation pipes with PVDF lined pipes is estimated to have a present worth value of $20 million. The WASSTRIP/Ostara alternative has a present worth value of $44 million. This alternative would produce struvite for use as a fertilizer, which would be distributed by the vendor, and is the only alternative that provides beneficial reuse. However, the success of this alternative depends on the process performance; bench-scale testing is recommended to predict performance.

6.4 Discussion of Alternatives

The current cost associated with struvite formation at the WPCP is considerably less than any of the alternatives, with the exception of the anti-scaling chemicals. Adding $FeCl_3$ will increase secondary capacity, reduce aeration requirements and result in higher gas production. Furthermore, regular $FeCl_3$ addition would reduce the H_2S content of the digester gas. If nitrogen removal is necessary in the future, the MLE process could be implemented; the MLE process would require additional aeration tanks. If $FeCl_3$ addition were performed for struvite control, it could significantly reduce or eliminate the tankage requirements. This capital savings is expected to make $FeCl_3$ addition more economical than the existing conditions in terms of net present value.

Of all the alternatives, the WASSTRIP/Ostara process is the only one that takes advantage of beneficial reuse of nutrients. However, since phosphorus removal is not expected to be necessary in the future, it is not certain if the secondary system would continue to use biological phosphorus removal. Since the process is not specifically designed for phosphorus removal, we do not recommend implementing WASSTRIP/Ostara process.

We recommend that anti-scaling chemicals are testing at bench-scale and demonstration-scale to determine if they can be successfully used. If anti-scaling chemicals are not successful, we recommend implementing CEPT using $FeCl_3$ addition. Once implemented, the digester recirculation lines and heat exchangers should be routinely inspected to determine if excessive vivianite accumulation is occurring. Enhancing current practices by more frequent scheduled cleanings may be a method of reducing costs and operational impacts. If other alternative control measures do not prove cost effective, more frequent, budgeted and scheduled cleanings can be evaluated for a greater measure of control.

Table 6-4. Planning level cost estimate for struvite prevention alternatives[a,b]

Description	Capital Project Cost	Net Present Value	Location of Struvite Control	Capital Project Cost Considerations	O&M Cost Considerations
Existing Operation	0	$5,410,000	---	---	• Chemical cleaning of export pipe • Hydrojetting supernatant line • DSEPS inspection and maintenance • Digester cleaning • Recirculation pumping • Recirculation system maintenance • Increased pumping costs from struvite formation
Add Anti-Scaling Chemicals	$376,000	$2,170,000	All Locations	• Includes chemical metering station • Recommend bench-scale and full-scale testing before complete implementation	• Struvite associated O&M costs are reduced by 90 percent • Struvite associated cost is eliminated from digester cleaning cost • Included cost of anti-scaling chemical
Add Secondary Effluent Dilution System to DSEPS	$3,450,000	$9,220,000	DSEPS/Export Pipe	• Assume both export pipes would be put in service • Includes secondary effluent pumping station, secondary effluent pipe to DSEPS and one-time acid cleaning of each export pipe • Recommend testing to confirm dilution requirements	• Struvite associated O&M costs in DSEPS and export pipe are reduced by 90 percent, all other costs remain • Includes cost to pumps secondary effluent
Add Ferric Chloride to Plant Influent	$1,070,000	$18,000,000	All Locations	• Includes chemical metering station and storage tanks	• Struvite associated O&M costs are reduced by 75 percent • Chemical costs and savings from added gas production and reduced secondary aeration requirements are included • Savings from the elimination of $FeCl_2$ for H_2S mitigation is included
Replace Existing Export Pipe with HDPE and all Digester Piping with PVDF Lined Piping	$18,640,000	$20,000,000	Digester Recirculation System and Export Pipe	• Recommend testing to confirm that materials do not promote struvite formation	• Struvite associated O&M costs in recirculation line and export pipe are reduced by 90 percent, all other costs remain
WASSTRIP/Ostara	$20,670,000	$43,500,000	All Locations	• Includes a fermenter tank for WAS and Ostara units for phosphorus recovery • Jar testing is required to confirm that WASSTRIP would work at San Jose	• Struvite associated O&M costs are reduced by 70 percent • Annual cost is paid to Ostara and includes chemicals, electricity, maintenance and amortized equipment cost • Ostara markets and retains all benefits from sale of struvite
Add pH control system at DSEPS	$1,630,000	$53,600,000	DSEPS/Export Pipe	• Includes HCl storage tanks and acid metering pumps • Recommend bench-scale and full-scale testing before complete implementation	• Struvite associated O&M costs in export pipe and DSEPS are reduced by 90 percent, all other costs remain • Includes cost of HCl

[a] Present worth was calculated at a 2% discount rate over 30 years. Electrical costs were calculated at $0.105/kWhr.

[b] For detailed cost estimates, refer to Attachment B.

7. RECOMMENDATIONS

Using the results of field data collected and analyzed by City staff, a water chemistry model was developed to predict struvite formation potential. In general, the model was in agreement with plant observations of struvite formation. The model was used as a tool to evaluate the effectiveness of several struvite prevention strategies. The strategies that proved to be the most effective were further evaluated in terms of net present value.

There was a significant difference in net present values of alternatives ranging from \$2.2 million to \$54 million. Only the anti-scaling chemicals (\$2.2 million) had a net present value less than the existing condition (\$5.4 million). Even though $FeCl_3$ addition has a higher net present value than the existing condition, it provides additional benefits including added aeration capacity, additional gas production and H_2S control in the digester gas.

Brown and Caldwell recommends the following:

- Further evaluate mixing upgrades and consider benefits of struvite control in the analysis. Different mixing alternatives can be problematic if struvite control measures that improve formation in the digesters are not implemented (see TM 4.2). Mixing improvements were determined to have a significant impact on digester cleaning costs.
- Implement anti-scaling chemicals if they can be proven effective in full scale trials. Further evaluate anti-scaling chemicals for struvite control in the digesters, DSEPS and digested sludge export line. Work with chemical vendors to design bench-scale analyses to determine dosing and responses and if struvite control can be realized at reasonable cost. If bench scale tests show effective performance, test at full scale on one digester before full implementation.
- Continue to consider CEPT using $FeCl_3$ addition to increase organics and solids removal in the primary clarifiers, reduce aeration costs, control H_2S in digester gas, and to control struvite formation in the digesters by preferentially forming vivianite. Cost effectiveness of this option is sensitive to the cost of chemicals and benefits of secondary treatment system improvements. If costs and benefits improve from assumptions used in this analysis, consider implementation after adjusting for costs of struvite mitigation adopted at the time (i.e. anti-scaling chemicals). Historically, $FeCl_3$ was added directly to the digester recirculation lines and resulted in excessive localized vivianite formation in the recirculation lines and heat exchangers. Adding the $FeCl_3$ to the headworks may eliminate this. Regardless, the digester recirculation lines and heat exchangers should be routinely inspected to determine if excessive vivianite accumulation is occurring.
- If anti-scaling chemicals are not effective and CEPT with $FeCl_3$ addition is not implemented, consider enhancing existing struvite control measures through increased digester cleaning frequency, more frequent scheduled elbow and valve cleaning/replacement in the recirculation line. Enhancing current practices by more frequent scheduled cleanings may be a method of reducing costs and operational impacts. If other alternative control measures do not prove cost effective, more frequent, budgeted and scheduled cleanings can be evaluated for a greater measure of control. Although struvite removal will not be possible using cleanouts, cleanouts should still be considered for routine maintenance when piping is replaced or modified for other reasons. Consider replacing any pipes when replacement is necessary with smooth pipe such as HDPE or Kynar lined pipe. When replacing piping in struvite-prone areas for struvite control or other reasons, replace elbows where possible with long radius elbows.
- The high influent WPCP wastewater magnesium and phosphorus concentrations could be due to industrial wastewater discharges to the collection system. We recommend investigating if these

discharges exist, and if they can be reduced. A reduction in influent magnesium and phosphorus could reduce struvite formation. WPCP staff have requested additional sampling for magnesium in the collection system as a part of the Salinity Management Consulting Services (email from Alex Ekster to Eric Rosenblum, March 18, 2010).

- The Ostara process cannot alone be considered as a cost-effective struvite control measure. If the City elects to consider it as a revenue generation alternative in the future, consider benefits of cost reduction if any of struvite mitigation adopted at the time (i.e. anti-scaling chemicals). Consider Ostara in the future if the plant moves to mechanical dewatering. The higher concentration return stream is an effective feed for Ostara that can be funded privately in exchange for struvite revenues. This would reduce struvite formation in the digesters and downstream piping by removal of recycle loads of phosphorus.
- Any new designs or future pipe replacements driven by maintenance or capacity upgrades should utilize long radius elbows and other gradual flow transition arrangements, utilize cleanouts at strategic locations, and should consider use of HDPE pipe or PVDF liners to minimize struvite formation in susceptible lines. Digester recirculation piping could be designed with a cleaning loop for acid cleaning.

REFERENCES

Ali, I. Struvite crystallization from nutrient rich wastewater. Diss. James Cook University, Australia, 2005. ResearchOnline@JCU. Web. 30 June 2010.

Baur, R. (2008) Struvite control and prevention in centrate. *Proceedings WEFTEC 2008,* Chicago, Il.

Baur, R., Prasad, R., and Britton, A. (2008) Reducing ammonia and phosphorus recycle loads by struvite harvesting. *Proceedings WEFTEC 2008,* Chicago, Il.

Britton, A. Pilot scale struvite recovery trials from a full-scale anaerobic digester supernatant at the City of Penticton Advanced Wastewater Treatment Plant. MS thesis. University of British Columbia, Canada, 2002. Print.

Dezham, P., Rosenblum, E., and Jenkins, D. (1988) Digester gas H2S control using iron salts. *Wat. Environ. Res.* 60 (4) 514-517.

Diaz, O.A., Reddy, K.R., and Moore Jr., P.A. (1993). Solubility of inorganic phosphorous in stream water as influenced by pH and calcium concentration. *Wat. Res.* 28 1755-1763.

Doyle, J.D., Philip, R., Churchley, J., and Parsons, S.A. (2000) Struvite formation and control in sludge treatment. *Proceedings WEFTEC 2000,* Anaheim, CA.

Doyle, J.D., and Parsons, S.A. (2002) Struvite formation, control and recovery. *Wat. Res.* 36 3925-3940.

Gustafsson, J. (2005) Visual MINTEQ, ver 2.32. Royal Institute of Technology, Stockholm, Sweden, Department of Land and Water Resources Engineering <http://hem.bredband.net/b108693>.

Harada, H., Shimizu, Y. Miyagoshi, Y., Matsui, S., Masuda, T., and Nagasaka, T. (2006) Predicting struvite formation for phosphorous recovery from human urine using an equilibrium model. *Water Sci. Technol.* 54 247-255.

Jenkins, D. (2010a) Personal Communication, January 21, 2010. (Confirmed by email, Feb 12, 2010)

Jenkins, D. (2010b) Personal Communication, March 27, 2010.

Mamais, D., Pitt, P., Cheng, Y., Loiacono, and Jenkins, D. (1994) Determination of ferric chloride does to control struvite precipitation in anaerobic sludge digesters. *Wat. Environ. Res.* 66 (7) 912-918.

Meeting Minutes-Discussion of Struvite Occurrence, May 2, 2009. Brown and Caldwell and WPCP.

Musvoto, E.V., Ekama, G.A., Wentzel, M.C., and Loewenthal, R.E. (2000a). Extension and application of the three-phase weak acid/base kinetic model to the aeration treatment of anaerobic digester liquors. *Water SA,* 26 417-438.

Musvoto, E., Wentzel, M., and Ekama, G. (2000b) Integrated chemical-physical processes modeling-II. Simulating aeration treatment of anaerobic digester supernatants. *Wat. Res.* 34 1857-1867.

Pastor, L., Marti, N., Bouzas, A. and Seco, A. (2007) Calcium effect on struvite crystallization of liquors from an anaerobic digestion of perfermented and EBPR sludge. Proceedings from the Nutrient Removal Conference.

Prasad, R., Britton, A., Balzer, B. and Schafran, G. (2007) Nutrient recovery by struvite crystallization process: Virginia Experience. *Proceedings WEFTEC 2078,* San Diego, CA.

Ronteltapa, M., Maurera, M., and Gujer, W. (2007) Struvite precipitation thermodynamics in source-separated urine. *Wat. Res.* 41 (5) 977-984.

Ohlinger, K., Young, T. and Schroeder, E. (1998) Predicting struvite formation in digestion. *Wat. Res.* 32 (12) 3607-3614.

Salimi, M., Heughebaert, J., and Nancollas, G. (1985) Crystal growth of calcium phosphates in the presence of magnesium ions. *Langmuir* 1, 119-122.

Sen, D., Knocke, W., and Randall, C. (1988) Release, precipitation and recycle of phosphorus from anaerobic digesters sequencing biological phosphorus removal systems. *61st WPCF Annual Conference*, Dallas, Texas.

Snoeyink, V. and Jenkins, D. (1980) *Water Chemistry*. John Wiley and Sons, Inc., New York, NY.

Tchobanoglous, G., Burton, F., and Stensel, D. (2003) *Wastewater Engineering Treatment, Disposal, and Reuse – Fourth Edition*. McGraw-Hill, New York, NY.

Wild, D., Kisliakova, A., and Siegrist, H. (1997) Prediction of recycle phosphorous loads from anaerobic digestion. *Wat. Res.* 31 2300-2308.

WPCP staff. Meeting Discussion of Struvite Occurrence, May 2, 2009.

WPCP staff. Meeting Discussion of Struvite Costs, August 13, 2010.

ATTACHMENT A

Summary of Special Testing

	First Round of Testing						Second Round of Testing					
Parameter	**Primary A&B**	**Primary C&D**	**TWAS**	**Combined Digester Feed**	**Lagoon Sludge**	**Lagoon Supernatant**	**Primary A&B**	**Primary C&D**	**TWAS**	**Combined Digester Feed**	**Lagoon Sludge**	**Lagoon Supernatant**
TS, %	3.09	2.86	3.47	3.12	1.53		3.44	3.58	4.23	3.72	1.68	
VS,%	2.65	2.44	2.63	2.56	1.06		2.92	3.04	3.07	3.01	1.12	
Total Alkalinity, mg CaCO3/L	1,096.67	1,110.00	2,533.33	1,533.00	2,640.00	2,110.00	1,365.00	1,410.00	1,975.00	1,550.93	3,870.00	2,055.00
Dissolved Alkalinity, mg CaCO3/L	498.67	582.33	468.00	522.93	2,373.33	1,850.00	526.00	546.50	505.50	529.32	2,570.00	2,060.00
pH	5.60	5.73	6.80	7.03	7.03	7.80	6.20	6.35	6.70	7.50	7.50	7.55
Total Mg, mg/L	137.33	124.00	417.67	216.10	190.33	6.11	136.00	160.00	501.50	246.12	197.00	12.70
Diss Mg, mg/L	54.83	56.37	101.70	69.51	21.83	4.54	53.60	54.45	102.70	67.36	20.10	1.70
Total Ca, mg/L	700.33	622.33	580.00	633.03	599.33	36.10	763.00	896.50	906.50	860.17	677.00	35.10
Diss Ca, mg/L	136.67	130.33	56.77	110.16	29.87	29.25	110.50	103.50	55.40	92.43	31.75	24.40
Total NH3-N, mg-N/L	61.67	64.00	51.00		714.67	495.33	72.30	76.60	72.60		809.00	665.00
Total NH4+, mg/L	79.29	82.29	65.57	76.37	918.86	636.86	92.96	98.49	93.34	95.47	1,040.14	855.00
Total TKN, mg/L	1,315.00	1,160.00	1,676.67	1,361.50	1,675.00	710.67	1,150.00	1,100.00	2,650.00	1,537.37	1,650.00	755.00
Diss TKN, mg/L	223.00	245.00	193.33	222.90	954.67	680.33	<300	400.00	<300	258.67	950.00	705.00
Total Fe, mg/L	373.67	346.67	511.67	404.27	406.33	3.27	456.00	533.00	1,190.00	689.66	548.50	6.96
Diss Fe, mg/L	6.74	6.49	2.44	5.35	0.33	0.14	8.53	7.07	3.65	6.56	0.33	0.16
Total Total PO4, mg/L	3,533.33	3,666.67	11,333.33	5,926.67	4,166.67	733.33	1,200.00	1,200.00	6,000.00	2,509.13	2,200.00	500.00
Diss Total PO4, mg/L	300.00	270.00	1,466.67	638.00	800.00	406.67	160.00	160.00	600.00	280.00	350.00	350.00
OrthoPhosphate, mg/L	89.30	92.97	0.25		0.25	<0.5	10.40	112.00	<0.5		<0.5	<0.5
Total Al, mg/L	143.33	130.00	116.67	130.00	113.33	<1	145.00	160.00	165.00	156.97	125.00	<1
Dissolved Al, mg/L	0.50	0.50	0.50	0.50	0.50	<1	<0.5	<1	<0.5		0.50	<1
Dissolved Cl, mg/L	178.33	182.33	178.00	179.83	190.00	367.00	154.00	162.00	153.00	157.20	177.00	305.50
Dissolved K, mg/L	33.00	33.00	114.33	57.40	159.00	205.50	27.50	27.00	119.50	52.37	155.50	213.50
Dissolved Na, mg/L	140.00	149.00	148.33	146.10	43.60	282.50	119.50	121.50	121.50	120.91	142.00	232.50
Dissolved SO4, mg/L	8.00	3.00	74.00	25.80	5.67	42.33	<0.2	<0.2	95.00	25.98	2.00	92.00

Summary of Influent Data	**Value**
Total Alkalinity, mg CaCO3/L	310.2
Total Fe, mg/L	5.06
Total Mg, mg/L	30.82
NH3, mg-N/L	23.42
pH	7.4
TSS, mg/L	356.8
VSS, mg/L	312.2
Temp, degC	20.22
Total TKN, mg/L	47.92
Total Phosphate, mg/L as PO4	37.4
OrthoPhosphate, mg/L as PO4	10.1

ATTACHMENT B

Summary of Cost Evaluation

Net Present Value Detail

San Jose/Santa Clara WPCP	Results ($000s)			
Digester Project	Capital Cost	Annual O&M Cost	30-year NPV	Benefit over Status Quo
Existing Operation		$202,638	($5,407,580)	
Add Anti-Scaling Chemicals	$375,619	$73,433	($2,169,942)	$3,237,638
Add Secondary Effluent Dilution Sys	$3,453,450	$242,208	($9,219,145)	($3,811,565)
Replace Piping	$18,637,044	$54,568	($20,008,360)	($14,600,780)
Add Ferric Chloride	$1,072,663	$709,826	($17,965,665)	($12,558,085)
WASSTRIP/Ostara	$20,661,367	$960,791	($43,502,842)	($38,095,262)
pH Control System	$1,625,813	$2,200,908	($53,601,149)	($48,193,570)

	Markup	Alt 1 Existing Operation	Alt 2 Add Anti-Scaling Chemicals	Alt 3 Add Secondary Effluent Dilution Sys	Alt 4 Replace Piping	Alt 5 Add Ferric Chloride	Alt 6 WASSTRIP/Ostara	Alt 7 pH Control System
Electrical and Instrumentation	20%	0					1,525,000	120,000
Construction Cost Estimate		0	201,000	1,848,000	9,973,000	574,000	11,056,250	870,000
Estimating Contingency	15%	0	30,150	277,200	1,495,950	86,100	1,658,438	130,500
Const. Cost w/ Estimating Contingency		0	231,150	2,125,200	11,468,950	660,100	12,714,688	1,000,500
Contruction contingency	25%	0	57,788	531,300	2,867,238	165,025	3,178,672	250,125
Subtotal		0	288,938	2,656,500	14,336,188	825,125	15,893,359	1,250,625
Contractor overhead and profit	**27%**	0	78,013	717,255	3,870,771	222,784	4,291,207	337,669
Total Construction Cost in 2010 dollars		0	366,951	3,373,755	18,206,958	1,047,909	20,184,566	1,588,294
Engineering, Legal and Administration	30%	0	86681	796950	4300856	247538	4768008	375188
Total Project Cost		0	375,619	3,453,450	18,637,044	1,072,663	20,661,367	1,625,813
Notes		Existing operation will have not capital outlays	Includes the concrete slab, chemical metering pumps and piping, and chemical storage pumps	Includes secondary effluent pumping station, 2500 ft of 8-inch pipe ($30/in-ft) to transfer secondary effluent to DSEPS. Include two acid cleanings of existing pipes ($300,000 each)	Includes 1 miles of HDPE pipe and replacement of digester piping, fittings and valves with PVDF lined pipe	Includes the concrete slab, chemical metering pumps and piping, and chemical storage pumps	Includes building (150'x150'@ $200/sf), 1.7 MG tank (w/Al cover and concrete tank at $975/CY, cover $85/sf), 25 percent for mechanical, 28 percent of mechanical for electrical	Includes the concrete slab, chemical metering pumps and piping, and chemical storage pumps

From Summary Sheet:		Risk adjustments (+/- percent):	
Year of analysis	2010	Benefits	
Escalation rate	3.00%	Capital costs	
Discount rate	5.00%	Running costs	

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 1 - Existing Operation

	Year															
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab																
Total capital outlays																
Annual Running Costs:																
Chemical Cleaning of Export Pipe						119,500					119,500					119,500
DSEPS Inspection and Maintenance		2,885		2,885		2,885		2,885		2,885		2,885		2,885		2,885
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600
Pumping Costs	1,730	3,460	5,190	6,920	8,650	1,730	3,460	5,190	6,920	8,650	1,730	3,460	5,190	6,920	8,650	1,730
Total running costs	**202,638**	**207,252**	**206,098**	**210,712**	**209,558**	**325,022**	**204,368**	**208,982**	**207,828**	**212,442**	**322,138**	**207,252**	**206,098**	**210,712**	**209,558**	**325,022**
Net Benefit/(cost)	**(202,638)**	**(207,252)**	**(206,098)**	**(210,712)**	**(209,558)**	**(325,022)**	**(204,368)**	**(208,982)**	**(207,828)**	**(212,442)**	**(322,138)**	**(207,252)**	**(206,098)**	**(210,712)**	**(209,558)**	**(325,022)**

	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Cost from Capital Cost Tab															
Total capital outlays															
Chemical Cleaning of Export Pipe					119,500					119,500					119,500
DSEPS Inspection and Maintenance		2,885		2,885		2,885		2,885		2,885		2,885		2,885	
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600
Pumping Costs	3,460	5,190	6,920	8,650	1,730	3,460	5,190	6,920	8,650	1,730	3,460	5,190	6,920	8,650	1,730
Total running costs	**204,368**	**208,982**	**207,828**	**212,442**	**322,138**	**207,252**	**206,098**	**210,712**	**209,558**	**325,022**	**204,368**	**208,982**	**207,828**	**212,442**	**322,138**
Net Benefit/(cost)	**(204,368)**	**(208,982)**	**(207,828)**	**(212,442)**	**(322,138)**	**(207,252)**	**(206,098)**	**(210,712)**	**(209,558)**	**(325,022)**	**(204,368)**	**(208,982)**	**(207,828)**	**(212,442)**	**(322,138)**

From Summary Sheet:		Risk adjustments (+/- percent):	
Year of analysis	2010	Benefits	
Escalation rate	3.00%	Capital costs	
Discount rate	5.00%	Running costs	

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 2 - Add Anti-Scaling Chemicals

	Year															
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab	375,619															
Total capital outlays	**375,619**															
Annual Running Costs:																
Chemical Cleaning of Export Pipe						11,950					11,950					11,950
DSEPS Inspection and Maintenance		288		288		288		288		288		288		288		288
Digester Cleaning																
Recirculation System Maintenance	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260
Pumping Costs	173	346	519	692	865	173	346	519	692	865	173	346	519	692	865	173
Chemical Addition	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000
Total running costs	**73,433**	**73,894**	**73,779**	**74,240**	**74,125**	**85,671**	**73,606**	**74,067**	**73,952**	**74,413**	**85,383**	**73,894**	**73,779**	**74,240**	**74,125**	**85,671**
Net Benefit/(cost)	**(449,052)**	**(73,894)**	**(73,779)**	**(74,240)**	**(74,125)**	**(85,671)**	**(73,606)**	**(74,067)**	**(73,952)**	**(74,413)**	**(85,383)**	**(73,894)**	**(73,779)**	**(74,240)**	**(74,125)**	**(85,671)**

	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Cost from Capital Cost Tab															
Total capital outlays															
Chemical Cleaning of Export Pipe					11,950					11,950					11,950
DSEPS Inspection and Maintenance		288		288		288		288		288		288		288	
Digester Cleaning															
Recirculation System Maintenance	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260
Pumping Costs	346	519	692	865	173	346	519	692	865	173	346	519	692	865	173
Chemical Addition	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000	57,000
Total running costs	**73,606**	**74,067**	**73,952**	**74,413**	**85,383**	**73,894**	**73,779**	**74,240**	**74,125**	**85,671**	**73,606**	**74,067**	**73,952**	**74,413**	**85,383**
Net Benefit/(cost)	**(73,606)**	**(74,067)**	**(73,952)**	**(74,413)**	**(85,383)**	**(73,894)**	**(73,779)**	**(74,240)**	**(74,125)**	**(85,671)**	**(73,606)**	**(74,067)**	**(73,952)**	**(74,413)**	**(85,383)**

From Summary Sheet:		Risk adjustments (+/- percent):	
Year of analysis	2010	Benefits	
Escalation rate	3.00%	Capital costs	
Discount rate	5.00%	Running costs	

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 3 - Add Secondary Effluent Dilution Sys

	Year															
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab	3,453,450															
Total capital outlays	**3,453,450**															
Annual Running Costs:																
Chemical Cleaning of Export Pipe						11,950					11,950					11,950
DSEPS Inspection and Maintenance		288		288		288		288		288		288		288		288
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600
Power	41300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300
Total running costs	**242,208**	**242,496**	**242,208**	**242,496**	**242,208**	**254,446**	**242,208**	**242,496**	**242,208**	**242,496**	**254,158**	**242,496**	**242,208**	**242,496**	**242,208**	**254,446**
Net Benefit/(cost)	**(3,695,658)**	**(242,496)**	**(242,208)**	**(242,496)**	**(242,208)**	**(254,446)**	**(242,208)**	**(242,496)**	**(242,208)**	**(242,496)**	**(254,158)**	**(242,496)**	**(242,208)**	**(242,496)**	**(242,208)**	**(254,446)**

	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Cost from Capital Cost Tab															
Total capital outlays															
Chemical Cleaning of Export Pipe					11,950					11,950					11,950
DSEPS Inspection and Maintenance		288		288		288		288		288		288		288	
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600
Power	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300	41,300
Total running costs	**242,208**	**242,496**	**242,208**	**242,496**	**254,158**	**242,496**	**242,208**	**242,496**	**242,208**	**254,446**	**242,208**	**242,496**	**242,208**	**242,496**	**254,158**
Net Benefit/(cost)	**(242,208)**	**(242,496)**	**(242,208)**	**(242,496)**	**(254,158)**	**(242,496)**	**(242,208)**	**(242,496)**	**(242,208)**	**(254,446)**	**(242,208)**	**(242,496)**	**(242,208)**	**(242,496)**	**(254,158)**

From Summary Sheet:
Year of analysis 2010
Escalation rate 3.00%
Discount rate 5.00%

Risk adjustments (+/- percent):
Benefits
Capital costs
Running costs

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 4 - Replace Piping

	Year														
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Expressed in 2010 dollars, unescalated															
Capital Outlays															
Cost from Capital Cost Tab	18,637,044														
Total capital outlays	**18,637,044**														
Annual Running Costs:															
Chemical Cleaning of Export Pipe						11,950					11,950				
DSEPS Inspection and Maintenance		2,885		2,885		2,885		2,885		2,885		2,885		2,885	
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260
Total running costs	**54,568**	**57,452**	**54,568**	**57,452**	**54,568**	**69,402**	**54,568**	**57,452**	**54,568**	**57,452**	**66,518**	**57,452**	**54,568**	**57,452**	**54,568**
Net Benefit/(cost)	**(18,691,611)**	**(57,452)**	**(54,568)**	**(57,452)**	**(54,568)**	**(69,402)**	**(54,568)**	**(57,452)**	**(54,568)**	**(57,452)**	**(66,518)**	**(57,452)**	**(54,568)**	**(57,452)**	**(54,568)**

	Year															
	2025	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab																
Total capital outlays																
Annual Running Costs:																
Chemical Cleaning of Export Pipe	11,950					11,950					11,950					11,950
DSEPS Inspection and Maintenance	2,885		2,885		2,885		2,885		2,885		2,885		2,885		2,885	
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260	16,260
Total running costs	**69,402**	**54,568**	**57,452**	**54,568**	**57,452**	**66,518**	**57,452**	**54,568**	**57,452**	**54,568**	**69,402**	**54,568**	**57,452**	**54,568**	**57,452**	**66,518**
Net Benefit/(cost)	**(69,402)**	**(54,568)**	**(57,452)**	**(54,568)**	**(57,452)**	**(66,518)**	**(57,452)**	**(54,568)**	**(57,452)**	**(54,568)**	**(69,402)**	**(54,568)**	**(57,452)**	**(54,568)**	**(57,452)**	**(66,518)**

From Summary Sheet:
Year of analysis 2010
Escalation rate 3.00%
Discount rate 5.00%

Risk adjustments (+/- percent):
Benefits
Capital costs
Running costs

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 5 - Add Ferric Chloride

	Year														
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Expressed in 2010 dollars, unescalated															
Capital Outlays															
Cost from Capital Cost Tab	1,072,663														
Total capital outlays	**1,072,663**														
Benefits:															
Benefit from H2S Gas	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000
Benefit from Additional Gas Producti	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459
Benefit from Aeration Costs	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374
Total benefits	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**
Annual Running Costs:															
Chemical Cleaning of Export Pipe						29,875					29,875				
DSEPS Inspection and Maintenance		721		721		721		721		721		721		721	
Digester Cleaning	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577
Recirculation System Maintenance	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650
Pumping Costs	433	865	1,298	1,730	2,163	433	865	1,298	1,730	2,163	433	865	1,298	1,730	2,163
Chemical Addition	2022000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000
Total running costs	**2,072,659**	**2,073,813**	**2,073,524**	**2,074,678**	**2,074,389**	**2,103,256**	**2,073,092**	**2,074,246**	**2,073,957**	**2,075,111**	**2,102,534**	**2,073,813**	**2,073,524**	**2,074,678**	**2,074,389**
Net Benefit/(cost)	**(1,782,489)**	**(710,980)**	**(710,691)**	**(711,845)**	**(711,556)**	**(740,423)**	**(710,259)**	**(711,413)**	**(711,124)**	**(712,278)**	**(739,701)**	**(710,980)**	**(710,691)**	**(711,845)**	**(711,556)**

	Year															
	2025	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab																
Total capital outlays																
Benefits:																
Benefit from H2S Gas	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000
Benefit from Additional Gas Producti	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459	747,459
Benefit from Aeration Costs	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374	501,374
Total benefits	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**	**1,362,833**
Annual Running Costs:																
Chemical Cleaning of Export Pipe	29,875					29,875					29,875					29,875
DSEPS Inspection and Maintenance	721		721		721		721		721		721		721		721	
Digester Cleaning	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577	9,577
Recirculation System Maintenance	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650	40,650
Pumping Costs	433	865	1,298	1,730	2,163	433	865	1,298	1,730	2,163	433	865	1,298	1,730	2,163	433
Chemical Addition	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000	2,022,000
Total running costs	**2,103,256**	**2,073,092**	**2,074,246**	**2,073,957**	**2,075,111**	**2,102,534**	**2,073,813**	**2,073,524**	**2,074,678**	**2,074,389**	**2,103,256**	**2,073,092**	**2,074,246**	**2,073,957**	**2,075,111**	**2,102,534**
Net Benefit/(cost)	**(740,423)**	**(710,259)**	**(711,413)**	**(711,124)**	**(712,278)**	**(739,701)**	**(710,980)**	**(710,691)**	**(711,845)**	**(711,556)**	**(740,423)**	**(710,259)**	**(711,413)**	**(711,124)**	**(712,278)**	**(739,701)**

From Summary Sheet:
Year of analysis 2010
Escalation rate 3.00%
Discount rate 5.00%

Risk adjustments (+/- percent):
Benefits
Capital costs
Running costs

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 6 - WASSTRIP/Ostara

	Year														
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Expressed in 2010 dollars, unescalated															
Capital Outlays															
Cost from Capital Cost Tab	20,661,367														
Total capital outlays	**20,661,367**														
Annual Running Costs:															
Chemical Cleaning of Export Pipe						35,850					35,850				
DSEPS Inspection and Maintenance		865		865		865		865		865		865		865	
Digester Cleaning	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492
Recirculation System Maintenance	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780
Pumping Costs	519	1,038	1,557	2,076	2,595	519	1,038	1,557	2,076	2,595	519	1,038	1,557	2,076	2,595
Annual Contract w/Ostara	900000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000
Total running costs	**960,791**	**962,176**	**961,829**	**963,214**	**962,867**	**997,507**	**961,310**	**962,695**	**962,348**	**963,733**	**996,641**	**962,176**	**961,829**	**963,214**	**962,867**
Net Benefit/(cost)	**(21,622,158)**	**(962,176)**	**(961,829)**	**(963,214)**	**(962,867)**	**(997,507)**	**(961,310)**	**(962,695)**	**(962,348)**	**(963,733)**	**(996,641)**	**(962,176)**	**(961,829)**	**(963,214)**	**(962,867)**

	Year															
	2025	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab																
Total capital outlays																
Annual Running Costs:																
Chemical Cleaning of Export Pipe	35,850					35,850					35,850					35,850
DSEPS Inspection and Maintenance	865		865		865		865		865		865		865		865	
Digester Cleaning	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492	11,492
Recirculation System Maintenance	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780	48,780
Pumping Costs	519	1,038	1,557	2,076	2,595	519	1,038	1,557	2,076	2,595	519	1,038	1,557	2,076	2,595	519
Annual Contract w/Ostara	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000	900,000
Total running costs	**997,507**	**961,310**	**962,695**	**962,348**	**963,733**	**996,641**	**962,176**	**961,829**	**963,214**	**962,867**	**997,507**	**961,310**	**962,695**	**962,348**	**963,733**	**996,641**
Net Benefit/(cost)	**(997,507)**	**(961,310)**	**(962,695)**	**(962,348)**	**(963,733)**	**(996,641)**	**(962,176)**	**(961,829)**	**(963,214)**	**(962,867)**	**(997,507)**	**(961,310)**	**(962,695)**	**(962,348)**	**(963,733)**	**(996,641)**

San Jose/Santa Clara WPCP
Digester Project
Life Cycle Alternative Cost Analysis ($000s)
Alternative 7 - pH Control System

From Summary Sheet:		**Risk adjustments (+/- percent):**	
Year of analysis	**2010**	**Benefits**	
Escalation rate	**3.00%**	**Capital costs**	
Discount rate	**5.00%**	**Running costs**	

	Year															
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Expressed in 2010 dollars, unescalated																
Capital Outlays																
Cost from Capital Cost Tab	1,625,813															
Total capital outlays	**1,625,813**															
Annual Running Costs:																
Chemical Cleaning of Export Pipe						11,950					11,950					11,950
DSEPS Inspection and Maintenance		2,885		2,885		2,885		2,885		2,885		2,885		2,885		2,885
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600
Chemical Addition	2000000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Total running costs	**2,200,908**	**2,203,792**	**2,200,908**	**2,203,792**	**2,200,908**	**2,215,742**	**2,200,908**	**2,203,792**	**2,200,908**	**2,203,792**	**2,212,858**	**2,203,792**	**2,200,908**	**2,203,792**	**2,200,908**	**2,215,742**
Net Benefit/(cost)	**(3,826,720)**	**(2,203,792)**	**(2,200,908)**	**(2,203,792)**	**(2,200,908)**	**(2,215,742)**	**(2,200,908)**	**(2,203,792)**	**(2,200,908)**	**(2,203,792)**	**(2,212,858)**	**(2,203,792)**	**(2,200,908)**	**(2,203,792)**	**(2,200,908)**	**(2,215,742)**

	Year														
	2026	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Expressed in 2010 dollars, unescalated															
Capital Outlays															
Cost from Capital Cost Tab															
Total capital outlays															
Annual Running Costs:															
Chemical Cleaning of Export Pipe					11,950					11,950					11,950
DSEPS Inspection and Maintenance		2,885		2,885		2,885		2,885		2,885		2,885		2,885	
Digester Cleaning	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308	38,308
Recirculation System Maintenance	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600	162,600
Chemical Addition	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Total running costs	**2,200,908**	**2,203,792**	**2,200,908**	**2,203,792**	**2,212,858**	**2,203,792**	**2,200,908**	**2,203,792**	**2,200,908**	**2,215,742**	**2,200,908**	**2,203,792**	**2,200,908**	**2,203,792**	**2,212,858**
Net Benefit/(cost)	**(2,200,908)**	**(2,203,792)**	**(2,200,908)**	**(2,203,792)**	**(2,212,858)**	**(2,203,792)**	**(2,200,908)**	**(2,203,792)**	**(2,200,908)**	**(2,215,742)**	**(2,200,908)**	**(2,203,792)**	**(2,200,908)**	**(2,203,792)**	**(2,212,858)**