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ODOUR CONTROL AT A WWTP IN A COMBINED STORMWATER SEWAGE CATCHMENT TREATING DOMESTIC AND INDUSTRIAL WASTEWATER

Effects of managing WWTP odour through the addition of ferrous chloride

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ABSTRACT

TasWater operates the Ti-Tree Bend (TTB) wastewater treatment plant (WWTP), a continuous mixed activated sludge (CMAS) plant, in Launceston, Tasmania. The combined sewer system dates back to the 1860s, with the WWTP commissioned in 1974. TTB receives combined wastewater including; stormwater, domestic and industrial waste.

Sulphide in wastewater can cause significant odour issues through the generation of hydrogen sulphide (H_2S) gas in sewers and WWTPs. Ferrous chloride (iron salts) are added in excess to enable the precipitation of iron sulphide, reducing the potential for H_2S release from the wastewater. The historical sulphide concentration was 0.1 – 1.1 mg/L, the initial iron dosing was based on 1 mg/L.

Following iron salts dosing commencing in September 2015 a statistically significant decrease in the mean monthly H_2S was detected at two locations of between 20 – 70%. The initial dose rate increased from 3.5 mg Fe/L to 15 mg Fe/L during the period September to March as the temperature increased.

A secondary effect of the iron dosing was a 38% reduction in total phosphorus in the effluent, decreasing the environmental phosphorus load by approximately 11,000 kg/y. Historically the wastewater entering TTB has low alkalinity, analytical data indicated that iron salts dosing had no effect on the levels in the Activated Sludge Tank, however, there were significant reductions in the pH.

INTRODUCTION

Background

TasWater operates the Ti-Tree Bend (TTB) wastewater treatment plant (WWTP), a continuous mixed activated sludge (CMAS) plant, in Launceston, Tasmania. Launceston was one of the first cities in the southern hemisphere to have a sewer system dating back to the 1860s. The WWTP was commissioned in 1974 and receives combined wastewater including; stormwater, domestic and industrial waste.
The WWTP is located on reclaimed flood plains in the upper reaches of the Tamar Estuary. The influent wastewater is pumped from sewerage pump stations (SPS) via rising mains to the plant.

TTB receives approximately 12 ML/d average dry weather flow (ADWF) and during significant wet weather events the flow can increase by 10 times ADWF.

The STP consists of screening and grit removal, contained in the Inlet Works building with Archimedes pumps lifting the wastewater to the primary sedimentation tanks (PST). During wet weather the PST bypass at flows >800 L/s to protect the activated sludge tank (AST) treatment train. Due to historically low alkalinity, magnesium hydroxide is dosed to the AST aiming for a residual of 100 mg/L. Floc separation occurs in two secondary clarifiers, with chlorine disinfection. Primary and secondary sludge is treated in a mesophilic anaerobic digester, with sludge pumped to drying beds.

The main driver for installing the iron salts dosing system was community odour complaints. An odour abatement plan was developed for TTB and iron salts dosing was stage one of three stages.

Due to the rising mains and the relatively long detention times in the SPS during low flow periods the odour emitted at TTB leads local residents to file odour complaints. An iron salts chemical dosing unit was commissioned in September 2015 with dosing points in the two rising mains. During dry weather flows 100% of the influent was dosed, however, due to the combined system a high flow set point automatically turns dosing off in wet weather events.

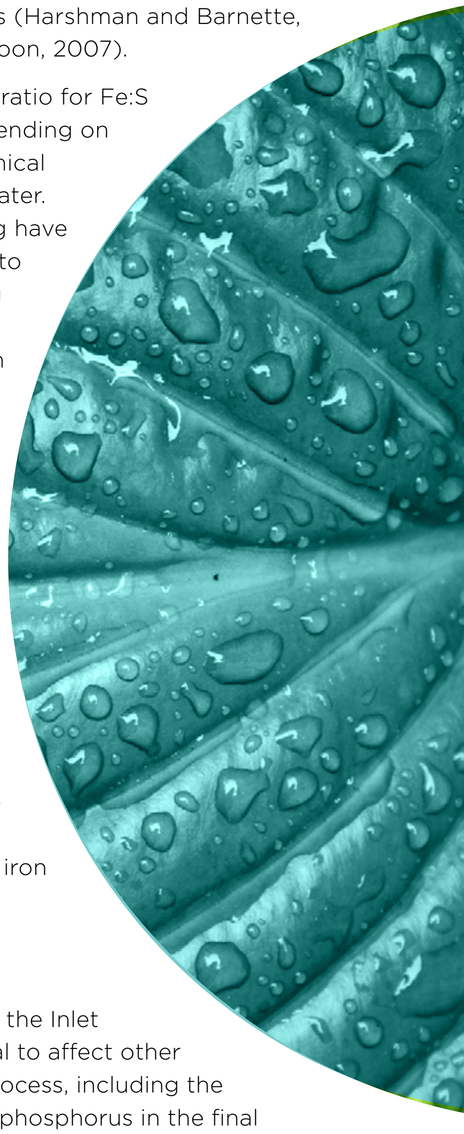
Iron Salts dosing for Odour Control

Hydrogen sulphide (H_2S) is commonly generated in rising mains and in turbulent primary wastewater treatment processes with anaerobic conditions, elevated temperature and low pH, (Harshman and Barnette, 2000, Zhang *et al*., 2010). This can be a major cause of odour related complaints. Generally H_2S is the most prevalent compound, however, other odorous compounds, including mercaptans and amines, are usually present in rising mains and WWTPs which are not affected by iron salts (Harshman and Barnette, 2000).

The addition of iron salts has been used effectively in the past as a chemical method for odour abatement by removing sulphide in sewer systems (Zhang et al., 2010). This is a highly acidic solution which has the potential to decrease pH and alkalinity in the WWTP. Within the aeration process of the treatment plant the ferrous sulphide is oxidised to sulphate and ferric iron, the ferric iron then can be used for chemical precipitation of phosphorus (Harshman and Barnette, 2000, Apgar and Witherspoon, 2007).

The reported optimal dose ratio for Fe:S can be vastly different depending on infrastructure and the chemical composition of the wastewater. Laboratory and field testing have shown removal rates of up to 90% downstream of dosing points when ferrous iron is dosed at a ratio of between 3.1:1 and 66:1 Fe:S (Zhang et al., 2010, Nielsen et al., 2008, Apgar and Witherspoon, 2007).

To achieve a target residual sulphide concentration in the inlet works at TTB of <0.1 mg S^{2-}/L the expected dose ratio has been estimated to be ≥ 3.5:1 Fe:S (de Hass et al., 2008). However, as the target residual sulphide level decreases below 1.0 mg/L a higher dose rate of iron salt will be required.



Effects on Post Inlet Processes

The addition of iron salts at the Inlet Works also has the potential to affect other aspects of the treatment process, including the suspended solids and total phosphorus in the final effluent. Activated sludge flocs are a complex mixture, comprising microorganisms, exocellular biopolymer or extracellular polymeric substances and debris. Due to the majority of exocellular biopolymers being negatively charged, cations become an important structural component as a binding agent within the biopolymeric network (Park et al., 2006, Tchobanoglous and Burton, 1991). The addition of divalent cations has been reported to have a significant effect on the final effluent quality through the reduction of suspended solids and BOD (Park et al., 2006, Barnett et al., 2012). It is also expected that the effluent quality could be affected through the oxidation of iron sulphide in the AST, where ferric iron (Fe^{3+}) will be available in excess to form iron phosphate.

Materials and Methods

Portable App-Tek 0 – 50 ppm H_2S odour loggers, with a resolution of 0.1 ppm and accuracy of ± 2 ppm at 20 ppm, were installed at the TTB WWTP in the same locations where a historical odour survey was undertaken by external consultants. Two main sites were identified, the Inlet Works Channel and the Archimedes Wet Well. The Inlet Works Channel logger was situated in an enclosed site at the inlet channel before screening and the Archimedes Wet Well logger was situated at the base of the Archimedes screw pumps in an enclosed wet well.

Data was collected from the odour logger on a fortnightly basis with the sample frequency being every minute. Odour loggers were calibrated and serviced annually during winter by Thermo Fisher Scientific onsite loggers which were maintained by operators, with in situ recalibrations and filter replacement as required.

The ANOVA comparison of means statistical analysis was undertaken using MINITAB software program.

RESULTS AND DISCUSSION

Initially jar tests were undertaken before the chemical dosing unit was commissioned to determine the optimal dose rate, which was determined to be 5 mg/L Fe^{-2} :1 mg/L S^{-2} (Barnett, 2014). Theoretically the ratio for sulphide removal through ferrous iron addition should be 1:1 according to the stoichiometric demand. However, the iron dose ratio can also be affected through competitive reactions between iron and other anions. Due to reactions with other anions, as the target residual sulphide concentration decreases, a higher iron to sulphide dose ratio is required. Generally the achievable residual sulphide concentration in wastewater treatment is within the range of 0.5 – 1.0 mg S^{-2}/L, to reduce the residual sulphide concentration to < 0.1 mg S^{-2}/L a much higher dose ratio is required (Zhang et al., 2010).

Of all the sites from the initial odour survey the H_2S in the highly turbulent Archimedes Wet Well was significantly higher than other sites, therefore, this site was determined to be representative of potential H_2S reduction from iron salts dosing.

Validating Control Data

Monitoring of H_2S at Ti Tree Bend started in May 2014, flow paced chemical dosing started in September 2015, and therefore, considerable H_2S data was available before the chemical dosing system was commissioned.

The mean H_2S data from the Archimedes Wet Well for May 2014 and 2015 was compared, also the whole winter 2014 and 2015 data sets were also analysed to determine if there was any variation between two comparable periods while dosing was not occurring. At the Archimedes Wet Well there was no significant difference between the May 2014 and May 2015 data (P – 0.306; df – 41610) (see Table 1). There was also limited difference between the winter 2014 and 2015 data sets.

Data from November 2014 and 2015 was analysed to determine the mean differences. To ensure climatic conditions did not affect the results, the in-situ temperature and ambient temperature data was also compared. As temperature increases H_2S significantly increases and in the combined system rain events considerably decrease odour due to fresh water flushing.

Table 1: A comparison of TTB mean H2S data during periods of no chemical dosing with standard deviations.

	H2S (ppm)	In-situ Temp (°C)
May 2014	2.30 ± 3.1	15.1 ± 0.9
May 2015	2.27 ± 2.9	14.2 ± 1.1
Winter 2014	1.13 ± 1.8	11.7 ± 1.4
Winter 2015	1.01 ± 1.3	11.7 ± 1.4
Nov 2014 All data	8.2 ± 7.2	
Nov 2015 All data	2.5 ± 6.2	
Nov 2014 No Rain Events	8.6 ± 7.4	
Nov 2015 No Rain Events	3.1 ± 6.8	

The data showed there was a statistically significant decrease in the H_2S in the Archimedes Wet Well and PST Inlet while chemical dosing occurred, 70% and 67% respectively. To determine if whole data sets were valid all data from rain events was removed. With dry weather data only, there was no change in the level of H_2S reduction compared to the whole data set. There was also no significant difference between the in-situ temperature data for all sites, and the ambient Bureau of Meteorology temperatures recorded at TTB (P – 0.830; df – 59). This indicated that changes in temperature were unlikely to have influenced the H_2S levels. Therefore, it was proposed that differences between dosing and non-dosing periods can be confidently reported as a real difference and not variance in the data.

Effects of Iron Salts dosing on H_2S Levels

At the TTB inlet the sulphide and sulphate concentration was found to be between 0.1 mg/L – 1.1 mg/L and 1 mg/L – 41 mg/L, respectively. This can lead to sulphide generation further along the treatment process.

A standard dose ratio recommended by consultants for iron salts dosing, of 3.5 mg/L Fe^{-2}: 1 mg/L S^{-2} had also been recommended for TTB (Chua and Shammay, 2012). Chemical dosing started September 2015 at the recommended 3.5 mg Fe/L and increased to 15 mg Fe/L in February and March 2016, based on an assumed sulphide level of 1 mg/L. Literature indicated that the optimal dose ratio would be between 4 – 12 mg/L Fe^{-2}: 1 mg/L S^{-2} for maximum removal efficiency (Apgar and Witherspoon, 2007).

Table 2. Comparison of the Inlet Works Channel and Archimedes Wet Well mean monthly H2S and temperature data with standard deviations. The % reduction is from the Archimedes Wet Well.

Month	Year	Inlet Works Channel		Archimedes Wet Well		Dosing	% Reduction
		H2S (ppm)	In-situ Temp (°C)	H2S (ppm)	In-situ Temp (°C)		
September	2014	0.79 ± 1.83	13.4 ± 1.4	1.5 ± 2.5	13.9 ± 2.0	0	
	2015	0.52 ± 1.83	13.1 ± 1.3	0.6 ± 2.3	14.9 ± 1.3	3.5	60%
October	2014	1.79 ± 3.83	15.2 ± 1.4	4.2 ± 4.7	16.5 ± 2.4	0	
	2015	1.55 ± 2.71	15.9 ± 1.3	3.4 ± 6.7	17.5 ± 1.9	3.5 – 7.5	20%
November	2014	1.17 ± 1.77	17.3 ± 1.6	8.2 ± 7.2	19.6 ± 2.5	0	
	2015	1.29 ± 2.30	17.7 ± 1.3	2.5 ± 6.2	18.9 ± 1.2	3.5 – 7.5	70%
December*	2014	0.79 ± 1.33	19.1 ± 1.4	5.9 ± 7.4	21.1 ± 1.4	0	
	2015	2.25 ± 6.56	20.0 ± 2.0	4.7 ± 10.3	21.3 ± 2.3	5 – 10	20%
January#	2015	1.57 ± 4.55	20.3 ± 1.6	13.7 ± 15.7	22.3 ± 1.5	0	
	2016	1.23 ± 5.66	21.4 ± 1.4	4.3 ± 9.2	22.7 ± 1.3	10	69%
February^	2015	2.17 ± 3.35	21.2 ± 1.4	20.1 ± 20.5	23.4 ± 1.5	0	
	2016	1.82 ± 11.6	21.1 ± 1.7	8.3 ± 15.4	22.5 ± 1.4	10 – 15	59%
March	2015	2.05 ± 2.00	18.7 ± 1.2	5.4 ± 8.3	20.2 ± 1.7	0	
	2016	2.34 ± 9.0	20.4 ± 1.6	2.7 ± 8.9	20.6 ± 2.3	15	50%

***Chemical dosing issues with pump during Christmas New Year period.**
#Dosing pit flooded, no dosing for 8 days
^Carrier water pipe burst, no dosing for 3 days

The monthly mean difference in data comparing previous months before dosing and those following dosing indicated that there was a significant impact on the H2S levels at TTB (see Table 2). The highest removal rates were 70% and 69% in November 2015 and January 2016 respectively. From September 2015 to March 2016 only two months showed a removal below 50%. In December there were issues with the dosing system during the Christmas and New Year period which were not resolved until January 2016, having a considerable impact on the H2S levels. This event **corresponded with community odour complaints.**

During the operation of the dosing unit the actual dose rate was optimised according to the rates of removal. Initial benchtop studies indicated that a dose rate of 5 mg/L Fe was the most effective, however, in reality there are interferences in a dynamic changing influent. The most effective way to control dosing and reduce the chemical dose rate to an optimal level would be to install a H_2S probe with telemetry for operations staff to adjust dosage as required.

Spikes in H_2S detected in the Archimedes Wet Well occurred during iron salt dosing. The primary cause of the spikes occurring during dosing has been attributed to tankered trade waste, which can contain anaerobic waste with considerable levels of H_2S. The tankered waste receival point is after the chemical dose point where there would be no residual iron in solution to bind with the sulphide ions. Options for tankered waste receival are being reviewed.

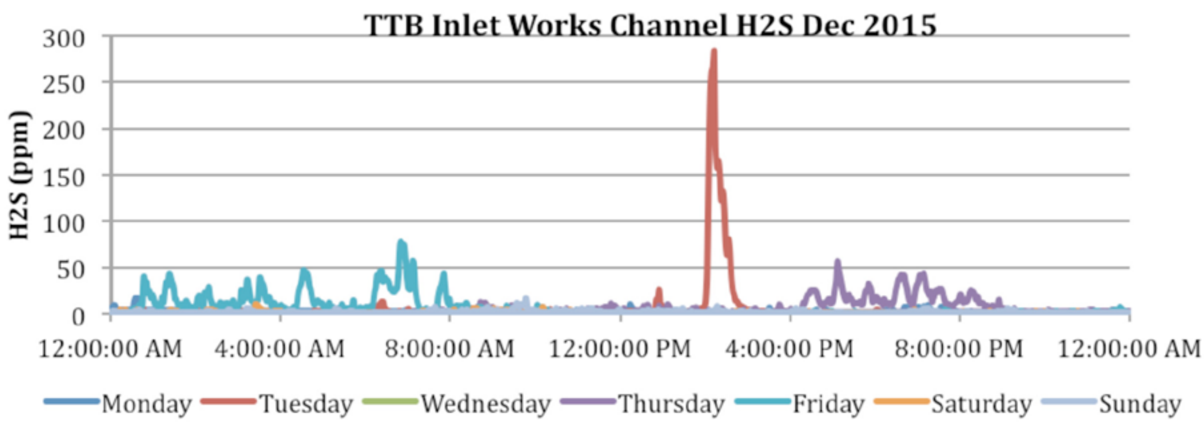


Figure 1. Daily H2S patterns detected at the TTB Inlet Works Channel from 7th to 13th December 2015

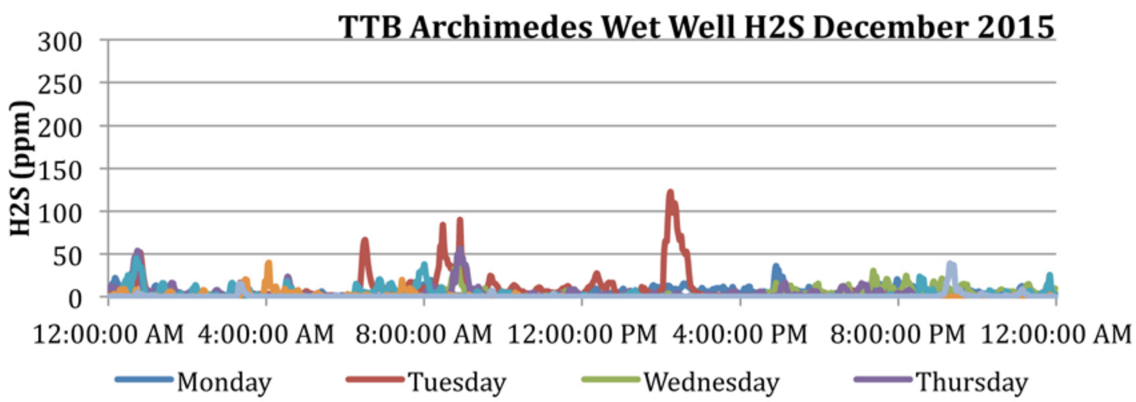


Figure 2. Daily H2S patterns detected at the TTB Archimedes Wet Well from 7th to 13th December 2015.

Due to the considerable inputs to TTB from trade waste customers daily trends were analysed (see Figure 1-2). The levels of H_2S appear to be lower on the weekends compared to week days, this could be due to trade waste discharges. A diurnal pattern was evident in the Archimedes Wet Well through all data analysed, showing an increase in H_2S from 7:30 am.

Inlet Works Channel daily H_2S patterns were not comparable to the Archimedes Inlet. During December 2015 there was a period the morning of Tuesday 8th where the H_2S was significantly higher than any other time, this spike corresponded with a spike in the Archimedes Wet Well. This event could have overloaded the odour removal in the Inlet Works Building. However, other elevated H2S events at the Inlet did not appear downstream. The timing and duration of the event suggests that there was a significant trade waste input to cause prolonged elevated H2S levels.

There was no H2S correlation detected between the Inlet Works Channel and the Archimedes Wet Well. There was no statistically significant difference detected between the before and after dosing data in the Inlet Works Channel. Therefore, it appears that the levels of H2S at the Inlet Works Channel were not affected by dosing iron salts. It is assumed that the odour extraction at the Grit Building is effective and the H2S detected in the treatment system is generated onsite most likely due to the turbulence in the flume and at the wet well. During summer additional iron salts dosing could decrease H2S further in the treatment plant, however, inline monitoring could optimise dosing rates.

EFFECTS OF IRON SALTS DOSING ON THE WWTP OPERATIONS

To ensure that the chemical dosing was not having a detrimental effect on the operation of TTB, operational data was analysed from around the plant.

Activated Sludge Tank (AST)

Ferrous chloride is a concentrated acidic solution which can react with carbonate, reducing both the available iron to react with the sulphide and the alkalinity. Alkalinity is important as a biological buffer for nitrification in wastewater treatment, especially at TTB, where there are significant trade-waste inputs contributing to acidic spikes and where the concentrations are historically low. The minimum residual of alkalinity required for nitrification is between 70 – 80 mg/L. Following the iron salts dosing there was no significant statistical difference found between the before dosing and after dosing results (126 ± 54 mg/L and 135 ± 57 mg/L respectively).

Effluent

From the effluent data TTB effluent there was no difference found in the total iron or total suspended solids (TSS) levels (see Table 3). However, there was a significant reduction in total phosphorus (TP) and pH (See Table 3).

Iron salts dosing turned the primary sedimentation tank dark grey/black in colour, however, in the AST there was no visible change due to the oxidation of iron sulphide. Ferric iron has a high affinity with phosphate anions, which forms stable ferric phosphate (Stumm and Morgan, 1996, Zhang et al., 2010, Ge et al., 2013). The reaction half-time for the oxidation of ferrous iron to ferric iron has been found to be approximately 16 minutes at pH 7.0, 2 mg/L DO and 25°C (Zhang et al., 2010).

Table 3: Mean Ti Tree Bend STP effluent data from before and after dosing with standard deviations.

	Unit	Before Dosing	After Dosing	Stat (ANOVA)	% Reduction
Total Iron	µg/L	301 ± 287	325 ± 140	P – 0.753; df - 53	NA
Total Phosphorus	mg/L	4.8 ± 2.2	3.0 ± 1.3	P – 0.004; df – 70	38%
Total Suspended Solids	mg/L	13 ± 7	11 ± 7	P – 0.447; df – 138	NA
pH		7.12 ± 0.35	6.51 ± 0.88	P – 0.006; df - 34	0.61 units

Ferric phosphate precipitates will become enmeshed in the activated sludge floc and be transferred to the digesters via the waste activated sludge. Although this report did not consider the effects of iron salts dosing on the anaerobic digesters it is expected that the bonds between the ferric and phosphate ions should be broken in anaerobic conditions and iron to precipitate with sulphide due to the relatively low solubility (Ge et al., 2013).

Usually to reduce the phosphorous levels in wastewater treatment, chemical additives are required. A significant reduction of 38% was observed in the effluent, this equates to approximately 11,000 kg/y reduction (see Table 3). This is a significant environmental outcome for the receiving environment, as WWTP effluent has been identified as major contributor of nutrients to the estuary. When initially proposing iron salts dosing as a business case, the reduction of phosphorus was not considered.

There was a significant statistical reduction in mean effluent pH from 7.12 to 6.51. The pH compliance level at TTB is from 6.5 – 8.5, the mean result following dosing indicates that there will be pH non-compliances. TTB have some trade waste customers who are proposing to amend low pH discharges, a consideration could be given for the optimal pH and chemical amendments used to improve outcomes at TTB. The WWTP consists of nitrification only, the optimum pH for nitrifying bacteria is 7.2, at 6.5 the nitrifiers growth rates is reduced to approximately 50%.

Odour Complaints

Odour complaints have been the primary driver to develop and implement an odour abatement plan. The complaints to the EPA and TasWater are presented below in Table 4.

Table 4: TTB historical odour complaints.

	2014-15	2015-16
EPA	14	3
TasWater	4	7
Total	18	10

The communications department actively engaged community stakeholders during the planning and commissioning of the iron salts dosing unit, this may be why there has been an increase in complaints directly to TasWater in 2015-16. Location of complaints also changed from primarily being residential in 2014-15 to the closer industrial properties in 2015-16. Anecdotally the industrial properties accepted the proximity of TTB and following consultation had an avenue for complaints. At least four of the complaints in 2015-16 were associated with dosing system failures and plant maintenance work.

Indicating that there had been a considerable reduction in odour complaints, which could be further reduced by implementing better maintenance practices and ensuring the dosing system failures are promptly rectified.

An olfactometric survey in March 2016 found that there was limited difference in the overall odorous gasses detected onsite, with the Archimedes Wet Well slightly lower than the initial survey in March 2012. It is important to remember that, although the sampling was undertaken at comparative times, they were effectively two random grab samples representing a dynamic system four years apart.

CONCLUSION

Iron salts dosing commenced September 2015 and showed a statistically significant decrease in the mean monthly H_2S levels detected at the Archimedes Wet Well between 20 – 70%. The optimal dose rate was estimated relative to the residual H_2S detected on-site, however, with inline monitoring the dose rate could be optimised further.

There were significant H_2S diurnal patterns identified at TTB. There were also spikes identified throughout the system, indicating that tankered waste could be contributing to the H_2S levels at the inlet and that there is considerable H_2S generated on-site within the treatment train.

A significant reduction in effluent total phosphorus of 38% will reduce the total load discharge by approximately 11,000 kg/y. This will have a significant benefit on the receiving environment. Alkalinity in the AST can be lower than the recommended levels for effective biological treatment, however, the data indicated that iron salts dosing had no effect on the levels in the AST. However, there were significant reductions in the pH in both the AST and the effluent. The mean effluent pH after dosing started was 6.51, this will result in pH non-compliances for the effluent.

Following commissioning of the dosing unit and a community engagement program, total odour complaints dropped from 18 to 10 in 2014-15 and 2015-16 respectively. A considerable number of complaints corresponded with the dosing system being off-line and maintenance work practices. Although point source H2S at the Archimedes Wet Well was significantly reduced, olfactometric testing determined that there was minimal difference in the total odorous gas on-site.

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