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Sydney Water's innovative approach for optimising chemical dosing into sewer networks

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ABSTRACT

For over 130 years, Sydney Water has provided reliable water and wastewater services that are central to liveability. In keeping with Sydney Water's Lifestream strategy to remain a leading utility, it is essential to pioneer processes to optimise asset performance and improve operational efficiency. A culture of innovation enables Sydney Water to continue to change, adapt and embrace new technologies to stay at the forefront and deliver the best possible outcomes.

Hydrogen sulphide (H_2S) gas generated in wastewater networks presents a complex management issue worldwide. Corrosion of concrete and metallic sewer assets result in expensive rehabilitation cost, while customer odour complaints and worker health and safety are also major issues. Our aim is to reduce concrete corrosion by minimising the generation and release of H_2S with smarter network operation and design. Liquid phase chemical dosing in the wastewater network is integral in achieving this. Sydney Water currently operates more than 65 chemical dosing units (CDU) that dose either ferrous chloride, magnesium hydroxide or calcium nitrate.

To control dosing and achieve optimal chemical use, several innovative and best practice methods have been implemented. Dosing rates are adjusted monthly using a seasonal dosing factor (SDF). Ongoing analysis of monitoring data collected using a network of online instrumentation, is used to track the effectiveness of dosing and make profile adjustments. The introduction of automated wet weather interlocks on CDUs to stop dosing during periods of high rainfall further achieves significant chemical use savings. These interlocks utilise intelligent flow monitoring systems interfaced with Sydney Waters Supervisory and Control Data Acquisition (SCADA) system for networks - IICATS. Design standards ensure new CDUs meet all operational and maintenance requirements. Our long-term goal is to develop an online control system that is reliant on machine learning to further optimise chemical usage.

INTRODUCTION

Sydney Water provides wastewater services to over 5 million customers through a network of over 25,000 km of pipes (Sydney Water 2018). Of these, 900 km are critical sewers and must avoid failure. Wastewater networks are highly complex, subject to dynamic conditions in terms of both hydraulics and compositions. Wastewater contains sulphates which through bacterial respiration are converted to sulphides and subsequently results in the formation and release of hydrogen sulphide (H_2S) gas in the sewer gas phase. H_2S generation in wastewater has several determining factors, including: velocity and residence time of wastewater flow, discharge of industrial wastewater with highly variable organic composition; pH, sulphate concentration in wastewater, temperature, and the presence of electron acceptors such as oxygen and ventilation conditions (Melbourne and Metropolitan Board of Works 1989) (Sharma, et al. 2008).

Figure 1: Examples of concrete corrosion in wastewater networks due to the generation of H_2S and rehabilitation of large concrete sewer mains

Release of H_2S into the gaseous phase is a significant contributor to wastewater network corrosion and odour issues, resulting in expensive rehabilitation works and customer odour complaints. Annually Sydney Water spends in excess of $40 million dollars on corrosion related rehabilitation. As Sydney Water has customer at the heart of all its operations, maintaining liveability around it's network assets is integral in achieving this goal. To reduce the concrete corrosion rate to less than 1 mm/year, Sydney Water's Corrosion and Odour Strategy specifies an average gas-phase H_2S level of less than 5 ppm, and average dissolved sulphide levels of less than 0.5 mg/L across all wastewater networks. Critical to Sydney Water's corrosion and odour strategy is liquid phase chemical dosing at key locations in the wastewater network. Sydney Water currently operates more than 65 chemical dosing units (CDU) that dose either ferrous chloride, magnesium hydroxide or calcium nitrate. However, the transient nature of networks and the presence of time delay introduces an inherent complexity, making traditional process control very difficult.

METHODOLOGY

As part of its corrosion and odour strategy Sydney Water spends more than $6 M annually on chemicals for dosing across its wastewater networks. The chemicals that are dosed for corrosion and odour control are ferrous chloride, magnesium hydroxide and calcium nitrate. Each of the three chemicals dosed achieves H_2S control via a different mechanism, therefore a detailed understanding and careful consideration of network characteristics is required to ensure dosing effectivness. Ferrous chloride ($FeCl_2$) is dosed and reacts with dissolved sulphides to precipitate either iron (II) sulphide (FeS) or iron (II) disulphide FeS_2 (Yuan and Cesca 2017). Magnesium hydroxide ($Mg(OH)_2$) slurry has buffering capacity that maintains pH at an elevated level to maintain sulphides in solution as HS^- and reduce the activity of sulphate reducing bacteria. Calcium nitrate ($Ca(NO_3)_2$) is dosed to prevent the formation of septic conditions and the generation of H_2S. Given that chemical dosing of wastewater networks is integral in Sydney Water's Corrosion and Odour strategy, innovative approaches for the ongoing optimising of CDUs is crucial to ensure efficiency.

Chemical Dosing Operations

Chemical Dosing Unit Standards

The importance of having a well designed and properly constructed CDU for enabling long term effective chemical dosing to control wastewater network H_2S levels should not be overlooked. Following the occurance of issues stemming from poorly designed and built CDUs, the need for a way to address the causes became apparent. In response to this Sydney Water developed detailed CDU Standards to ensure all of the necessary process criteria, safety and environmental requirements are met (Sydney Water 2018). Development of the CDU standards has greatly improved the performance and reliability of Sydney Water CDUs and the standards have been recognised as one of the most comprehensive documents of its kind by the other water utilities across Australia.

Dosing Profiles

Efficient operation of CDUs requires continual review of wastewater network data and where necessary adjustment of CDU dosing profiles. The first CDUs installed in the Sydney Water wastewater network utilised constant dosing where a set dosing rate was in place and remained unchanged. As this doesn't consider natural fluctuations in H_2S concentrations, there is minimal efficiency in chemical use. In 2005, sewer-flow paced dosing was introduced as an advancement on constant dosing to improve chemical use effectiveness. The preferred approach of the flow paced dosing was to control the dosing rate proportional to the flow in the target sewer such that the concentration of dosed chemical in the sewer is generally constant regardless of flow. Figure 2 shows an example of a daily sewer-flow paced dosing profile which is designed to achieve constant chemical concentrations in wastewater.

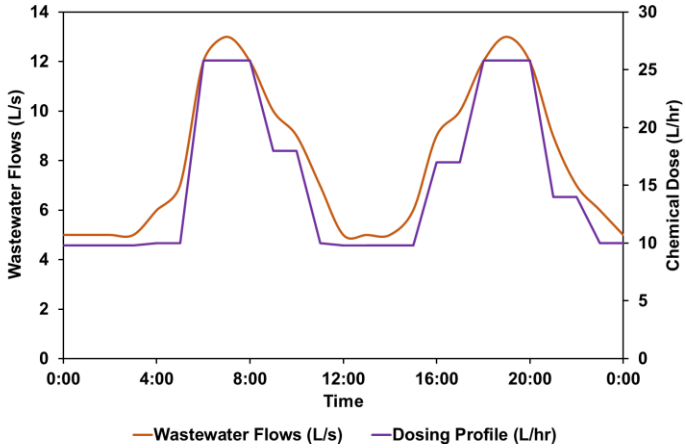

Figure 2: Example of sewer-flow paced dosing over a day

A more recent improvement was the introduction of targeted profile dosing which is designed to vary the hourly chemical dosing rate proportional to downstream network H_2S concentrations determined through statistical analysis of monitoring data. Targeted profile dosing does not revolve around attempting to keep the chemical load in the downstream sewer constant, since H_2S production in the sewer is not solely proportional to dry weather flow volume. Targeted dosing profiles are generated based on an understanding of typical diurnal hydraulic retention time (HRT) characteristics which influence wastewater travel time and the statistical analysis of H_2S data to understand what the typical diurnal patterns are. The HRT characteristics of a wastewater network are derived from flow gauging data and/or sewer pumping station wet-well level data, while H_2S concentrations are measured and logged at strategic locations where the control of H_2S is required. A conceptual targeted dosing profile is shown in Figure 3. Hourly dose rates in targeted dosing profiles can be either increased or decreased depending on where H_2S levels at the target location are within the desired limits.

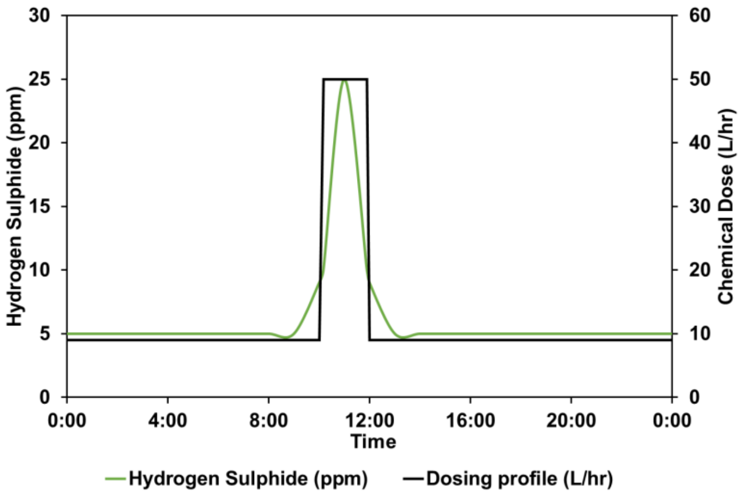

Figure 3: Schematic of Targeted Dosing

Seasonal Dosing Factor (SDF)

As aforementioned, dissolved sulphides generation rates and the H_2S equilibrium are influenced by wastewater temperature which fluctuates seasonally. During summer when temperatures are warmer, dissolved sulphides generation rates and H_2S concentrations are greater compared with winter when temperatures are cooler. To account for this, the seasonal dosing factor (SDF) adjusts dosing rates each month, with maximum rates during summer and minimum rates during winter. For over 15 years, Sydney Water has implemented a SDF for its ferrous chloride CDUs to adjust network dose rates in response to H_2S levels at the downstream network and treatment plants. A saving of up to 34 % in annual ferrous chloride usage is achieved by implementing the SDF. Reduced ferrous chloride dosing also results in less solids content at treatment plants, thereby reducing treatment costs downstream.

In 2017 a desktop review of the ferrous chloride SDF was undertaken to determine if changes could be made to enable improved network H_2S control within the desired 5 ppm average daily target. The review used historical monitoring data collated as part of a project undertaken with Data61 for the development of a predictive analytics toolkit for H_2S estimation and sewer corrosion (Li, et al. 2017). Approximately 5 years of sewer flow, chemical dose rate, H_2S gas, and temperature data was analysed for the Malabar (Figure 4) and North Head (Figure 5) wastewater networks from over 20 monitoring locations. Erroneous data and data corresponding with periods of significant wet weather were excluded from the analysis. The analysis compared monthly average gas phase temperature across all monitoring sites where the existing SDF was being used. The SDF was modified to more closely follow the pattern of measured seasonal temperature variation. Analysis of H_2S data across the same network monitoring locations was used to evaluate the impact of the modified SDF.

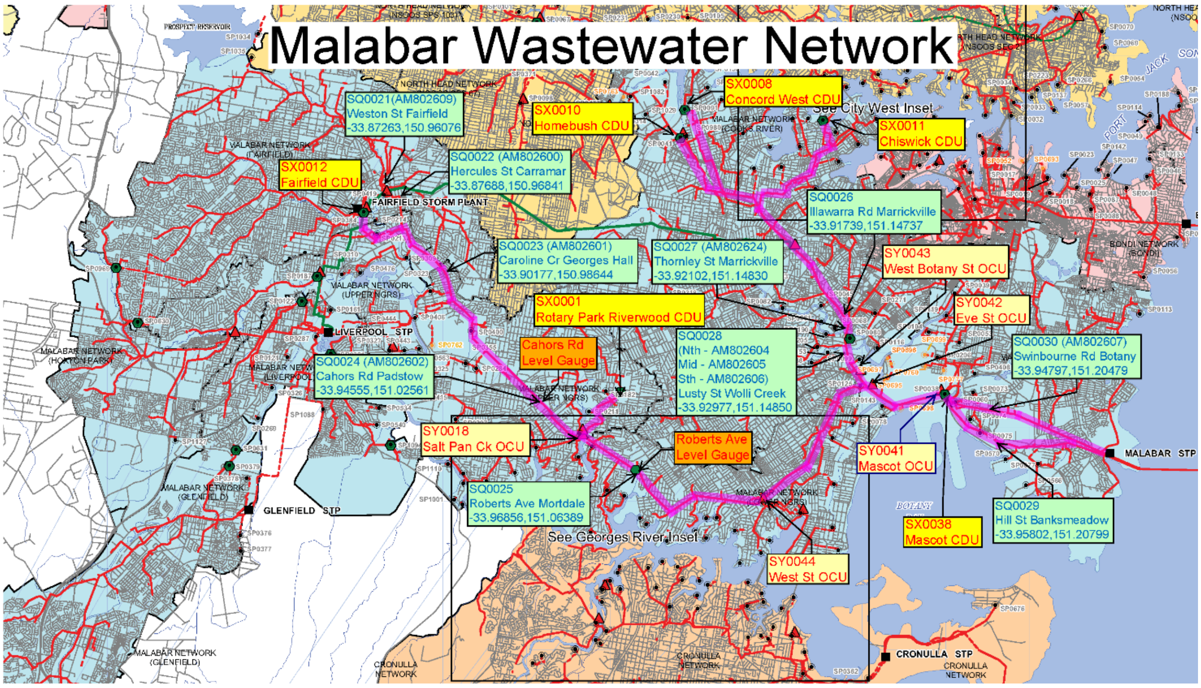

Figure 4: Malabar wastewater network schematic indicating dosing and monitoring locations

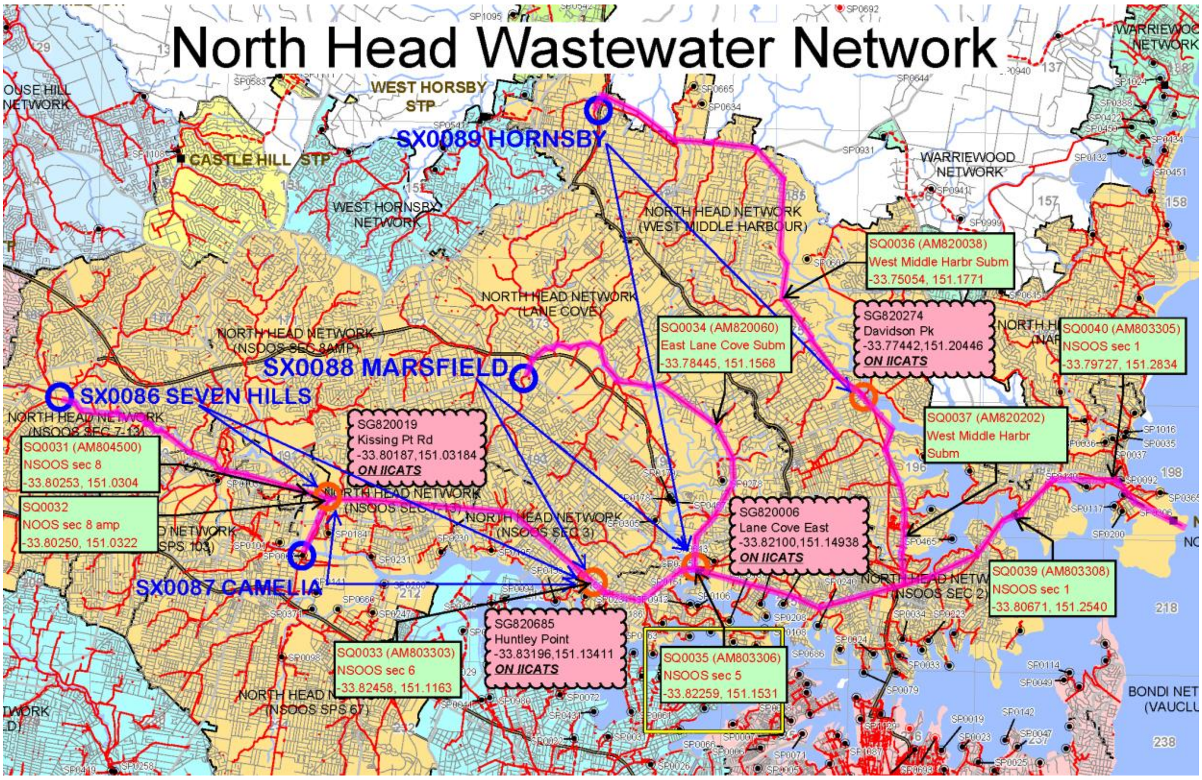

Figure 5: North Head wastewater network schematic indicating dosing and monitoring locations

Based on the successful outcomes achieved by utilising an SDF for network ferrous chloride CDUs conservative SDFs were devised and introduced for magnesium hydroxide and calcium nitrate modelled on seasonal temperature variation. For trialling these new SDFs, two CDUs were selected for each chemical and H_2S gas monitors installed at the sewage pumping station pressure main discharge maintenance hole and at a second location downstream. Field trials commenced with the aim of testing and optimising these SDFs. Quarterly liquid phase monitoring of sewage pH, temperature, conductivity and oxidation reduction potential (ORP) was also undertaken to examine impacts from dose rate changes on sewage quality. The impacts on H_2S levels are being monitored and the initial signs are positive particularly for the magnesium hydroxide SDF.

Wet Weather Interlocks

During significant wet weather, there is increased flow in the wastewater network because of unwanted rainwater infiltration. This dilutes the sewage and reduces the hydraulic retention time, in turn leading to a reduction in H_2S gas levels. During these significant wet weather events chemical dosing of wastewater for corrosion and odour control is not required. To reduce unnecessary chemical usage, automatic wet-weather interlocks have been implemented at CDUs across the Malabar and North Head wastewater networks and are in the process of being implemented at CDUs in other networks. The wet weather interlocks utilise online sewer level gauges that are installed throughout Sydney Water's wastewater networks and connected to its IICATS system. The wet weather interlocks have been developed to trigger CDUs to stop and start operation automatically depending on pre-determined cut in and cut out sewer levels. Determination of the cut in and cut out sewer levels was made through statistical analysis of long-term wastewater level data. The first wastewater network that this system was installed in was the Malabar network and studies indicated that savings of approximately 8 % were possible in a typical year. Figure 6 depicts an operational schematic of the wet weather interlock control system and its key components.

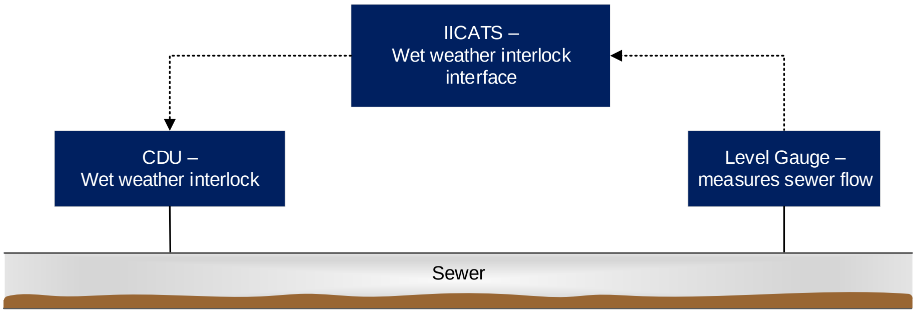

Figure 6: Operational schematic of wet weather interlock

Figure 7 demonstrates the process steps of wet-weather interlock operations.

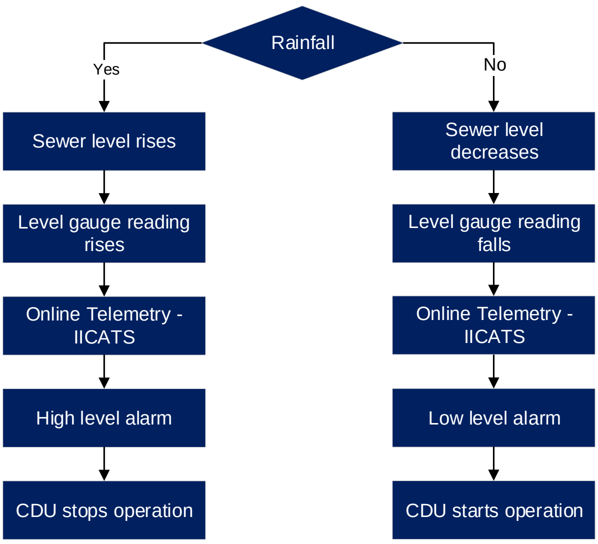

Figure 7: Flow chart of automatic wet weather interlock operations

Online Instrumentation and Data Analysis

The development of online monitoring equipment that is compatible with the Sydney Water IICATS system, has enabled data to be collected and analysed alongside other relevant operational data and actioned much quicker than was previously possible. This has allowed for optimisation of chemical dosing rates involving many incremental adjustments to be performed significantly quicker, compared with the 6 to 8 weeks required for a single adjustment prior to the development of this equipment (Iori, et al. 2016). Sydney Water has installed over 20 permanent, online H_2S gas monitoring units at strategic locations in two of its largest wastewater networks. Expansion of the online H_2S monitoring network is now underway across other wastewater networks, with plans to have at least one unit downstream of every CDU. Figure 8 shows an example of a typical online monitoring point at ground level.

Figure 8: Online instrumentation around the network

The process of analysing large multiple sets of time series data as part of CDU dosing profile optimisations is a laborious task when using existing commercial spreadsheet applications. As profiles need to be frequently reviewed and optimised, this can result in a significant amount of time being spent on this task. Figure 9 outlines the processes involved in a typical CDU optimisation.

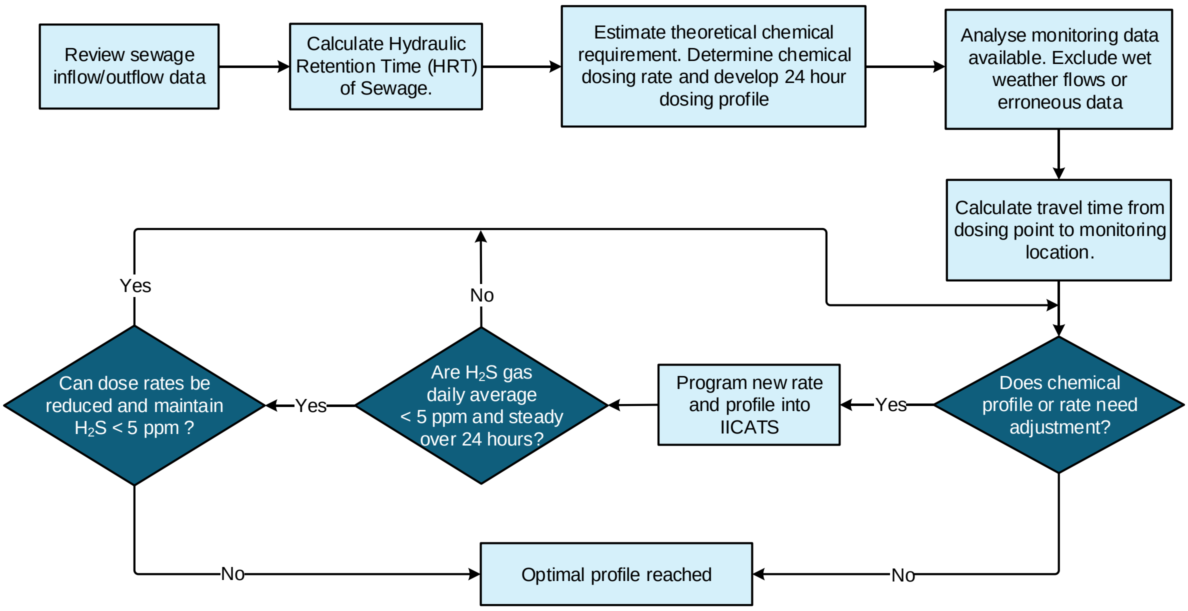

Figure 9: Methodology for the optimisation of CDUs

To address this issue, Operational Sewer Data Analysis Toolkit (OSDAT) was developed by Data61 and Sydney Water to facilitate rapid data visualisation and analysis (Zhang, et al. 2019). The evolution of OSDAT followed a previous project to develop a predictive analytics toolkit for both H_2S gas estimation and sewer corrosion (Li, et al. 2017). Figure 10 shows the OSDAT interface.

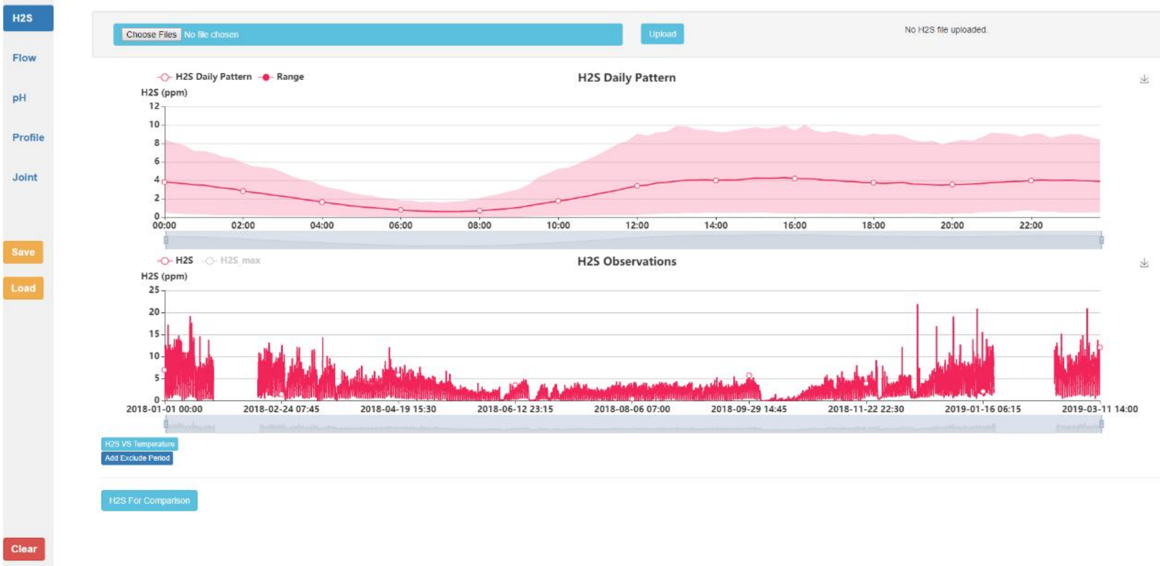

Figure 10: OSDAT

The key benefits that have been realised through using OSDAT are that it is user friendly and enables significant time saving when analysing multiple large timeseries data sets enabling the exclusion of data that is deemed erroneous. With the use of OSDAT and online monitoring systems, the ongoing routine optimisation of dosing profiles has been streamlined enabling the process to be undertaken more often leading to enhanced network corrosion and odour outcomes.

RESULTS AND DISCUSSION

From the desktop analysis that was undertaken on the ferrous chloride SDF, changes were made to the SDF consisting of rate reductions from February to August and rate increases from October through to December as shown in Figure 11. With these changes the revised SDF more closely matches the seasonal trend with respect to the monthly average sewer gas phase temperature.

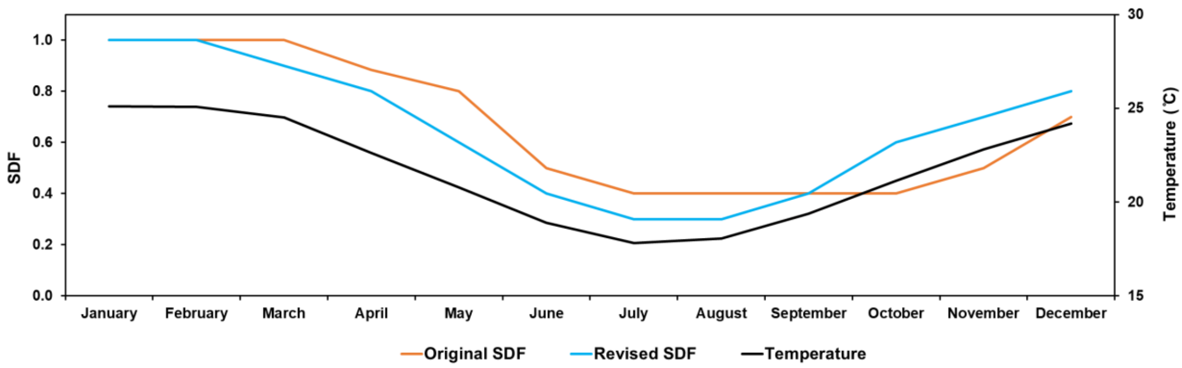

Figure 11: Traditional SDF plotted with revised SDF and average monthly gas phase temperatures

While the annual volume of chemical dosed is unchanged under the revised SDF, analysis of one year worth of network H_2S monitoring data post implementation indicates that the monthly average H_2S concentrations have generally decreased as shown in Figure 12.

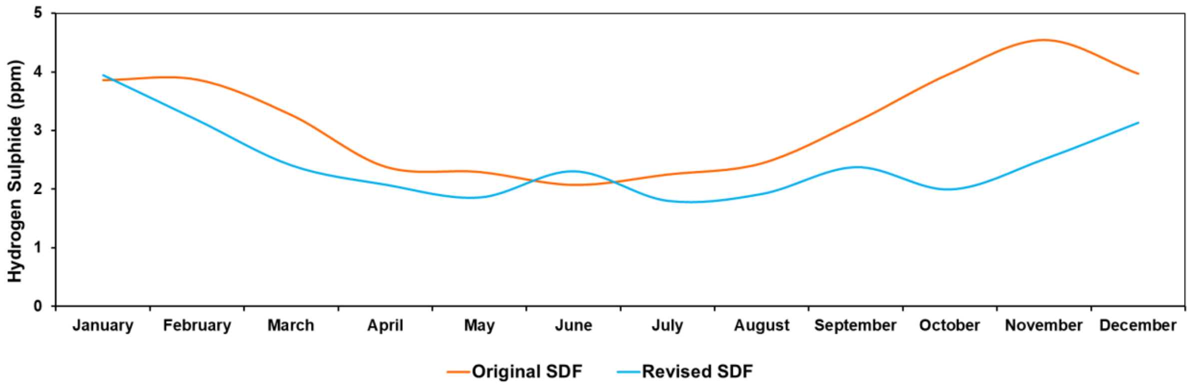

Figure 12: Gas phase H_2S levels before and after change in Sydney Water SDF

The general reduction in monthly H_2S concentrations identified from the analysis of data post implementation of the revised SDF are indicative of the success of the project.

Data analysis undertaken as part of developing an SDF for magnesium hydroxide found that under fixed dosing rates H_2S concentrations were lower in winter. Following on from this, rate reductions of 20% to 30% were implemented at a magnesium hydroxide CDU during winter and monthly average H_2S concentrations were successfully maintained below target levels as shown in Figure 13. Ongoing field trials are required to fully develop and refine an optimal SDF for magnesium hydroxide.

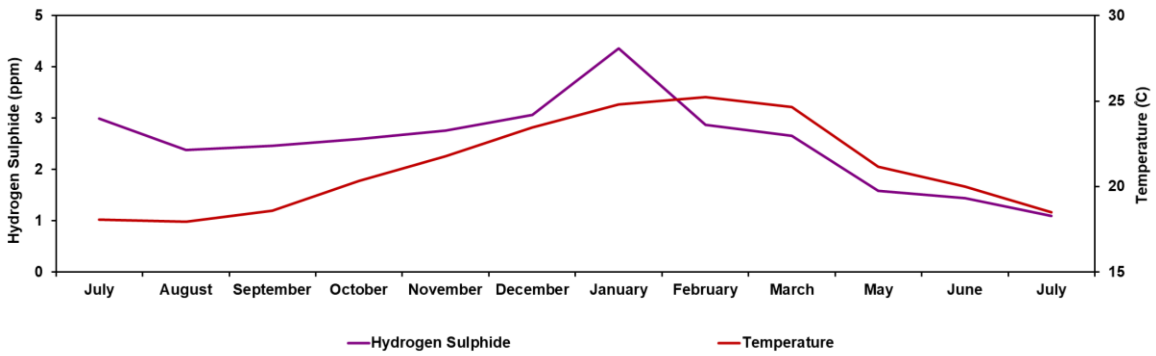

Figure 13: H_2S and Temperature with Magnesium Hydroxide SDF modifications

The project to develop an SDF for calcium nitrate experienced setbacks brought about by renewal of aging CDUs and upstream network changes. Stable dosing at both of the test calcium nitrate CDUs has resumed and is approaching one year. Implementation of dosing rate changes is planned to take place in the second half of 2019 and will continue the project to determine if development of an SDF for calcium nitrate is possible. The proposed SDF rate changes for calcium nitrate are outlined in Figure 14.

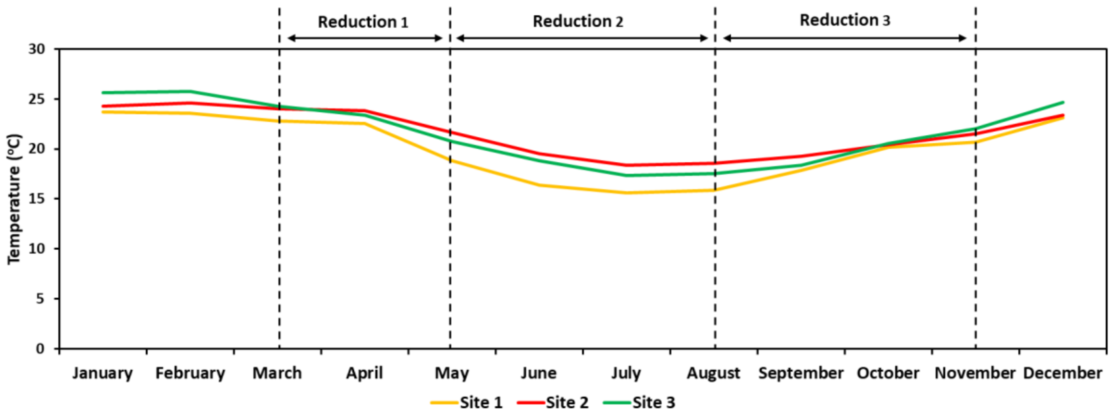

Figure 14: Calcium Nitrate Proposed SDF

Process Control of Chemical Dosing Units

Traditional feedback control involves the design of a control scheme that applies corrective action based on the measurements of the process variables to be controlled. However, the nature of wastewater networks makes traditional feedback control ineffective as the chemical dosing unit cannot perform corrective action based on the feedback, since the sewer flow has already moved downstream. Feed-forward control is essentially an open loop model that attempts to correct for conditions downstream. However, this requires accurate models and a reliable method to measure disturbances which are not available. Integrated feedback - feed forward process control may offer a solution if it is possible to accurately determine and monitor the liquid phase dissolved sulphide concentrations.

There are major challenges in implementing any online dosing control system for chemical dosing units in wastewater networks. Firstly, chemical dosing units are located several kilometres upstream of key points of interest. Therefore, there is a significant time delay from the dosing point to the monitoring location.

Secondly, uncontrolled sewer discharges with changing composition (pH, COD, BOD etc) and weather fluctuations introduce significant variability. As flows in wastewater networks are intrinsically transient in nature, random disturbances are prevalent and make traditional process control based on a feedback loop very difficult.

Thirdly, liquid phase parameters are difficult to measure due to the physical and chemical properties of wastewater. The harsh environment in sewers does not allow for prolonged performance of sensors as they are often rapidly coated in biological or chemical matter as well as the rags and debris found in sewers. Therefore, they require frequent maintenance protocol to ensure reliable and accurate measurements. Furthermore, installation, operation and maintenance of liquid phase monitoring is difficult and expensive. The periodic collection of data from offline monitoring units across different sites also presents an arduous task considering the sheer size of the network. Due to these practical limitations, online gas phase monitoring of H_2S is the preferred approach for evaluating the effectiveness of chemical dosing upstream.

As discussed, utilising liquid phase wastewater parameters for CDU process control applications are not currently commercially feasible. Hence, an alternative method is required to improve dosing as currently practised by Sydney Water. Using OSDAT as part of the foundations of future development of an online dosing system using machine learning is currently being considered. Ultimately, it is hoped that this work will pave the way to an automated, learning process control system that will maintain satisfactory H_2S levels while reducing chemical use.

CONCLUSIONS

To maintain liveability around its networks and continue having the customer at heart, Sydney Water has implemented a suite of innovative measures to control H_2S concentrations such that corrosion and odour problems are minimised. Sydney Water's corrosion and odour strategy aims to maintain average gas phase H_2S levels to below 5 ppm and average dissolved sulphide levels of less than 0.5 mg/L across the network. Chemical dosing of wastewater is integral to the implementation of the corrosion and odour strategy. To ensure that all new and replacement CDUs meet performance and operational requirements, a comprehensive standard has been created. The development of targeted dosing profiles through the statistical analysis of monitoring data has lead to more effective use of chemical. Establishment and long term use of an SDF for ferrous chloride has enabled a annual chemical saving of up to 34%. Projects to trial and optimise SDF for magnesium hydroxide and calcium nitrate are in progress. To minimise the unecessary use of chemical dosing during significant wet weather events, Sydney Water has implemented wet weather interlocks that cease chemical dosing until sewer flows return to typical levels. During a typical rainfall year, it has been estimated that chemical savings of up to 8% can be achieved using wet weather interlocks. Development and implementation of online H_2S monitoring instrumentation has enabled rapid access to data and an efficient means by which to continually monitor network chemical dosing effectiveness. Access to online monitoring data in IICATS combined with OSDAT has improved the speed at which data analysis and chemical dosing profile optimisations can be undertaken. It is hoped that significant future gains in chemical use efficiency can be achieved through the development of an automated learning process control system.

REFERENCES

Iori, Gino, Derek Cunningham, C Rout, and Elline Camilet. 2016. “Optimisation of Chemical Dosing in Sewer Networks Using Online Monitoring Equipment.” *Ozwater'16.*

Li, B, S Kodagoda, X Fan, J Zhang, Y Wang, F Chen, L Vorreiter, et al. 2017. “Predictive Analytics Toolkit for H2S Estimation and Sewer Corrosion.” *Ozwater'17.*

Melbourne and Metropolitan Board of Works. 1989. *Hydrogen Sulphide Control Manual - Vol 1.* Melbourne: Melbourne and Metropolitan Board of Works.

Sharma, KR, Z Yuan, D de Hass, G Hamilton, S Corrie, and J Keller. 2008. “Dynamics and dynamic modelling of H2S production in sewer systems.” *Water Research* 2527-2538.

Sydney Water. 2018. “ACP0002 Chemical Dosing Unit Standard Specifications.” Sydney.

Sydney Water. 2018. “Sydney Water Annual report 2017-18.”

Yuan, Z, and J Cesca. 2017. “Principles of Sewer Systems.” Queensland: IWES - The University of Queensland.

Zhang, J, Y Wang, F Chen, R Lockett, Gino Iori, Michael Kacprzak, Luke Walsh, and D Vitanage. 2019. “OSDAT - Operational Sewer Data Analysis Toolkit.” *OzWater'19.*

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He is a Scientist working for Sydney Water in the Wastewater Programs Corrosion and Odour portfolio. He started his career in the water industry working for private consultancy specialising in wastewater corrosion and odour undertaking projects for a range of major and regional utilities. Michael has gained significant experience in relation to the monitoring of wastewater networks and data analysis. Since joining Sydney Water in 2014 Michael has worked in roles across hydrometrics and instrumentation with his current position as a Senior Networks Program Scientist.

Lalitha Parthasarathy

She graduated with an honours degree in Chemical Engineering from UNSW Sydney. She did her Honours Thesis on CO_2 methanation using novel Metal Organic Framework (MOF) based catalysts at PARTCAT UNSW. She joined Sydney Water in 2019 in the Networks – Odour and Corrosion team.

Rebecca Lockett

She graduated with an honours degree in Chemical Engineering from the University of Sydney. She spent her first year at Sydney Water as an undergraduate working at Bondi Wastewater Treatment Plant. She then transitioned into the Sydney Water graduate program and spent a year working in corrosion and odour management in wastewater networks. She is now in her 2nd year of the graduate program, working in a consulting team for potable water filtration plants.

Luke Walsh

He graduated with an honours degree in Chemical Engineering from the University of Sydney in 2017. He spent his first year at Sydney Water as an industry experience trainee working at Winmalee Wastewater Treatment Plant, where he wrote his thesis on Capacitive Deionisation (CDI) for Wastewater Treatment. He then moved through to the Sydney Water engineering graduate program and spent a year working in corrosion and odour management in wastewater networks. He is now working as a project engineer for Sydney Water's capital growth program delivering growth assets (sewage pumping stations, pressure mains and reservoirs) in the Illawarra region.

Tiffany Chen

She is a chemical engineer working in Analytics and Spatial Capability at Sydney Water. Her focus is on driving business value through analytics and integrated problem solving. She has worked across waterway modelling, strategic planning, regulation application and development, commercial operations and safety. Tiffany has promoted collaboration, communication and team work through her ongoing work as a project scrum master and Engineering Community of Practise committee member. Prior to the water industry she spent 5 years in the manufacturing industry as a Process Engineer specialising in process optimisation, operations and sustainability.

Gino Iori

He graduated with an honours degree in Chemical Engineering from the University of NSW in 1988. He holds a Fellow membership grade with Engineers Australia, and is an Associate Member of IChemE. He has been with Sydney Water since 1993 with experience in quality assurance, water quality, recycled water, and his current portfolio of corrosion and odour in wastewater networks. Prior to joining Sydney Water he worked at ICI Australia as a shift supervior and quality engineer and as a gradute engineer with Transfield Construction in protective coatings. He is the current chairperson of Sydney Waters Engineering Community of Practice.

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