IMPROVING THE LONG TERM MANAGEMENT OF SEWER SYSTEMS

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ABSTRACT

Experiencing cost increasing pressures and competing demands for public money, it is necessary for water utilities to be able to prioritise expenditure to meet asset management objectives in a cost effective and transparent manner. The largest proportion of the asset value of a water utility lies in the buried networks of pipes that form the water supply and sewer collection systems. These assets require significant and ongoing expenditure to maintain their functionality and to service the changing and expanding cityscape above.

Sewer collection systems have historically presented unique challenges in terms of asset planning because of the corrosion and odour management required to achieve the network assets design life, prevent failure and meet communities' expectations. This paper outlines an applied approach to sewer network management that includes innovative modelling and analysis tools resulting from specific applied research into the mechanisms of corrosion and odour generation in sewers. These tools improve the reliability of the data upon which long term planning relies. The outputs from these tools can be integrated with hydraulic and financial analysis tools to give a complete network analysis, enabling a technically complete and financially justifiable long-term sewer network management plan to be developed.

KEYWORDS

Asset Management, Sewer Networks, Odour, Corrosion, Long Term Planning, Works Prioritisation,

1 INTRODUCTION

Water utilities and departments worldwide are grappling with competing pressures of increasing costs and cost minimisation drivers - New Zealand is no exception. For utilities, increasing costs arise particularly through specific requirements for renewals of extensive aging asset bases, the need to service growth in rapidly growing areas and from the need to meet legislative requirements. Cost minimisation drivers are applied as more general principles by governing organisations and customers. Unlike the private sector, without a mandate to increase revenues by increasing charges for the "products" of water supply and wastewater collection, public sector water utilities (or public sector organisations managing private sector service providers) must seek innovative and technically sound methods of continuing to meet production requirements in response to these cost pressures. They need to demonstrate cost effective and justifiable prioritised expenditure, works programmes and long term plans.

For many utilities, investing in asset management practices has been seen as a sound way to optimise existing assets as far as practicable in order to minimise capital expenditure and free up capital for alternative uses. The goal of optimising asset use or "sweating the assets" is fundamental to the asset management practices that seek to make the most use of assets and resources to maximise efficiency and minimise wasted effort or expenditure. The largest proportion of the asset value of a water utility lies in the buried networks of pipes that form the water supply and sewer systems. These extensive buried networks require significant and ongoing expenditure to maintain their functionality as they deteriorate over time and as the cityscape above expands and changes.

Wastewater networks present unique "asset-sweating" challenges in terms of corrosion and odour management that is required to extend asset life, prevent failure and meet the communities' expectations. It has historically been difficult to take an accurate high-level long-term planning view of sewer networks from a perspective of complete asset management that includes odour and corrosion management. This has been caused by limited understanding of several key in-sewer processes contributing to the problems, and the lack of tools and reliable technologies to support strategic decisions.

2 WHAT IS THE PROBLEM?

A wastewater collection system collects wastewater from households and industry and transports it to the wastewater treatment facilities for further processing, before the treated water is returned to the natural environment. When septic (no-oxygen) conditions prevail in the wastewater collection system, sulphate present in the wastewater is reduced to sulphide by sulphide-reducing bacteria residing in biofilms on the walls of pipelines. This results in emissions of corrosive and odorous gasses (mainly hydrogen sulphide (H_2S) to the sewer atmosphere, causing corrosion and odour problems in pipe sections and other places (Sharma et al., 2008).

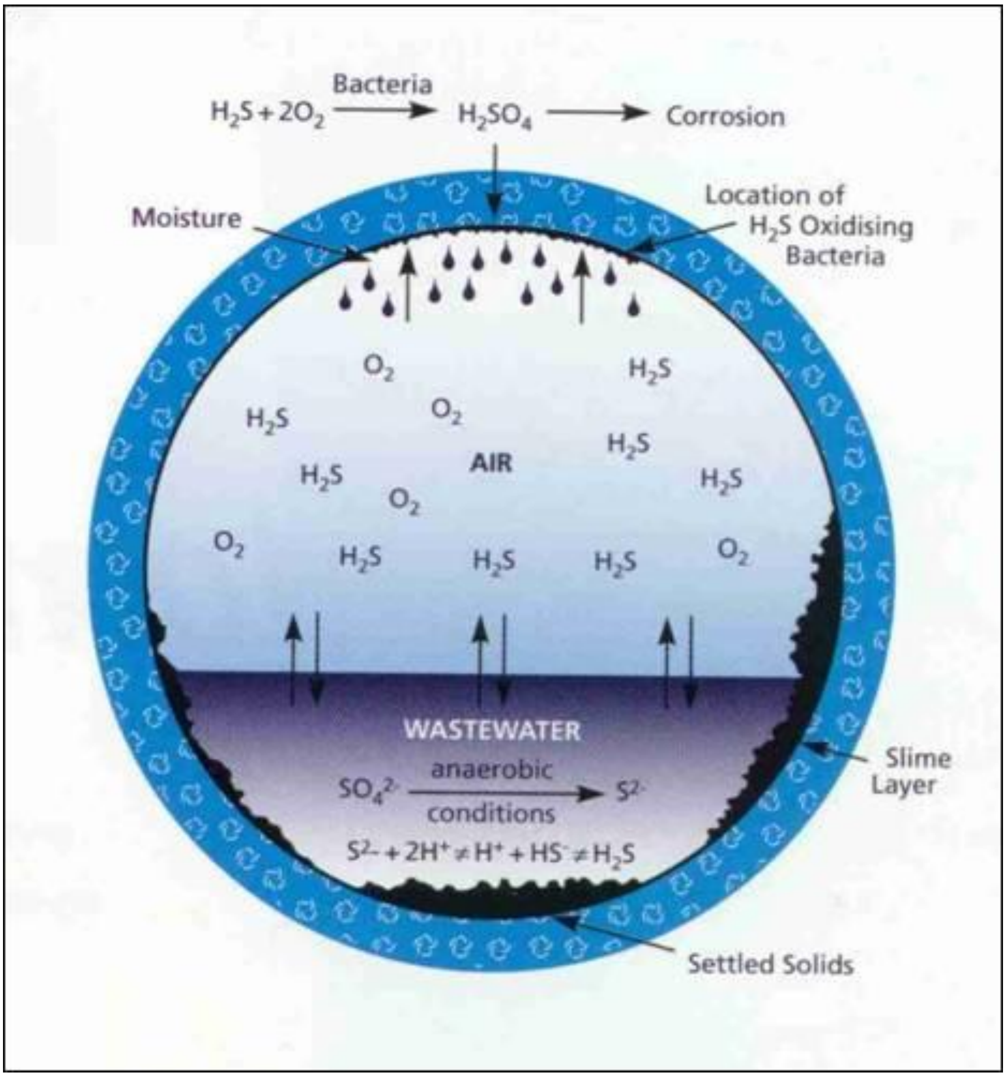

Figure 1: The basic process of sulphide release in a septic environment

Odours are primarily a problem for community members, whilst corrosion can seriously impact the lifespan of sewer assets and increase the need to bring forward expenditure on replacement or renewal of network assets.

Historically odour and corrosion issues have been managed in a reactive manner, providing a temporary solution that in some cases is not the ideal or the most holistically optimum solution. For example, repair of concrete corrosion was undertaken with little effort provided to understanding or mitigating the cause. Coating methods such as plastic liners provided excellent corrosion protection for that section of pipe but resulted in accelerated corrosion and bigger odour problems downstream of the coated section. Similarly a common method for addressing odour problems from vents was to block the vent. This solved the local problem but resulted in increased odour and corrosion problems downstream and in extreme cases sewer collapse.

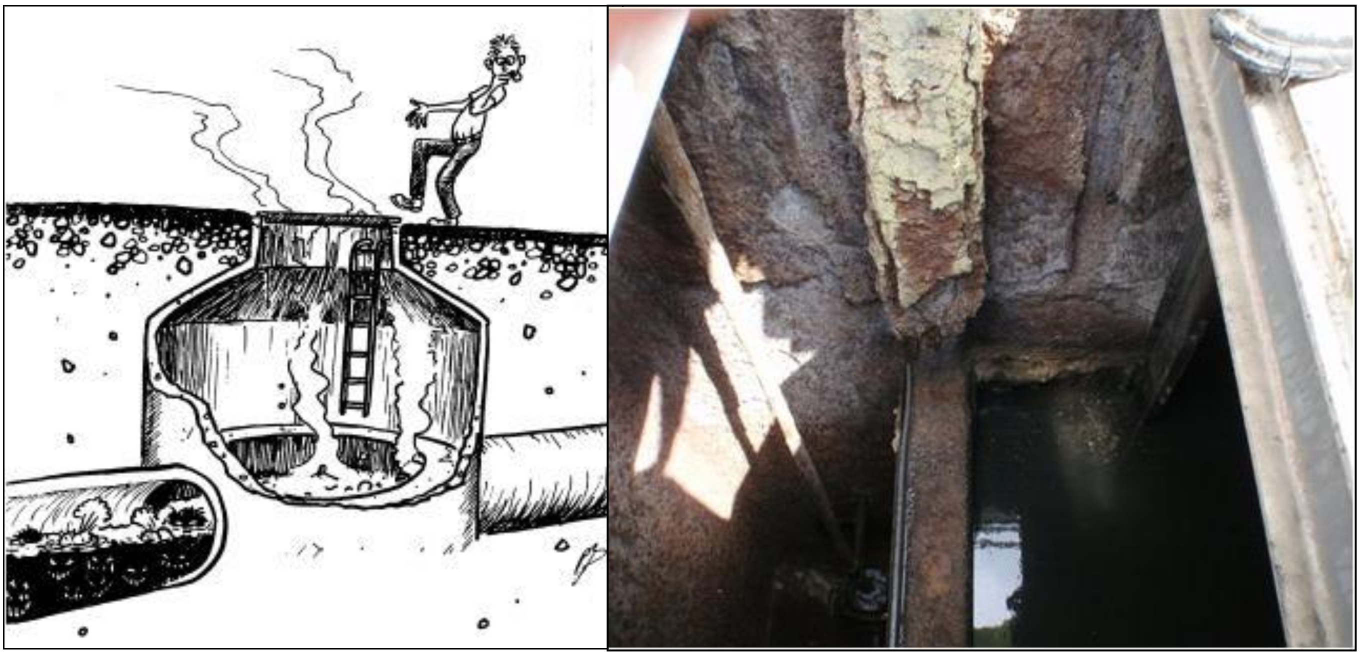

Figure 2: Odour and corrosion in sewers, a problem for the community and the utility paying to fix it

Microbial induced corrosion (MIC) of reinforced concrete sewer pipe is currently considered one of the most serious and costly problems currently affecting the world's sewer infrastructure with the global repair bill for MIC of sewer piping estimated to be in the order of billions of dollars per year. Based on the estimates of the Water Industry Network (USA) survey in 2000, annual rehabilitation costs in the USA are estimated to be $13.75 billion per year. The cost for the repair of corrosion damaged sewer pipe in Germany is estimated to be over $50 billion (Hewayde et al., 2007). In Australia, the total length of sewer pipes is over 110,000 km which worth $28 billion (Wells et al., 2009). In 2001, the annual cost due to the failure of water/wastewater pipeline alone in Australia was estimated to cost $250 million (CSIRO news release).

3 ODOUR AND CORROSION MECHANISMS IN SEWERS

3.1 THE HISTORY OF CONCRETE CORROSION

Concrete sewer pipe corrosion was first observed towards the end of the 19th century when it was rightly concluded that sulphuric acid (H_2SO_4) was the corrosive agent. However it was not until the 1940s that the biological nature of the concrete corrosion process was established through work undertaken in Australia and the USA when the bacterium "Thiobacillus concretivorous" (later renamed Acidithiobacillus Thiooxidans) was identified amongst the acidic corrosion products. Today we know that there are many bacterial and fungal species involved in the concrete sewer pipe corrosion cycle (Wells, et al 2011)

MIC of concrete sewers increased significantly after the mid 1980s in the USA, Europe and Australia. At this time tighter controls placed on industrial wastewaters to be discharged to the sewer system (e.g. the US Clean Water Act) led to significantly lower levels of biologically toxic metals such as lead, mercury and arsenic in the sewer system and as a consequence bacterial levels (and consequently MIC) increased dramatically. Modern day increases in corrosion activity are also linked to increasing use of hot water sulphate containing detergents and longer sewers. Historically, the most widely used corrosion algorithm is the US EPA corrosion model (Volersten et al 2011) developed by Pomeroy in 1974. This model assumes:

- Corrosion is proportional to H_2S flux to dry pipe area
- Corrosion is inversely proportional to concrete alkalinity
- All H_2S escaping liquid oxidizes to acid
- Acid may “drip” off before reacting

These simple assumptions have resulted in people having to apply different correction factors that can vary significantly and decreases the accuracy of model predictions.

Similarly prediction of sulphide generated in sewers relied on empirical equations such as:

- Pomeroy’s Equation (Pomeroy, 1959)
- Boon and Lister’s Equation (Boon and Lister, 1975)
- Thistlethwaite’s Equation (Thistlethwaite, 1972)

The limitation of these equations results in significant variation in predictions and a limited understanding of the critical parameters affecting sulphide generation.

3.2 RECENT RESEARCH AND DEVELOPMENTS

During the past few years, there has been a concerted effort to determine the biochemical, physical, and chemical mechanisms in sulphide corrosion. The research has been completed mostly in Denmark by the University of Alborg (2008–2015) and Australia through the Australian Research Council funded Sewer Corrosion and Odour Research (SCORe) Project (2010–2015). The results have led to a significant increase in the understanding of sewer corrosion mechanisms and the ability to better model and predict sulphide corrosion rates. Recent advancements include improved understanding of the biochemical corrosion mechanism, sulphide generation, sulphide mass transfer, ventilation of sewers and the effectiveness of sulphide control chemicals. Improved understanding of physical, chemical and biological processes occurring within sewers has led to the development of several advanced mathematical models which are capable of predicting both spatial and temporal variations in sulphide concentration.

New research on concrete corrosion has improved our understanding of:

- The headspace-to-pipe mass transfer rate
- H2S oxidation rate
- The fate of H2SO4
- The impacts of Relative Humidity on corroison

This research has increased our fundamental understanding of the role of sulphur in concrete corrosion and is providing a more informed approach to corrosion rate predictions.

There has also been considerable recent research into the parameters affecting the sulphide generation rate in sewers (Hvitved-Jacobsen et al, 2002; Freudenthal et al, 2005) and these provide significant improvements over previous equations as more biological, chemical, and physical processes have been included. However, the kinetic expression for sulphide production still used an empirical approach limiting these models to steady-state conditions. (Rootsey et al. 2014). More recent sulphide models now incorporate sufficient understanding of the sulphide process to allow dynamic modelling of the biochemical processes involved providing a better appreciation of the factors affecting sulphide generation. This understanding allows for more accurate evaluation of sulphide control approaches.

3.2.1 VENTILATION AND MASS TRANSFER

There have been several empirical algorithms proposed for predicting natural ventilation air movements, the most popular being the Pescod & Price Equation (Pescod and Price, 1982), but these have not been widely used for the ventilation of sewers as the results have been unreliable. Design of natural ventilation systems has generally been by rules of thumb. However these systems have often failed to protect nearby residents from escaping odours and in many cases the vents have been either closed or forced ventilation systems installed.

The natural forces influencing ventilation are a fine balance between:

- Relative density between sewer air and outside air
- Wastewater flow induced drag
- Friction on pipe walls
- Changes in barometric pressures along a sewer
- Wind velocities over ventilation stacks

In association with Water Environment Research Foundation (WERF) in the USA, the SCORe Project has developed a new algorithm based on the conservation of momentum (Ward et al, 2010; Hamer et al, 2012) which accounts for the forces outlined above. The model has been proven in field testing in Adelaide and Perth to be much more reliable than previous models. A tool has been developed based on the conservation of momentum algorithm which can be used to predict both natural and forced ventilation air movements in sewers. This SCORe Ventilation Tool is now being used by many of the water utilities involved in the project to develop a better understanding of their systems and ventilation control strategies. More importantly however the new ventilation algorithm is being used to provide prediction of air movements that are used for estimating gas phase H_2S concentrations and subsequently corrosion rates within a sewer network. Air movement in collection systems is one of the most critical parameters for estimating both H2S concentrations and corrosion rates so the new tool provides another critical step to improving corrosion rate predictions.

3.2.2 SULPHIDE CONTROL CHEMICALS

The methods for controlling odour and corrosion in sewers (primarily through chemical control) have not changed significantly since 1989. Although the methods have not changed, the popularity of various chemicals used by the water industry in Australia to control odour and corrosion has seen some changes. A recent survey carried out by the SCORe Project (Ganigue et al, 2011) identified that there are five chemicals that are now popularly used by the Australian water industry:

- Magnesium Hydroxide
- Sodium Hydroxide
- Nitrate
- Iron Salts
- Oxygen

Detailed laboratory and field testing has been conducted with these five chemicals (Gutierrez et al, 2008; Zhang et al, 2009; Jiang et al, 2009; Gutierrez et al, 2009; Pikaar et al, 2011) to gain a better understanding of the physical, chemical and biological processes involved with each chemical to enable:

- Calculation of optimal dosing rates
- Selection of appropriate dosing locations
- Mathematical modelling of the processes

This understanding has been built into models to better estimate chemical usage and impacts on the sewer biochemical process. To further optimise the dosing of chemicals, on-line control strategies have been developed for the five popular chemicals using a level of sophistication of sensors appropriate to the application (Ganigue et al, 2012). Significant savings in chemical use of up to 50% have been achieved with the use of on-line control.

3.3 SEWER MATHEMATICAL MODELS

There are several examples of advanced mathematical that incorporate the above developments. These models are capable of predicting both spatial and temporal variations in sulphide concentration as well as other physical, chemical and biological processes occurring within sewers. These models for predicting sulphide generation in sewers, such as SeweX (developed by the University of Queensland and augmented as part of SCORe) has enabled desktop evaluation of the performance of various chemicals with various dosing locations to optimise the control method selected (Sharma et al, 2008). The combination of these new advanced models, many years of research and experience at applying these models and significant advances in computing power and electrochemical sensors has meant that we can now more than ever, know more about our buried assets and the best ways to manage them using proven scientifically based approaches that provide a sound basis for justification of expenditure.

4 A MODERN APPROACH TO NETWORKS PLANNING

The importance of developing a better network wide understanding of the causes, severity and optimal solutions for corrosion and odour has gained wider acceptance due to the cost and potential risks involved in managing these assets. Greater investment into applied research to develop the tools and understanding needed to establish a more scientifically based approach has resulted in improved analytical tools as identified above. Application of these tools in a thoughtful manner, integrated with traditional network planning tools (such as hydraulic models) is now a useful means of improving the asset management of sewer networks. An approach that uses these tools is outlined in the methodology below and illustrated in the following case studies.

1. **Setting clear strategic and service level objectives** for the sewer network remains a fundamental first step in beginning a long-term planning exercise for a sewer network. Once agreed with all relevant stakeholders, this provides the basis for making and prioritising investment decisions. Typical objectives could include
    - Achieving the desired design asset life (i.e. “acceptable” corrosion rates);
    - Minimizing the whole of life cycle cost of corrosion and odour management; and,
    - Ensuring that no adverse odour impacts are experienced from any network asset.

2. **Defining the extent of the problem -** to what degree the strategic objectives will or will not be met over the selected planning horizon. In this exercise, the corrosion and odour risk profile of the wastewater collection system is established by developing a calibrated system wide sulphide and corrosion model. Having reliable data for this is critical to the success of the project and often requires some degree of additional data collection in the form of liquid and gas phase sulphide sampling and physical corrosion assessment to calibrate parts of the model. As with all modelling exercises, the degree of model calibration that is required using additional data will depend on the specific outcomes that are sought. In utilising advanced analysis tools that use data to provide better planning outcomes, it is imperative that a plan for managing data is developed and implemented.
3. **Develop and evaluate potential control strategies**. Once the calibrated model is developed corrosion and odour strategies for the wastewater system can be evaluated. This process uses an established “hierarchy of controls” based on addressing; the sulphide precursors such as industrial waste and infiltration; the causes of sulphide generation such as rising main configurations and detention times, keeping the sulphide in solution using liquid phase treatment and then consider gas phase treatment if required and for localised odour solution. It is also important to understand the impacts to the wastewater treatment plant (WWTP) when developing network control strategies as the collection system is really just an extension of the WWTP. So what happens in the collection system will impact

the WWTP in several ways including treatment performance, treatment costs as well as odour and corrosion potential. Control strategies need to be evaluated against the ability to achieve the strategic objectives.

4. **Develop specific plans and implementation strategies** for each wastewater collection system documenting the benefits and measurable objectives that can be used to refine the strategy as time goes on.
5. **Develop guidelines, standards and costing tools** for ongoing effective corrosion and odour management. This helps to capture the knowledge gained. Data capture and management for input to these tools is important for evaluating and refining existing strategies and also for better development of new strategies over time in response to changing service level drivers.

The following case studies provide some examples of the application of these tools used recently by two Australian state water authorities.

5 LESSONS FROM SYDNEY WATER

5.1 THE PROJECT

Historically, corrodible infrastructure was placed on inspection plans giving a re-inspect or repair date. Odour complaints were dealt with as a local issue resulting in the application of either odour control or chemical dosing. This approach developed over the years resulted in large costs. To better manage these costs, and to more accurately estimate expenditure into the future, system-wide corrosion and odour strategies needed to be developed based on technical and economic assessment of performance against corrosion and odour objectives.

Sydney Water decided to specifically and urgently develop integrated strategies to ensure cost effective management of the corrosion and odour in its wastewater collection systems (Gonzeles et al). The approach as outlined above included the following steps:

- Establishment of the odour and corrosion risk profile of each wastewater collection system
- Development of corrosion and odour strategies for each category of wastewater system (collection systems and wastewater treatment plants)
- Development of individual plans for each wastewater collection system
- Development of guidelines, standards and costing tools for effective corrosion and odour management

Sydney Water had already developed a hydraulic model for each of its systems based on the Denmark Hydraulic Institute’s MOUSE model (Hvitved-Jacobsen et al., 1998 and Hvitved-Jacobsen, 2002). A sulphide generation model was added and a ventilation model was also added to describe the mass transfer of sulphides and allow for modelling of forced ventilation options.

The model output was overlaid with operational data and field measurements and assessed for accuracy in its representation of the current state. This allowed a holistic high-level assessment of the catchment prior to detailed work. The “problem” was then defined as being local or systemic, and involving corrosion and/or odour. A local problem applied to a small area of a catchment, one tributary of the collection system or one single pump station and had an end point. A systemic problem applied to all parts of the catchment and/or gradually increased along the collection system. A systemic issue might be caused by multiple minor inputs causing significant problems in the carrier as it travels downstream. The purpose of this classification was to narrow down the possible solutions that could be applied to the problem, thus arriving at the preferred option more expediently.

Having built and calibrated a model, it could then be used to test selected solutions. A prescribed “Hierarchy of Controls” was used to limit the number of model runs to only those that included measures that were technically feasible and were expected to give a cost effective outcome. At this stage in the process potentially better mitigation ’solutions’ were linked to the identified problem. A sequential generation of model runs was then prepared, which allowed effective combinations of control measures to be assessed.

Finally, the best solutions were costed against the ‘do nothing’ option taking into account the cost of rehabilitation of corroded sewers and the ‘odour risk’. The cost of rehabilitation was calculated based on a concrete corrosion rate dependency on the level of sulphide in the sewer head space, and this relationship was derived from work undertaken by the ARC SCORe project. Odour risk is determined by considering the area of impact of fugitive odours from the sewer at the modelled hydrogen sulphide concentration against the known population in that area.

A feature of this approach is that the outputs of these new technical analytical tools can then be integrated with standard financial and mapping tools to provide easily understandable outputs for asset managers that capture relevant technical information. Figure 3 shows the type of output that can be delivered by Sydney Water’s Corrosion and Odour Management Tool developed for this assessment.

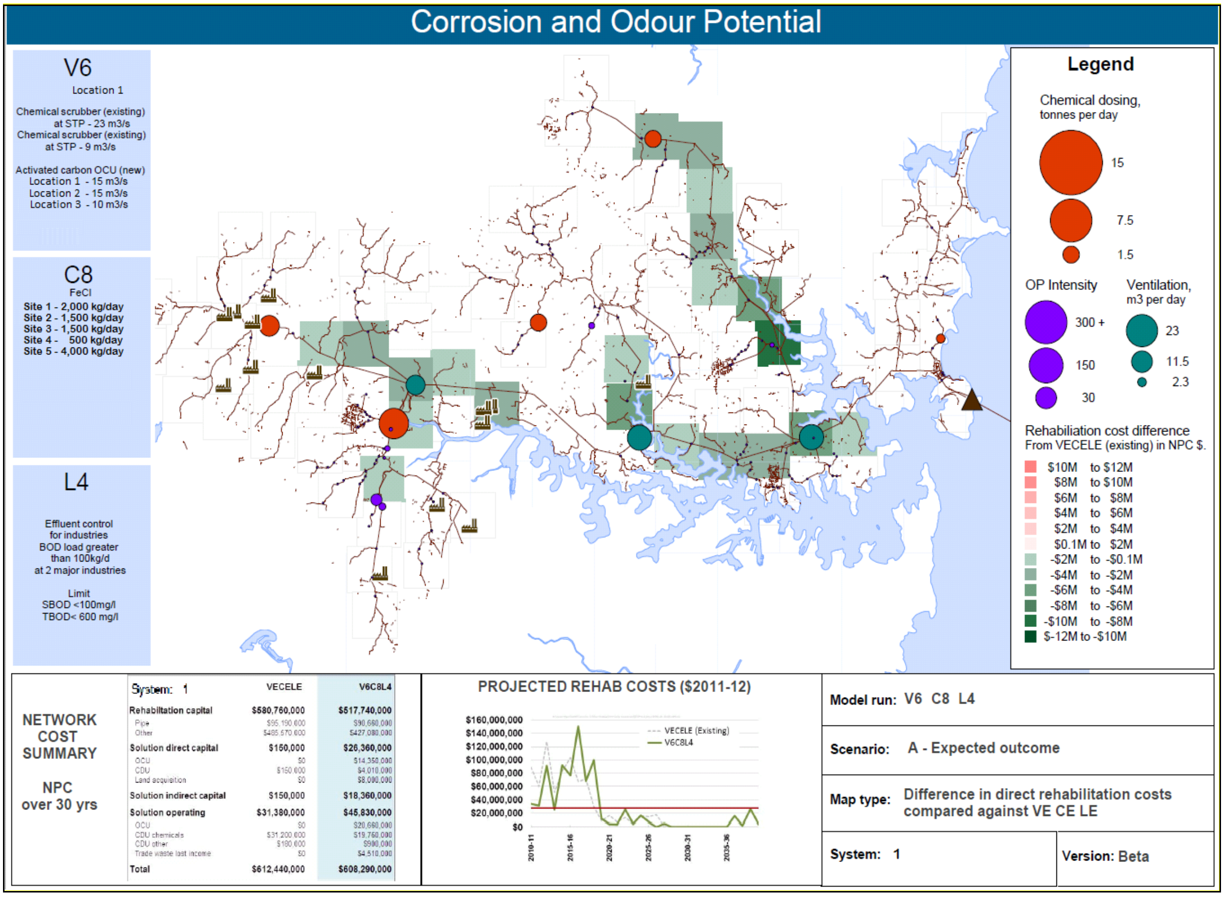

Figure 3: An example of the output map of the Corrosion and Odour Management Tool.

5.2 THE OUTCOMES

The Corrosion and Odour Management Tool was applied to all the 23 wastewater collection systems operated by Sydney Water. For each system, individual risk profiles and management strategies were developed as well as plans to implement measures to obtain the most cost effective outcome. For some systems it was identified that only local odour problems existed, and so the solutions were rather simple to derive. In other systems, systemic corrosion and odour issues existed and more complex solutions were required. Sydney Water’s new approach toward corrosion and odour issues also validated the overall corrosion and odour risks and helped prioritise the implementation of measures for each network system.

Lessons learned from this process included:

1. The confirmation of the “hierarchy of controls” approach as a short cut to identifying the most cost effective corrosion and odour control operating strategy.

2. The importance of monitoring the final dissolved sulphide levels entering the treatment plant. Despite the difficulty that is often present in getting reliable time series data, the dissolved sulphide level at the treatment plant is essential for the calibration of the network model.
3. The importance of taking into consideration the impact of trade waste discharges that are high in readily biodegradable BOD, temperature, and acidity. A tighter trade waste control program towards just a few strategically located industries can give in some cases a significantly better outcome.
4. The importance of including the wastewater treatment plant in the overall assessment of the corrosion and odour strategy. For example, lining and sealing the sewer all the way to the treatment plant transfers the corrosion and odour issues to the plant, and this may not be the best way to manage the corrosion and odour.
5. Input and support from all relevant organisational stakeholders is essential to develop accurate, system-wide corrosion and odour strategies.

6 LESSONS FROM SA WATER

6.1 THE PROJECT

South Australian Water engaged CH2M and the Australian Water Management Centre (all SCORe partners) to apply the knowledge, tools and practices developed as part of the SCORe project to support strategic decisions for cost-effective odour and corrosion management of three catchments in the Adelaide Metro area. An integrated approach was applied for the development and evaluation of management strategies for sewer collection systems.

South Australian water had the following strategic objectives:

For chemical dosing options

- H_2S sewage/liquid phase ≤ 0.5mg/L
- H_2S sewer gas space ≤ 5 ppm (95%'ile of < 10 ppm)
- Measured corrosion rates ≤ 1.0mm p.a. for concrete / corrodible sewers.

For odour control systems

- Odour released from the treatment system is less than 1,000 odour units (ou)
- The air extraction system is sufficient to prevent air pressure surges in the sewer

Having these specific targets also allow for effective performance monitoring and assessment upon implementation of solutions.

Existing data, including physical sewer characteristics and flow data, was analysed to develop an understanding of the networks. Accurate representation of the sewer network is critical for model simulations. Therefore development of reliable data inputs is essential. The information collected and analysed is outlined below:

- **Physical sewer characteristics**: this was imported from SA Water's Geographical Information System (GIS) database of their network.

- **Hydraulic sewer profiles**: this was developed from pumps station records (SCADA data and physical dimensions) with an allowance for gravity sewer inflows and infiltration and validated against monitored sewer wastewater depths.

- **A detailed sampling and monitoring plan** with clear objectives was produced for the networks to be modelled. Detailed field and laboratory testing was conducted based on the sampling plan and using methods developed as part of SCORe.

The following wastewater parameters were sampled as grab samples over a 24 hour period:

- Sewage temperature;
- Dissolved oxygen (DO) concentration;
- Chemical oxygen demand (COD);
- pH; and
- Alkalinity and conductivity.

Aqueous sulphur speciation was also undertaken on grab samples over a 24 hour period. Determining the concentrations of the different sulphur species is important when analysing the different chemical and microbiological processes that affect sulphide generation. Sulphide, sulphate, thiosulphate and elemental sulphur seem to be the major components in aqueous systems. For the SCORe project an ion chromatographic method developed by the University of Queensland for the simultaneous determination of these sulphur species was used (Keller-Lehmann B. et al 2010). The study demonstrated the extreme importance of a careful sample handling and preservation procedure for these samples as oxidation with air and volatilisation of hydrogen sulphide can severely impact upon the accuracy of the analytical results. For this reason a second comparative sulphide analysis method which can be used in the field is recommended. For this application an onsite titration method was used, however, in subsequent work sulphide ion tubes were found to be more accurate.

H_2S and temperature data was collected at a number of locations over several weeks using Odalogs. The SCORe project also demonstrated the important role of Relative Humidity (RH) for assessing corrosion rates in concrete sewers (Wells et al 2009), therefore an RH probe with a logger was used to collect RH data over several weeks.

The pressure and air velocity in the sewer was measured to derive headspace velocities for input into modelling. This data and the SCORe ventilation tool were used to establish the best relationship between air and water velocity and pipe sizes in the sewers tested.

The sampling data was then analysed to develop inputs for sewer network modelling. The in-sewer processes of the three networks investigated were modelled using SeweX. Model calibration and validation was undertaken to confirm that the models had been appropriately configured to represent the sewer networks being investigated.

To identify odour and corrosion hot spots, the following data was analysed for each network:

- SeweX modelling results;
- Complaints data from SA Water’s MAXIMO System; and,
- Condition ratings from CCTV inspections.

Comparison of the modelling results with sampling data, and complaints and condition assessment data found that the model predicted sulphide levels reflected reality, meaning that the model could be used to assess control options with confidence. Figure 4 shows an example output from the modelling used to identify corrosion hotspots in one of the sewer catchments.

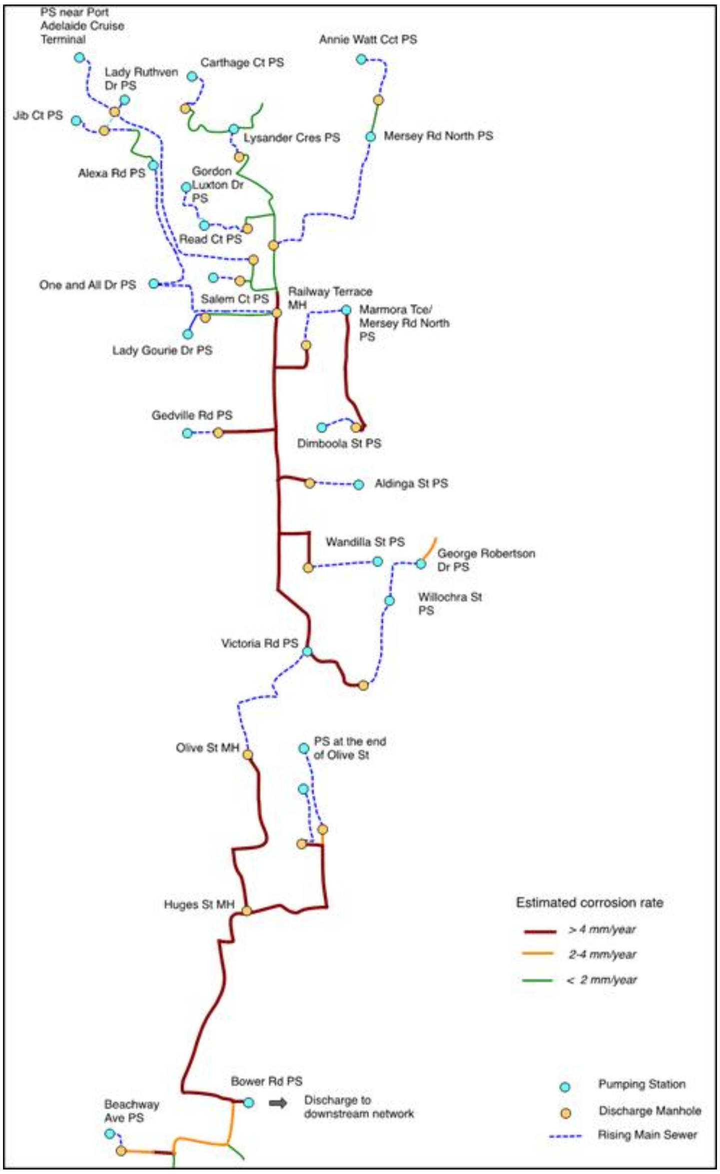

Figure 4: Corrosion rates in gravity sewers in the SA Ethelton Catchment, determined by SeweX using measured RH values

6.2 THE OUTCOMES

Development and evaluation of several potential control solutions followed using SeweX and the SCORe ventilation tool. Solutions evaluated included:

- Chemical dosing using iron salts, magnesium hydroxide and free nitrous acid
- Ventilation of the sewer and treated of extracted air in odour control systems
- Sewer rehabilitation

The SeweX model and SCORe ventilation tool determined optimal locations for control solutions including optimal dosing rates and ventilation rates. A preferred management strategy was selected for each network taking into account costs, benefits and drawbacks, and the ability to meet the following measurable targets for achievement of SA Water's strategic objectives.

7 CONCLUSIONS

Good asset management decision-making depends on reliable, good quality information and appropriate analysis tools, particularly when the assets need to be "sweated" to maximise useful lifespan and minimise expenditure. Wastewater networks present unique "asset-sweating" challenges in terms of the corrosion and odour management that is required to extend asset life, prevent failure and meet the communities' expectations. It has historically been difficult to take an accurate high-level long-term planning view of sewer networks from a perspective of complete asset management that includes odour and corrosion management. This has been caused by limited understanding of several key in-sewer processes contributing to the problems, and the lack of tools and reliable technologies to support strategic decisions.

By developing a greater fundamental understanding of the processes involved in various aspects of odour and corrosion, it has been possible to develop tools and reliable technologies to improve the reliability of the data upon which long term planning relies and to better support strategic decision making for sewer management. The outputs from these tools can be integrated with hydraulic and financial analysis tools to give a complete network analysis, enabling a technically complete and financially justifiable long-term plan to be developed.

This new knowledge has allowed utilities in Australia to undertake more effective planning to better utilise their sewer network assets and extend their life, while providing effective corrosion and odour management that does not result in unforeseen longer term problems.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Sydney Water and South Australia Water for their contribution to the SCORe project and in applying this new knowledge.

The Australian Research Council and the Sewer Corrosion and Odour Research or SCORe project team. This project, was jointly delivered and by CH2M HILL with the Advanced Water Management Centre of the University of Queensland, the University of Queensland, the University of New South Wales, the University of Newcastle, the University of Sydney, Curtin University of Technology, Sydney Water Corporation, Barwon Water Corporation, City of Gold Coast, Hunter Water Corporation, Melbourne Water Corporation, South Australian Water Corporation, South East Water Limited, Veolia Water Australia and New Zealand, Water Research Australia Limited, and Western Australia Water Corporation and remains the largest, world-wide research project focused on sewer corrosion and odour.

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