Engineering

Technical Guideline

TG 0530 - Sewer Network Hydraulic Design Considerations to Minimise Network Odour Impact

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Only the current revision of this Guideline should be used which is available for download from the SA Water website.

Significant/Major Changes Incorporated in This Edition

Nil.

This is the first issue of this Technical Guideline.

Document Controls

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Executive Summary

This Technical Guideline outlines sewer network design considerations for minimisation of network odour impacts. It only considers odour generation and is not intended as a hydraulic design standard. Any sewer design undertaken by SA Water shall follow all the relevant procedures, with hydraulic design requirements taking precedent over this Guideline document.

Designing a sewer network that has no odour is prohibitively expensive but the effort made to reduce and manage the causes of odour and corrosion during design can reduce some of the impacts and will provide considerably longer term benefit to SA Water.

The cause of sewer odour and corrosion problems starts with the formation of sulphide in the wastewater. Sulphide formation is a biological process that reduces sulphates and other sulphur compound to sulphide under anaerobic conditions. Anaerobic conditions exist in rising mains, siphons, in the sediment and deeper levels of sewers and wet wells. The sulphide formed is subsequently released to the sewer headspace, where it can cause corrosion of concrete and metals or be released to the atmosphere where it may cause odour problems.

The preferred approach in sewer design for odour control is:

1. Prevention of sulphide formation
1. To release the sulphides to atmosphere in a location where there will not be adverse impacts if possible (to remove sulphides from the system)
2. To keep the sulphide in the liquid phase by reducing turbulence and maintaining adequate sewer head space to allow air flow with minimal restriction
3. If the above are insufficient or not possible, some form of control to prevent corrosion and odour problems.

Minimising sulphide formation is the first step in managing odour and corrosion for sewer design, and key considerations are:

- Controlling the hydraulic retention time in rising mains and wet wells to avoid anaerobic conditions
- Achieving adequate sewage velocity to achieve natural reaeration, scouring of sediments, and striping for minimising slime layers on pipes

Once formed, the sulphide will be released to the sewer headspace at a faster or lower rate depending on the level of turbulence. Rising main discharge locations, steep slopes and drops all promote turbulence and faster sulphide release to the sewer headspace. Ideally the air in the sewer headspace should be released to atmosphere at these locations to prevent the build-up of H_2S levels in the network. If this is not possible due to the sensitive nature of the locations, adopting strategies to reduce turbulence, ensure that the sewer headspace is not too restricted (and does not surcharge) and to allow the free flow of sewer air will be required. The reason for this is that restriction in headspace will increase the pressure which will force air out at uncontrolled locations. Managing the release of sewer gases requires effective containment so that gases are only released at designed locations, such as educts**.**

The Table below provides a quick reference guide to the sewer network design considerations for minimisation of network odour impacts that are covered in this Guideline.

Design Consideration	Reference
Process of sulphide formation and corrosion	Section 5.2
Odour risk level related to HRT and sulphide concentration (for high level analyses only)	Table 5-2
Quantifying Odour Risk	Section 5.6
Hydraulic drop design with internal and external drop pipes	Figure 6-2
Applicability of vortex drop structures	Section 6.3
Design requirements for vortex drop structures	Section 6.3
Design Standards to avoid hydraulic jumps and surges	Section 7.4
Gravity sewer design to minimise sulphide generation	Section 8.3.1
Rising main design to minimise sulphide generation	Section 8.3.2
Design of rising main discharge manholes	Section 9
Rising main discharge design to promote non-turbulent conditions	Table 9-1
Design of SPS wet well/control manhole incoming sewer discharge	Section 10
Requirements for seals on wet wells and manhole covers	Section 11.1
Design of wet well inducts and educts	Section 12
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1 Introduction

SA Water is responsible for operation and maintenance of an extensive amount of sewerage infrastructure.

This Guideline has been developed to outline sewer network design considerations to minimise network odour impacts.

1.1 Purpose

The purpose of this Guideline is to provide guidance for use in the design of sewer assets to minimise network odour impacts.

This Guideline only considers odour generation and is not intended as a hydraulic design standard. Any sewer design undertaken by SA Water shall follow all the relevant procedures, with hydraulic design requirements taking precedent over this Guideline document.

1.2 Glossary

The following glossary items are used in this document:

Term	Description
BOD	Biochemical Oxygen Demand
BWL	Bottom Water Level
CO_2	Carbon Dioxide
DMDS	Dimethyl Disulphide
DMS	Dimethyl Sulphide
DO	Dissolved Oxygen
HRT	Hydraulic Retention Time
H_2S	Hydrogen Sulphide
H_2SO_4	Sulphuric Acid
MM	Methyl Mercaptan
ORP	Oxidation Reduction Potential
ou	Odour Unit
ppb	Parts Per Billion
ppm	Parts Per Million
SA Water	South Australian Water Corporation
SPS	Sewage Pump Station
SRB	Sulphate Reducing Bacteria
STEL	Short Term Exposure Limit
RM	Rising Main
TS	SA Water Technical Standard
TG	SA Water Technical Guideline
TWA	Time Weighted Average
VFA	Volatile Fatty Acids
WSAA	Water Services Association of Australia

1.3 References

1.3.1 Australian and International

The following table identifies Australian and International standards and other similar documents referenced in this document:

Number	Title
WSA 02-2002-2.2	Sewerage Code of Australia, WSA 02—2002-2.2 (Sydney Water Edition, Version 4), Water Services Association of Australia (WSAA), 2017.
WSA 04-2005-2.1	Sewage Pumping Station Code of Australia, WSA 04—2005-2.1 (Sydney Water Edition), Water Services Association of Australia (WSAA), 2012.
	Hydrogen Sulphide Control Manual: Septicity, Corrosion and Odour Control in Sewerage Systems. Volume 1, Technical Standing Committee on Hydrogen Sulphide Corrosion in Sewerage Works, Melbourne and Metropolitan Board of Works, 1989.
	US EPA Design Manual - Odour & Corrosion Control in Sanitary Sewerage Systems & Treatment Plants, US EPA, 1995.
	Water Security Agency of Saskatchewan Sewage Works Design Standard, 2012.
	City of Omaha Wastewater Collection Systems Design Manual (Pre-Final), 2018.

1.3.2 SA Water Documents

The following table identifies the SA Water standards and other similar documents referenced in this document:

Number	Title
	Standard on Odour Control in Wastewater Networks and Wastewater Treatment Plants, Version 0.01, Draft, SA Water 24/12/15.
TG 0531	Gravity Network Ventilation Design

1.4 Definitions

The following definitions are applicable to this document:

Term	Description
Hydraulic Drop	SA defines a hydraulic drop as any difference of greater than 0.3 m in water level between sections of pipes
Hydraulic Jump	A jump or standing wave formed when the depth of flow of water changes from supercritical to subcritical state
SA Water's Representative	The SA Water representative with delegated authority under a Contract or engagement, including (as applicable): • Superintendent's Representative (e.g. AS 4300 & AS 2124 etc.) • SA Water Project Manager • SA Water nominated contact person
Responsible Discipline Lead	The engineering discipline expert responsible for TG 0530 defined on page 3 (via SA Water's Representative)

2 Scope

This Technical Guideline provides guidance on sewer network hydraulic design to minimise network odour impacts. Details of the main odorous compounds in sewage are outlined, followed by a high-level design overview which presents the recommended design approach to minimise network odour impacts. Each of the following design aspects are then outlined in a separate section in the Guideline:

1. Hydraulic retention time (HRT) and its impact on sulphide generation and odour production
2. Hydraulic drops and vortex droppers
3. Hydraulic jumps and surges
4. Sewage velocities, sewer gradient and turbulence in rising mains and gravity sewers
5. Rising main discharge manhole design considerations
6. Sewage pump station (SPS) wet well/control manhole incoming sewer discharge arrangement
7. Seals on wet well covers
8. Design of wet well inducts and educts
9. Gravity sewer surcharging conditions and performance criteria

It is noted that this Guideline considers hydrogen sulphide (H_2S) in terms of its odour impacts only.

3 Odorous Compounds in Sewers

This Section outlines the chemical compounds found in sewers which are known odorants, along with their characteristics and how they are generated.

There are many different compounds that occur in sewer air, ranging from those with no odour to those that are highly odorous. The odorous compounds come from a range of chemical species including mercaptans, amines, aldehydes, volatile fatty acids (VFAs), and H_2S which fits into no specific group.

Despite the variety, only a handful of odorants occur frequently and with a significant presence. H_2S and methyl mercaptan (MM) are the most predominant, followed by dimethyl sulphide (DMS) and dimethyl disulphide (DMDS). The properties of these compounds are shown in Table 3-1.

Table 3-1 Properties of the Most Predominant Odorous Compounds in Sewers

Odorant	Odour Description	Odour Threshold	Means of Generation
Hydrogen Sulphide (H_2S)	rotten eggs	0.51 ppb_v (low)	• Bacteria in wastewater reduce sulphides to H_2S, which is then released to the air phase, especially during turbulence or under low pH.
Methyl Mercaptan (MM)	rotten cabbage	0.077 ppb_v (very low)	• Generated by humans and released in faeces. • Anaerobic decomposition of sulphur-containing proteins.
Dimethyl Sulphide (DMS)	disagreeable rotten vegetable / decayed cabbage	3.0 ppb_v	• Produced by the bacterial metabolism of methyl mercaptan in sewers. • Forms under anaerobic conditions. Assumed that rising mains, siphons and sewage pump stations (SPS) would favour formation.
Dimethyl Disulphide (DMDS)	garlic-like	0.022 ppb_v (very low)	• Forms under anaerobic conditions. Assumed that rising mains, siphons and SPSs would favour formation.

H_2S is one of the most predominant odorous compounds in sewage. The physiological effects of H_2S are summarised in Figure 3-1, and established limits for workplace H_2S exposure are provided in Table 3-2 for information only, but will not be considered further. Designers should note that very low concentrations of this gas can cause serious health hazards, and the ability to sense it by smell is quickly lost as concentrations increase. Death has resulted from concentrations of 300 ppm by volume in air. [8] Such concentrations can be obtained in an enclosed chamber with high turbulence, from wastewater containing 2 mg/l of dissolved sulphide at a pH of 7.0. [4]

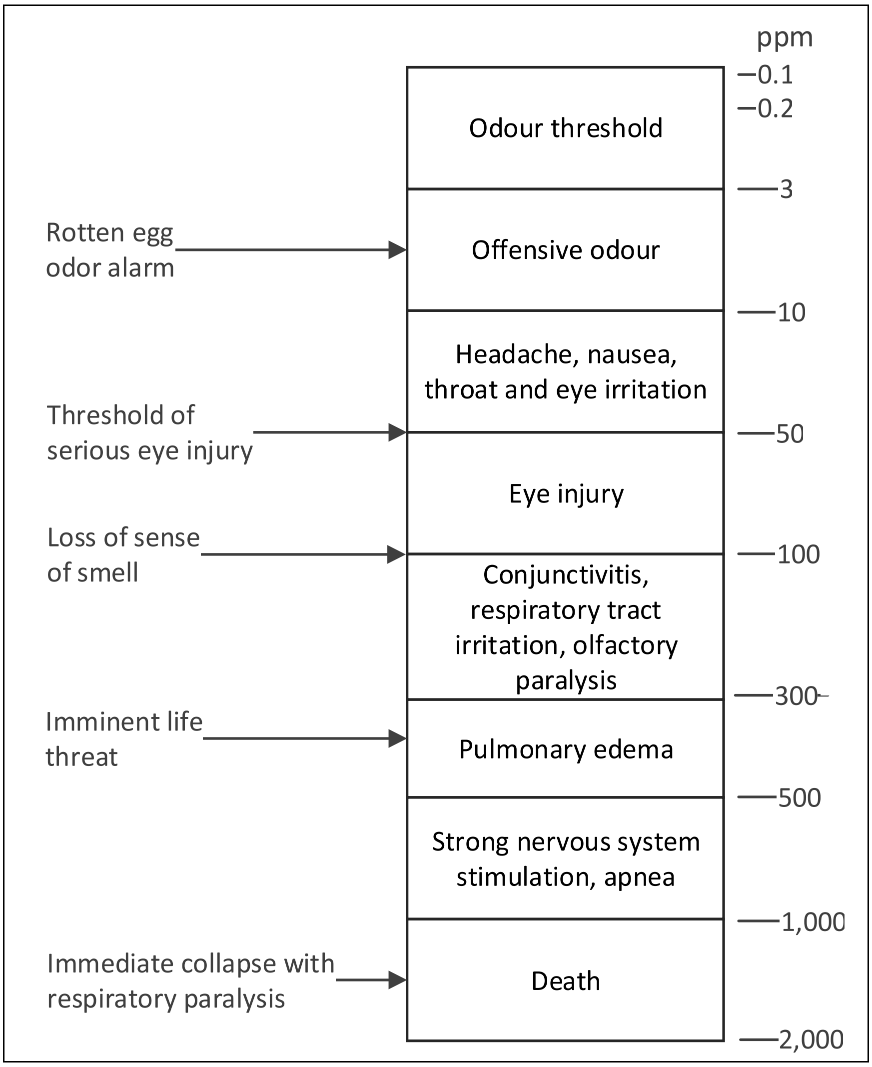


Figure 3-1 Physiological Effects of H_2S [4]

Table 3-2 Established Limits for Hydrogen Sulphide in the Workplace

Metric	SafeWork Australia Limit (ppm)
Eight Hour Time Weighted Average (TWA)	10
Short Term Exposure Limit (STEL)	15

4 High Level Design Overview

This Section outlines a high-level design approach that should be used to minimise network odour impacts. It outlines the prioritisation strategy for adopting the recommendations in the following sections based on specific circumstances.

Designing a sewer network that has no odour will be prohibitively expensive but the effort made to reduce and manage the causes of odour and corrosion during design can reduce some of the impacts and will provide considerably longer term benefit to SA Water.

The cause of sewer odour and corrosion problems starts with the formation of sulphide in the wastewater which is subsequently released to the sewer headspace. In the sewer headspace it will cause corrosion of concrete and metals or be released to the atmosphere where it may cause odour problems. Sulphide formation is described in **Section 5.2.** It is a biological process that reduces sulphates and other sulphur compound to sulphide under anaerobic conditions.

Anaerobic conditions exist in rising mains, siphons, in the sediment and deeper levels of sewers and wet wells. Standards for the hydraulic retention time (HRT) in rising mains and wet wells to quantify impacts of anaerobic conditions are provided in **Section 5.5**. Standards for ensuring the velocity of the sewage is such that;

- natural reaeration;
- scour of sediments; and
- striping for minimising slime layers on pipes;

occur should be a key consideration to minimise sulphide formation and are described in **Section 8**. Minimising sulphide formation is the first step in managing odour and corrosion for sewer design.

Once formed the sulphide will be released to the sewer headspace at a faster or lower rate depending on the level of turbulence. Rising main discharge locations, steep slopes and drops all promote turbulence and faster sulphide release to the sewer headspace. Ideally the air in the sewer headspace should be released to atmosphere at these locations to prevent the build-up of H_2S levels in the network. If this is not possible due to the sensitive nature of the locations, adopting strategies to reduce turbulence, ensure that the sewer headspace is not too restricted (and does not surcharge) and to allow the free flow of sewer air will be required, and are described in **Sections 7**, **9** and **13**. The reason for this is that restriction in headspace will increase the pressure which will force air out at uncontrolled locations. Managing the release of sewer gases requires effective containment so that gases are only released at designed locations. Containment is discussed in **Section 11,** and inducts and educts for ventilation of wet wells are discussed in **Section 12.**

Options for reducing impacts of hydraulic drops are discussed in **Section 6.**

In summary, achieving scour and shear velocities to prevent/ minimise sulphide generation, should be the first priority in sewer design. Risk of sulphide release in sensitive areas should then be evaluated on a case by case basis for areas such as rising main discharge locations or other areas where sulphide will be high. The preferred approach for these areas should be:

10. To release the sulphides to atmosphere in a location where there will not be adverse impacts if possible (to remove sulphides from the system)
11. To keep the sulphide in the liquid phase by reducing turbulence and maintaining adequate sewer head space to allow air flow with minimal restriction
12. If the above are insufficient or not possible, some form of control if required.

Put succinctly, the order or priority in sewer design for odour control should be prevention of sulphide formation, mitigation of release to sensitive locations then control to prevent corrosion and odour problems.

5 Hydraulic Retention Time and Odour Risk

5.1 Introduction

This Section considers HRT and its impact upon sulphide generation and odour production. It outlines the following:

- Formation of H_2S
- Precursors for sulphide generation
- Explanation of odour risk and how it is impacted by HRT
- Risks of sulphide generation, and what constitutes low, medium and high risk
- Quantification of odour risk

5.2 Hydrogen Sulphide Formation

H_2S formation begins in the wastewater stream. Colonies of anaerobic sulphate reducing bacteria (SRB) active in biofilm layers that line submerged sewer walls reduce sulphates and oxidise biodegradable organic carbon producing H_2S, VFAs and carbon dioxide. H_2S is generally the most prevalent sewer gas and generally the greatest contributor to odour risk from sewers. The processes described are shown in Figure 5-1.

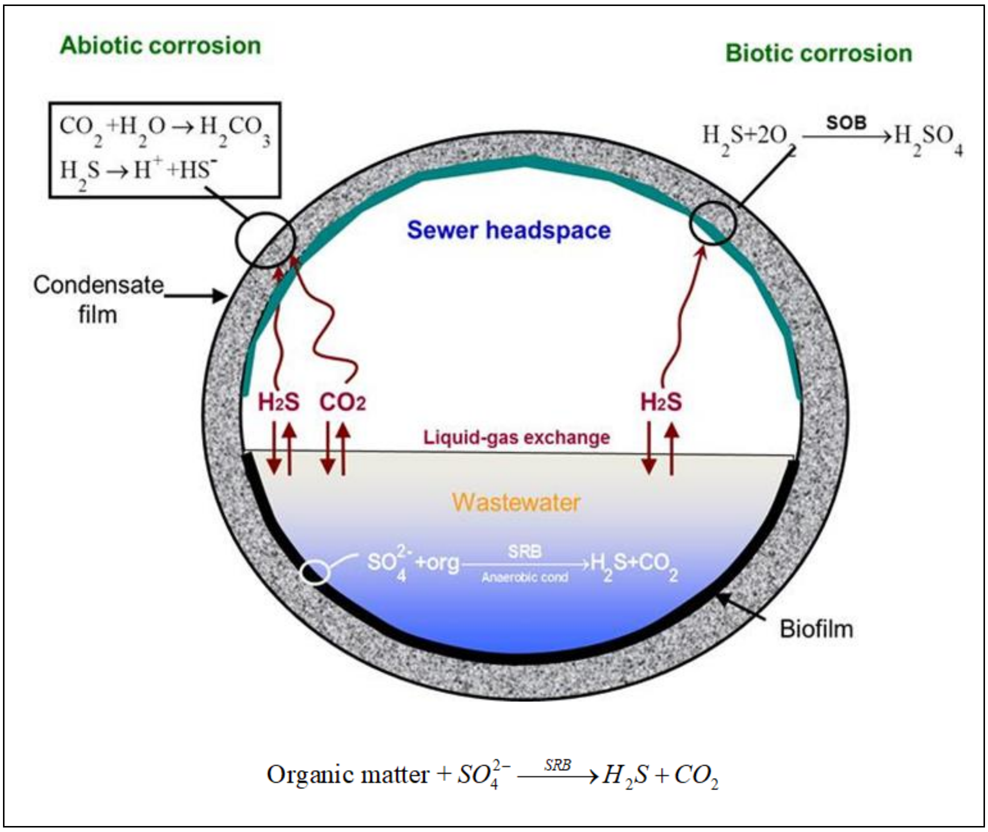


Figure 5-1 Schematic of sewer processes driving H_2S and corrosion

Sulphide (S^{2-}) in the wastewater can combine with hydrogen (H^+) to form HS^- and H_2S. The amounts of the three-sulphide species present (H_2S, HS^-, and S^{2-}) are also pH dependent. As oxidation-reduction potential (ORP) indicates stronger anaerobic conditions in the wastewater and the longer the wastewater is anaerobic, more VFAs are formed which lower the pH of the wastewater. The relative distribution of the three species, as a function of pH, is presented in Figure 5-2. As can be seen, the amount of H_2S is very sensitive to pH. At a pH of 7, 50% is present as H_2S. At pH < 5.5, almost all sulphide is H_2S (> 97%) while at pH > 8.5, less than 3% is present as H_2S.

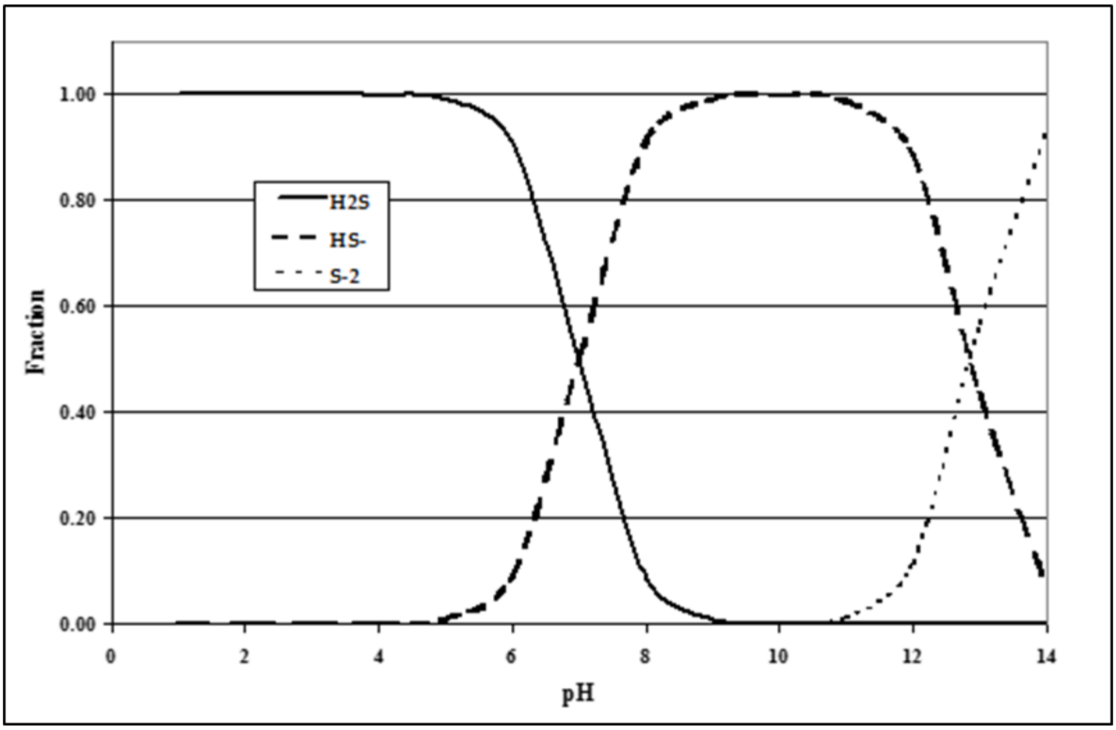


Figure 5-2 Liquid-Phase Sulphide Distribution vs pH

H_2S and carbon dioxide (CO_2) are transported through the biofilm into the wastewater stream where some is volatilised into the sewer headspace when the pH is below about 8.5. This H_2S can then be oxidised to sulphuric acid by aerobic biomass on concrete and steel surfaces which leads to corrosion.

Sewage detention times in rising mains, wastewater characteristics and temperature are the common parameters that impact sulphide levels, and sulphide transfer to gas phase (as H_2S) is mostly driven by turbulence and pH with some temperature impacts.

Sulphuric acid (H_2SO_4) forms as the H_2S leaves the wastewater, enters the air in the headspace between the wastewater and the top (crown) of the sewer pipe, and diffuses into the condensation present on the crown and walls of the gravity sewer. Along the crown and pipe walls, the H_2S is oxidised by the action of *Thiobacillus* bacteria to form sulphuric acid. Sulphuric acid formation is initially a slow rate process on new concrete due to the high alkalinity of the concrete itself (pH ranging from 11 to 13). *Thiobacillus* are unable to survive under high pH conditions. Aging of the concrete results in a decrease of surface pH to between 7 and 8. At this pH, a different species of *Thiobacillus* colonises the concrete surface, further reducing the pH of the condensate to less than 5. From this point corrosion proceeds faster if other environmental agents (H_2S, humidity and temperature) are present. Figure 5-3 summarises the processes of bacteria colonising the pipe, the change in pipe pH, and the damage done to the pipe.

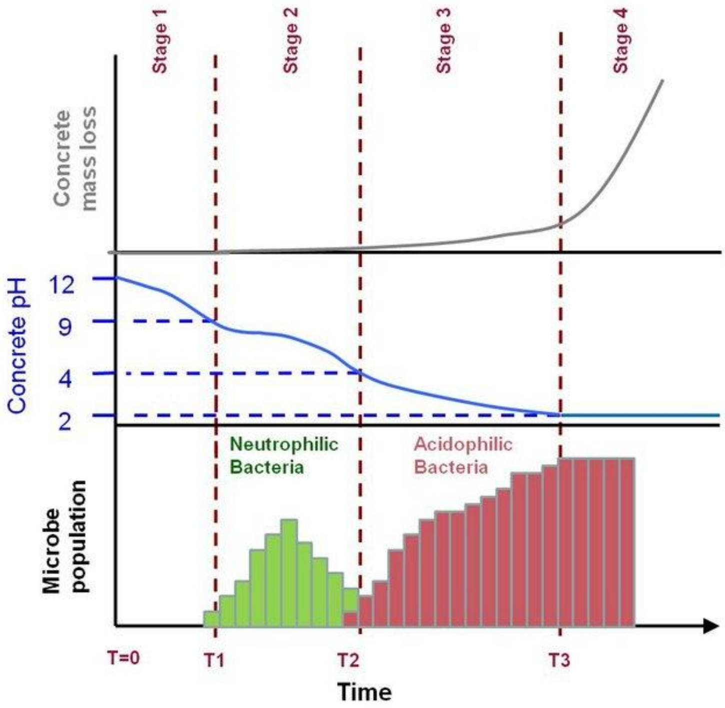


Figure 5-3 Progression of microbial corrosion of sewer pipe

5.3 Precursors for Sulphide Generation

Many variables directly or indirectly affect sulphide generation in sewers, and hence H_2S release, and sulphuric acid corrosion. These variables are summarised in Table 5-1 and discussed further below. [9]

Table 5-1 Factors Affecting Sulphide Generation in Sewers [9]

Factor	Effect
Wastewater Characteristics	
Dissolved oxygen (DO)	Low DO favours proliferation of anaerobic bacteria and subsequent sulphide generation.
Biochemical oxygen demand (BOD)(organic strength)	High soluble BOD encourages microbial growth and DO depletion.
Temperature	High temperatures increase microbial growth rate and lowers DO solubility.
pH	Low pH favours shift to dissolved H_2S gas.
Presence of sulphur compounds	Sulphur compounds required for sulphide generation. The concentrations of these compounds can be very significant when they are the result of groundwater and sea-water infiltration and in some cases due to trade waste.
Sewer System Characteristics	
Slope, velocity and change in direction	Affects degree of reaeration, solids deposition, H_2S release, thickness of slime layer. Note that change in direction can cause similar effects, as velocity suddenly decreases and turbulence increases.
Hydraulic Drops	Can promote H_2S release, turbulence and may cause outgassing. Refer to section 6.2.
Turbulence	Same effect as slope/velocity.
Surcharging	Reduces oxygen transfer and promotes sulphide generation, will not corrode while surcharged. Can also cause foul air release as the sewer headspace is restricted, causing pressurisation and driving air out of the sewer.
Presence of force mains and inverted siphons	The full pipe will prevent reaeration and provides a large wet area for biofilm growth which can lead to H_2S formation under anaerobic conditions. The inlet end will restrict sewer airflow causing it to be released. The turbulent discharge end will cause release of H_2S.
Sewer pipe materials	Corrosion resistance of pipe materials varies widely. Porous materials, such as concrete, favour biofilm attachment, while comparatively less porous materials such as plastic support a smaller a biofilm and the biofilm is more easily scoured off. However, the reduced biofilm in the headspace means less H_2S is oxidised to H_2SO_4. This can result in higher H_2S concentrations downstream.
Concrete alkalinity	Higher alkalinity reduces corrosion rate.
Accumulated grit and debris	Slows wastewater flow, traps organic solids.

For H_2S to be formed, the wastewater must be anaerobic. In properly designed gravity sewers, the velocity of the sewage is such that natural reaeration occurs from the atmosphere in the sewer, helping to replenish any losses of oxygen due to microbial activity. Certain structures and flow conditions often create turbulence of the wastewater, increasing the rate of reaeration and helping to maintain aerobic conditions. Sources of turbulence include:

- Manholes with flows dropping in from the side
- Manholes with flows colliding
- Metering flumes

- Drops in the line
- Sections with steep slopes
- Rising main discharges. [9]
- Sharp changes in pipe direction

Under certain conditions oxygen is depleted faster than it is supplied, causing a change from aerobic to anaerobic conditions. Such conditions can occur in the following:

- Gravity sewers with low sewage velocities or long detention times
- Rising mains which convey wastewater through a full pipe under pressure with no opportunity for reaeration
- Wet wells of sewage pump stations (SPS) having detention times sufficiently long as to cause oxygen depletion due to uptake by bacteria
- Other structures or processes where wastewater is detained under near-stagnant conditions with insufficient opportunity for reaeration
- Sections of sewer that can lead to significant solids deposition over time
- Industrial discharges with high concentrations of BOD

5.4 Risks of Sulphide Generation

The major risks related to sulphide build-up in sewers are:

- Corrosion of sewer structures and equipment
- Odour nuisance
- Health impacts on sewer workers

Corrosion of sewer structures and equipment can be significant, even at low H_2S concentrations. It can lead to pipe or even street collapses resulting from sewer pipe failure, as well as premature replacement or rehabilitation of pipes, manholes, lift stations and SPSs. Corrosion also compromises structural integrity by corroding equipment, pipe and equipment supports, storage tanks, and guard rails, walkways, and grating. Electrical components (e.g. brushes, switches, relays), process instrumentation, air conditioning and ventilation units, and computer systems at SPS and lift stations are particularly vulnerable to H_2S corrosion. Corrosion causes increased maintenance requirements, poor reliability of control systems and often premature replacement or rehabilitation of assets is required.

H_2S is recognisable to receptors in the vicinity of air release points from the sewer due to its rotten egg character. The release of sewer odour results in odour complaints from sensitive receptors. Ongoing odour releases from a sewer can cause reduced liveability, and may result in a poor public perception of SA Water, as well as failure to comply with environmental license requirements and possible fines

H_2S generated in sewers also has potential health impacts on workers. High H_2S levels under manhole covers can cause operator/s to become unwell or even die due to inhaling high levels when covers are opened or, entering a confined space without appropriate ventilation and safety precautions.

5.5 Impacts of HRT and Odour Risk

Controlling sulphide production will assist in minimising odour risks associated with sewers. As HRT in sewers and rising mains increases, the oxygen consumption increases, the ORP decreases, and organic matter becomes increasingly solubilised. These conditions favour the activity of the SRB, which generate odour and can cause corrosion. Thus, in the design of collection systems, minimising HRT can limit the activity of the bacteria and thus the rate of sulphide production. [4]

However, sulphide production itself is not of major concern in terms of odour. Sulphides in sewage only have the potential to pose an odour risk if they leave the liquid phase and enter the vapour phase as H_2S. Sulphides generally leave the vapour phase as a result of turbulence or when pH is lower than 8.5 (which is generally the case).

Odour release from sewers is a part of their operation and so forms part of their design; educts allow air to escape where forces pressure the headspace, and inducts allow air in to facilitate ventilation and sewer reaeration. Odour from sewers only poses a risk if foul air is released from the sewer and there are nearby sensitive receptors or operators are affected. The presence of odour where there is minimal to no risk of receiving odour complaints is generally of little concern. However, where there are sensitive receptors or there is a need for operators to access the sewer by cracking manholes thus releasing odour, the presence of H_2S poses an odour risk.

Table 5-2 below provides a general indication of the odour risk from sewers structures such as rising mains and wet wells at different HRTs and sulphide levels. The odour risk assumes that foul air is released from the sewer headspace and there are nearby sensitive receptors. It is noted that the sulphide concentrations shown do not necessarily occur at the associated HRTs, as this will be system dependent. The sulphide concentration and HRT are risk indicators; it is not necessary for both conditions shown in the table to exist in order to determine the risk level – either indicator can be used. These indicators are intended for high-level analyses, flagging areas where further investigation should occur.

Table 5-2 HRT in Rising Mains/Wet Wells and Odour Risk

Odour Risk Level	Risk Indicators	
	Sulphide Concentration (mg/L)[1]	Hydraulic Retention Time (Hours)[2]
Low	<0.5	<2
Medium	0.5 - 3	2-4
High	>3	>4

Notes

1. Hvitved Jacobsen, 2002 [17]
2. It is recommended that HRT is calculated using ADWF and minimum overnight flows.

Recommended HRTs for the design of pump stations are detailed in Section 10.

While the design of a pump station influences the HRT, sometimes an idea arises that involves reducing odours without additional costs by changing the operational times of the pumps. In the case where pumps run only a few times a day, the adjustments seek to increase the frequency of pump operation. There are pros and cons to doing this. Unfortunately, though, for a single line rising main there is no difference in the HRT. Running the pump longer and less often means incoming wastewater spends more time in the wet well. Conversely, running the pump more often but for shorter periods means that wastewater spends more time in the rising main than the wet well.

This is not to say that how the pumps are operated will not affect odour risk, but that it will not make any difference to the HRT, which is ultimately determined by the rising main size. Running the pump longer, less frequently will help scour both the rising main and downstream gravity sewer, though it may also cause foul air to be released if the gravity pipe experiences a surge. Running the pump for less time, more often will avoid surging but may encourage biofilm growth and sediments to build up.

5.6 Quantifying Odour Risk

As indicated above, odour problems occur when sulphide emissions leave the sewer atmosphere in the form of H_2S. The amount of gas released determines the severity of odour risk, and the public’s perception of odour is related to the following factors, referred to as the FIDOL factors:

- Frequency of the occurrence
- Intensity of the odour
- Duration of exposure to the odour
- Offensiveness of the odour
- Location

Odour risks are generally higher for new developments for the following reasons:

- Initially developing areas only having a low number of connections, causing long HRT which results in higher sulphides
- Proximity to sensitive receptors, who have invested in new properties and are more sensitive to odour issues
- Sometimes backlog developments result in a daisy chain arrangement of pump stations, or use pressure sewers, both of which causes long HRT under anaerobic conditions

In order to quantify odour risk from a sewer network or asset, an odour risk assessment should be undertaken to rank the risk and determine a suitable approach to manage odour risks. This risk assessment should consider the following:

- Proximity to sensitive receptors
- Upstream HRT in rising mains noting that multiple rising mains in series can have an accumulative effect.
- SPS size
- Daisy chain SPS arrangements
- The presence of certain industries that may discharge high BOD, high temperature, or low pH waste
- Whether low start up connections will be an issue

To quantify odour impacts based on H_2S and dissolved sulphide concentrations, Table 5-3 defines low, medium, and high-risk odour in terms of dissolved sulphide concentrations in sewage, and H_2S levels in the sewer headspace. The table adopts the widely recognised rule of thumb that 1mg/L of sulphide in the liquid phase in a normal concrete sewer can generate up to 10ppm (90th percentile) of H_2S in the sewer headspace (based on mass transfer between the liquid and vapour phase) and about 20ppm of H_2S for more turbulent areas[1].

Table 5-3 also shows the actions that should be considered in terms of odour control at exit points for air from the sewer, such as vents and pump stations. It is noted that the need for odour control will be driven primarily by the risk of receiving odour complaints. The risk below assumes that there are nearby sensitive receptors that will be impacted by emissions from sewer assets. If there are no sensitive receptors in the vicinity of emission points, there is unlikely to be a driver for installation of odour control equipment even if H_2S levels are high.

Further details of odour control requirements are outlined in SA Water's *Technical Guideline on Gravity Network Ventilation Design*, including selection of suitable odour control based on sewer infrastructure.

[1] Higher H_2S to dissolved sulphide ratios can be experienced in very turbulent areas, if the pH of the sewage is less than 7, or when the temperature is greater than 25°C.

Table 5-3 Odour Risk

Risk	Sulphide Concentration (mg/L)	Approximate Headspace H_2S Concentration * (ppm, 90th percentile)	Potential Management Response
Low	< 0.5 [10]	5 - 10#	No action necessary
Medium	0.5 - 3	10 - 30	Investigate further if release point is: • Close to critical infrastructure, like schools or hospitals • Within 50m of other sensitive receptors
High	>3	>30	Consider installing odour control depending on proximity of sensitive receptors.

* For concrete sewers with non-turbulent flow. Concentrations are 90th percentiles – maximum concentrations can be above these ranges.

Up to 20 ppm H_2S for turbulent sections of sewer.

6 Hydraulic Drops and Vortex Droppers

6.1 Introduction

Hydraulic drops and vortex droppers are sources of turbulence can promote stripping of volatile gases such as H_2S, or increase the rate of reaeration. If the sewage is fresh with low sulphide concentrations, drops and other causes of turbulence will increase the rate of reaeration and reduce the risks of anaerobic degradation, sulphide generation and H_2S stripping. However, if sewage is septic or may not always be fresh, then turbulence should be avoided to reduce the release of sulphide from sewage, generating odours and potentially deteriorating the structure.

This Section describes hydraulic drops and vortex droppers, and the risks and benefits of each. Methods to minimise the impact of hydraulic drops are outlined, along with situations where vortex droppers should be considered for installation and design requirements.

6.2 Hydraulic Drops

While technically any reduction in elevation between two adjacent sewer sections could be considered a hydraulic drop, SA Water defines a hydraulic drop as any location where there is a step change down in the sewer level of 0.3 m or more. However, drops less than 0.3 m difference in water level between sections of pipe can cause H_2S and odour to be stripped from the sewage and so step changes should be avoided or their impacts evaluated and mitigated if necessary. An example of a hydraulic drop in a drop structure is shown in Figure 6-1. Drops can promote aeration of fresh sewage and minimise sulphide generation, and a drop in a large sewer will have approximately the same effect on DO levels as a drop in a small sewer [4]. However, as the HRT of sewage increases, the sudden drop in water level at drop structures will cause turbulence and stripping of H_2S from sewage into the sewer headspace. If the water level in the manhole rises above the outlet pipe, the manhole will become a source of air release as the air will be pressurised and not have any other means of depressurising.

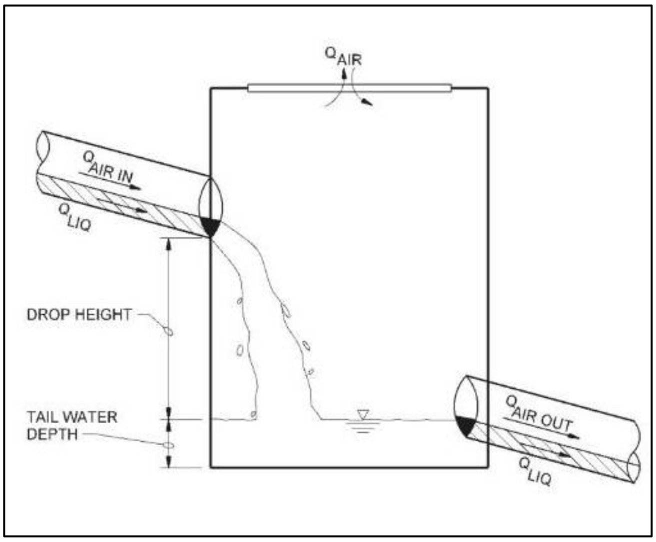


Figure 6-1 Hydraulic Drop

If potential for sulphide generation exists, hydraulic drops should be designed to minimise turbulence. If possible, to reduce turbulence and striping, a transition that allows flow from a higher level to be introduced to below the water level at the base of a drop should be adopted. SA Water has installed drop pipes to limit the free drop and hence the stripping process at SPSs, which appears to be successful.

Figure 6-2 below shows typical installations of an internal and external drop pipe.

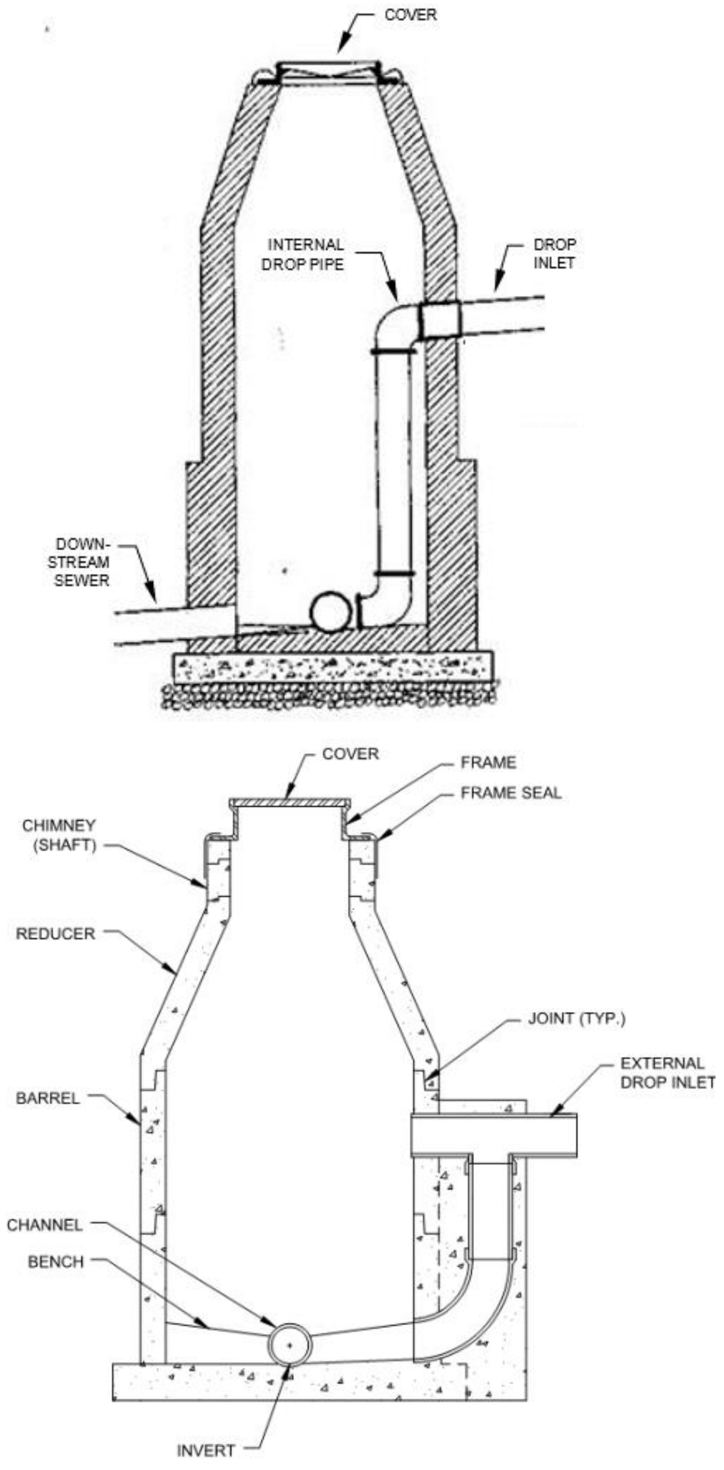
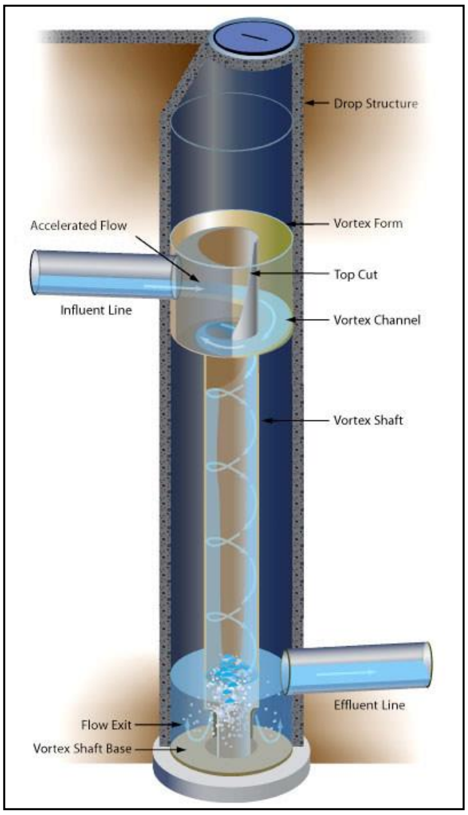


Figure 6-2 Typical Installations of Hydraulic Drop with Internal and External Drop Pipes

The materials used to construct drop structures must be selected based on anticipated corrosion problems.

6.3 Vortex Droppers

Vortex droppers are used to lead wastewater flows through relatively large drop distances. In a vortex dropper, the flow is directed tangentially to produce a spiral flow pattern. Vortex droppers reduce turbulence and hence the emission of H_2S and odorous gases, protecting the drop structure from corrosion. A schematic diagram of a vortex dropper is shown in Figure 6-3.



Reference: http://www.vortexflow.com/HowItWorks.htm

Figure 6-3 Vortex Dropper

The risks and benefits of vortex droppers are summarised in Table 6-1.

Table 6-1 Risks and Benefits of Vortex Droppers

Risks	Benefits
• Does not accommodate multiple inlet sewers • Access for people and equipment can be difficult • Installation costs may be higher than steepening the sewer elsewhere	• Maintenance of a continuous air core down the shaft • Excellent conditions for oxygen uptake • Minimal accumulation of solids or scum • Less likelihood of stoppages • Better energy dissipation • Virtually maintenance free • Where sulphide generation potential exists, well designed drops are effective techniques for maintaining aerobic conditions and preventing sulphide generation • If a traditional drop exists, replacement with a vortex dropper can decrease odour emissions[2], and potentially save the need for external odour control

Larger deep sewers ventilate more dramatically and with higher pressures, due to drop structures, and fewer manholes and connections. Drop structures on deep tunnel sewers can be the source of significant additional pressurisation in sewers. Friction drag with the falling water causes eduction and pressurisation from drop structures. The WSAA Sewerage Code of Australia WSA 02—2002-2.2 Sydney Water Edition Version 4 states that vortex droppers provide suitable flow conditions for an inlet to a tunnel or very deep sewer. It recommends that vortex

[2] While vortex droppers can decrease odour emissions, there may still be an odour risk with them.

droppers are only installed when simpler and less expensive drop inlet would have a potential for damage or for causing service difficulties. The requirements for vortex droppers in this Code are shown in Table 6-2. Note that SA Water does not currently have drop structures that are greater than 10 m.

Table 6-2 Drop Requirements [1]

Sewer size DN	Drop length m	Requirements
375 to 525	<6	Drop inlet
	6 – 20	Drop inlet with water cushion at bottom of drop
	>20	Vortex inlet with water cushion at bottom of drop
≥600	<3	Drop inlet
	3 – 10	Drop inlet with water cushion at bottom of drop
	>10	Vortex inlet with water cushion at bottom of drop

Although SA Water currently does not have sufficient drops to justify the installation of vortex drops structures this section is left for completeness as they may be required at a future date.

Design of the vortex drop should incorporate the following [1]:

- Vortex drops shall have one inlet only, which shall be to the access chamber at the top.
- The receiving sewer shall be traversable so as to enable connection
- Ventilation shall be provided at both the top and bottom of a drop shaft
- Construction materials must be selected based on anticipated corrosion problems

The deep sewer must accept air from the drop shaft to avoid pressurisation and odour release, and usually a vortex dropper requires forced ventilation and/or return air recycle. It is noted that return air concentrates emissions. A typical design for a vortex dropper with an air return is shown in Figure 6-4.

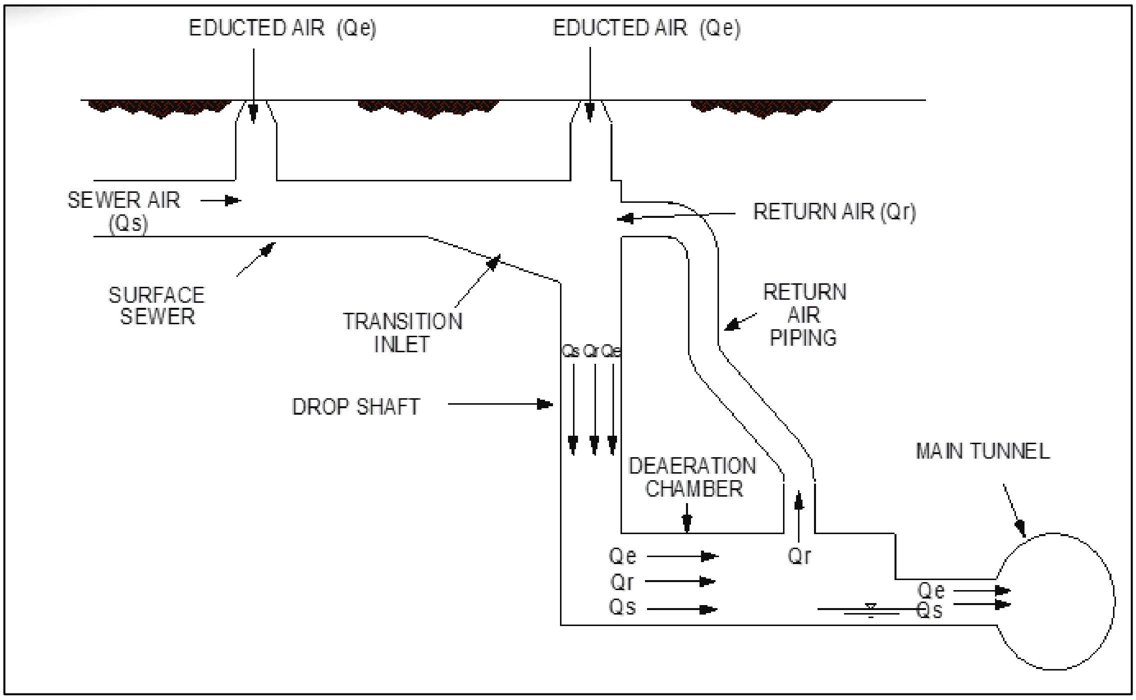


Figure 6-4 Typical Vortex Dropper with Air Return

The volume of air educted for a vortex dropper is proportional to the area of falling water and the diameter of the drop shaft. To estimate the air flow through a vortex dropper, air velocity contours are used to develop empirical relationships for various configurations based on the depth and size of the structure. Deeper drops are affected more by the drop eduction and shallower drops are affected more by the sewer pressure.

7 Hydraulic Jumps and Surges

7.1 Introduction

This Section describes the impacts of hydraulic jumps and surges on air movement and release of H_2S in the sewer, along with design practices to avoid these.

7.2 Hydraulic Jump

A hydraulic jump is a jump or standing wave formed when the depth of flow of water changes from supercritical to subcritical state, as shown in Figure 7-1. A hydraulic jump is often caused by an impediment downstream, such as a weir, a bridge abutment, a dam, or simply channel friction. High velocity flow discharges into a zone of lower velocity, resulting in an abrupt rise in water depth where energy is dissipated as turbulence.

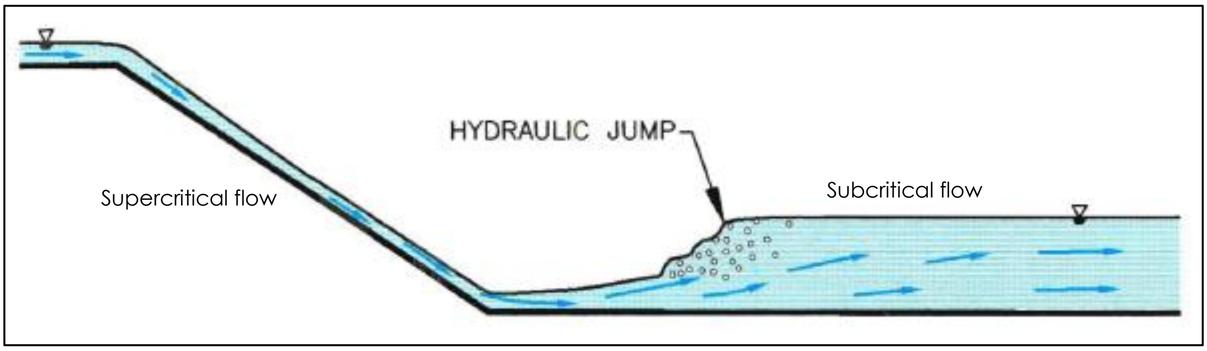


Figure 7-1 Hydraulic Jump

The impact of a hydraulic jump in terms of air movement and H_2S production in the sewer is shown in Figure 7-2. As can be seen, hydraulic jumps are not advantageous in terms of odour within the sewer, and pose the following risks:

- Potential sewer surcharging at the bottom of sewers with steep grade
- Turbulence that will release odorous gases
- Surging that will reduce or prevent air flow along the sewer, with potential to cause sewer pressurisation and odour release
- Increased water levels in nearby manholes that may impede flow from incoming sewers
- If the increased water level caused by a hydraulic surge drops quickly, negative pressure can be generated in the sewer, with enough suction to pull the water traps from connected properties, which can result in odour complaints

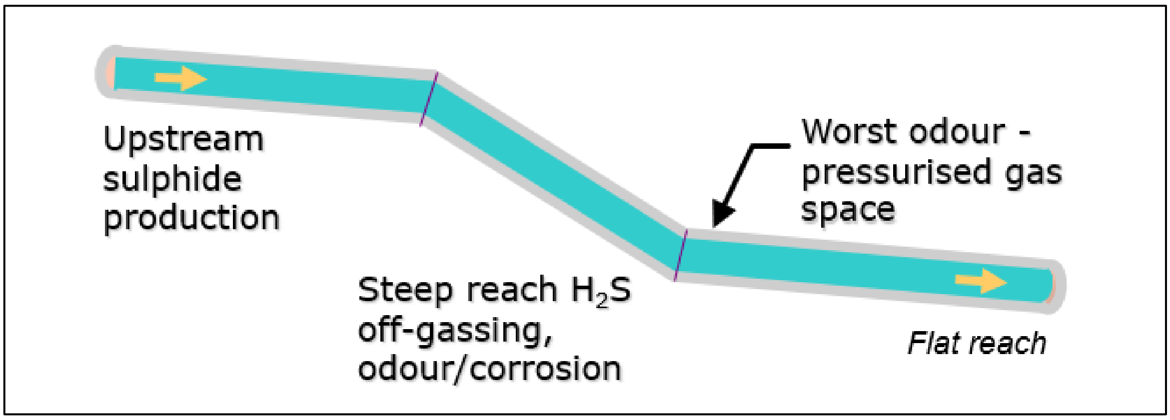


Figure 7-2 Air Flow Movement at Hydraulic Jump

There is an instance where the air movement generated by a hydraulic jump can be advantageous. Normally air moves downstream in the sewer in the direction of sewage flow.

If there is to be a hydraulic jump in the sewer, it should be located in the pipe downstream from a manhole. A major junction may be constructed within a vault or chamber entered by a manhole at its upstream end and designed so that air that has been exposed to the high turbulence of the junction will be carried downstream and not exhaled from the manhole (shown diagrammatically in Figure 7-3). As the sewage will contain sulphides, the junction structure will need to be protected by a lining, and the sewer pipe will need to be protected or constructed of non-corrodible material. The distance downstream that abnormal sulphide concentration will prevail will depend upon the turbulence of the air stream, its velocity and the sewer size. [11]

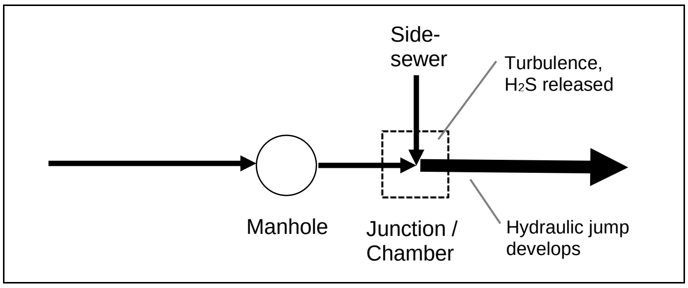


Figure 7-3 Sewer Design to Avoid Hydraulic Jumps

7.3 Hydraulic Surges

Hydraulic surges are created when the velocity of sewage suddenly changes and becomes unsteady or transient. Fluctuations in the velocity are generated by restrictions such as a pump starting/stopping, a valve opening/closing, or a reduction in line size. Hydraulic surges are different from hydraulic jumps although they can have similar impacts of restricting air movement and air pressurisation. Hydraulic jumps are the result of sewer velocity drop or restriction downstream. Hydraulic surges are the result of a sudden increase in flow usually caused by a pump starting, causing the water level in the receiving sewer to suddenly rises.

These surges commonly occur downstream of rising main discharges when pumps start. The sudden surge in sewage flow restricts air flow in the sewer, causing pressurisation which generates turbulence releasing H_2S into the sewer headspace. The restricted headspace then causes odour release from the sewer, often at uncontrolled locations and with significant air flow, causing odour complaints in the network. The surges can also cause water seals to blow out or be sucked out, resulting in odour complaints at connected properties.

Figure 7-4 below shows smoke testing of the impacts of a hydraulic surge in a sewer upon operation of upstream pumps during morning peak flow. It can be seen that there is a significant volume of air being released close to ground level.

Figure 7-4 Uncontrolled Air Release Caused by Hydraulic Surge

7.4 Design Standards

In terms of odour generation, hydraulic jumps and surges are best avoided. The following design standards should be followed:

- Incorporate a transition to a flatter grade in sewers to absorb some of the momentum slowly and reduce the surge in water levels resulting from grade changes. This could also include using a larger pipe downstream. The design objective is to reduce the water level rise so that the restriction of air movement in the sewer headspace is minimal. Some suggested standards are minimising the pressure differential between the upstream and downstream ends of the pipe (e.g. to less than 5 Pa), or ensuring that at least 30% of the sewer pipe is open for air movement.
- Avoid flows from branch sewers dropping into trunk sewers [4]; instead aim to have branch sewers enter the trunk pipe below the lowest level of the sewage surface in the trunk sewer, with the incoming branch sewer facing the downstream direction [12] rather than entering the trunk at 90 degrees. See Figure 6-2, Figure 7-5 and Figure 7-7 for examples of this.
- If a branch sewer joins a trunk with a significant difference in invert levels, consider having the branch sewer end in a manhole which drains into the trunk. This will provide an even transfer of the flow the trunk. Elements of this are illustrated in Figure 7-6, where flow from a branch sewer drops into side chamber which then drains into the trunk sewer at the trunk invert level.

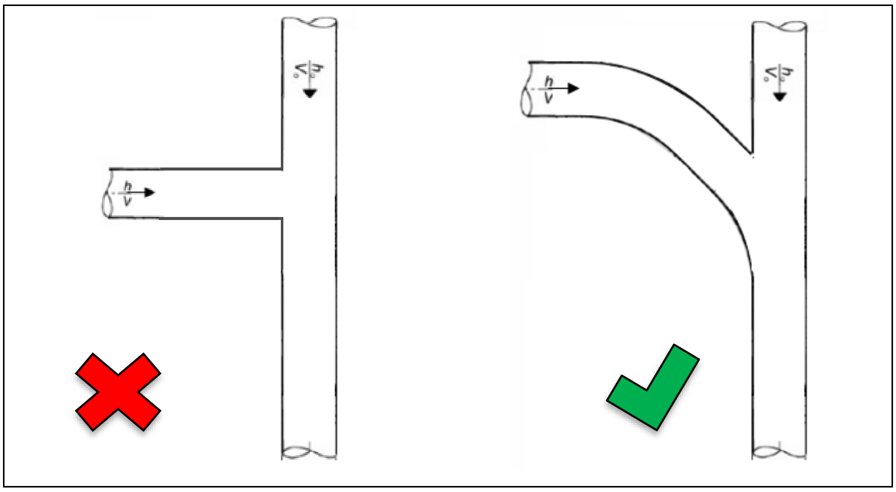


Figure 7-5 Streamlining branch sewer connections on trunk mains

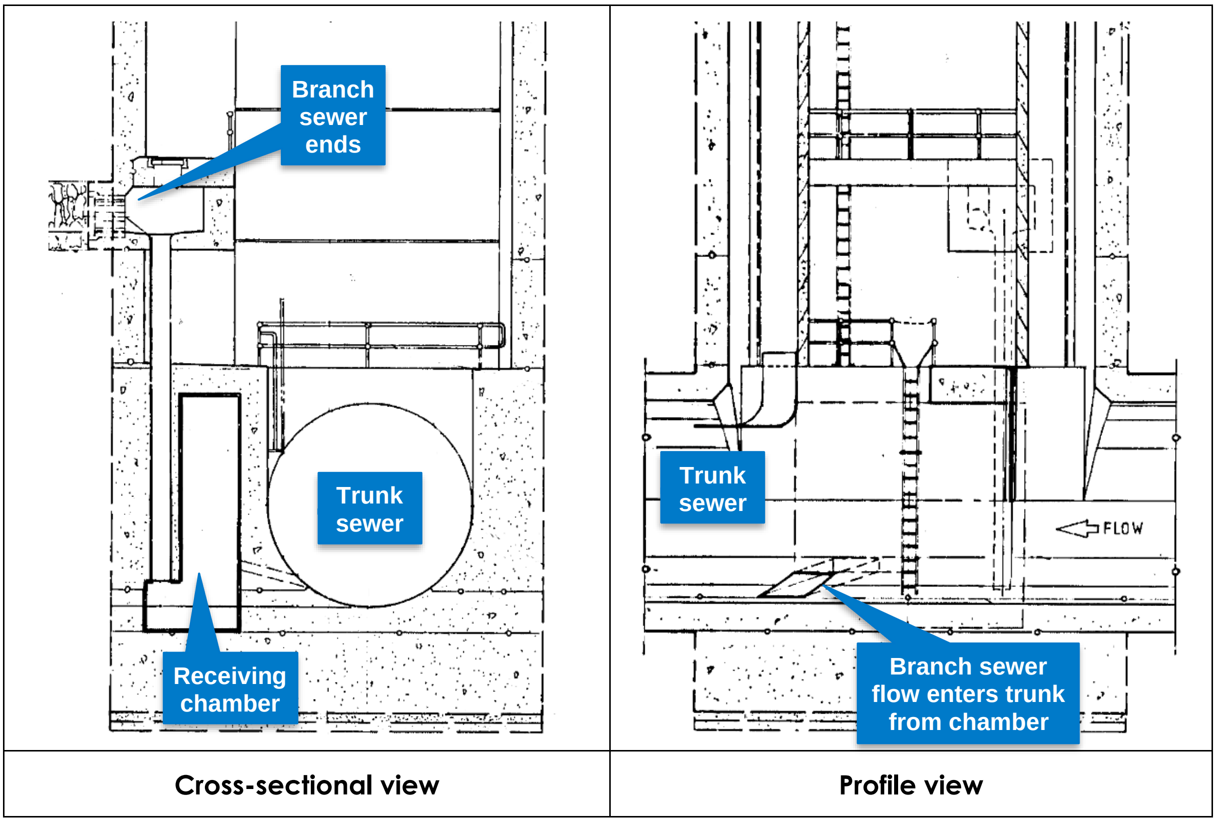


Figure 7-6 Side chamber for merging flow from branch sewer

- Avoid abrupt changes in grade between upstream and downstream sewer lines.
- Avoid large differences in velocity between two or more upstream sewer lines entering the same manhole.
- Make sure the downstream receiving sewer is sized to ensure an air-gap as follows:
  - For gravity sewers > DN 300, design for 30% of headspace availability during PDWF.
  - For gravity sewers < DN 300, design for 20% of headspace availability during PDWF.

  This is particularly important near rising main release points.
- Avoid acute angles between upstream and downstream lines.
- Avoid large changes in upstream flow, particularly when there is more than one stream that could have significant variation. This can be achieved by minimising intermittent

pumping using VSDs on SPSs, and networking SPSs through SCADA so that multiple SPSs do not run as the same time.

- Energy loss through transitions should be minimised by streamlining junctions, as illustrated in Figure 7-7, by meeting the following conditions:
  - The angle of convergence of the channels within the junction zone (Θ_1 and Θ_2) is as small as possible.
  - The channels are constructed so that the lateral momentum ($Q_1V_1 \sin\Theta_1$ and $Q_2V_2 \sin\Theta_2$) of each of the incoming lines is reduced by the channel geometry before convergence of the two streams.
  - Velocity changes at the junction should occur gradually.

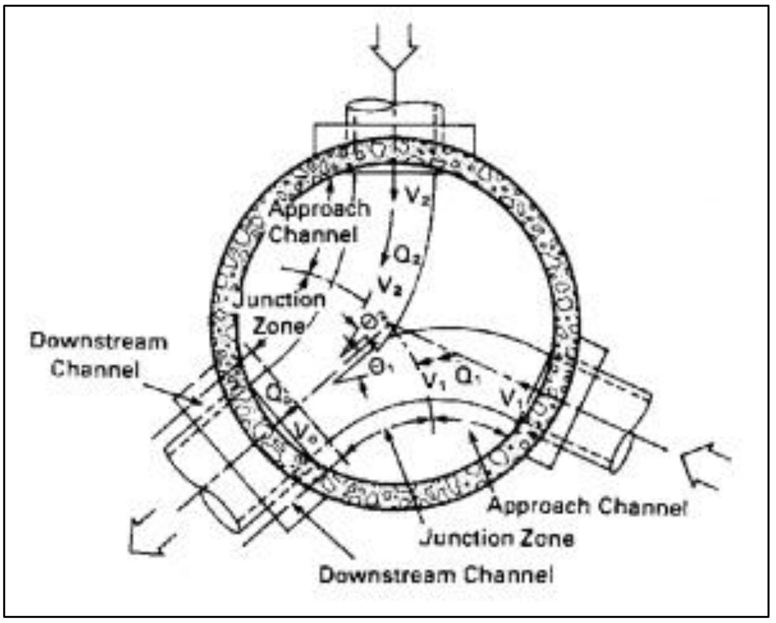


Figure 7-7 Streamlined Junction [4]

The Water Services Association of Australia (WSAA) Sewerage Code of Australia WSA 02—2002-2.2 Sydney Water Edition Version 4 states that where hydraulic jumps exist, adequate educt / induct ventilation should be provided on either side of the possible hydraulic jump, and design should aim to avoid jumps from occurring in manholes by providing horizontal and/or vertical curves in the sewer at changes of grade and/or direction. The curve should be located at sufficient distance from the manhole such that the jump will not occur in the manhole, and the radius of curvature should not be less than approximately 8x the pipe diameter.

This curving of the sewer is not to be confused with a jump up structure, which may also address hydraulic jumps in some cases. For clarity, an example of an issue with a hydraulic jump occurring in a manhole being solved by curving the sewer in the vertical and by using a jump up structure is shown in Figure 7-8.

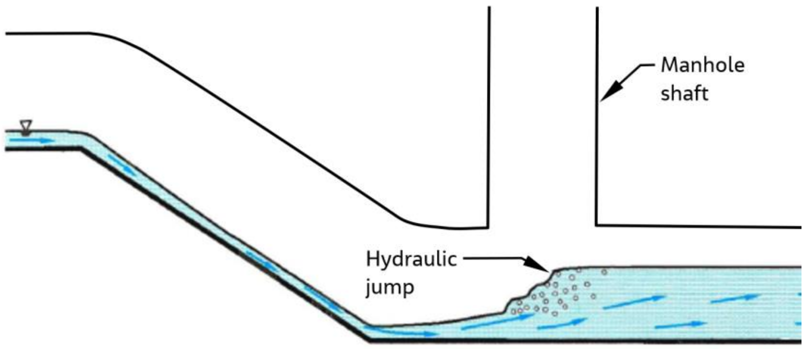
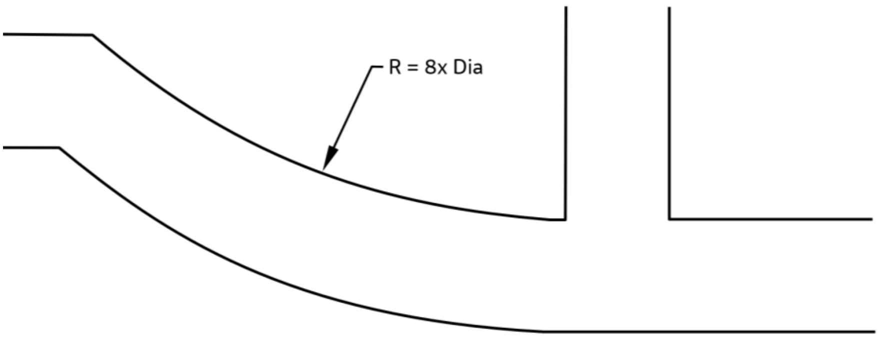
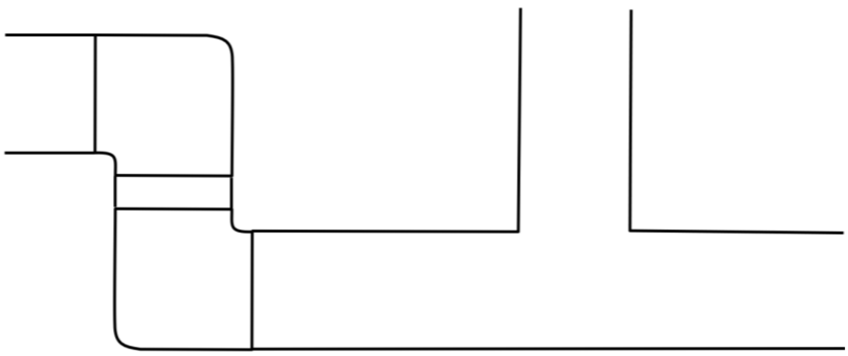
Problem: Hydraulic jump in manhole	
Solution 1: Curve the sewer	
Solution 2: Jump up structure	

Figure 7-8 Potential Solutions to a Hydraulic Jump in a Manhole

8 Velocities, Gradient and Turbulence in Rising Mains and Gravity Sewers

8.1 Introduction

This Section outlines the following:

- The impacts of sewer velocities for scouring and reaeration of sewage
- Recommended sewage velocities and gradient to minimise sulphide generation
- Impact of sewage velocities for stripping and release of H_2S, and when this should be avoided/minimised

8.2 Impacts of Sewer Velocities for Scouring and for Reaeration of Sewage

The effects of velocity on sulphide build-up are complex. At low velocity, solids may settle and move slowly and intermittently along the bottom. The loosely deposited solids quickly become depleted of oxygen, and sulphide generation proceeds until the depletion of sulphate or organic nutrients. If the solids are then disturbed by the motion of the water, sulphide is released into the stream. Higher velocities prevent this from happening, and increase oxygen absorption into the stream, increase the rate of oxygen transfer to the slime layer, and shorten HRT, all of which lead to lower sulphide concentrations.

In sewer network systems, H_2S transfer to the gas phase mainly occurs in drops, at rising main discharges and in turbulent gravity pipes. The sewage flow principally depends on the mass flow, the sewer slope and geometry and the frictional resistance. Each parameter may vary with space and time. The mass flow is directly linked to the pumping time and the pumping capacity. It fluctuates and may turn the flow regime into subcritical or supercritical. The pipe slope can change locally due to local topography, and the frictional resistance varies according to concrete degradation. In gravity sewers, high slope (>1%) and high velocity conditions enhance the transfer process. [10]

Adopting higher velocities to increase the reaeration rate, although very effective, requires steeper slopes, which usually result in additional costs, in terms of additional construction costs (increased excavation and number of SPS) and additional power costs for pumping. These increased costs must be compared with the benefits resulting from a significant reduction in the contribution of sulphides to the sewage or the reaeration requirements of the sewage to prevent sulphide build-up.

8.3 Recommended Sewage Velocities and Gradients to Minimise Sulphide Generation

Consideration of sulphide generation and corrosion is critical in the design of wastewater collection systems. The most cost-effective and rational engineering approach is to develop a hydraulic design that minimises sulphide generation and maintains aerobic conditions in the wastewater. Pipe sizes and slope should be selected to provide sufficient velocities to maintain aerobic conditions, prevent solids deposition, provide adequate cleansing, and prevent sulphide problems and odour generation. Slope is the key criterion in designing a wastewater collection system to avoid sulphide problems. Sewers designed with long runs at minimum slope are prone to sulphide generation due to long residence times, poor oxygen transfer, and deposition of solids. Sulphide generation can be a serious problem in new sewers, where actual flows are much less than design flows during the early lifetime of the system, and velocities are inadequate to maintain solids in suspension. Steeper slopes increase turbulence and oxygen transfer, thus maintaining aerobic conditions in the wastewater and preventing significant sulphide generation. [4]

The use of rising mains, inverted siphons, and surcharged sewers should be minimised as these promote anaerobic conditions and thus sulphide generation. [9]

8.3.1 Gravity Sewers

Gravity sewer design needs to consider the following:

- Self-cleansing velocity – pipes should be sized to achieve self-cleansing velocities as least once a day [1]
- Slime control velocity – in sewers with a diameter of 300mm and above, self-cleansing velocities may not be sufficient to prevent build-up of slime and therefore higher velocities are required for slime control. Refer to Figure 8-2 for recommended velocities for different sewer sizes.
- Optimise grades in branch and trunk sewers to minimise turbulence and H_2S release when dissolved sulphide levels are elevated and the location includes sensitive receptors. This is a balancing act to achieve adequate reaeration and scour velocities while minimising sulphide release and should be assessed on a case by case basis. If sulphides are low, then turbulence is less of an issue. Minimum scour velocities should also be achieved at least once a day to prevent solids deposition.

In reticulation sewers, entry of wastewater from connections is likely to maintain quite high DO levels. In addition, small sewers are generally constructed of uPVC or vitrified clay and are not subject to corrosion due to H_2S generation. Therefore, sewers less than 300 mm in diameter are therefore commonly not designed for slime control. [3]

Adoption of a slope commensurate with slime control usually allows selection of a smaller diameter pipe. Whether slime control slopes are warranted will depend on several factors including:

- The ratio of average dry and peak wet weather flows
- Natural surface slopes
- Age and composition of sewage
- Availability of other methods for increasing the level of DO in the sewage. [3]

Absolute minimum grades recommended by WSA Sewerage Code of Australia WSA 02—2002-2.2 Sydney Water Edition Version 4 for achieving self-cleansing are shown in Table 8-1. The larger the sewer, the greater the overall velocity required to achieve the same self-cleansing effect. [3]

Table 8-1 Absolute Minimum Grades Recommended for Self-Cleansing [1]

Pipe Sizes (DN)	Absolute Minimum Grade (%)
Reticulation	
150	0.59
225	0.37
300	0.27
Branch and trunk	
375	0.19
450	0.15
525	0.13
600	0.11
750	0.09

Table 8-2 below shows the recommended sewer velocities for design of gravity sewers. Figure 8-1 and Figure 8-2 are referred to in the table and respectively show the critical sewer slopes and minimum sewer velocities for slime control.

Table 8-2 Recommended Gravity Sewer Design Methods

Criteria	Recommended Velocity (m/s)	Notes	Source
Minimum velocity during average flow conditions	>0.6 [1,2]	• Prevent deposition of solids • Maintain a self-cleaning action in sewers	[4, 5]
Desirable velocity	>0.9	• Where practical	[4]
PWWF velocity	>1.1	• Avoid sulphide problems • Provide adequate cleansing velocity • Prevent sulphide and odour generation	[6]
For trunk and branch sewers, wetted cross section average velocity at PDWF	0.7	• To achieve self-cleansing of grit and debris	[1]
Maximum velocity in branch and trunk sewers when sewer flowing full	<3	• To minimise turbulence and H_2S generation	[1, 5]
Maximum velocity where practicable in reticulation sewers when sewer is flowing half full	<3	• Desirable to minimise turbulence and H_2S generation	[1]
Minimum flow velocity in an inverted siphon	>0.75 (at ADWF) >1.0 (at design flow)	• To ensure flow is capable of transporting solids against gravity	[1]
Critical sewer slopes for slime control		See Figure 8-1 below	[3]
Minimum sewer velocities for slime control		See Figure 8-2 below	[3]
Critical average wall shear stress of 3.35 Pa (see explanation below)		For slime control	[3]
Construct two pipelines instead of one. A flushing system which can add enough flow to achieve the scouring velocities		• Where practical to accommodate future and or peak flows • Prevent deposition of solids • Maintain a self-cleaning action in sewers	[7]

Notes:

1. The recommended scouring velocity of 0.6 m/s for pipes flowing one-half full at design flow can result in velocities as low as 0.2 m/s during low flow periods early in the design lifetime of the system, thus allowing deposition of sewage solids. While this is undesirable, it cannot be economically avoided in certain instances. Sulphide generated from accumulated solids is generally much less critical than that generated from the slime layer, especially when the accumulated solids are flushed from the system on a daily basis. [4]
2. Sewers shall be designed and constructed with such slopes to give a mean velocity of not less than 0.6 m/s during average flow conditions with due consideration given to actual depth of sewage flowing in the pipe. Slopes slightly less than those required for 0.6 m/s may be considered if the depth of flow will be 0.3 of the diameter or greater for design average flow and provisions can be made for frequent cleaning. Sewers larger than the minimum size required shall be chosen so that the maximum velocity at the peak design flow is not greater than 3.0 m/s to minimise turbulence and pipe wear, especially where high grit loads are expected. If higher velocities are unavoidable, special precautions shall be taken to protect against displacement and pipe erosion. [5]

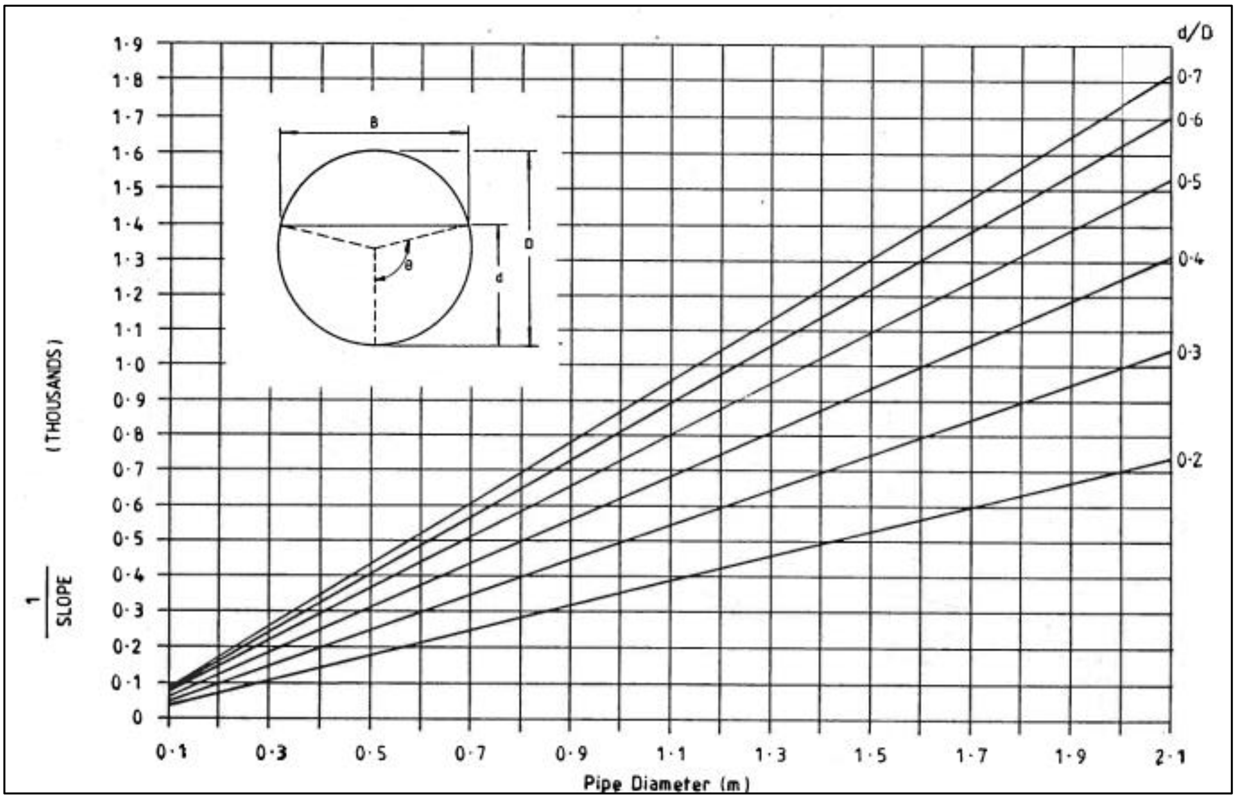


Figure 8-1 Critical Sewer Slopes for Slime Control [3]

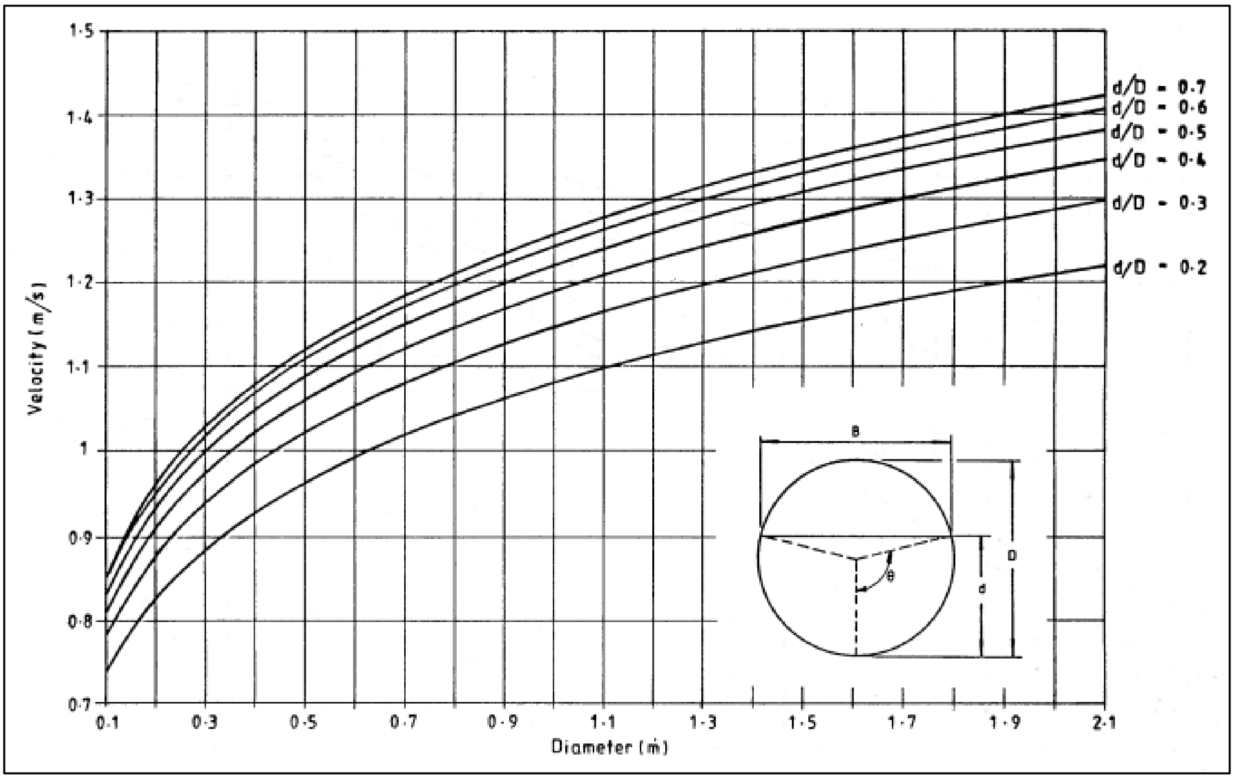


Figure 8-2 Minimum Sewer Velocities for Slime Control [3]

An alternative approach to design of gravity sewers based on gradient and velocity to achieve slime control is to maintain a minimum boundary shear stress to prevent suspended particles from settling out on the invert. [4] As indicated in Table 8-2, the recommended design criterion to adopt for slime control is a critical average wall shear stress of 3.35 Pa [3]. For sewers with Manning's n = 0.013 or less, a design boundary shear stress in the range of 0.1 5 to 0.20 kg/m^2 will likely keep self-cleaning sewer systems free from sulphide problems. For sewers with n = 0.015 or greater, a design shear stress of 0.2 kg/m^2 should be used. [4]

Under certain conditions, sulphide generation may be unavoidable. Sulphide build-up and rates of corrosion can be estimated using Figure 8-3 or using more sophisticated sulphide models that are available such as the WATS model developed by the University of Aalborg. Where sulphide generation is anticipated, corrosion resistant materials can be selected or the alkalinity and thickness of concrete pipe can be specified to help reduce the effects of hydrogen sulphide corrosion. [9]

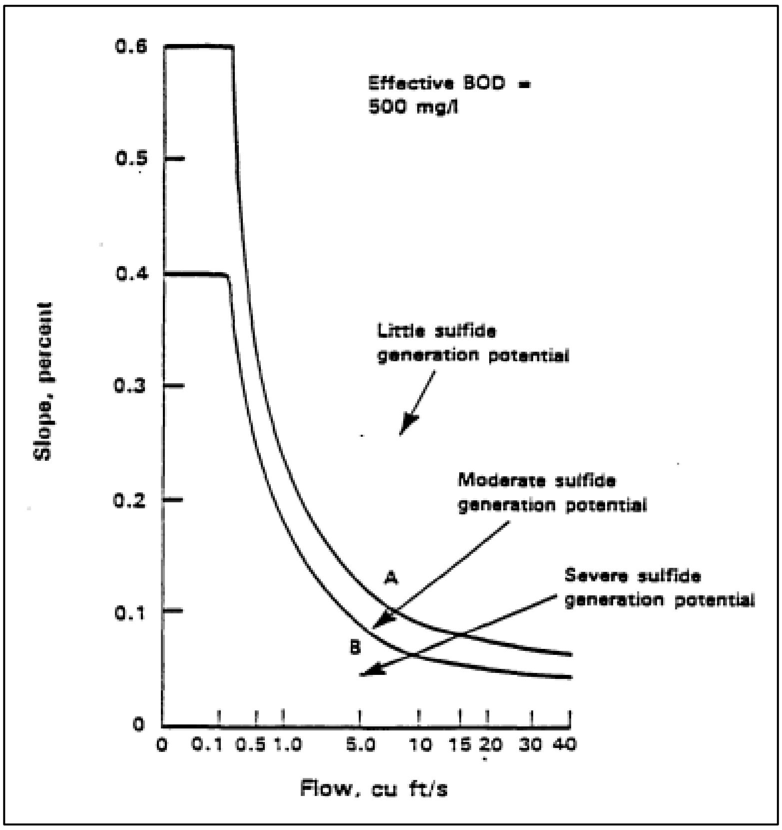


Figure 8-3 Guide for Estimate Sulphide Generation Potential [9]

8.3.2 Rising Mains

Unlike gravity sewers, rising mains flow full, so there is no opportunity for natural aeration to occur whilst the wastewater is in the main. Hence only the oxygen dissolved in the wastewater prior to its entry into the rising main is available for bacterial respiration and sulphide oxidation. Since sulphide generation within rising mains is due primarily to surface slime, larger rising main sizes reduce the sulphide generation potential for a given design flow and wastewater characteristics, since they result in a smaller surface-area to cross-sectional-area ratios. [5]

Recommended design considerations for rising mains include:

- Pumps and rising main systems must be designed to provide a minimum velocity of 0.7 m/s [2] in the downstream gravity sewer when pumping.
- For rising mains of diameter less than DN 300, a minimum velocity of 0.9 m/s is recommended for satisfactory transport of solids through the rising main, though the preferred minimum is 1.5 m/s [2].
- Pumps and rising main systems must be designed to meet the minimum velocities for slime control shown in Figure 8-4.
- Scouring velocity must be maintained at a minimum of 1.1 m/s in rising mains. [7]

- If designing a rising main for a new development and the resulting detention time is significant, consider the following [2]:
  - o Design the RM to serve only the first stage of the development, or
  - o Design for two (or more) RMs, with the first intended to serve the initial stage of development, and the second RM (and additional RMs) to serve the main stage (or later stages) of the development.
- Chemical dosing systems may be required for rising mains with a detention time of greater than 3 hours at ultimate ADWF if the discharge is in a sensitive area. Detention time is determined by dividing the internal volume of the pipe in m^3 (cross-sectional area times length) by the flow in m^3/hr. Figure 8-5 shows the detention time for different flows and pipes sizes, per 100 m of pipe.
- Standard design to be adopted for scenario's whereby odour risks exist with air valves associated with rising mains. The standard design is depicted in SAW drawing 2018-00450-19 showing the air valves venting through a 200L carbon canister.

Note that decisions around the detention time do not necessarily have to be based on its average. Take for example an SPS that has relatively short detention times during the day, but a long detention time overnight. It is up to the designers and operators to determine if that is a problem based on whether sensitive receptors are located near the wet well and rising main discharge, what time the sewage is pumped out (e.g. during peak hour when people leave for work), and what the configuration of the discharge is (e.g. non-treated vent or active OCU). A chemical dosing system can be installed and programmed to treat either all of the flow, or only problematic periods of the day when the incoming flow reduces.

If the criteria listed above are not met, and if the rising main discharge is in a sensitive area and causing problems, remedial measures may need to be considered in consultation with SA Water. [7] Forced ventilation is one remedial measure as it is used to contain odours and prevent fugitive emissions[3]. However, ventilation is not very effective in preventing corrosion; it reduces the H_2S concentration, but the H_2S flux and so corrosion rate will be similar.

In terms of managing existing SPSs:

- There is no requirement on how often to run the pumps or what frequency per day. Varying the pump run times just changes how long the wastewater spends in the wet well or the RM, but does not change the overall detention time.
- To manage non-pumping times, there are installations that recirculate water in the wet well, injecting oxygen into the flow before returning it to the wet well, however this can be expensive. Well washers however are relatively cheaper in not using oxygen injection equipment but instead aerating the sewage by cycling it up in the wet well and dropping it back to the bottom via a spray (the well washer).
- Some SPSs have in-well mixers to keep the sewage turning over and reduce the chance of septicity. As for well washers, the basic approach is to keep moving the sewage during non-pumping times.
- One action that can benefit the downstream sewer is to change the pump run time (if the pump flow can be varied), reducing it to the minimum to prevent wet well flooding will reduce turbulence at the rising main discharge end.
- Keep in mind that despite actions taken in the wet well, once wastewater is in a rising main, it will go septic unless chemicals (or oxygen) are added.

It is possible that older parts of the network do not meet the criteria listed in this section. When an area of the network is due for renewal would be an ideal time to see if more can be done to align with the recommendations presented here. The same applies for when odour complaints are received from a particular area – the design of the sewer should be reviewed

[3] The WSA Code [2] mentions putting an induct and educt on the receiving manhole; where odour issues occur with these in place, forced ventilation might be considered.

and consideration given to implementing any recommendations that are not currently part of the sewer design, in case this can resolve the odour issue.

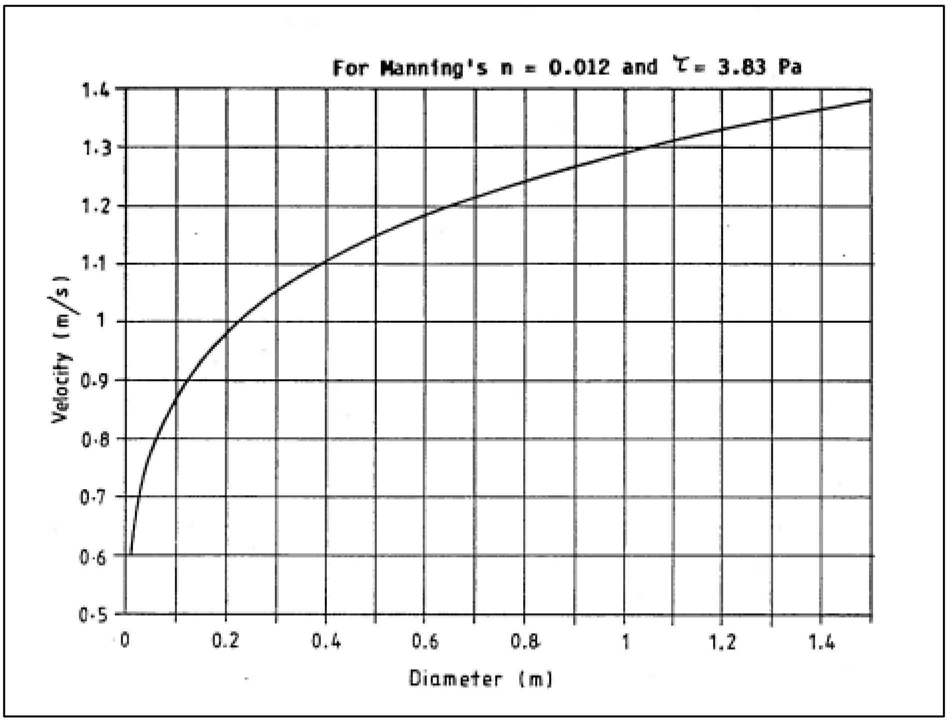


Figure 8-4 Minimum Velocities for Slime Control in Rising Mains [3]

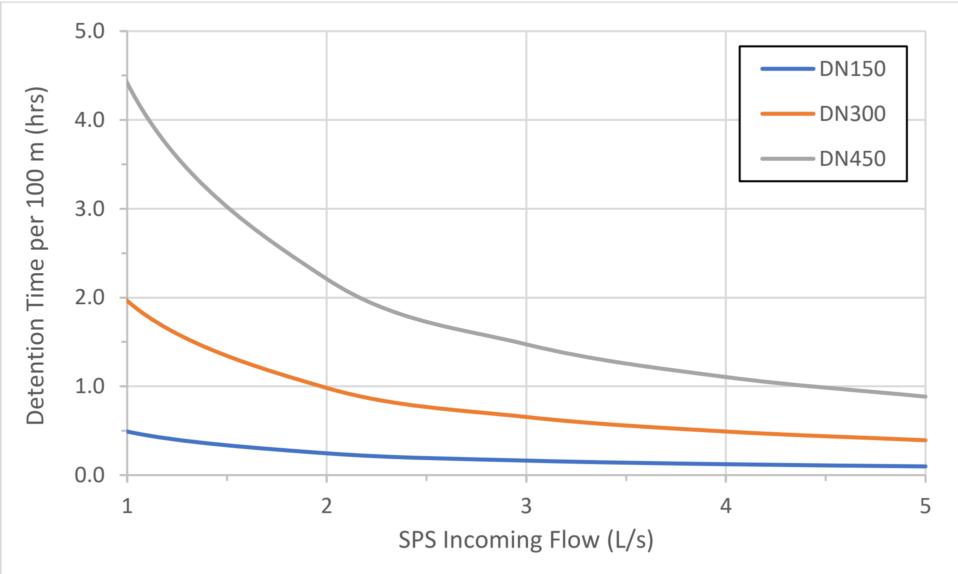


Figure 8-5 Detention Time per 100 m of Rising Main

8.4 Impact of Sewage Velocities for Slime Stripping and Release of H_2S

The overall thickness of wall slimes has been shown to be a function of the shear stress on the pipe wall which is related to the pipe slope and depth of flow. These factors also influence wastewater velocity. Thus, wastewater velocity and thickness of wall slimes can be related. The rate of sulphide production however remains substantially unaffected by varying velocities until a critical shear stress is reached, above which significant slime growth is prevented. Wastewater velocity can be increased to the point where the slimes are sheared from the pipe wall. This is a very effective method of sulphide control when it is possible to obtain the necessary slope. [3] Section 8.3.1 above outlines design requirements for achieving critical shear stress in gravity sewer design and Section 8.3.2 outlines design requirements for achieving critical shear stress in rising main design.

Although steeper slopes increase turbulence and oxygen transfer, thus maintaining aerobic conditions in the wastewater and preventing significant sulphide generation they can also promote sulphide release. Achieving scour and shear velocities to prevent sulphide generation, if possible, should be the first priority in sewer design. Risk of sulphide release in sensitive areas should then be evaluated on a case by case basis in areas such as rising main discharge locations or other areas where sulphide levels will be high. The priority for these areas should be to try and keep the sulphide in the liquid phase by reducing turbulence and maintaining adequate sewer head space to allow air flow with minimal restriction and then some form of control if required. The recommended approach is prevention, mitigation and then control to prevent corrosion and odour problems.

9 Rising Main Discharge Manhole Design Considerations

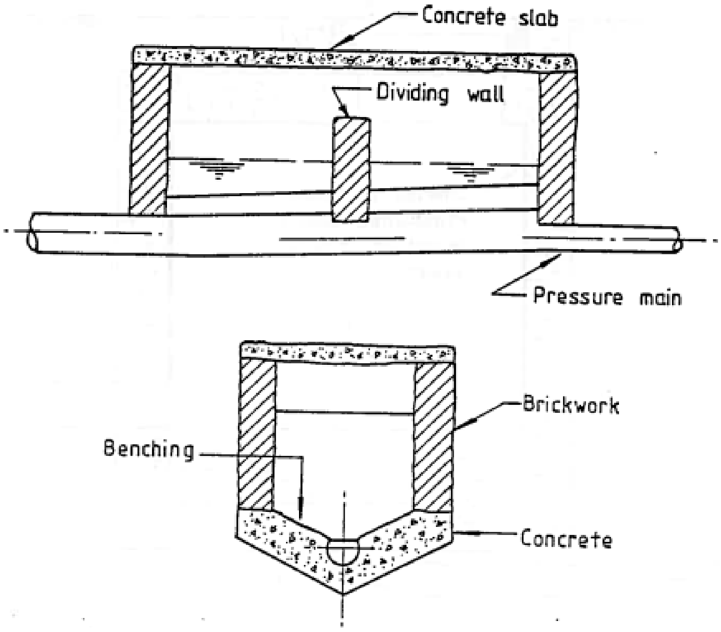
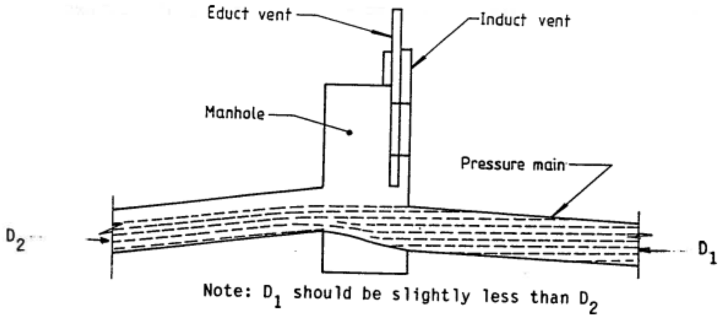
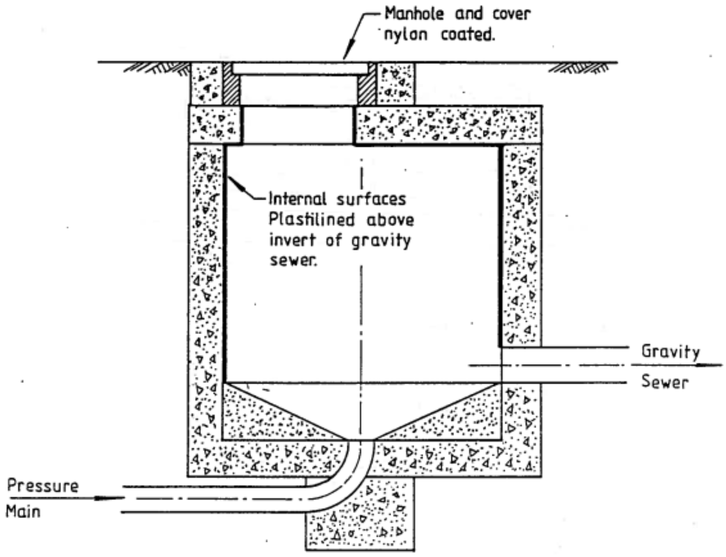
Rising mains can generate a significant amount of sulphide which can cause substantial H_2S release at the rising main discharge manhole. This is especially so during the morning diurnal flush, when the wastewater has been sitting in the pump station and rising mains for longer overnight periods, and during the afternoon flow peak when turbulence becomes a significant factor for H_2S release.

The following design standards are recommended to decrease turbulence and reduce the risks of surcharging rising main discharge manholes:

- The rising main should connect to the receiving manhole to minimise turbulence. This includes ensuring that the last 5 metres (or 10 times the RM diameter; whichever is greater) of the rising main having a straight alignment with the gravity pipe, and aligning the invert of the rising main with the invert of the gravity sewer pipe for a smooth transfer of flow. [2]
- Rising mains entering a gravity sewer should enter as close to the flow line of the receiving manhole or at a point not more than 600 mm above the flow line of the receiving manhole [5], and discharge should face downstream. Internal or external drop pipes similar to Figure 6-2 or those used in wet wells can be considered to achieve this.
- Discharge manholes should be constructed from corrosion resistant material, lined or epoxy coated to minimise corrosion risk
- Discharge manhole and downstream sewer must be adequately sized to accommodate rising main discharge and the flow from any gravity area
- Ensure that the discharge manhole and receiving pipe are adequately sized to avoid surcharging when pumps starts
- Rising main discharge manholes would normally have educt vents to depressurise a hydraulic surge during pump run times. For new sewers in sensitive locations the manhole should be well-sealed to avoid fugitive emissions, but the receiving sewer should be designed to mitigate the hydraulic surge so that the air can move downstream. If this is not possible, controls may be required to treat the air that needs to be released and green domes may be considered for this.
- Consider the need for additional ventilation or collection and treatment of the odorous air, based on the odour risk posed by the release
- Refer to SA Water Technical Guideline TG 0531 - Gravity Network Ventilation Design for guidance on when to install vents such as educts and green domes on rising main discharges.

Three examples of discharge streamlined arrangements minimising H_2S liberation are shown in Table 9-1. [3]

Table 9-1 Rising Main Discharge Promoting Non-turbulent Conditions [3]

Type	Description	Figure
A	A dividing wall is arranged so that it does not quite reach the top of the chamber and partially obstructs the channel. When the pressure main discharges, the wastewater initially builds up behind the dividing wall due to the restriction. A stage is reached where the build-up produces an equilibrium between inflow and outflow and the level ceases to rise. The wastewater flow into the chamber is less turbulent because the discharge is submerged and the flow under the wall is streamlined. This type of discharge arrangement also requires minimal maintenance to keep the structure clean.	
B	The most common streamlined form of discharge with operational experience proving them to be the least troublesome. However, this type can be subject to problems particularly where discharge velocities are high, resulting in wastewater being jetted across the structure creating considerable turbulence. One method of overcoming this problem is to use a larger diameter pipe for the section of pressure main immediately adjacent to the structure.	
C	The standard configuration used in Brisbane. Similar to Type C, this type can be subject to problems particularly where discharge velocities are high, resulting in wastewater being jetted across the structure creating considerable turbulence. One method of overcoming this problem is to use a larger diameter pipe for the section of pressure main immediately adjacent to the structure.	

10 Sewage Pump Station Wet Well/Control Manhole Incoming Sewer Discharge Arrangement

The design of SPSs is a critical element of sewer networks. Ideally, SPSs should be designed so as not to increase the total sulphide generation potential of the network. This is often difficult, however, since design practice for SPSs can require some wet well storage of wastewater plus retention in the rising main. When supplementary aeration is not provided, both of the above conditions will tend to increase the potential for sulphide generation by increasing the HRT in the system, and by increasing the contact time of the wastewater with sulphide-generating slimes within the rising main and the wet well surfaces. Potential also exists for sulphide generation from solids deposition in the wet well if the wet well design does not contain adequate bottom slopes and suction piping arrangements for their continuous removal. [4]

Pumping station wet wells shall be designed based on the following objectives:

- Eliminate or minimise the deposition and accumulation of solids and scum to minimise maintenance and reduce septicity, odours, corrosion, and release of hazardous gases. [6]
- In addition to design, management practices can also assist. SA Water has a daily automated pump down operation as standard practice to clear depositing material.
- Minimise the potential for vortexing, swirling, and excessive turbulence from incoming flow to control manhole and SPS wet well that can result in submerged and free surface vortices, entrainment of air, formation of rag balls, and pump reliability problems. [6]
- Minimise drop where incoming sewer enters SPS with respect to bottom water level (BWL). Where this cannot be achieved, design shall include an inlet drop pipe to BWL to minimise turbulence in the SPS, thus decreasing odour emissions.
- Avoid frequent starting of pumps [6], i.e. ideally less than 6 starts per hour. This includes considering how the size to the wet well will impact the frequency the pumps run for the projected flow, and seeking to minimise the number of starts as much as possible. Variable drives also decrease start times by allowing the pump to run longer at a slower rate and so less intensity. Wet wells should be as small as possible to minimise the wet well detention time and the potential for sulphide generation. [4] The consensus from several sources in literature is that detentions times should be:
    - Less than 30 minutes in sensitive areas [4, 5, 13, 6]; and
    - Less than 2 hrs [4] for less sensitive areas (i.e. nearest residents are distant to the SPS) or where shorter times are impractical.
- Avoid storage or backup of wastewater into influent lines:
    - Constant-speed pump stations should be operated with start-stop cycles that are short enough to avoid backup of wastewater into influent lines [4]
    - To prevent short-cycling of pumps, consider multiple pumps or multiple-speed pumps to reduce the incremental change in the pumping rate and therefore the required volume. [13]
    - If it is not possible to avoid using the storage in the incoming sewers, ensure that adequate velocities are maintained in the sewers [13] (refer to Section 8.3.1 for velocities, particularly those related to sewer scouring)
- Set the lowest liquid level in the well above the sloping portion of the wet well. This can be accomplished by making this level the stop point for the lead pump in the sequence. [13]
- Wet well interiors should be coated with an approved H_2S resistant coating

- A vent line shall be provided from the control manhole to the SPS educt vent shaft [2]. While design of the line may vary from case to case, some general standards are:
  - A nominal diameter of 300 mm
  - Keep the line above the highwater mark so that it does not become a passage for wastewater in a surge event
  - If the distance from the control manhole to the SPS educt is long, consider a dedicated educt for the control manhole
- In order to minimise accumulation of odorous air inside the wet well, there should be a fresh air induct on the wet well and an educt that preferentially releases air when required. While an induct should not become a source of odour release when there is an educt connected to the same air space, if for any reason an induct becomes problematic, a non-return damper can be added to it.
- Should odour control be required at a SPS, consideration shall be given to extraction of air for treatment from the control manhole, including potentially the incoming sewer and other areas of the SPS where there is common headspace in addition to the wet well. It may be possible to extract air from one extraction point, or multiple extraction points may be required. Design of extraction systems shall be undertaken on a case by case basis.
  - Note: The incoming gravity sewers can benefit becoming an air inlet to the wet well.
  - If an induct is added to the wet well, then its opening will have to be considered to maximise ventilation of the incoming sewer and avoid short-circuiting through the induct. Consideration can be given to the induct being from the control manhole if there is an air path to the wet well.
- Guidance for sizing of odour control equipment at SPS is contained in the *SA Water Technical Guideline TG 0531- Gravity Network Ventilation Design*.

11 Seals

11.1 Wet Well and Manhole Covers

A common problem with wet well and manhole covers and frames is the entry of surface water and escape of odours through holes in the lid, through spaces around the lid between the frame and the cover, and under the frame if it is poorly sealed. Seals on manholes are quite often damaged by road work and heavy traffic.

EPDM or silicone rubber seals shall be installed on all wet well and manhole covers to minimise fugitive emissions. Where possible, the seals shall be attached to the covers to avoid them falling into the sewer when covers are opened. Care should be taken when removing and reinstating covers to ensure that the seals sit flat and a continuous seal is achieved around cover edges.

11.2 Water Seals

Water seals are vital for preventing the flow of sewer gas into customers' homes. Water seals are found in the home in toilets and under sinks. Usually these seals are sufficient when the home is directly connected to the sewer reticulation system.

When the nearest sewer available for connection is a trunk sewer, more planning must be undertaken. Direct connection to a trunk can impact customers with water seals being blown or sucked out either due forced ventilation systems attached to the truck sewer or the pulsing of air resulting from large changes in sewage flow in the trunk. Once water in seals are lost in a customer's home, sewer gas can enter unhindered.

To mitigate against the risk of these problems, SA Water does not have direct customer connections on trunk sewers with a diameter of greater than 500mm. Instead, several homes in a street are connected to a reticulation (shallow) sewer which then connects to a (deeper) trunk sewer with a water seal in between. This single water seal provides the barrier to the above problems for all homes upstream. This configuration is illustrated in Figure 11-1.

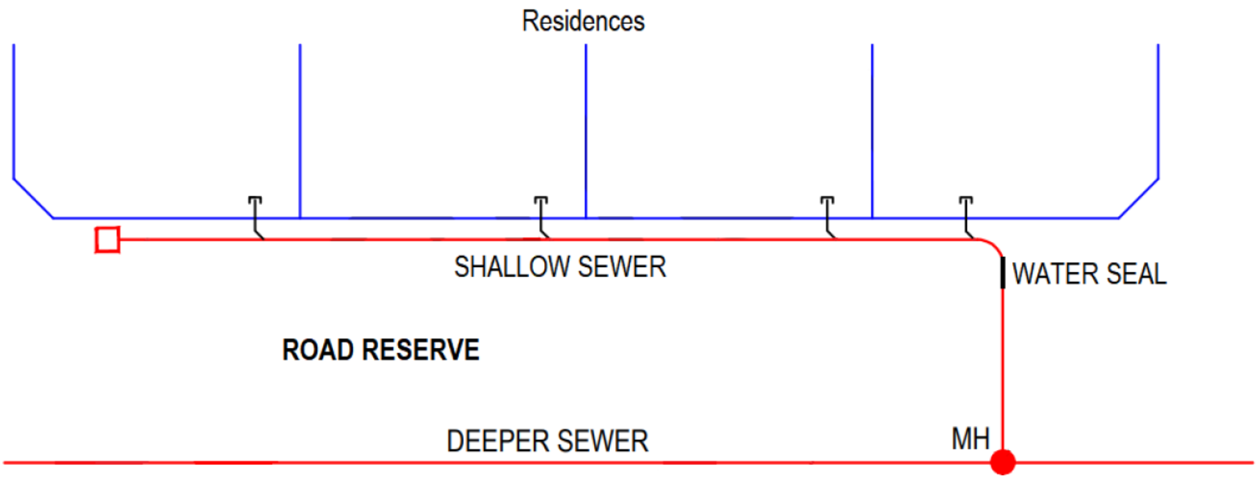


Figure 11-1 Connection of residences to a trunk sewer via reticulation sewer with water seal

12 Design of Wet Well Inducts and Educts

The intermittent discharge of odorous air caused by rapid changes in the sewage level can be problematic. The sewage level changes most impacted are those occurring in the wet well of the receiving SPS and those that occur in and just downstream of a vented rising main discharge manhole. As sewage levels rise, air must be expelled from the sewer at the same rate to avoid pressurisation of the headspace. Pressurisation should be avoided, primarily because it can cause odorous air to be forced out into the environment through any gaps or weak seals. The most severe form of pressurisation due to increasing sewage levels can be avoided if the air is able to flow back up the sewer while the sewer obvert is unsubmerged or through a high level connection installed to allow air to be directed into the sewer upstream.

Pressurisation can be avoided by the following:

- Installation of inducts and educts on wet wells
- Extraction of air through an SPS ventilation system
- Keeping the level in the wet well steady by matching the pumping rate to the rate of sewage inflow. [16]

Of the above, installation of inducts and educts on wet wells is preferable. As well as accommodating air displacement due to the rise and fall of the water level in the wet well, these vents will prevent accumulation of foul air.

Design of vents should ensure:

- Inducts and educts are adequately spaced to avoid short-circuiting of fresh air from the induct to the educt.
- The educt vent should have a minimum diameter of one-half the diameter of the incoming sewer. The vent pipe can be connected to the nearest sewer maintenance hole where possible.
- Educts shall be sized to vent at a rate that is 25% greater than the maximum pumping rate,
- Minimum vent diameter is 100mm, and velocity should not exceed 3m/s through a vent pipe [14].
- Where the wet well is located away from any sensitive area, educt could be extended above the roof line with a minimum of 3 metres from any window or fresh air inlet at the SPS itself. [15]
- Inducts and educts are to be fitted with screening to prevent entry of birds and insects to the wet well.
  - While entry of rain into the wet well via the vents is not a major concern, as the volume of rain is minimal compared to the flow handled by the SPS, rain covers can be added to the vents if desired.
  - A typical rain cap over the induct would be fine, but these should be avoided for the educt as they cause a loss in flow. Instead, a collar type or "no-loss" rain guard as shown in Figure 12-1 is recommended (if a rain guard is desired at all).

Figure 12-1 Collar-type rain guard for a stack

13 Gravity Sewer Surcharging Conditions and Performance Criteria

When sewers become surcharged, there is no opportunity for reaeration, resulting in anaerobic conditions, generation of H_2S, and often severe corrosion and odour complaints in the vicinity. Surcharging sewers restrict air flow by limiting headspace for air movement, which can lead to the accumulation of H_2S and differential pressure levels. Any turbulence in the area drives sulphides from the liquid to the vapour phase and could result in odour issues. Once the surcharge clears, air can once again flow and H_2S levels drop.

Unlike the condition described above, shorter duration surcharged conditions caused by freshwater infiltration/inflow can have a positive impact on sewers. Freshwater infiltration surcharge conditions are often characterised by weaker sewage and colder temperatures that may result in reduced sulphide generation due to higher flow velocities, scouring of accumulated solids, and reduced biological activity. [4] These benefits of infiltration are not realised though for SA Water's networks, as infiltration often contains high salinity groundwater which is rich in sulphate and so encourages sulphide generation, odour and pipe corrosion. Infiltration in SA Water's network is flagged by high salinity in the wastewater.

Installation of surcharged sewers should be avoided whenever possible. Where required, design velocities should be selected to avoid solids deposition, and detention times should be minimised [3].

To avoid surcharging, the following design standards should be followed:

- Sewers should be sized to accommodate peak flow from upstream rising mains and gravity sewers
- Sudden changes in sewer grade should be avoided

14 References

No.	Reference
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3	*Hydrogen Sulphide Control Manual: Septicity, Corrosion and Odour Control in Sewerage Systems*. Volume 1, Technical Standing Committee on Hydrogen Sulphide Corrosion in Sewerage Works, Melbourne and Metropolitan Board of Works, 1989.
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6	*City of Omaha Wastewater Collection Systems Design Manual* (Pre-Final), 2018.
7	*Standard on Odour Control in Wastewater Networks and Wastewater Treatment Plants,* Version 0.01, Draft, SA Water 24/12/15.
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