Guideline

Design guideline for minimising odour-causing turbulence in wastewater networks

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Revision details

Version No.	Clause	Description of revision
1.0	-	Original issue

Introduction

This guideline is intended to minimise odour causing turbulence in wastewater networks.

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Acronyms

Acronym	Definition
ADWF	Average dry weather flow
AS	Australian standard
BOD	Biological oxygen demand
CDU	Chemical dosing units
DF	Design flow
DO	Dissolved oxygen
EP	Equivalent population
EPA	Environmental Protection Agency
HDD	Horizontal directional drilling
HGL	Hydraulic grade line
MH	Maintenance hole
MS	Maintenance shaft
O&M	Operation and maintenance
OCU	Odour control units
PDWF	Peak dry weather flow
SOB	Sulphur oxidizing bacteria
STAMP	Sewer Trunk Asset Management Plan
SRB	Sulphate reducing bacteria
STEL	Short term exposure limit
TWA	Time weighted average
VSD	Variable speed drive
WSAA	Water services association Australia

1. General

1.1 Introduction

This guide has been developed as a set of design considerations to minimise odour impacts resulting from excessive flow turbulence in Sydney Water's wastewater networks.

One characteristic by which wastewater networks are known to the public is its potential for creating odour nuisances. The nature of wastewater collection in the warm climate of Australia has made odour one of the main nuisances to the public amenity.

The main cause of odours in wastewater networks is hydrogen sulphide (H_2S), a gas detectable in very low concentration. Odour issues are exacerbated by excessive release of H_2S through wastewater infrastructure and components that promotes turbulent flow conditions. Hydrogen sulphide is also noted for its toxicity and for its ability to cause corrosion of various materials used in wastewater networks. Optimising the design to reduce H_2S levels not only controls odour but also enhances operational safety and helps protect infrastructure by limiting corrosive damage.

Sydney Water operates and maintains an extensive amount of wastewater infrastructure and as with all similar operators, there are odour issues across various parts of its wastewater network, for instance at maintenance structures and pumping stations.

Strategies to limit odour issues involve the management of excessive hydrogen sulphide in wastewater. This guide aims to provide good design practice to reduce odour issues by reducing turbulence in sewage flows.

1.2 Purpose

The purpose of this guideline is to provide design guidance to minimise odour issues in the network, in particular focussing on limiting excessive odour release through minimising turbulence in the wastewater flow.

This guideline consolidates current design guidance primarily from the Sewerage Code of Australia, Sydney Water Edition (WSA 02), the Sewage Pumping Station Code of Australia, Sydney Water Edition (WSA 04) and the Hydrogen Sulphide Control Manual Volume 1 into a single document. In addition to design guidance, it provides users with background information on H_2S generation, its mechanisms and influencing factors. While it is not intended to serve as a hydraulic design standard, it provides users with guidance on hydraulic engineering principles and best practices to reduce odour caused by excessive fluid turbulence in wastewater systems.

Although odour generating gasses are closely coupled with corrosion and work health and safety issues, this guide focusses only on odour. Requirements to manage corrosion is covered in various other standards, documents and guidelines issued by Sydney Water.

This document is intended for use on Sydney Water infrastructure for the design of wastewater network up to DN750 gravity mains, pressure mains and pumping stations and presents a best practice design approach to minimize odour causing turbulence in standard network components. It should be noted that the principles provided in this guideline can also be applied to the pipeline design of larger mains.

2. Odour in wastewater

Odour management is an essential aspect of wastewater network design and operation, as the release of gases such as hydrogen sulphide can lead to significant public nuisance and structural degradation of wastewater systems. Hydrogen sulphide, often produced under anaerobic conditions, is a major contributor to odours, commonly recognized by its characteristic "rotten egg" smell. Left unmanaged, the accumulation of H_2S can result in complaints from nearby communities and pose health risks to workers within confined spaces, where exposure to this gas can be hazardous and potentially fatal.

In order to understand the source of the problem and the mechanism whereby turbulence contributes to odour issues, it is important to consider the underlying causes of sulphide generation, the mechanisms of odour release, the impacts of sulphide on wastewater infrastructure and the properties of wastewater that influence sulphide production. Through effective odour management strategies, the longevity of wastewater networks can be safeguarded and public nuisances can be minimized.

2.1 Sulphide generation and properties

Sulphide generation in wastewater networks occurs primarily due to anaerobic conditions, where dissolved sulphates (SO_4^{2-}) present in the wastewater are reduced by sulphate-reducing bacteria (SRB) to form sulphides (S^{2-}). This process takes place in environments where oxygen is either absent or severely limited, such as pressure mains, siphons and low-flow sections of the network. These anaerobic zones are also typically found within the biofilms that form on submerged surfaces inside wastewater pipes. The biofilm serves as a matrix for the anaerobic bacteria, which thrive by consuming organic matter in the wastewater and using sulphates as an electron acceptor.

The most common sulphide product is H_2S, a gas that is both malodorous and corrosive when converted to sulphuric acid when the H_2S gas is exposed to moist, oxygenated surfaces. The formation of H_2S depends on several factors, including the availability of organic matter, the concentration of sulphates, the thickness of the biofilm and environmental factors such as temperature and pH. In systems where oxygen levels are depleted and sulphates are abundant, sulphide production becomes a significant concern.

H_2S is problematic because it readily transitions from the dissolved aqueous phase to the gas phase when turbulence or low pH levels prevail, releasing odorous emissions into the wastewater headspace. Refer to Figure 1 for diagrammatic depiction of gas release in a wastewater pipe. The headspace is the air-filled region above the wastewater, where gases like H_2S accumulate before potentially being vented to the environment through maintenance holes, pump stations, vent shafts, inlet works and/or other openings in the wastewater system. Odour complaints from the public often stem from these releases of H_2S, especially in urban areas where wastewater ventilation interacts with densely populated environments.

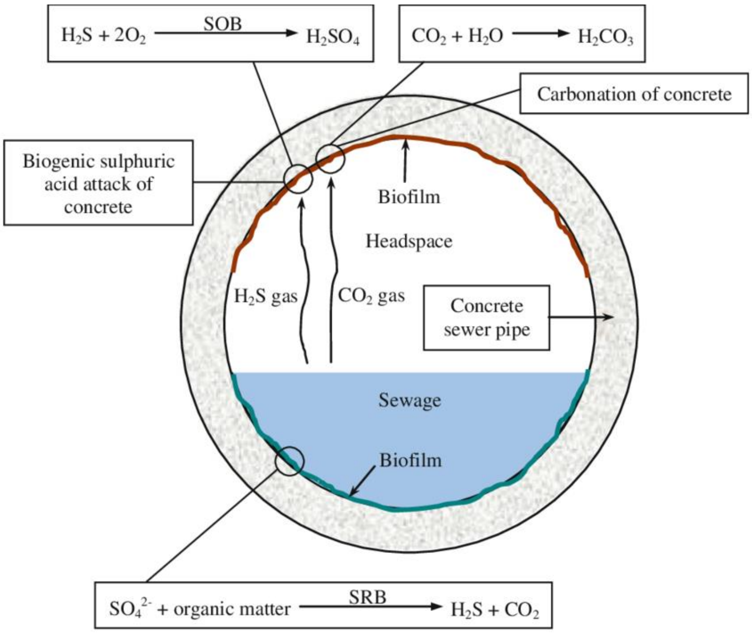


Figure 1: Diagram of corrosive and harmful gases within wastewater pipes within the headspace

2.2 Odour generation due to sulphide

H_2S is one of the primary causes of odour generation in wastewater networks. Its presence in the wastewater headspace leads to odour nuisances, especially as it escapes into the atmosphere. The process of H_2S escaping into the headspace is exacerbated by turbulence in the wastewater flow, which can be caused by hydraulic drops, bends, junctions, or components of a pumping stations such as wet-wells and discharge maintenance holes. Refer to Figure 2 that provides a visual representation of areas in the wastewater network where gas release can be expected. Turbulence increases the surface area of wastewater exposed to the pipe headspace, facilitating the transfer of H_2S from the liquid phase into the air. In gravity wastewater mains with low slopes or areas of stagnant flow, odour problems are more likely because the conditions favour prolonged anaerobic environments. Pumping stations wet wells are particularly prone to high turbulence, which further aggravates the release of H_2S.

The odour produced by H_2S is not merely a nuisance aesthetic concern; it also poses potential health risks. Prolonged exposure to elevated H_2S concentrations can lead to headaches, dizziness and irritation of the respiratory system. At high concentrations of H_2S—typically above 100 parts per million (ppm)—can be lethal. Therefore, controlling the generation and release of H_2S is important to maintaining public amenity and the health and safety of personnel working on or around wastewater infrastructure.

Moreover, beyond the odour, H_2S plays a role in the corrosion of the wastewater network. When H_2S gas interacts with moisture in the wastewater system, it is oxidized to form sulfuric acid (H_2SO_4), which is highly corrosive to concrete and metal components of the wastewater infrastructure. This dual threat of odour and corrosion makes H_2S management a major aspect of wastewater network operation and maintenance.

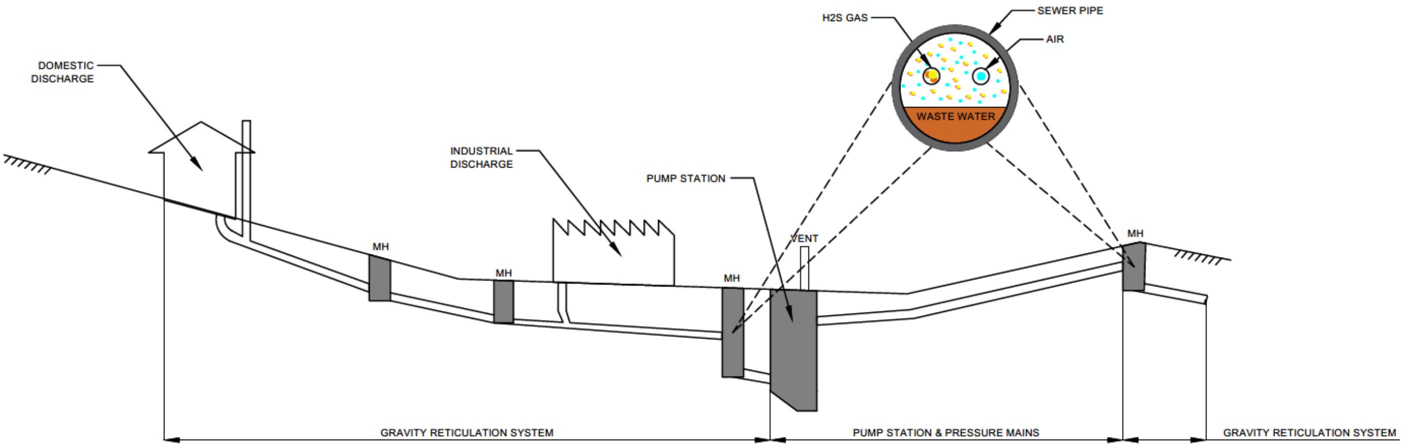


Figure 2: Diagram illustrating the release of H_2S gas, showing in typical areas in the network where turbulence occurs.

2.3 Factors affecting sulphide and odour generation

Several key properties, including pH, detention time, flow velocities and temperature, significantly influence sulphide generation and odour production in wastewater networks:

- Wastewater composition: Wastewater composition influences sulphide generation. Increased levels of organic matter provide nutrients for sulphate-reducing bacteria, while higher sulphate concentrations supply the necessary electron acceptors for sulphide production. This reaction can lead to greater odour issues and may contribute to corrosion.
- pH: The pH of wastewater is an important factor in determining the release of sulphide. At lower pH levels, <7, a greater proportion of sulphide is present as H_2S gas, which readily volatilizes into the wastewater headspace. As the pH increases above 8.5, most of the sulphide remains in the aqueous phase as HS^-, which is less likely to cause odour problems. Wastewater systems that experience pH drops due to industrial discharges or other factors are more prone to odour issues.
- Detention time: The longer wastewater remains stagnant in a wastewater network, particularly in pressure mains or sections with low flow velocities, the greater the likelihood of sulphide generation. Prolonged detention time allows for anaerobic conditions to develop, enabling sulphate-reducing bacteria to proliferate and produce sulphides. Detention times should be considered from a planning level prior to design development to ensure the overall network is being managed in a holistic approach.
- Flow conditions: Maintaining proper flow velocities in wastewater networks prevents sedimentation, blockages and H_2S-related odour and corrosion. Self-cleansing velocities keep solids in suspension, while slime control velocities minimize biofilm growth that promotes bacterial activity. Designers must also minimise turbulence where possible due to hydraulic jumps from bends, drops and or other discontinuities along the pipeline. For sewers ≥DN375, Sydney Water consultation is necessary to determine appropriate grades and velocities through hydraulic analysis.
- Temperature: Higher temperatures accelerate bacterial activity, increasing the rate of sulphide production. In warmer climates or during summer months, wastewater systems may experience increased odour complaints as sulphide generation intensifies. Temperature also affects the

solubility of H_2S, with higher temperatures decreasing the solubility and promoting its release into the headspace.

The management of these factors is necessary to effectively manage odour generation in wastewater networks.

3. Odour management framework

Reducing odour from excessive turbulence is only one component of a much larger odour management framework to mitigate odour issues. Effective management of odour in wastewater systems requires a comprehensive framework that addresses the entire asset creation process and required controls. The odour management framework is built upon a holistic and systematic approach that integrates various stages of the wastewater system lifecycle, ensuring that odour generation is minimized from the outset and effectively managed through ongoing operations. In order to understand the role of turbulence in odour management, this section will briefly outline the odour management framework, emphasizing the importance of a hierarchy of controls that encompasses source control, design and planning, implementation and operational measures. Refer to Figure 3 for the depiction of the hierarchy of controls for odour management across the lifecycle of wastewater systems.

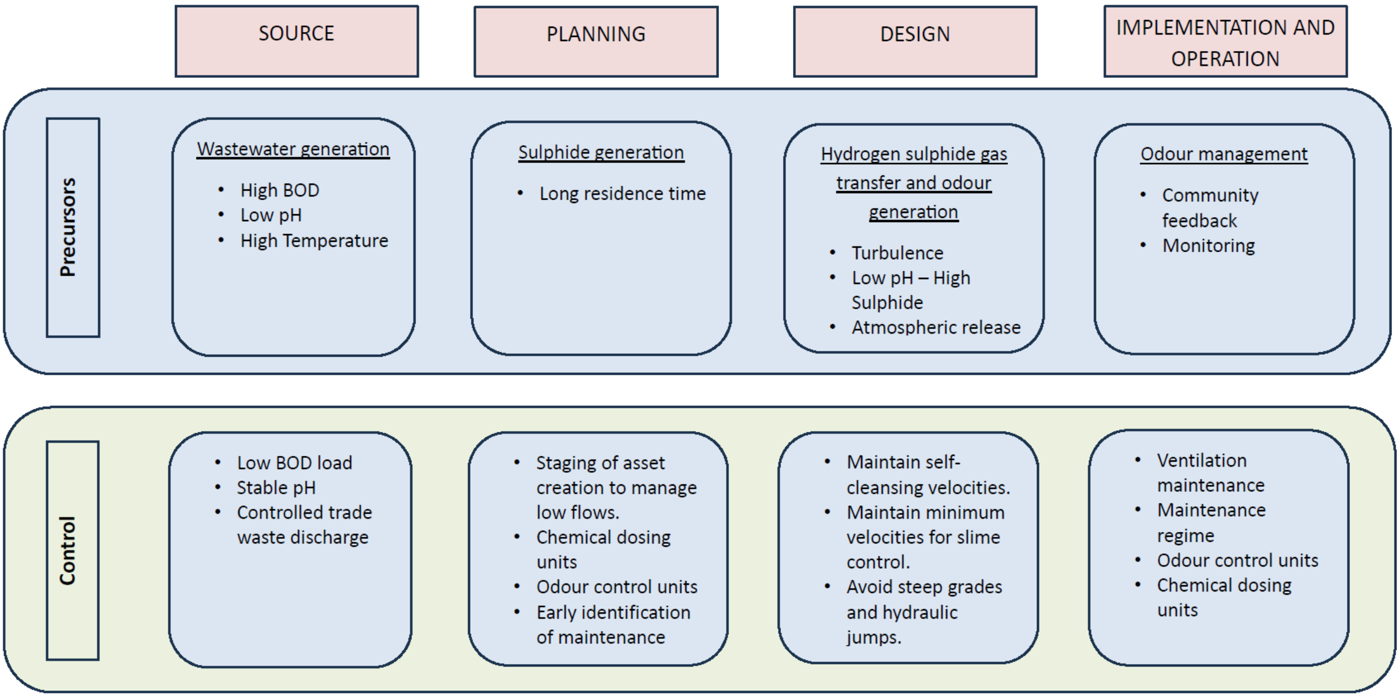


Figure 3: Hierarchy of controls for odour management during lifecycle of wastewater.

3.1 Sydney Water targets and acceptable limits

Sydney Water has established specific criteria for assessing and managing odour within its wastewater network. The primary goal is to maintain odour levels that do not result in offensive emissions or repeat complaints from the community. Additionally, the network must meet regulatory standards set by the EPA, which are designed to limit the release of harmful gases and protect public amenity.

To achieve these objectives, Sydney Water has set tactical targets for the strategic management of odour and corrosion program as part of the Sewer Trunk Asset Management Plan (STAMP). These targets include:

- Ensuring that dissolved sulphide concentrations in sewage remain below 0.5 mg/L.
- Keeping the pH of the wastewater above 7; and,
- The average concentration of H_2S in the wastewater gas space should not exceed 5 ppm.

Complaints from the public are a key indicator of the effectiveness of odour management strategies. Sydney Water aims to minimize these complaints by proactively managing odour sources and responding quickly to any reported issues. Compliance with EPA requirements is also required, as these regulations are designed to ensure that the network operates within safe and acceptable limits.

The management of H_2S exposure in wastewater networks is also important for the safety of workers and the general public. H_2S is a hazardous gas that poses serious health risks at elevated concentrations. At low concentrations (0.1–3 ppm), H_2S may be detectable by smell but generally does not pose a serious health risk. As concentrations increase to 3.1–10 ppm, the gas becomes offensive and in the range of 10.1–50 ppm, it can cause symptoms such as headaches, nausea and irritation of the eyes and throat. Prolonged exposure to higher concentrations (50.1–100 ppm) can result in more severe health effects, including serious eye injuries and a loss of the sense of smell. At concentrations above 300 ppm, H_2S exposure becomes life-threatening, with the potential to cause respiratory paralysis and death. Therefore, controlling the generation and release of H_2S is crucial to maintaining public amenity and ensuring the health and safety of personnel working on or around wastewater infrastructure.

Safe Work Australia has established specific exposure standards to guide the management of H_2S in the workplace, ensuring that the risks associated with this toxic compound are effectively controlled.

Safe Work Australia has set the following workplace exposure limits for H_2S (refer to Table 1):

Table 1: Acceptable exposure limits of H_2S set by Safework Australia

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

Incorporating these requirements into the design and operational framework of wastewater systems is necessary for maintaining worker safety and minimizing environmental impact. It is important that all personnel engaged in wastewater management are educated about these limits and the associated health risks to ensure safety and compliance.

3.2 Planning controls

Odour management starts during the planning phase of a project, with effective planning controls aiming to minimize H_2S generation. This involves optimizing network routes, managing detention times and staging assets strategically.

In greenfield areas, detention time calculations should be carefully considered early to determine the need for odour management measures, such as CDUs or OCUs, particularly when HRT exceeds 2 hours in pump station wet wells and pressure mains.

Reducing detention time is essential to limit anaerobic conditions that facilitate sulphide formation, particularly in pressure mains and wet wells, ensuring that wastewater is transported efficiently. However, it should be noted that controlling detention time in existing wastewater networks can lead to significant cost.

Asset staging further supports effective flow management by phasing the development of pump stations and pressure mains, allowing smaller mains to handle initial low flows and introducing larger infrastructure only when necessary to maintain minimum velocities and mitigate the risk of H_2S generation.

Odour nuisance is particularly problematic in new developments where components are designed with a long design life such as 100 years. In the early years of the development, pipes tend to be oversized with accompanying low flow, leading to low velocities such that slime stripping and grit removal is not achieved. This creates ideal situations for odour nuisance and resultant maintenance issues.

For new developments, designers must consider and consult with Sydney Water Planning for the option of dual symmetrical mains to accommodate expected low flows for early development and provision for accommodation of the future design horizon flows. If this option is not found to be feasible, designers should consult with Sydney Water Operations for the control of odour by curative and operational measures such as ventilation, chemical dosing, regular flushing regimes, etc. This assessment should include a risk assessment, options analysis, cost estimate (life cycle costs) and recommendation to Sydney Water on the best way forward.

3.3 Design controls

The management of odour is a system-wide issue that should be considered holistically, from source control to end-point treatment. It is therefore necessary to develop a high-level design strategy aimed at minimizing odour generation and its impacts on the network. The design control strategies can be categorized into preventative measures, which focus on optimizing system design to mitigate odour formation and curative measures, which involve interventions to address odour issues once they arise. Many of these strategies fall outside the scope of this guideline i.e. to minimise turbulence as a strategy, but it is worth noting them in order to consider odour nuisance holistically – odour nuisance is a system wide issue and cannot be controlled by reduction of turbulence alone.

The following flow chart (refer to Figure 4) illustrates a framework for managing odour in wastewater systems. It serves as a visual representation of the strategies and design considerations necessary to effectively manage H_2S generation and emissions throughout the wastewater generation and conveyance process. By delineating specific measures for various components of the system such as gravity wastewater, pumping stations and pressure mains, this provides the designer a structured approach and framework to odour management that integrates both preventative and curative measures.

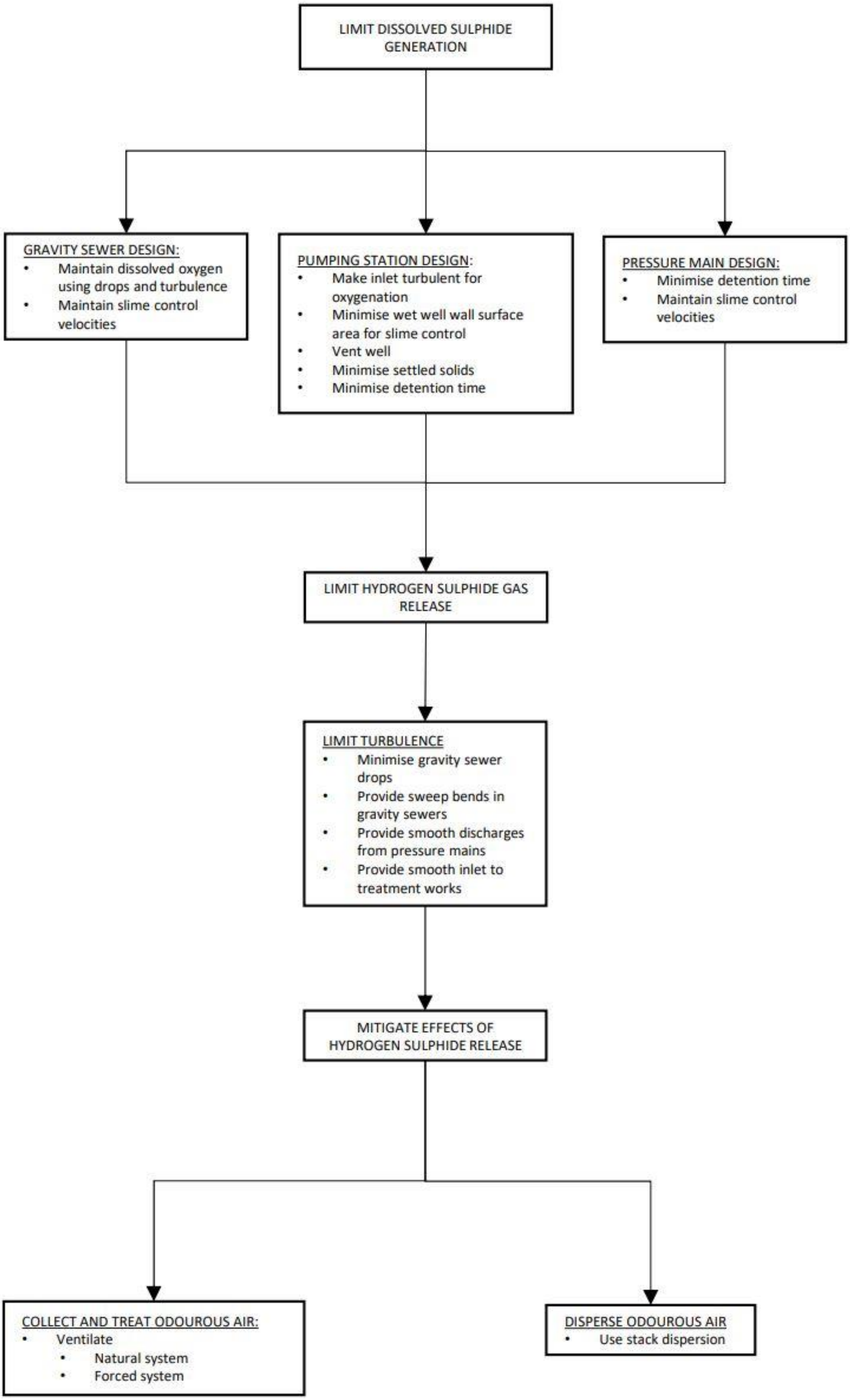


Figure 4: Flowchart depicting framework for design controls to address odour in wastewater network

3.3.1 Preventative measures

Preventative measures in wastewater network design focus on minimizing the conditions that lead to the generation of odorous compounds, particularly H_2S. For gravity reticulation systems, this involves optimizing pipe sizes, gradients and layouts to sustain aerobic conditions and limit septic conditions. Proper slopes are essential to maintaining self-cleansing velocities, reducing sedimentation and controlling slime growth, thereby minimizing sulphide production. For non-reticulation systems, including branch and trunk mains, detention time must be minimized to prevent septicity and appropriate ventilation strategies should be implemented to manage air displacement and gas accumulation. Trunk and branch sewers must maintain self-cleansing velocities and be graded to reduce sedimentation risks. Where necessary, chemical dosing should be considered to mitigate sulphide formation. Pumping stations are designed with facilities for chemical dosing and oxygen reserves to inhibit anaerobic conditions during wastewater conveyance. Wet-wells must be designed with self-cleansing bases to prevent sludge buildup and ventilation must be incorporated into valve chambers and wet-wells to manage air movement and reduce H_2S accumulation. Detention time within pump stations should be limited to prevent prolonged anaerobic conditions and where unavoidable, mitigation strategies such as aeration or chemical dosing should be applied. Additionally, operational strategies must ensure consistent flow to limit the retention of wastewater that may lead to odour issues. In pressure mains, reducing detention times and achieving self-cleansing and slime stripping velocities to prevent slime buildup and control biofilm formation periodically. Air release valves should be installed at high points in pressure mains to prevent air entrapment and associated corrosion risks.

3.3.2 Curative measures

Curative measures address odour issues once they have arisen, with strategies tailored to specific network components. In gravity reticulation systems, chemical oxidizing agents like chlorine, or hydrogen peroxide are added to convert H_2S into less harmful compounds. For trunk and branch sewers, sulphide control may require CDUs to mitigate septicity in large-diameter pipelines. Additionally, ventilation can help manage air displacement and reduce gas build up at critical points. Pumping stations can deploy forced ventilation systems to dilute and expel odorous gases while adjusting chemical dosing to maintain optimal conditions during peak flows. Wet well washing systems may also be required to prevent the accumulation of organic matter that contributes to H_2S generation. In pressure mains, raising the wastewater's pH helps retain H_2S in the liquid phase, reducing gas release. Additionally, scouring mechanism and increased flushing cycles may be used to remove sediment accumulation in long pressure mains. These targeted interventions work collectively to restore optimal operating conditions and minimize the impact of odour in wastewater systems.

Refer to Figure 5 for an illustrative depiction of the preventative and curative design measures necessary at various locations in the wastewater system to manage odour.

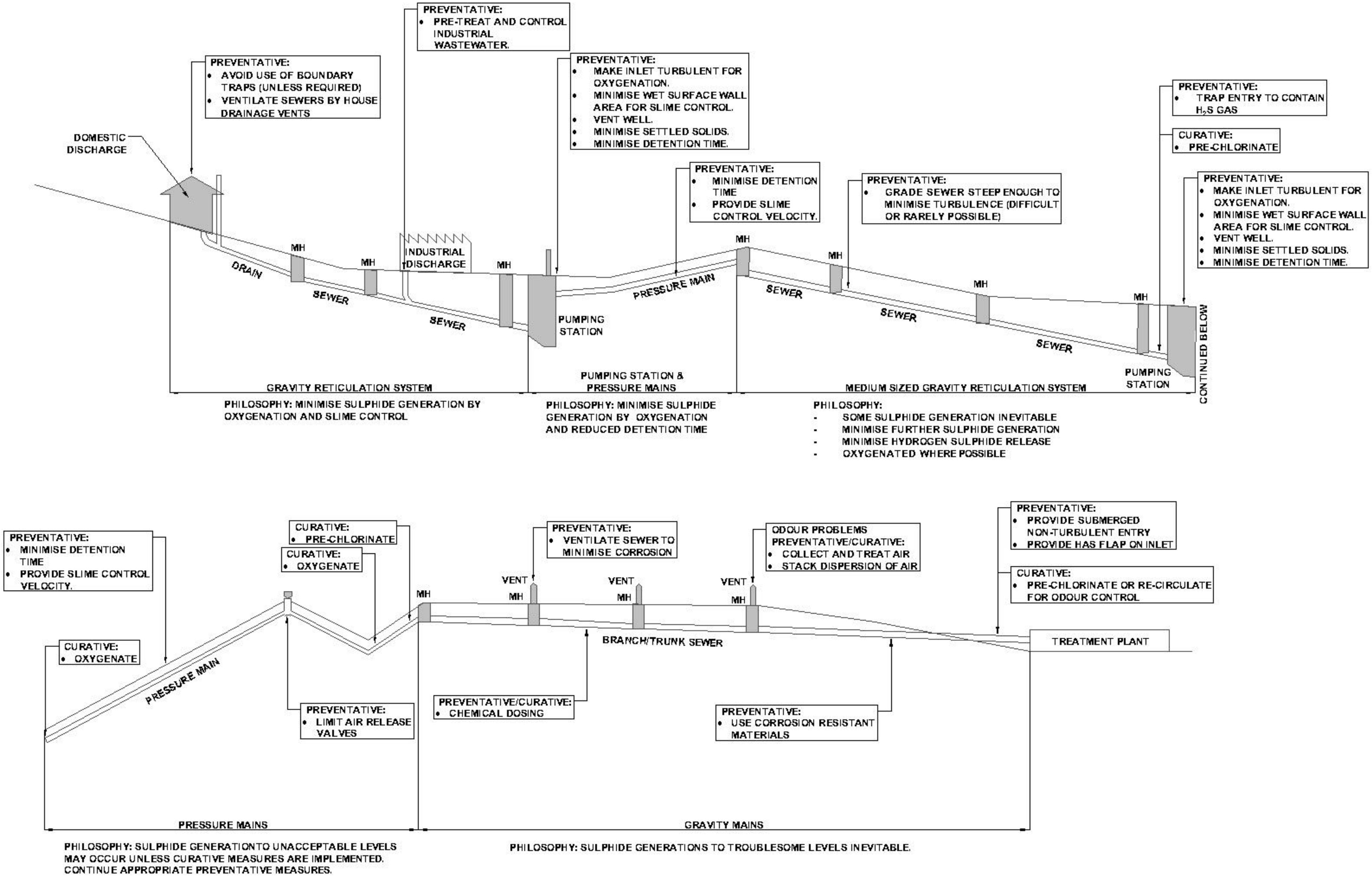


Figure 5: Visual depiction of odour management in wastewater systems—identifying when and where preventative and curative measures should be applied.

3.4 Operation and Maintenance controls

Routine inspections of assets such as pump stations, maintenance holes and vent shafts can help identify potential issues. Monitoring H_2S levels within the network provides insight into areas where odour problems may arise, enabling timely interventions. Adjustments to operational parameters, such as reducing detention times in wet wells and pressure mains, may help mitigate the risk of odour generation. However, reducing detention times after the system is already in commission may be limited and result in excessive costs with additional infrastructure requirements.

Monitoring the performance of CDUs and OCUs is beneficial in managing odour, particularly during peak dry weather flows. Installing H_2S gas monitors at strategic points, such as vent shafts, allows real-time tracking of odour levels. If concentrations rise above acceptable thresholds, adjustments to chemical dosing or ventilation settings could provide a responsive approach to managing odour impacts. However, consideration on monitoring programs should be included at a planning stage to account for overall design, construction and ongoing maintenance costs. The frequency on monitoring should also be considered based on the severity of expected odour release and the resulting consequence of the released odour in relation to safety, health and public amenity.

Adopting appropriate O&M practices can support the effective management of H_2S generation, reduce odour complaints and help maintain wastewater system performance with minimal disruption to the surrounding community.

4. Design Considerations

This chapter focuses on the role of wastewater network design in managing turbulence as a primary means of odour control.

Turbulence in water flow is generally a function of the Reynolds number with parameters of fluid density, flow velocity, characteristic length and viscosity of the fluid. In addition to a measure of turbulence, velocity also has a complex effect on sulphide buildup.

At low velocity, sediment is loosely deposited on the bottom of the pipe and become depleted of oxygen, promoting generation of sulphides until organic nutrients are depleted. Increased velocity leads to increased turbulence, which then disturbs the settled solids, thereby releasing sulphide into the stream. Increased turbulence will eventually result in H_2S transfer into the gas phase.

At higher velocity, solids are prevented from loosely settling at the bottom of the pipe. Increased turbulence promotes increased oxygen absorption into the stream thereby increasing the rate of oxygen transfer to the slime layer, which in turn leads to lower sulphide concentrations.

An effective design process that limits odour nuisance is a continued evaluation between a wide variety of design considerations and practical onsite conditions. While adopting a higher velocity leads to an increased reaeration rate, depending on the age of the sewage i.e. location within the collection network, a higher velocity (within a gravity network) typically requires steeper slopes which usually costs more to construct. In addition, deeper gravity pipes necessitate deeper maintenance holes with associated operational constraints, both in terms of additional financial burden but also safety concerns for operational and maintenance teams.

While the emphasis is on reducing turbulence to minimize odour issues, other design considerations that are related to odour, such as ventilation, are also included.

The guidance in this chapter consolidates relevant design principles from Sydney Water specifications, WSAA Standards and industry best practices to assist in the effective design of wastewater systems. These principles aim to address septicity and odour management while considering broader factors that influence system performance and compliance with Sydney Water standards.

4.1 Gravity systems

The following section will cover design requirements limited to gravity reticulation, branch and trunk mains up to DN750, however the design principles in this guideline can be applied to larger mains.

The main design considerations for gravity sewage networks are:

a. Pipe sizing and grading
b. Self-cleansing velocities
c. Slime control velocities
d. Maintenance structures, bends & drops
e. Hydraulic jumps surcharge

4.1.1 Pipe sizing

The sizing and grading of wastewater pipes are significant in the design process, ensuring optimal flow conditions and preventing issues such as blockages, odours and corrosion. Proper design criteria must balance hydraulic efficiency, system longevity and cost-effectiveness.

The designer must ensure that the required pipe size provides for adequate ventilation by means of having suitable air space in the pipe at the peak dry weather flow (PDWF) or at design flow (DF) water level. Within Sydney Water's gravity pipelines are to be sized to ensure no air space at DF and ratio of PDWF to pipe full capacity does not exceed 0.6.

Wastewater from property connections and flows in small diameter reticulation networks are likely to maintain high levels of DO and be aerobic and as a result are not typically designed for slime control.

In WSA Sewerage Code of Australia WSA02, Sydney Water provides minimum pipe sizes for property connections and reticulation network based on the empirical relationship between equivalent population (EP), pipe grade and pipe size. Refer to Table 2 for the maximum EP based on pipe size and grade.

For pipes larger than DN 300, the designer must undertake a bespoke design with due consideration of the relevant design principles as outlined in this guide.

Table 2: Maximum EP for reticulation network based on pipe size and grade.

Pipe size	Grade		Maximum EP
DN150	1 in 70	0.59 %	500
	1 in 150	0.67 %	550
	1 in 125	0.80 %	625
	1 in 100	1.00 %	725
	1 in 80	1.25 %	850
	1 in 60	1.67 %	1,050
DN225	1 in 270	0.37 %	1,600
	1 in 250	0.40 %	1,700
	1 in 200	0.50 %	1,950
	1 in 150	0.67 %	2,350
	1 in 125	0.80 %	2,650
	1 in 100	1.00 %	3,025
	1 in 80	1.25 %	3,450
	1 in 60	1.67 %	4,100
DN300	1 in 370	0.27 %	3,225
	1 in 250	0.40 %	5,000
	1 in 200	0.50 %	4,650
	1 in 150	0.67 %	5,500
	1 in 100	1.00 %	6,950
	1 in 80	1.25 %	7,900
	1 in 60	1.67 %	9,300
DN300 >	Bespoke design required		

4.1.2 Self-cleansing velocities

Self-cleansing velocities are necessary to keep solids suspended and prevent sedimentation within the wastewater system. In Sydney Water networks, a minimum wetted cross-sectional velocity of 0.70 m/s at peak dry weather flow is required to achieve self-cleansing of grit and debris. For systems with an EP of 600 or less, daily flows may be intermittent and hydraulic analysis may not yield favourable results for achieving self-cleansing velocities. In these cases, empirical pipe sizing, as provided in Table 2, should be used. Designers must also consider slime control velocities to reduce biological growth, which varies depending on pipe size and flow conditions.

4.1.2.1 Required minimum grades

Pipe grades are selected to maintain appropriate flow conditions and minimize detention time, which can lead to solids settling and the generation of H_2S. Proper slopes ensure wastewater remains suspended and reduce sedimentation risks, thereby limiting blockages, odour and corrosion.

For larger wastewater pipes (DN375 and above), consultation with Sydney Water is required to determine appropriate grades based on gauged flows and hydraulic modelling.

The Colebrook-White equation or Manning's equation (with k = 1.5mm or an equivalent roughness coefficient) is recommended for calculating minimum pipe grades to achieve self-cleansing conditions (refer to Table 3).

Table 3: Recommended manning's coefficient outlined

Pipe size	Recommended manning's friction coefficient, n – equivalent to Colebrook-White wall roughness k_s = 1.5mm
DN150	0.0128
DN300	0.0128
DN600	0.0130

Manning's equation:

$$V = \frac{1}{n} {R_h}^{2/3} S^{1/2} \qquad \text{(Eq. 1)}$$

Where,

V velocity (m/s)

n roughness coefficient

R_h hydraulic radius (m); calculated by A/P where A is the cross-sectional area of flow (m2) and P is the wetted perimeter (m).

S slope (m/m)

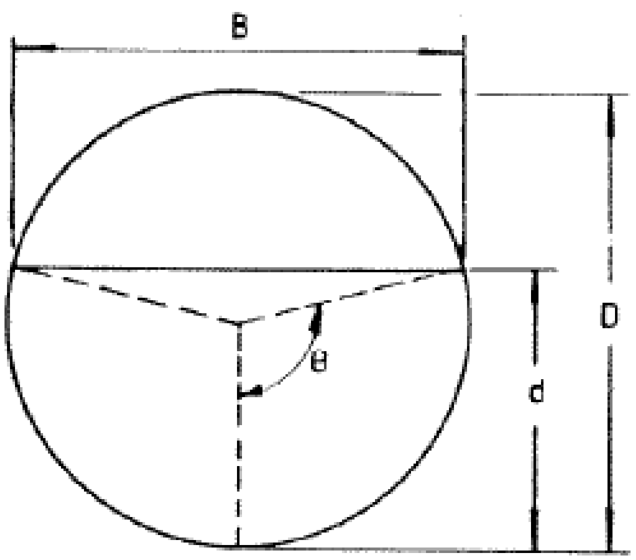
Colebrook-White equation:

$$V = -(32gR_hS)^{0.5} \times \log\left[\frac{k}{14.8R_h} + \frac{1.255\nu}{R_h(32gR_hS)^{0.5}}\right] \qquad \text{(Eq. 2)}$$

Where,

V	velocity (m/s)
k	Colebrook-White roughness coefficient (m)
R_h	hydraulic radius (m); calculated by A/P where A is the cross-sectional area of flow (m^2) and P is the wetted perimeter (m).
S	slope (m/m)
g	gravitational acceleration (m/s^2)
ν	kinematic viscosity of water (m^2/s)
d	Depth of flow (m)
D	Diameter of pipe (m)

The geometric parameters to calculate the flow in a circular pipe is presented in Figure 6 below.



$$\theta = \cos^{-1}\left(1-\frac{2d}{D}\right), \ \theta \text{ in radians}$$

$$A = \frac{D^2}{4}\left(\theta - \frac{\sin 2\theta}{2}\right) = RD\theta$$

$$R = \frac{D}{4}\left(1 - \frac{\sin 2\theta}{2\theta}\right)$$

$$B = D \sin\theta$$

Figure 6: Parameters for circular pipe

Irrespective of calculated minimum grades it is recommended that the design grade is no lower than that provided in Table 4 and Table 5. At low flows, flow estimate becomes unreliable and flow is intermittent rather than continuous. Self-cleansing in low-flow conditions is often achieved through impulse-shunting, where intermittent pulsing moves grit and debris downstream to sections of continuous flow.

Table 4: Absolute minimum grades outlined

Pipe size	Absolute minimum grade
Reticulation	
DN150	0.59 %
DN225	0.37 %
DN300	0.27 %
Branch and trunk	
DN375	0.19 %
DN450	0.15 %
DN525	0.13 %
DN600	0.11 %
DN750	0.09 %

Table 5: Minimum grades for property connection sewers and permanent ends

Situation	Minimum grade
DN100 property connection sewers	1.65 %
DN150 property connection sewers	1.20 %
Permanent upstream ends of DN50, DN225 and DN300 wastewater pipes in residential areas with EP ≤ 20	1.00 %

Table 6 provides an overview of the minimum and maximum recommended flow velocities for various pipe diameters under typical operational conditions, including self-cleansing and scouring.

Table 6: Recommended flow rates for different pipe diameters under various operational conditions.

Pipe size	Minimum velocity (m/s)	Maximum velocity (m/s)	Operational conditions	Notes
Reticulation pipes				
DN150	≥ 0.70	≤ 3.00	Intermittent pulsing expected to drive grit and debris control	
DN225				
DN300				
Branch and trunk pipes				
DN375	≥ 0.70	≤ 3.00	Self-cleansing at ADWF and slime stripping at PDWF	
DN450	≥ 0.70			
DN600	≥ 0.70			
DN750	Lower of 0.70 or slime stripping velocity			
Inverted siphons	≥ 0.75 at ADWF	-		Ensures solids are transported against gravity. Refer to HR Wallingford report SR559.
Pressure mains <DN300	Self-cleansing velocity	3.50	Scouring in pressure mains	Ensures satisfactory transport of solids
Pressure mains >DN300	Slime stripping velocity where minimum wall shear stress is 3.85 Pa	3.50	Scouring of pressure mains	

4.1.3 Septicity, slime control and maximum grades

Managing odour in gravity wastewater systems requires addressing both septicity and slime build-up, which are significant contributors to H_2S generation. Effective design must balance pipe grades and velocities to minimize conditions that promote slime accumulation and excessive turbulence, which can exacerbate odour issues.

For wastewater pipes larger than DN300, achieving slime control velocities early in the development lifecycle can be challenging due to low initial flows. This often results in slime accumulation and reduced hydraulic efficiency. Designers should assess the long-term implications and consult with Sydney Water Operations to identify site-specific solutions. Options include designing smaller pipes to achieve self-cleansing velocities early on, with the understanding that capacity will be limited over time, or opting for larger pipes with ongoing operational interventions, such as regular flushing, chemical dosing, or forced ventilation. This assessment should consider maintenance requirements, lifecycle costs and operational impacts to determine the most cost-effective and sustainable solution.

Pipe grades should be selected to achieve scour velocities that prevent solids deposition and limit slime build-up, particularly in areas prone to elevated sulphide levels. Designers should aim for flow velocities that reach scour conditions at least once per day to maintain system efficiency. For effective self-cleansing, it is recommended to target a minimum wall shear stress of 1.60Pa to prevent solid deposition and minimum wall shear stress of 3.35 Pa to prevent formation of visible wall slimes as outlined in the *Hydrogen Sulphide Control Manual – Monograph 5.1*.

In designing pipe grades and velocities, additional factors such as dry and wet weather flows, surface slopes and wastewater characteristics should be considered to ensure performance under varying conditions. Collaborative planning with Sydney Water and thorough assessment of lifecycle costs will help achieve a balanced design that meets both operational and long-term performance objectives.

The following formula can be used to determine if the nominated pipe size and grade is sufficient to achieve the required critical wall shear stress:

$$\tau = \rho g S R \qquad \text{(Eq. 3)}$$

Where,

τ	Critical average wall shear stress (Pa)
ρ	Density of wastewater (kg/m^3)
R	hydraulic radius (m); calculated by A/P where A is the cross-sectional area of flow (m^2) and P is the wetted perimeter (m).
S	slope (m/m)
g	gravitational acceleration (m/s^2)

For wastewater pipes with a Manning’s "n" value of 0.013 or less, this typically results in a boundary shear stress range of 1.5 – 2.00 Pa, where an average shear stress of 3.35 Pa is maintained; this has been shown to help prevent sulphide-related issues. For wastewater pipes with higher roughness coefficients (n ≥ 0.015), a boundary shear stress of at least 2.00 Pa should be maintained to support effective self-cleansing and reduce the risk of odour and corrosion.

4.1.4 Maintenance structures

Maintenance structures, including maintenance holes, drops and shafts, are necessary in wastewater systems to provide access for inspection, cleaning and operational management. By nature, these structures are sources of discontinuity that promotes turbulence and can either strip gases such as H_2S or increase the rate of reaeration. For fresh sewage with low concentrations of sulphide, reaeration can reduce the risk of anaerobic degradation in the downstream system, but conversely, turbulence in septic sewage should be avoided to reduce the release of sulphides from sewage. In each case, improper design will contribute greatly to odour issues.

This chapter presents design considerations that focus on minimizing turbulence within maintenance structures, improving hydraulic performance and managing odour generation.

4.1.4.1 Grading through maintenance holes

Grading is an important design consideration in minimizing turbulence. Even small step changes in level within a MH can cause H_2S and odour to be stripped from the sewage. Proper grading allows for smooth flow transitions through maintenance holes, preventing abrupt velocity changes that can cause hydraulic jumps or surcharge. The ideal approach is to maintain smooth slopes for both inlet and outlet pipes, avoiding sudden drops that could create excessive turbulence.

Key Considerations:

- Pipe Alignment: Inlet and outlet pipes should be aligned in a way that minimizes angular deflection. This reduces disturbances in the flow and helps avoid the formation of eddies and flow separation. Refer to Table 7 for summary of maximum allowable change of direction through MHs at sub-critical flows. Where supercritical flows are expected designer should take into considerations the use of long radius bends, increased MH diameter to allow for larger radius of curvature within the base. Further guidance can be sought from the report by R.L Stockstill Hydraulic design of channels conveying supercritical flow published by Coastal and Hydraulics Laboratory.

Table 7: Maximum allowable change of direction through MH.

Pipe size (DN)	Maximum change of direction (degrees)
150-300	Up to 90° within MH channel Up to 120° with the use of internal and external drop Up to 150° (DN150 only) with the use of internal and external drop chamber
375-750*	Up to 45° Where change of direction is > 45°, MH requires special design
≥ 900	Special design

* Refer to SEW-1309-V for additional limitations to change in direction through MH at differing MH diameters and pipe size.

- Pipe Slope: Steep slopes entering the maintenance hole should be minimized. High slopes can cause rapid flow velocities that are difficult to manage once inside the structure. A moderate slope (grades ≤7%) should be maintained to allow for consistent flow.
- For reticulation pipes (≤DN 300) with inlet and outlet pipes of the same diameter, compensation for friction head loss through bends within MHs must be achieved by maintaining a fall to the design gradient, evenly distributed along the channel within the MH. Refer to Figure 7 for diagram of grading through MH. The minimum internal fall in an MH where there is a change of direction must not be less than the values specified in Table 8. In contrast, for maintenance holes situated on branch and trunk pipes (> DN 300), no compensation for friction head loss through bends is necessary.

Table 8: Minimum internal fall through a MH joining reticulation pipes of same diameter.

Change in direction angle at MH (degrees)	Minimum internal fall (mm)
0 – 30	30
> 30 – 60	50
> 60	80

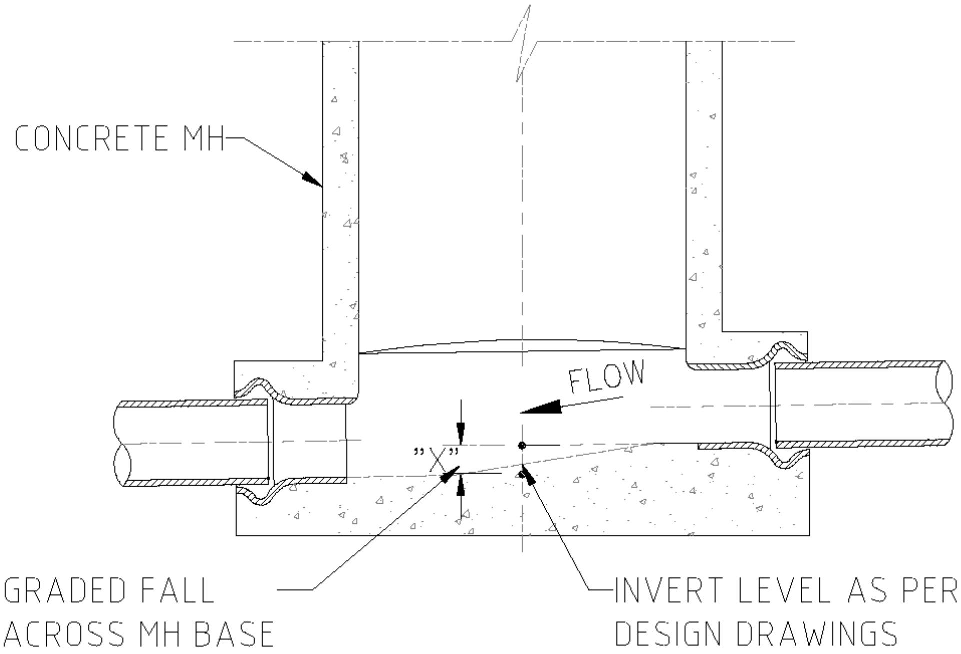


Figure 7: Example of pipe grading through a maintenance hole with controlled slope to ensure smooth transitions and minimize turbulence.

Where the outlet pipe diameters at a MH is greater than the inlet pipe diameter, the pipe should be generally designed soffit to soffit. However, if this cannot be achieved the inlet and outlet pipes can be aligned at their respective flow lines at PDWF subject to Sydney Water approval.

For reticulation mains where the inlet is smaller than the outlet by one or more standard pipe size and/or has a significant drop over the base, there can be potential for turbulent flow as there can be a transition from supercritical to subcritical flow. While ventilation is generally not required for ≤DN300, designers should assess the flow conditions within the MH and the potential for turbulence and air entrapment. In situations where significant flow transitions or turbulence are expected, increasing the MH diameter or depth may help reduce slope gradients and manage flow conditions to remain subcritical throughout. This approach can mitigate energy losses, minimize turbulence and improve flow stability.

Where differences in pipe elevations are significant and the specified internal fall cannot be achieved, the use of drop structures may be appropriate or alternatively regrading the sewer use of vertical curves. Selection between internal and external drops should consider site-specific factors, including hydraulic performance, maintenance access and flow characteristics. Complex hydraulic behaviour resulting from drops should be reviewed by a competent hydraulic specialist to ensure adequate performance.

4.1.4.2 Drop structures

Drop structures in Sydney Water's network manage elevation differences between inlet and outlet pipes, most commonly to reduce steep grades and minimise excavation but additionally drop structures also control flow behaviour, velocities and energy loss through the network. The choice of internal or external drops depends on site-specific conditions. Refer to Table 9 for limitation of uses of drop structures within the Sydney Water network.

Table 9: Limitation of uses of drop structures.

Type of drop	Maximum number of drops at MH	Allowable wastewater pipe size	Limitations of use
Internal drop	1 in 1050 diameter MH 2 in 1200 diameter MH	DN150	Contingent on other incoming wastewater lines, maximum 3 inlets into MH. Subject to Sydney Water approval.
External drop	3	DN150 - DN300	Contingent on other incoming wastewater lines, maximum 3 inlets into MH.

Drops should only be used when direct connection of the reticulation sewer to the base of the maintenance structure is impractical due to constraints such as deep excavations, alignment obstructions, or hydraulic conditions likely to induce turbulence and odour release. Where upstream flow operates under subcritical conditions, direct base connections are preferable as they minimize turbulence and reduce maintenance requirements. Within Sydney Water network external drops are preferred, internal drops are to be used with Sydney Water approval.

4.1.4.2.1 Internal Drops

Internal drops in MHs manage elevation differences in sewer networks, offering a compact solution where space is limited. While they can be effective, their design must address challenges such as turbulence, odour generation and maintenance requirements. Refer to Figure 8 for a typical example of an internal drop in a MH.

Incorporating effective ventilation at the MH can help manage gas accumulation and improve system performance.

The compact design of internal drops can have limitations. Maintenance can be challenging, particularly in cases of sediment accumulation or debris obstruction within the drop structure. Adequate access provisions should be included to facilitate regular inspection and cleaning.

Internal drops are not suitable for all scenarios. For larger sewers or cases with high flow velocities, external drops or alternative solutions may be more appropriate due to their better hydraulic performance and reduced maintenance requirements. Collaboration with hydraulic specialists is recommended for complex situations to ensure that internal drop structures are effectively integrated into the overall sewer network design.

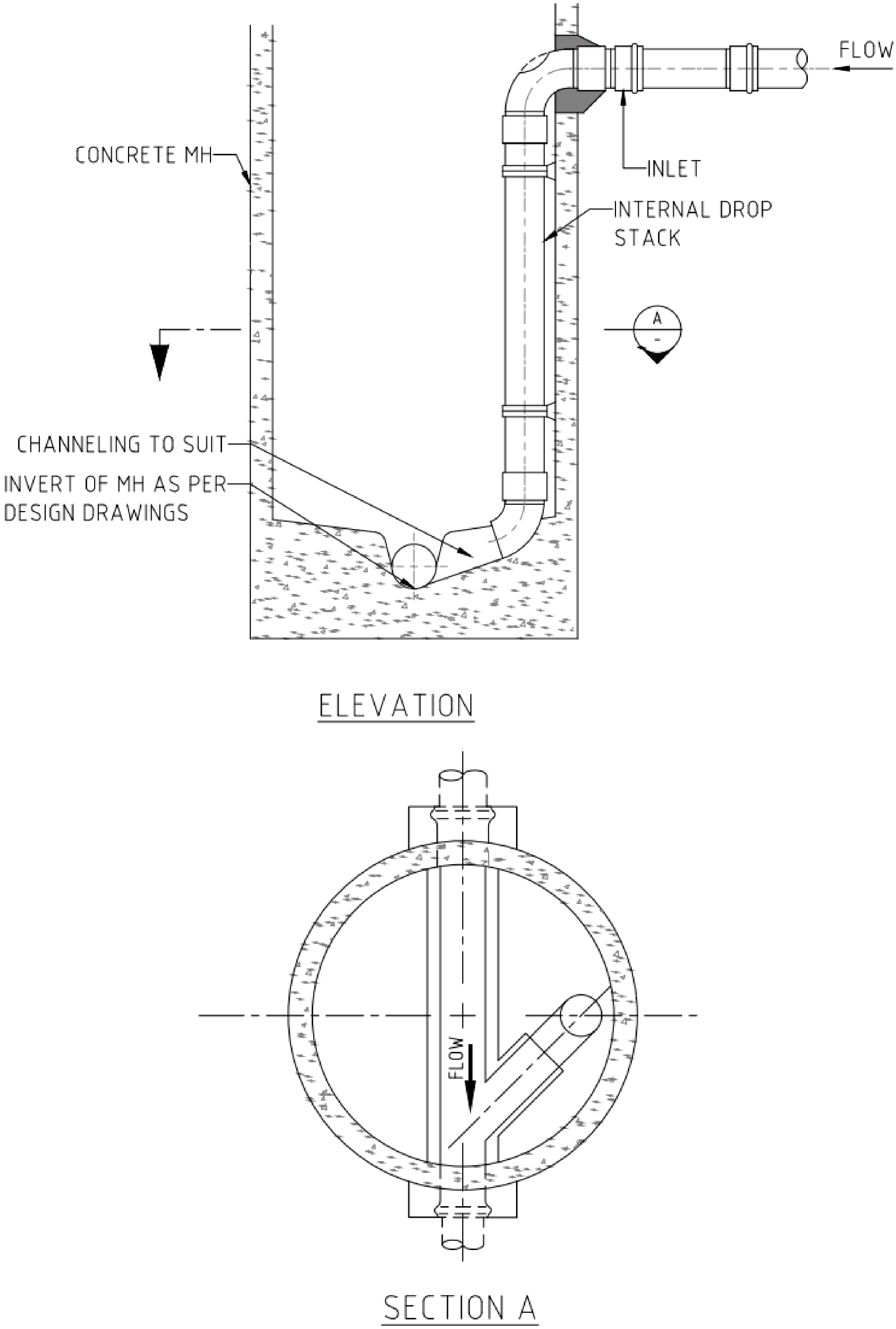


Figure 8: Example of internal drop structures as per WSA 02 drawing SEW-1306-V

4.1.4.2.2 External Drops

External drops manage elevation differences between inlet and outlet pipes in MHs by routing flows outside the MH structure. While hydraulically similar to internal drops, external drops can provide operational advantages by reducing obstructions within the MH, improving accessibility for maintenance and inspections. Designers should assess the feasibility of external drops based on site constraints, such as the availability of space around the MH and the complexity of installation. External drops should be considered where they improve long-term maintenance access and reduce the risk of operational issues associated with confined flow paths inside the MH. Refer to Figure 9 for a typical example of an external drop structures.

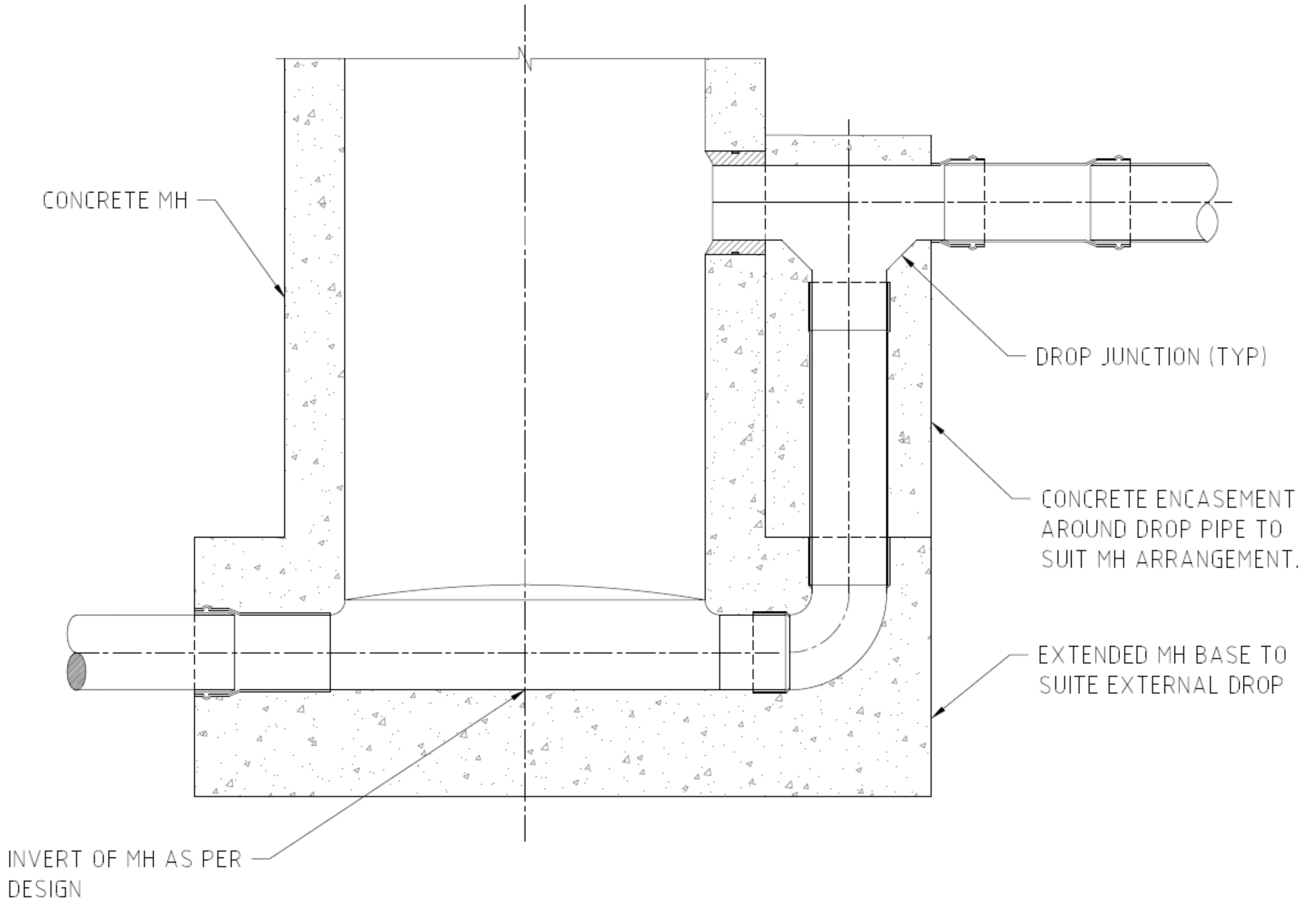


Figure 9: Example of external drop structures as per WSA 02 drawings SEW-1303

Designers must evaluate whether internal or external drops best meet hydraulic and operational requirements while ensuring proper alignment and slope to prevent sediment accumulation and maintain flow efficiency.

4.1.4.3 Horizontal, vertical and compound curves

In wastewater networks, horizontal, vertical and compound curves are primarily used to address spatial constraints and avoid obstacles while maintaining flow alignment.

Vertical curves are restricted to reticulation sewers only as a means of achieving a change of grade at a maintenance structure and/or maintaining verticality of a MS riser. Vertical curves should only be used adjacent to maintenance structures and are not permitted between maintenance holes i.e. inline of pipe alignment. This restriction ensures potential hydraulic disruptions, such as uneven flow or localized turbulence, are minimized. When used, vertical curves must be constructed with long-radius bends that match the material and strength class of the adjacent pipes. A maximum of two bends is permitted between maintenance structures, with each bend limited to a deflection of 45°. These requirements ensure structural consistency and hydraulic performance while mitigating turbulence and odour risks.

Horizontal curves are permitted adjacent to maintenance structures but must comply with specific requirements to maintain effective hydraulic flow. Bends ≤45° are allowed upstream of maintenance structures, provided they are clear of the benching and the external wall of the maintenance hole. Designers must adhere to the deflection limits based on pipe diameter, material and jointing system to prevent hydraulic inefficiencies and increased risks of turbulence and odour generation.

Compound curves, which combine horizontal and vertical changes in alignment, are restricted to DN150 and DN225 PVC pipes. These curves must not exceed a combined change of direction of 45° and require explicit approval from Sydney Water. Designers should evaluate the use of compound curves carefully to ensure they maintain steady flow conditions, avoid excessive turbulence and reduce the potential for odour release caused by hydraulic jumps.

The implementation of curves in sewers is a complex design solution and must ensure smooth hydraulic performance and effective odour management. Designers are encouraged to coordinate with Sydney Water and seek approval of use of curves to ensure factors such as a constructability, operation and maintenance are considered. Designers should consult Sydney Water for approval when deviations from standard practices are required and consider the impacts of deflection limits, pipe material and flow conditions to ensure the long-term reliability of wastewater networks.

4.1.4.4 Maintenance hole base layouts

The design of the base of a maintenance hole plays a vital role in directing flow and minimizing turbulence. Poorly designed bases can lead to the creation of dead zones where flow stagnates, encouraging the accumulation of sediments and promoting anaerobic conditions conducive to sulphide formation. A well-designed base should guide flow smoothly from the inlet to the outlet, minimizing the risk of turbulence.

Incorporating the following elements into MH base designs can enhance smooth flow transition:

- Benching: Benching directs any stray flow back into the main channel, preventing stagnation and ensuring that all wastewater flows efficiently toward the outlet. Proper benching can significantly reduce the likelihood of turbulence.
- Curved Channels: Provide the maximum possible radius of curvature. For pipe sizes of ≤DN300 a minimum radius of curvature not less than the pipe diameter and for pipe sizes of DN375 – DN750 a minimum radius of curvature of 2.5 times pipe internal diameter is to be used.
- Tangent Points: Tangent points of the curved channel fully contained within the MH base.
- Drop Inlets: For drop inlets, design straight-sided channels that direct wastewater flow directly to the outlet, preventing solids from settling on the bench.

4.1.4.5 Wastewater junctions and transitions

Wastewater junctions and transitions are a source of increased turbulence. The following design considerations can assist in smoothing turbulent flow within a junction:

- Minimize convergence angles: Keep the angles where pipes converge as small as possible to ensure smooth flow transitions and reduce turbulence. Ensure the centreline of the outlet is the tangent of the centre of the channel of all incoming wastewater pipes. However, if the outlet pipe is larger than the inlets, the tangent is to be closer to the outlet.

- Control lateral momentum: Design channels to balance flow rates and velocities of incoming wastewater pipes, avoiding abrupt changes that could cause lateral momentum imbalances and turbulence.
- Ensure gradual velocity changes: Maintain gradual velocity transitions within the junction to prevent sudden shifts that disrupt flow and cause deposition of solids, which contribute to odour issues.

Refer to Figure 10 for the diagram of typical manhole base layout with u-shaped channels.

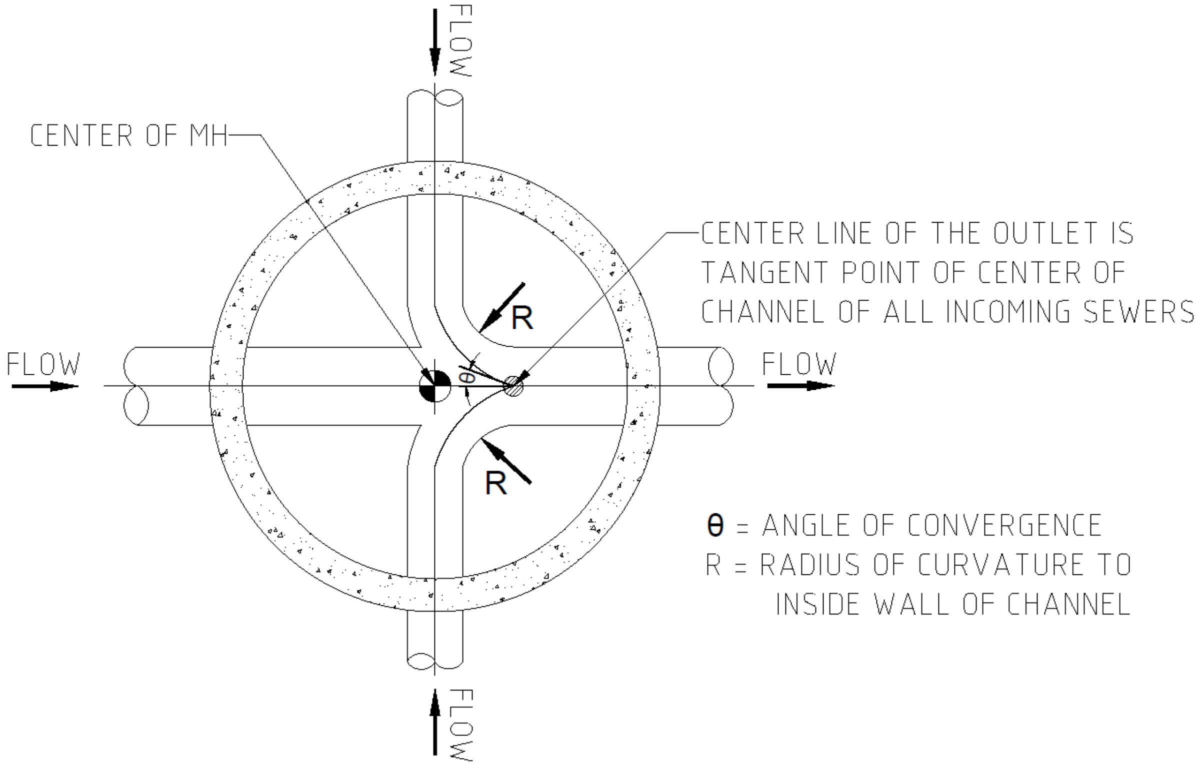


Figure 10: Cross-sectional view of a maintenance hole base layout featuring U-shaped channels and benching to ensure smooth, directed flow.

4.1.5 Hydraulic jumps and surcharge

Flow in wastewater systems is typically either subcritical or supercritical, with transitions between supercritical to subcritical being the primary source of turbulence often marked by a hydraulic jump. Subcritical flow is characterized by slower, deeper movement, dominated by gravity, while supercritical flow is fast and shallow, influenced primarily by inertia. Hydraulic jumps, require careful management to minimize odour and maintain system efficiency.

To manage hydraulic jumps effectively, design considerations should prioritize maintaining steady, subcritical flow conditions. This can be achieved by carefully aligning pipes and junctions, avoiding sudden changes in diameter or slope and ensuring smooth transitions at pipe connections. Abrupt flow changes at junctions or maintenance holes can often trigger hydraulic jumps, making proper junction design critical to minimizing turbulence and odour.

For wastewater systems, careful hydraulic analysis and coordination with Sydney Water are essential when designing for transitions between supercritical to subcritical flow conditions. Refer to Figure 11 for a diagram of a hydraulic jump in a partially full pipe and the schematical depiction of a straight-through maintenance hole.

Analysis of a hydraulic jump and its location is complicated and requires a detailed assessment by a hydraulic specialist.

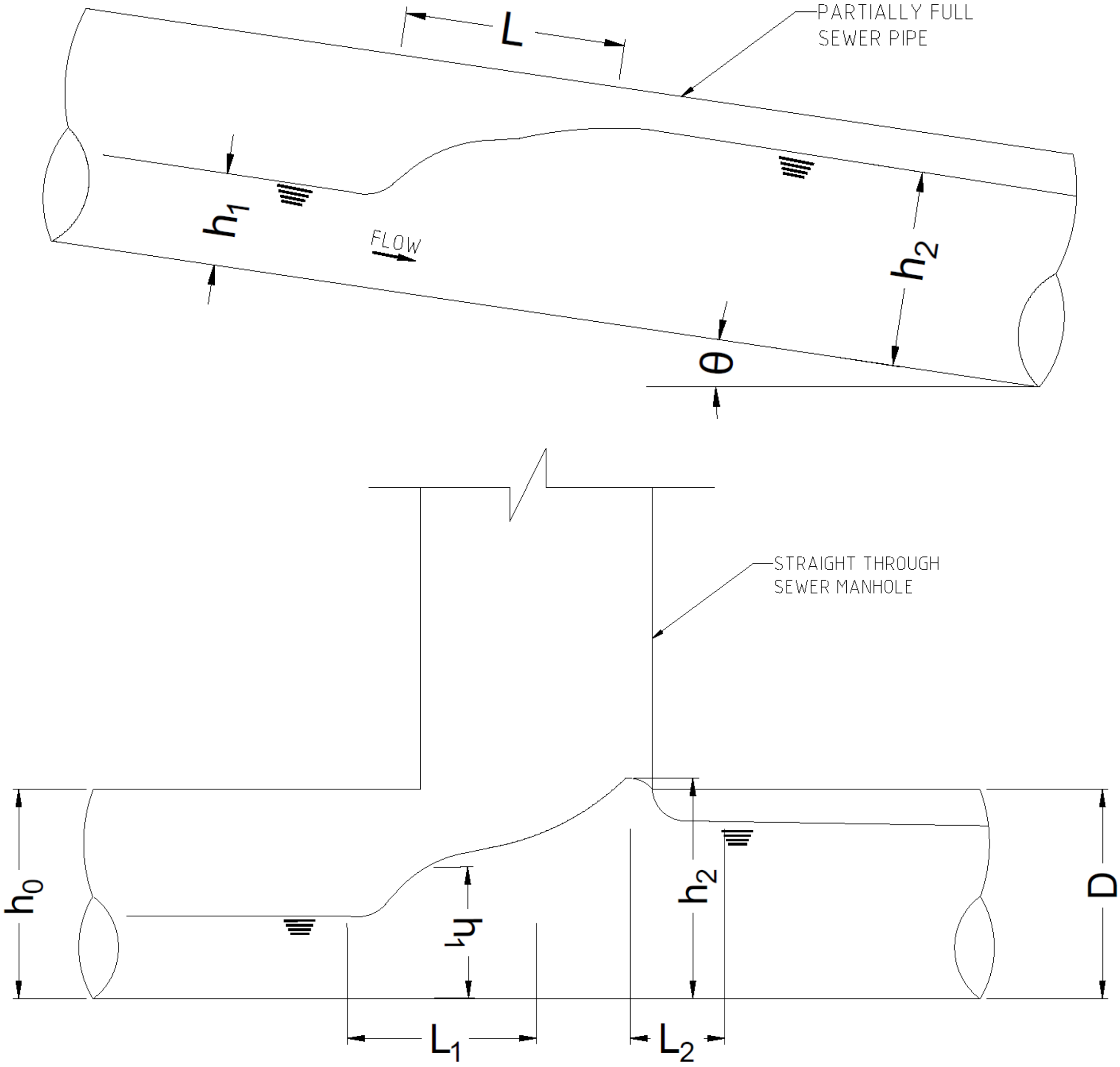


Figure 11: Diagram of a hydraulic jump in a partially full pipe and schematical depiction of a straight through maintenance hole.

4.2 Pressure systems

4.2.1 Pressure mains

Pressure mains require careful consideration during design and operation to ensure they function effectively. Pressure mains operate under pressurised conditions, preventing direct exposure to atmospheric oxygen and natural aeration. As a result, the only dissolved oxygen available for bacterial respiration and sulphide oxidation is the amount present at the point of entry. Once this oxygen is depleted, anaerobic conditions develop, promoting the activity of sulphate-reducing bacteria, which generate H_2S, leading to odour issues. The primary source of sulphide generation within a pressure main is surface slime. Achieving slime stripping velocity is therefore a major method of control for pressure mains.

Staging infrastructure and controlling pump operations are essential for managing flow conditions and minimizing odour and corrosion risks.

4.2.1.1 Pipe sizing

Proper sizing is essential to ensure hydraulic efficiency, minimize detention times and reduce operational risks such as odour generation. The following principles outline the design considerations for determining the internal diameter of pressure mains.

The minimum internal diameter is determined by ensuring the flow velocity does not exceed the maximum allowable velocity at the minimum allowable pump rate. This ensures that the flow remains within acceptable hydraulic limits, preventing excessive wear or turbulence within the pipe. To calculate the minimum internal diameter, the following formula can be used:

$$D_{min} = \sqrt{\frac{4Q_{pmax}}{\pi V_{sc}}} \qquad \text{(Eq. 4)}$$

Note: The internal diameter of the pressure main shall not be less than the pump outlet.

Where,

D_{min}	is the minimum internal diameter of the pressure main (m)
Q_{pmax}	is the absolute maximum pumping rate (L/s)
V_{sc}	is the self-cleansing flow velocity in the pressure main (m/s)

4.2.1.2 Design considerations

The alignment of pressure mains must prioritize smooth transitions to limit turbulence, which can promote the release of H_2S and odorous gases. Abrupt changes in pipe direction or diameter should be avoided, as these disrupt flow stability and increase agitation within the wastewater. Long-radius bends should be used to maintain steady flow conditions and in cases where elevation changes are necessary, proper air management is critical to avoid gas accumulation and mitigate odour risks.

4.2.1.3 Staging

Staging of pressure mains is necessary for developments with phased growth to avoid oversized pipes during initial stages, which can lead to low velocities and extended detention times. Low velocities increase the risk of sediment deposition and anaerobic conditions, both of which contribute to odour generation. By implementing dual symmetrical mains to cater for initial and future flows detention times can be minimized, maintaining aerobic conditions and reducing the potential for H_2S formation. Designers should consider future flow projections to ensure staged mains are adequately sized for both current and long-term conditions.

4.2.2 Detention time

Detention time is a key parameter in wastewater design, directly influencing the potential for septicity and odour generation. Therefore, it is essential to manage and optimize detention times during the planning phase to mitigate these risks.

In pressure mains, HRT is determined by the volume of the pressure main and the flow characteristics, including the pump operating patterns. The calculation of detention times involves understanding both average and peak detention times, as well as the differences between gravity and pressure systems.

Gravity systems generally exhibit more variable detention times compared to pressure systems. In gravity systems, the design focus should be on maintaining consistent flow conditions, especially in flat or low-gradient areas, to prevent excessive detention times. Conversely, in pressure systems, the detention time is more controlled by the operation of pumps, making it crucial to optimize pump cycles and staging.

To calculate the detention time of sewage in the wet-well and pressure main is determined by:

$$\mathrm{T} = \frac{\frac{V_w}{Q_p} + \frac{V_{pm}}{Q_d}}{3600} = \frac{0.25}{S_{max}} + \frac{\pi D^2 L_p}{3.6(4Q_d)} \quad \text{(Eq. 6)}$$

Where,

T	is the maximum combined detention time in the wet-well and pressure main (hours)
V_w	is the pump control volume in the wet well (cut-in/ cut-out volume) (L)
V_{pm}	is the volume of the pressure main (L)
Q_p	is the pump rate (L/s)
Q_d	is the design dry weather inflow to the wet-well (L/s)
S_{max}	is the maximum allowable number of pump starts per hour
D	is the internal diameter of the pressure main (m)
L_p	Is the length of the pressure main (m)

If the highest point of the pressure main is located before the receiving sewer, only the length of the pipe up to this high point is considered part of the pressure main. The section of the pipe beyond the high point will drain by gravity once the pump is turned off.

4.2.3 Self-cleansing velocities and septicity

Pressure mains must be designed to generate adequate shear stress to prevent sediment accumulation and reduce slime growth, thereby minimizing associated odour generation. The minimum wall shear stress necessary to prevent solid deposition in pressure mains is generally accepted to be 1.60 Pa, while the threshold to avoid the formation of significant visible wall slimes is typically 3.85 Pa. The following section outlines the method for calculating the minimum self-cleansing and sulphide slime control velocities required to achieve these shear stress levels.

4.2.3.1 Self-cleansing velocities

Pressure mains require higher velocities to maintain self-cleansing conditions and prevent slime formation. To mitigate the buildup of solids and prevent the formation of odorous conditions, minimum self-cleansing velocities must be established. The self-cleansing velocity (V_{sc}) required can be calculated using the formula:

$$V_{sc} = 0.267d^{\frac{1}{6}} \quad \text{(Eq. 7)}$$

Where:

V_{sc}	is the minimum self-cleansing velocity (m/s)
D	is the internal diameter of the pipe (mm)

This formula highlights the relationship between pipe diameter and the velocity required to maintain flow conditions. As the pipe diameter increases, the self-cleansing velocity must also increase to prevent sedimentation, where solids settle at the bottom of the pipe due to insufficient flow velocity. Sedimentation can occur in inclined and vertical sections of pressure mains, leading to blockages and reduced hydraulic efficiency.

Pressure mains shall be designed to maintain adequate velocities to prevent stagnation, which can lead to prolonged detention times, anaerobic conditions and the generation of H_2S and associated odour issues. Sufficient shear stress must be achieved to limit solid buildup, control sulphide slime formation and minimize odour generation. The design shall comply with both the minimum self-cleansing velocity and sulphide slime control velocity requirements to ensure effective flow conditions.

4.2.3.2 Slime stripping velocities

In addition to self-cleansing velocities, it is imperative to address slime stripping velocities, which are crucial for managing the growth of biofilms and associated odours. The required slime stripping velocity (V_{ssc}) can be calculated using the following formula:

$$V_{ssc} = 0.414d^{\frac{1}{6}} \quad \text{(Eq. 8)}$$

Where:

V_{ssc}	is the minimum sulphide slime control velocity (m/s)
D	is the internal diameter of the pipe (mm)

This calculation similarly indicates that larger pipe diameters necessitate higher velocities to effectively strip away slime deposits. It is recommended that these velocities be achieved regularly i.e. self-cleansing velocities continuously maintained where possible and slime stripping velocity achieved once per day to prevent the accumulation of sulphide-forming biofilms.

The design must also account for the maximum allowable velocity of flow within pressure mains, typically set at 3.5 m/s to help mitigate risks of pressure surges, water hammer and erosion of pipe linings. This maximum velocity is crucial to maintain system integrity while ensuring that sufficient shear stress is generated to limit sediment accumulation and slime growth.

4.2.3.3 Steeply inclined and vertical pressure mains and pumpstation discharge pipework

Steeply inclined and vertical sections of pressure mains, present unique challenges and requirements in wastewater design. These sections, which may include upward sloping legs of horizontal directional drills (HDD), barometric loops and wet-well risers, necessitate higher flow velocities to ensure the effective transportation of sediments. The required velocities are influenced by various factors such as pipe size, slope, sediment concentration and the characteristics of sediment particles.

To maintain efficient sediment transport and minimize the risk of sediment accumulation, it is important to achieve minimum recommended self-cleansing velocities in inclined and vertical pipes. Refer to Figure 12 for minimum self-cleansing velocities in steep and vertical pipes for various sediment concentrations and particle sizes. These velocities vary based on sediment concentrations and particle sizes. For effective operation, it is recommended that self-cleansing velocities be reached or exceeded at least once per day.

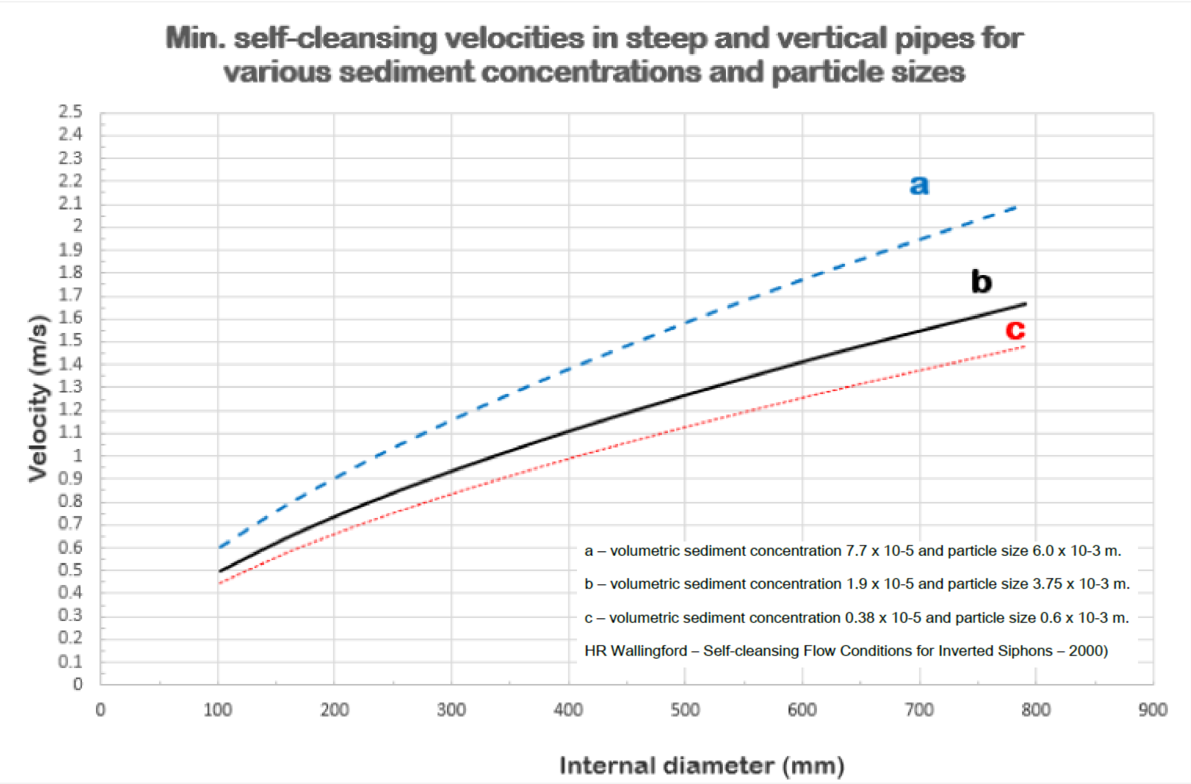


Figure 12: Self-cleansing flow conditions for inverted siphons.

In order to regularly achieve self-cleansing velocities, the flushing flow rate must be considered and can be achieved using a variable speed drive (VSD) or assist pumps. Long flushing cycles may be necessary, particularly in systems with a moving hydraulic grade line (HGL). The flushing process should be designed to hold back a known volume of sewage before being pumped at a specified flow rate for a predetermined duration. To effectively maintain a smooth pipe surface and reduce the potential for slime buildup, regular pump cycles are required rather than relying on infrequent flushing.

The volume of flushing flow should be at least double the volume of water contained between the lowest point and the discharge end of the pipe section being flushed. This ensures adequate flow to dislodge sediments and prevent their accumulation. Given the variability of sewage composition across the network, the duration and frequency of flushing will need to be tailored to the specific conditions of the system.

For pump station risers, it is imperative to maintain flushing velocities continuously to prevent solids accumulation at the pump discharge.

Additionally, the flushing of pressure mains should be considered, particularly in the early stages of a catchment's development, where the risk of sedimentation is higher. Flushing at higher velocities can help to strip accumulated slime, maintaining optimal flow conditions. The volume and frequency of flushing should be determined based on the specific characteristics of the wastewater and the pressure main design, ensuring that it effectively minimizes odour potential.

4.2.4 Discharge maintenance hole

The design of discharge MHs is an integral component in wastewater systems, particularly in relation to the transition from pressure mains to gravity wastewater network.

To achieve a smooth transition of flow from the pressure main into the discharge maintenance hole, the system must be designed to minimize turbulence. The pressure main discharge MH should facilitate this transition effectively.

A key design requirement is the alignment of the pressure main immediately upstream of the discharge MH. It should be straight and aligned with the outflowing gravity pipe for a minimum distance of ten times the pressure main's diameter or for a length of 5 meters, whichever is greater. This alignment helps reduce turbulence caused by abrupt changes in flow direction.

Moreover, the section of the pressure main leading into the discharge MH must be on a grade that gradually rises toward the maintenance hole. For small diameter typically reticulation pipes the soffit of the pressure main inlet should align with the soffit of the gravity pipe, ensuring that there is a drop in invert across the discharge MH. For larger diameter typically branch and trunk pipes consideration can be given to matching flow lines at PDWF subject to Sydney Water approval. In cases where, maintaining a continually rising grade is not feasible, Sydney Water may allow a falling grade for the last section of the pressure main.

To further mitigate odour generation, property connections are prohibited on downhill pressure mains to reduce the displacement of air, which could compromise seals and lead to the release of foul air within buildings. Vent shafts must be provided at the discharge maintenance hole to manage air displacement and minimize corrosion risks. These shafts serve distinct purposes: induct vents introduce fresh air to balance system pressure, while educt vents expel sewer gases to prevent odour generation.

Refer to Figure 13 for an example of discharge maintenance hole with vent shafts.

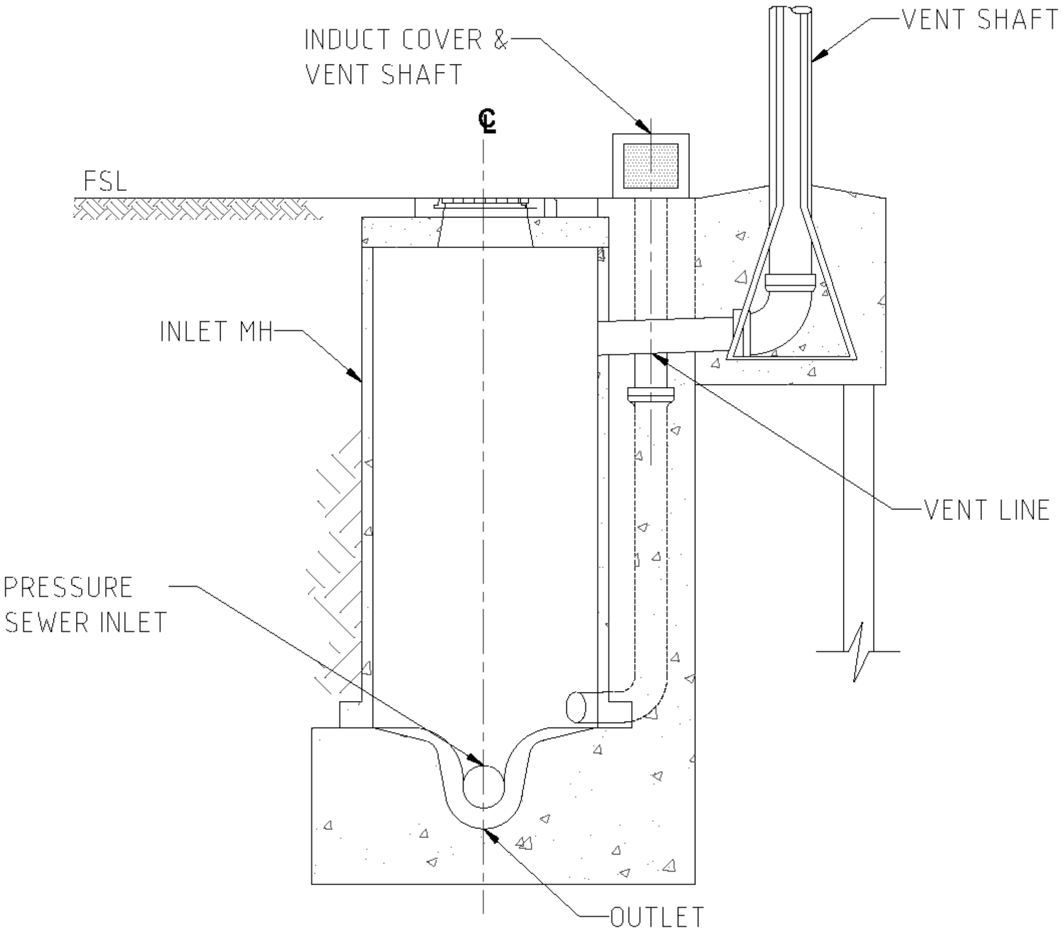


Figure 13: Example of a discharge maintenance hole as per WSA 04 SPS-1405.

4.3 Pump station inlet maintenance holes and wet wells

This chapter focuses on the design requirements for pump station inlet maintenance holes and wet wells in sewage systems, with an emphasis on managing turbulence and odour generation. Specific design considerations, including flow management, smooth transitions and appropriate ventilation, are critical to mitigating these issues and ensuring effective system performance.

4.3.1 Inlet maintenance hole

The design of the inlet MH should incorporate features that promote smooth flow transitions and minimize turbulence. The invert level must be set in accordance with the lowest incoming wastewater pipe, with a mandatory fall through the inlet MH to ensure gravity flow. A minimum fall of 30 mm is required for straight-through flow, while a fall of 80 mm is necessary for changes in flow direction.

To further manage turbulence, the inlet MH should connect to the wet well via a single low-level inlet pipe that includes an isolating valve and a drop tube. This configuration allows for the efficient transfer of wastewater while minimizing the risk of turbulence caused by abrupt changes in direction or elevation. Additionally, the grade and diameter of the inlet pipe should exceed the flow capacity of the pumping station, ideally aligning with the design flow of the upstream system.

A vent line must be incorporated from the inlet MH to the educt vent shaft, allowing for the safe release of gases that may accumulate in the system. This ventilation strategy is essential for managing air displacement, reducing odour buildup and minimizing the risk of gas accumulation.

Moreover, the inlet MH should be equipped with gastight, hinged aluminium covers and stainless-steel safety grilles to prevent the escape of odorous gases while ensuring safe access for maintenance personnel.

Refer to Figure 14 for an example of inlet maintenance hole.

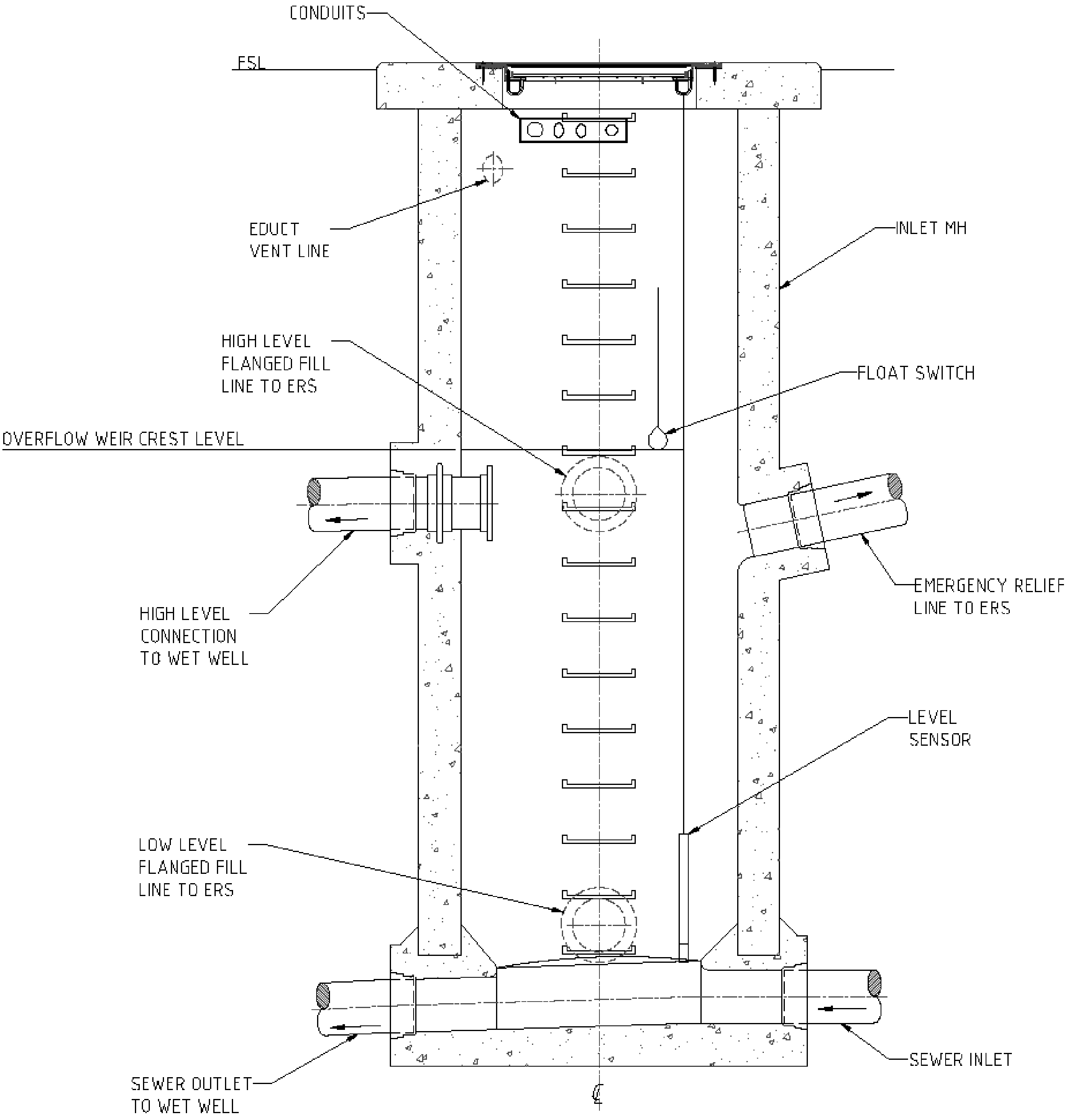


Figure 14: Example of an inlet maintenance hole as per WSA 04 SPS-1411.

4.3.2 Wet well detention times

The maximum allowable detention time for sewage in the wet well and pressure main should not exceed 2 hours unless specific treatment measures are implemented. Extended detention times can lead to septicity, which significantly contributes to the generation of H_2S and other odorous compounds.

To mitigate the risks associated with excessive detention times, designers should ensure that the wet well is designed to accommodate sewage volumes that allow for turnover. The dimensions of the wet well must be calculated to verify that sewage is adequately detained for the minimum time, effectively limiting stagnation whilst balancing other design considerations such as pump starts.

To calculate the detention time for wet-wells and pressure mains, refer to Equation 6.

If the detention time calculated for the wet well and pressure main exceeds the recommended maximum, several measures can be implemented. These include designing the pressure main to serve only the initial stages of development, thereby reducing the volume and allowing for better management of flow rates. Alternatively, providing multiple pressure mains can ensure that the system can handle varying inflow rates as development progresses.

When necessary, odour and septic control measures should be employed, particularly for pressure mains that cannot be adequately downsized. Options may include the use of sulphide-controlling chemicals, such as oxidizing agents, pH modifiers ferrous chloride and calcium nitrate can also be considered to further mitigate the risks of odour and septicity. However, these options come with increased complexity and operating costs and should be viewed as secondary solutions after other design strategies have been exhausted.

4.3.3 Ventilation

Effective ventilation in sewage pumping stations manages odours through the controlled release of gases, but it does not address turbulence within the system. Both natural and forced ventilation systems are used to dissipate odorous gases, particularly H_2S and maintain air quality in the wet well environment.

Natural ventilation relies on passive airflow, facilitated by components such as induct vents and educt vent shafts. Proper placement of these vents ensures foul air is released and dissipated above surrounding structures, minimizing the impact on nearby areas. Induct vents should be positioned to avoid contributing to turbulence near incoming flows, while educt vent shafts must allow air discharge without obstruction. Vent pipes must also be graded to ensure any liquid or condensation drains back into the wet well, maintaining the system’s efficiency.

Forced ventilation becomes necessary when natural ventilation cannot adequately manage gas release, particularly in situations with prolonged low flows or industrial wastewater. By controlling airflow and ensuring air exchange, forced systems assist in maintaining aerobic conditions and reducing the concentration of odorous gases. While forced ventilation can be combined with air treatment systems for enhanced odour management, it is not a solution for managing turbulence caused by hydraulic conditions within the network.

Designer should consider the use of air valves at high points in the pressure sewer network or where air entrapment is expected. The air valve assembly should be installed in a suitable location to prevent the release of gases around public areas. Further consideration should be given to additional ventilation at air valve chambers to allow for better dispersal of released gases.

4.4 Ventilation

Effective ventilation is essential in wastewater systems to manage odour generation and mitigate the risks associated with toxic gases, however, has minimal impact to turbulence in the wastewater. The design of ventilation systems varies across different types of wastewater infrastructure, including reticulation systems, branch and trunk systems. Note that ventilation for pressure mains network specifically at discharge maintenance holes and pumping stations is covered in Section 4.3.3. This section outlines the design considerations for ventilation in each of these systems, focusing on managing odour release.

4.4.1 Reticulation systems

In urban developments, gravity reticulation pipes typically utilize natural ventilation through property connection sewers and domestic waste pipe stacks. The air introduced at the head of the drainage system allows for the effective release of wastewater gases and the prevention of foul air accumulation.

4.4.2 Branch and trunk systems

Branch and trunk wastewater pipes benefit from a combination of induct and educt vents spaced at maximum intervals of 400 meters to facilitate natural draft ventilation. This dual-venting system ensures the effective dispersal of gaseous emissions while reducing the risk of septicity in the wastewater.

The vent shafts must be positioned above the 1:20-year flood level and away from future wastewater inlets to ensure reliability and functionality.

Educt vent shafts should be sized appropriately, matching the diameter of the pipe up to a maximum of DN300. Ventilation criteria set out in the Hydrogen Sulphide Control Manual, Volume 1 is to be adopted for branch and trunk wastewater pipe of sizes ≥DN450.

4.5 Special structures

4.5.1 Vortex dropper and water cushions

The effective management of flow transitions in wastewater systems is important for maintaining system integrity and minimizing operational issues. Vortex inlets and water cushions serve as key design components, particularly in scenarios involving significant vertical drops in branch and trunk pipes. This section outlines the design requirements and considerations associated with vortex inlets and water cushions, emphasizing their role in preventing turbulence and managing odour release.

Vortex inlets are specifically designed for applications where conventional drop inlets may lead to adverse conditions, such as turbulence or damage. Vortex inlets should only be employed in cases where simpler alternatives would pose risks to system performance or serviceability. The configuration of these inlets requires careful attention to hydraulic design to ensure compliance with local regulations and operational standards. Refer to Table 10 for the requirements for vortex inlets and water cushions based on sewer size and drop length.

Table 10: Requirements for vortex inlets and water cushions

Pipe size	Drop length (m)	Requirements
DN150 – DN300	>9	Water cushion
DN375 – DN525	< 6	Drop inlet
	6 – 20	Drop inlet with water cushion at bottom of drop
	> 20	Vortex inlet with water cushion at bottom of drop
≥ DN600	< 3	Drop inlet
	3 – 10	Drop inlet with water cushion at bottom of drop
	> 10	Vortex inlet with water cushion at bottom of drop

The design of vortex inlets must include a single inlet leading to the access chamber at the top, allowing for effective flow control while minimizing turbulence. It is essential that the receiving pipe is traversable, enabling maintenance access and ensuring continued functionality. Moreover, appropriate ventilation should be integrated at both the top and bottom of the drop shaft to mitigate odour generation and promote air circulation.

Hydraulic performance must be analysed to ensure that the vortex inlet effectively accommodates expected flow rates while preventing the build-up of sediments and associated odours. The design should also consider the long-term maintenance requirements of the inlet system, ensuring that all materials used are durable and resistant to corrosion, especially in environments where aggressive wastewater may be present. Figure 15 is an example of vertical drops with water cushions in the wastewater network. Further guidance on vortex drops can be obtain from HR Wallingford report SR559.

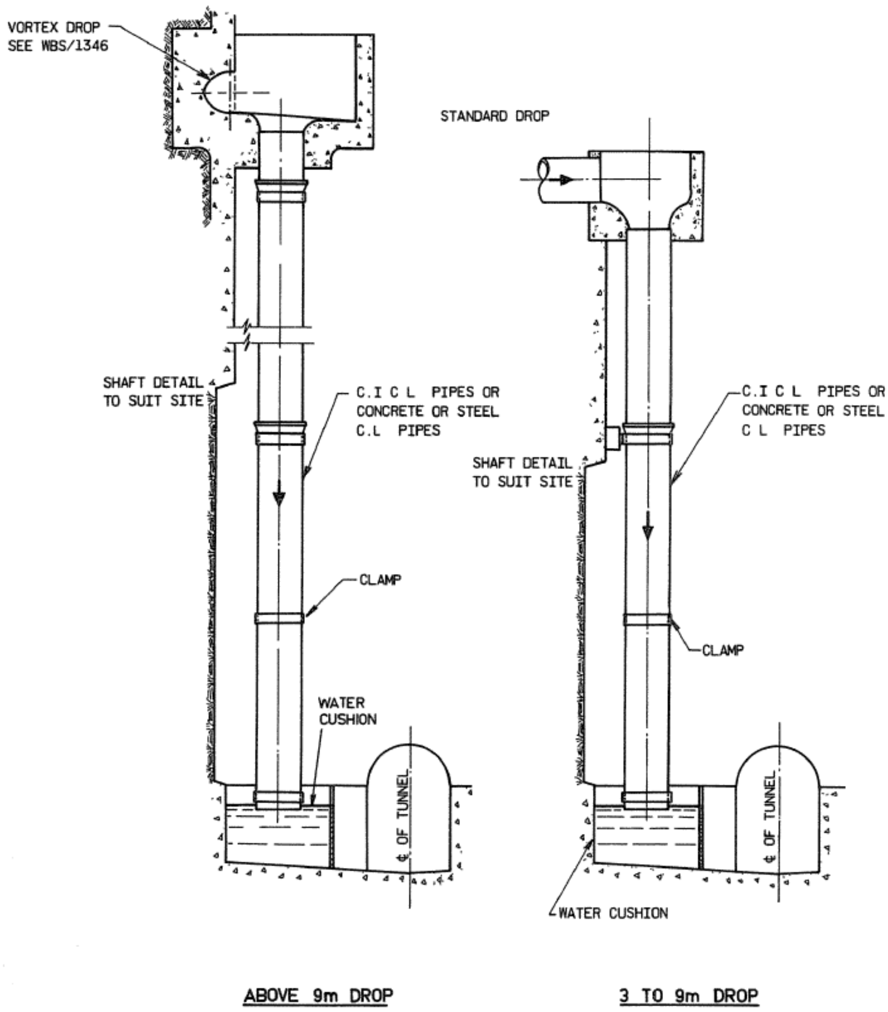


Figure 15: Extract from WBS 1505 - vertical drops in sewers provision of inlets and water cushions for DN600 pipes and above.

4.5.2 Barometric loops

Barometric loops are incorporated into pressure sewer systems to maintain a continuous water column and prevent column separation. Column separation can disrupt pump operation, promote erratic hydraulic performance and lead to the uncontrolled release of hydrogen sulphide, thereby exacerbating odour and corrosion issues. By integrating a barometric loop, the system is designed so that even under low flow or intermittent conditions, the pressure main remains fully pressurized. This continuous water column minimizes the entrainment of air, ensuring that any odorous gases generated by anaerobic conditions remain contained until they can be properly managed.

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Ownership

Ownership

Role	Title
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