WATER SERVICES
ASSOCIATION OF AUSTRALIA

GUIDELINES FOR POTENTIALLY EXPLOSIVE ATMOSPHERES

A guideline for the management of explosive atmospheres in wastewater infrastructure

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For more information

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About WSAA

The Water Services Association of Australia (WSAA) is the peak body that connects the Australian urban water industry, representing over 70 public and privately owned water or water related organisations. Our members provide water and wastewater services to over 20 million customers in Australia and New Zealand.

UN Sustainable Development Goals

Project outcomes contribute to the following UN Sustainable Development Goals:

SUSTAINABLE DEVELOPMENT GOALS

For more information about the water industry's contribution see Global Goals for Local Communities: Urban water advancing the UN Sustainable Development Goals.

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EXECUTIVE SUMMARY

Around Australia, in both regional and urban areas, flammable atmospheres requiring specific management and equipment occur in wastewater assets. This can occur due to different substances being present, not just the methane and hydrogen sulphide that has traditionally been used to classify wastewater assets. These flammable or explosive atmospheres have been responsible for incidents and near misses over the past 20 years, including:

- Explosion in a digester gas cogeneration system causing personal injury to a worker
- Explosion in a residential home, where methane gas backflowing from a pumping station was ignited, causing damage to a customer's bathroom
- Ignition of the atmosphere underneath a wet well pumping station, turned flammable due to an illegal dump of industrial waste, causing forceful ejection of the pumping station lid
- Ignition of the atmosphere at an inlet works due to repair work on a connected pipe

Incidents and near misses have increased water agency awareness of the risks associated with explosive atmospheres. Many have developed internal management plans with minimum standards specific to their requirements.

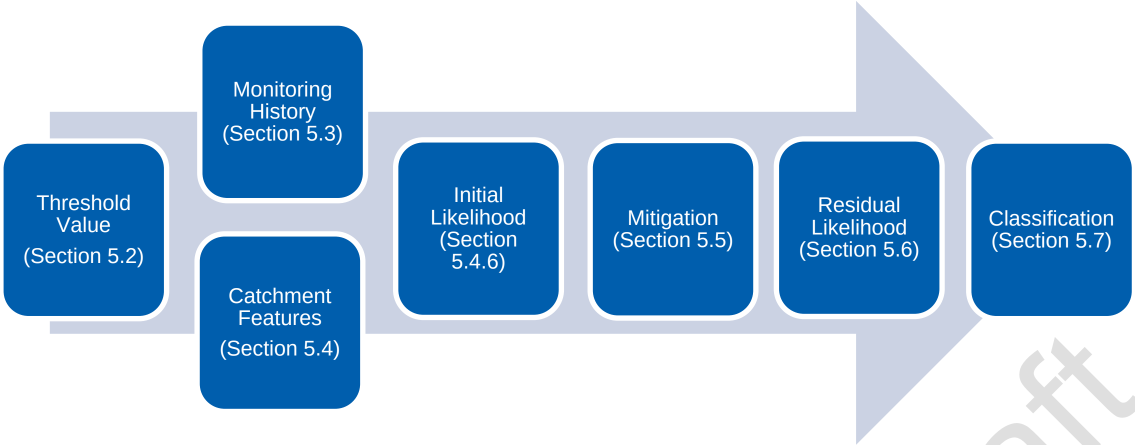
The Australian Standards for equipment design, selection and maintenance in a hazardous area are comprehensive. However, water agencies have found that classification of wastewater infrastructure can vary widely amongst hazardous area professionals.

This document provides a consistent basis from which water agencies can determine their approach to hazardous area management in their asset base. Guidance is divided into two categories: one aimed at wastewater networks, and the other at wastewater treatment plants.

A review of national and international literature such as guidelines, water agency specification documents, and Australian and industry standards was undertaken. The literature review has allowed information from other jurisdictions to inform an interpretation of local standards and assist in the development of this guideline.

An overview of common contaminants of concern in the wastewater sewerage network, flowing into treatment plants, is presented along with examples from Australian experience. This is followed by a description of monitoring techniques, describing sampling technologies, methods and campaigns to assist in determining the likelihood of hazardous areas and atmospheres being generated in the asset.

A guided risk assessment, applied under the generalised area classification, is provided to allow water agencies to classify wastewater assets. This ideally uses sampling data collected on contaminants and their grades of release, however, is also applicable in the absence of such data (in the example of a planned new asset).



The concept of the threshold value is introduced, allowing water agencies to set a threshold value for control of a potentially explosive atmosphere in accordance with their specific circumstances. Five key aspects of the wastewater system are assessed for their contribution to a potentially explosive atmosphere: hydraulic features, catchment composition, location, foreseeable misuse and possible ignition sources.

Guidance on mitigation measures is also provided, which can be used to mitigate or reduce the likelihood of an explosive atmosphere occurring. Ventilation best practice is briefly described with a reference asset used as an example of calculating ventilation rates for network assets. The calculations used for the reference asset are described in sufficient detail such that they can be applied to other assets. Having defined availability of ventilation in terms of common wastewater industry practice, and providing criteria for good and fair ventilation, the change in likelihood of explosive atmosphere associated with ventilation is provided for the user to apply. A final likelihood is then established taking into account any mitigation measures employed. The likelihood of an explosive atmosphere occurring is modified based on choice of threshold value. Examples of classification are provided, demonstrating the operation of the methodology in common wastewater scenarios.

Due to the predictable nature of their operation, the guideline recommends the use of one of the existing source of release methods outlined in AS/NZS 60079.10.1 to classify treatment plant assets. To assist hazardous area professionals in their classifications of wastewater assets, the threshold value concept is introduced for treatment plant classification, and some aspects to consider during the classification process are presented. In addition, a range of commonly installed treatment unit processes are described, and a minimum suggested classification is provided for reference.

Having described the methods by which classification can be made, some suggestions are made for the development of emergency response procedures to respond to common scenarios in both the wastewater network and within wastewater treatment plants. Key to this is early and ongoing communication with local emergency services.

Finally, a set of sample drawings are produced, based on guideline recommendations. In accordance with the forthcoming update to AS/NZS 60079.10.1, these drawings are provided as examples of standard industry practice with the intention that they be modified with the details of the particular situation.

PREFACE

This document has been prepared by WSAA with the assistance of Stantec Australia Pty Ltd, and with the valuable contributions of the working group of water agencies, to provide guidance in the management of potentially explosive atmospheres in wastewater treatment plants and wastewater networks. It is not intended to replace the role of expert opinion and advice for hazardous area classification, but rather to provide guidance to those professionals who are currently making those classifications and to inform other professionals not directly involved. It is important to note that this guideline does not supersede or overrule any relevant Australian standard or legislation and is to be read in conjunction with Australian standards and the relevant legislation for the jurisdiction where the classification is taking place.

When reading this document, the authors have made the following assumptions about the infrastructure in place at the water agency:

- Pumping stations have some minimal security to discourage ease of foreseeable misuse, such as lockable covers. Maintenance holes are such that members of the public cannot easily remove lids i.e. that specialist tooling such as lid lifters or bolt cutters are required to significantly dislodge the lids. This is to ensure that a minimum level of security can be assumed, providing protection from foreseeable misuse
- All equipment is maintained as per the manufacturer's instructions, kept in good working condition and not used outside of its design envelope.
- Asset owners follow the guidelines specified in AS/NZS 60079.17 for the regular service, maintenance and inspection activities associated with hazardous areas. This ensures that assumptions made regarding availability of ventilation or operation of equipment are in general true
- Maintenance and engineering personnel (whether internal or external) are sufficiently experienced in the requirements of working in hazardous areas. In general, these personnel should be competent as described in AS/NZS 60079.14 Annex A and AS 4761.1. This should be assessed by water agencies based on their circumstances e.g. local availability of specialist skills. This ensures equipment is maintained such that the Equipment Protection Level (EPL) is not compromised.

A hazardous area in the context of this guideline refers to an area in which an explosive or flammable atmosphere can form under certain conditions with air. Areas classified as non-hazardous in accordance with this guideline may not necessarily be safe in all respects (e.g. toxic and chemical hazards).

The effects of an explosion are often difficult to quantify; for this reason, existing Australian standards do not address the consequence of an explosion and classify areas solely on the likelihood of explosion occurring. There are broadly two categories of explosion which can occur: detonation or deflagration. Deflagration is subsonic combustion, driven by heat. Detonation is supersonic combustion, driving compressed unburnt gas ahead of a shockwave. In certain circumstances which are very difficult to model, deflagration can transition to detonation. This can be very dangerous. Further information on this topic can be found in Appendix B.

It is the objective of this document to set out guidelines for the classification of areas where flammable gas or vapour risks might arise, covering the range of activities required (monitoring, ventilation, design guidance and more) prior to establishing an EPL and selecting hazardous area equipment. Hazardous area definitions throughout this document are as per those listed in AS/NZS 60079.10.1. and other parts of the AS/NZS 60079 series.

This guideline has been written to be simple to understand by a technical professional with experience in the water and wastewater sector. However, classification of assets should ultimately be provided by an experienced hazardous area classification professional who is appropriately trained in accordance with AS 4761.1. Many of these professionals have backgrounds in other technical industries, such as oil and gas, where the levels of uncertainty are often lower. This guideline should be used as a reference and, in certain cases as a tool, to inform their decision making for the specific challenges of the water industry.

GLOSSARY

Abbreviation	Definition
AS	Australian Standard
ACPH	Air Changes Per Hour
BOD	Biological Oxygen Demand, usually measured over 5 or 7 days, the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions
CFD	Computational Fluid Dynamics
COD	Chemical Oxygen Demand, the amount of dissolved oxygen that must be present in water to oxidize chemical organic materials such as hydrocarbons
DBYG	Dial Before You Dig
Deflagration	Combustion which propagates through a gas or across the surface of an explosive mixture at subsonic speeds, driven by the transfer of heat
Detonation	A flammable mixture of gas which has supersonic flame propagation velocities, and substantial overpressures (up to 2 megapascals (MPa). The mechanism of detonation propagation is a powerful pressure wave that compresses the unburnt gas ahead of the wave to a temperature above the autoignition temperature, rather than the conduction of heat.
DDT	Deflagration to detonation transition. A phenomenon in ignitable mixtures of a flammable vapour/gas and air (or oxygen) when a sudden transition takes place from a deflagration type of combustion to a detonation type of explosion.
EEHA	Electrical Equipment in Hazardous Areas
ε (epsilon)	epsilon, the mixing effectiveness factor, applied to the airflow calculated in the provided calculations to increase required air flow in cases where air movement is restricted from mixing
EPL	Equipment Protection Level, which indicates the likelihood that an item of equipment can become a source of ignition. Three standard levels are Xa (most conservative), Xb and Xc (least conservative) where X is either G (gas), D (dust) or M (mines). This guideline deals only with flammable gases, so EPL ranges from Ga to Gc.
Explosive (gas) atmosphere	Mixture with air, under atmospheric conditions, of flammable substances in the form of gas or, vapour, which, after ignition, permits self-sustaining propagation

Abbreviation	Definition
Extent of zone	Distance in any direction from the source of release to the point where the gas/air mixture has been diluted by air to a value below the lower explosive/flammability limit.[1]
FAE	Fuel Air Explosive, such as thermobaric bombs
FID	Flame Ionisation Detector, a type of monitoring technology
FIP	Fire Indicating Panel, a panel which shows the fire department information about a building's heat, smoke and ventilation sensors in a single location
Flammable gas/vapour	Gas or vapour which, when mixed with air in certain proportions, will form an explosive or flammable gas atmosphere
Flammable liquid	Liquid capable of producing flammable vapour under any foreseeable operating condition
GC-MS	Gas Chromatography – Mass Spectrometry, a type of sampling technology
Grade of release **Continuous grade** **Primary grade** **Secondary grade**	There are three basic grades of release, listed below in order of decreasing frequency and likelihood of the explosive gas atmosphere being present: Release which is continuous or is expected to occur periodically or occasionally during normal operation Release which can be expected to occur periodically or occasionally during normal operation Release which is not expected to occur in normal operation and, if it does occur, is likely to do so infrequently and for short periods
Hazardous (gas) area	From the standard AS 60079.10.1: 2009. An area in which an explosive gas atmosphere is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment From the federal safety model code of practice: *"(a) an explosive gas is present in the atmosphere in a quantity that requires special precautions to be taken for the construction, installation and use of plant; or* *(b) a combustible dust is present, or could reasonably be expected to be present, in the atmosphere in a quantity that requires special precautions to be taken for the construction, installation and use of plant."*[2]
Hazardous atmosphere	From the federal safety model code of practice: *"(2) An atmosphere is a hazardous atmosphere if:* *(a) the atmosphere does not have a safe oxygen level; or*

[1] This includes a safety margin and is based on assumed initial conditions

[2] Model WHS regulations

Abbreviation	Definition
	(b) the concentration of oxygen in the atmosphere increases the fire risk; or *(c) the concentration of flammable gas, vapour, mist or fumes exceeds 5% of the LEL for the gas, vapour, mist or fumes; or* *(d) combustible dust is present in a quantity and form that would result in a hazardous area."*[3] Note that this definition has not yet been adopted for use in everystate and territory.
HRT	Hydraulic Residence Time
H_2S	Hydrogen Sulphide
IEC	International Electrotechnical Commission
IR	Infrared
LEL/LFL	Lower Explosive or Flammability Limit, the concentration of flammable gas, vapour, or mist in air below which an explosive gas atmosphere will not be formed
Linear Infrastructure	An asset related to moving wastewater through sewerage network, such as MH or pumping station
MB	Methanogenic Bacteria
MH	Maintenance Hole
MTBF	Mean Time Between Failures, a measure of the failure rate of a plant item
Normal operation	Situation where equipment is operating within its designed parameters Note 1: Minor releases of flammable material may be a part of normal operation. For example, releases from seals which rely on wetting by the fluid which is being pumped are considered minor releases Note 2: Failures (such as the breakdown of pump seals, flange gaskets or spillages caused by accidents) which involve urgent repair or shutdown are not considered to be part of normal operation nor are they considered to be catastrophic Note 3: Normal operation includes both start up and shutdown conditions
Network	A term for the various pipes, maintenance holes, pumping stations, holding tanks etc. which make up the sewerage system
Non-hazardous area	An area in which an explosive gas atmosphere is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment

[3] Model WHS regulations

Abbreviation	Definition
PCBU	Person Conducting a Business or Undertaking, a WHS term in NSW and QLD for the entity or person ultimately responsible for the safety of those working for them
PID	Photo-Ionisation Detector, a type of monitoring technology
RF	Radio Frequency
RTU	Remote Telemetry Unit
SOP	Standard Operating Procedure, describing how a process is operated during start up, shut down, automatic, and any emergency scenarios. Some overlap with UPG
Source of release	A point or location from which a gas, vapour, mist or liquid may be released into the atmosphere so that an explosive gas atmosphere could be formed
SRB	Sulphate Reducing Bacteria
SRT	Solids Residence Time
Threshold Value	A value, in percent LFL, above which the likelihood of explosion is deemed suitable for classification as a hazardous area. Ranges from 5% LFL (most conservative) to 40% LFL (least conservative)
UK HSE	United Kingdom Health and Safety Executive, a work health and safety regulator similar to SafeWork Australia
UPG	Unit Process Guidelines, describing the performance characteristics of a process, validation criteria, operating modes. Some overlap with SOP
UEL/UFL	Upper Explosive or Flammability Limit, the concentration of flammable gas, vapour, or mist in air above which an explosive gas atmosphere will not be formed
WHS	Work Health and Safety
Vapour pressure (P_v)	Pressure exerted when a solid or liquid is in equilibrium with its own vapour. It is a function of the substance and the temperature
Ventilation	Movement of air and its replacement with fresh air due to the effects of wind, temperature gradients, or artificial means (for example, fans and extractors)
VOC	Volatile Organic Compound
VT	Ventilation Threshold value, the modified threshold value for the selection of a ventilation rate. Ranges from 5% LFL (most conservative) to 25% LFL (least conservative)
z	Turbulence factor, applied to the calculated airflow used in the ventilation calculations provided to account for surface turbulence
Zones	Hazardous areas are classified into zones based upon the frequency of the occurrence and duration of an explosive gas atmosphere as follows:
Zone 0	An area in which an explosive gas atmosphere is present continuously or for long periods or frequently
Zone 1	An area in which an explosive gas atmosphere is likely to occur in normal operation occasionally

Abbreviation	Definition
Zone 2	An area in which an explosive gas atmosphere is not likely to occur in normal operation but, if it does occur, it will exist for a short period only

1. INTRODUCTION

Around Australia, the sewerage system encompasses thousands of kilometres of pipework, maintenance structures and pumping stations, and hundreds of treatment plants. Managing the potential for explosive and flammable atmospheres in these assets is critical to the safety of workers and the public.

1.1 Need for the guideline

In both regional and urban areas, potentially flammable atmospheres are occurring in wastewater assets. Flammable or explosive atmospheres have been responsible for incidents and near misses such as the below examples from the Australian wastewater industry over the past 20 years:

- Explosion in a digester gas cogeneration system causing personal injury to a worker
- Explosion in a residential home, where methane gas backflowing from a pumping station was ignited, causing damage to a customer's bathroom
- Ignition of the atmosphere underneath a wet well pumping station causing forceful ejection of the pumping station lid
- Ignition of the atmosphere at an inlet works due to repair work on a connected pipe

As a result of these incidents, and as appreciation of the risks associated with explosive atmospheres has increased, many water agencies have created their own internal management plans to advise on minimum standards regarding potentially explosive atmospheres. These plans have been aimed primarily at assets in treatment plants and have been developed in isolation or with limited cross-collaboration with broader industry. While there are relevant Australian standards for the determination of zoning and selection of equipment in hazardous areas, the existing standards can be ambiguous as to their direct application to common water industry practices. Internationally, wastewater assets have been zoned on a risk-based approach, with both national level guidelines and those developed by individual water agencies.

To provide a unified, nationally accepted approach, the working group identified three key items to be addressed by this guideline:

- Hazardous area consultants from different industry backgrounds unaware of the specifics of wastewater collection and treatment, leading to a lack of consistency in asset classification across asset bases.
- A lack of broad industry knowledge regarding hazardous atmospheres and their causes in wastewater linear infrastructure
- The desire to provide a framework which could provide consistency and reference to industry on the classification of wastewater networks and treatment plants, while providing some flexibility which allows for the circumstances unique to each water agency

This document aims to address these knowledge gaps and provide a consistent basis from which water agencies can determine their approach to hazardous area management in their asset base. This content is intended to inform and recommend rather than prescribe, as it is recognised that each agency will have different standards and risk frameworks. It is also intended that this document be live, evolving along with ongoing industry feedback, data sharing and changing Australian standards and legislation.

1.2 Explosive atmospheres, duty of care and relevant legislation

Managing the risks of hazardous or explosive atmospheres in the workplace is a requirement in the model code of practice issued by Safe Work Australia, the federal safety regulatory authority[4]. This code of practice states that:

> "*A person conducting a business or undertaking must manage the risk to health and safety associated with a hazardous atmosphere or an ignition source in a hazardous atmosphere at the workplace.*"[5]

For confined space entry, many States set an upper limit of 5% of the Lower Flammability Limit (LFL) in the atmosphere. 100% LFL is defined as the concentration (in air) at which a substance is present in sufficient concentration to cause an explosion. In states such as New South Wales and Queensland, the definition of a hazardous atmosphere is defined as 5% LFL in any workplace atmosphere a Person Conducting a Business or Undertaking (PCBU) has control over[6][7]. These states have adopted Division 8, 51 Section 2 of the Safe Work Australia Model Work Health and Safety Regulations which state:

> *"(2) An atmosphere is a hazardous atmosphere if:*
>
> *(a) the atmosphere does not have a safe oxygen level; or*
>
> *(b) the concentration of oxygen in the atmosphere increases the fire risk; or*
>
> *(c) the concentration of flammable gas, vapour, mist or fumes exceeds 5% of the LEL for the gas, vapour, mist or fumes; or*
>
> *(d) combustible dust is present in a quantity and form that would result in a hazardous area."*[8]

In the same document, Section 1.1.5, a hazardous area is defined as:

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[4] **Each State in Australia has their own Work Health Safety regulator which determines whether a Code of Practice defined by Safe Work Australia is applicable to that State.**

[5] **SafeWork Australia, Managing Risks of Hazardous Chemicals in the Workplace: Code of Practice, 2020, ISBN 978-0-642-78335-6**

[6] **Hazardous atmospheres | SafeWork NSW**

[7] **Controlling fire and explosion risks | WorkSafe.qld.gov.au**

[8] **Model WHS regulations**

"(a) an explosive gas is present in the atmosphere in a quantity that requires special precautions to be taken for the construction, installation and use of plant; or

(b) a combustible dust is present, or could reasonably be expected to be present, in the atmosphere in a quantity that requires special precautions to be taken for the construction, installation and use of plant."[9]

A hazardous atmosphere and a hazardous area are therefore defined differently. In the federal model code of practice, the PCBU is called upon to manage the risks of hazardous atmospheres, with hazardous area being used only in relation to dust. In addition, every electricity safety Act in all states requires compliance to AS/NZS 3000. AS/NZS 3000 in turn references AS/NZS 60079.10.1, which is concerned with hazardous areas and not with hazardous atmospheres. In this way, there can be conflict between the requirements of WHS legislation and the requirements of the Australian standard for the management of airborne contaminants which could lead to a potentially explosive atmosphere. This guideline considers that the limits set by the WHS legislation in the State or Territory where the water agency is operating should be used, however recognises that this may conflict with guidance provided in AS 60079.10.1.

In the water industry, water agencies encounter situations where concentrations may be greater than 5% LFL in two common work scenarios:

- Where staff or contractors enter a wet well, maintenance structure or gravity main to carry out repair, maintenance, or inspection activities
- Where staff or contractors work in or adjacent to an area of a treatment plant which may contain a flammable atmosphere e.g. an inlet works or a digester

For these tasks, water agencies have the same responsibility and duty of care that any PCBU has to its employees or contractors.

In the case of a wastewater treatment plant, where access to the plant is generally secure and members of the public are under the supervision of trained staff, the risk of an accidental or unmitigated exposure to atmospheres above 5% LFL is low.

In the case of the linear infrastructure, where assets do not have permanent staffing available and are in some cases easily accessible to the public, it is possible that a member of the public could become exposed to atmospheres above 5% LFL e.g. at a malfunctioning inlet cowl, a leaking maintenance hole or an open pumping station wet well. This may constitute an exposure of a visitor to a water agencies' "workplace atmosphere" i.e. an atmosphere over which a water agency has control as a PCBU. In addition, any ignition which could have been reasonably foreseen may have consequences which may be the responsibility of a water agency. This should be confirmed by a combination of expert engineering opinion and independent legal advice, whether broadly or on a case-by-case basis as appropriate, and may be especially impactful for assets near residential or commercial premises. A decision on this risk, based on both legal advice and internal or

[9] **Model WHS regulations**

external engineering judgement, is crucial in informing an individual water agencies' approach to hazardous atmospheres. The toxicity risk must also be considered; an area may be non-hazardous in terms of its potential for explosive atmosphere but exceptionally hazardous when considering exposure to toxic chemicals.

Due to the differences in the legislative environment between states, the classification framework this guideline describes contains discussion on the threshold value by which a water agency defines an area to be "hazardous" in the sense that the atmosphere may be potentially explosive. The threshold value should be informed by relevant state legislation, internal assessment of risk and community expectation. By assessing the likelihood of breaching the threshold value, and mitigating the effects of this breach should an assessment reveal that a breach is possible, water agencies can comply with their duty of care to their staff, contractors and the community they serve.

1.3 Structure

This guideline is structured in the following way:

- Chapter 1 introduces the guideline, its intent, some legislative background and a discussion of issues not discussed by the guideline as they are covered elsewhere
- Chapter 2 discusses flammable atmospheres which may be present in the wastewater system and their likely sources, providing some examples of common LFL events
- Chapter 3 provides guidance and recommendations on monitoring instruments and sampling campaigns
- Chapter 4 discusses how this guideline interacts with current Australian standards and provides guidance and interpretation for the water industry
- Chapter 5 provides a framework for generating a classification for wastewater conveyance linear infrastructure
- Chapter 6 provides guidance and advice on common wastewater treatment processes and a suggested minimum classification or suggested classification logic for use in detailed zoning exercises
- Chapter 7 provides commentary on zoning extents for linear infrastructure and wastewater treatment plants and the importance of well-designed ventilation
- Chapter 8 discusses mitigation measures and emergency responses to a flammable atmosphere, including guidance on implementation
- Chapter 9 provides selected case studies for reference, using the guidelines to classify them
- Chapter 10 provides zoning diagrams for some common cases

1.4 Use of the guideline

This guideline is intended to inform the water industry by providing reference information for hazardous area professionals, water agencies and design engineers about the likelihood of hazardous areas in wastewater networks and wastewater treatment plants.

Although the advice provided in this guideline is intended to inform future works in both network and treatment environments, there are many existing assets in use nationally which may not have been designed according to the concepts and recommendations outlined herein. This represents a challenge for many water agencies, as there are many assets of concern present in the network which have not previously been considered. For example, there are currently pumping stations, zoned as non-hazardous, which have monitoring data regularly exceeding 25 to 40% of the LFL. Many of these assets are located in highly developed urban areas, where an ignition or explosion may present a risk to the community.

It is recommended that all future greenfield work and brownfield upgrade, repair or rehabilitation work consider hazardous areas. It is recognised that this work is additional to current practice at many agencies and will therefore have a cost impact. However, as the range of monitoring data collected by water agencies increases, this data can be used as a reference in greenfield constructions and the costs associated with the additional work can decrease. This guideline encourages data sharing between agencies in the same state, or agencies with similar asset profiles, to create a wealth of sample data which can be used to inform planning and decision making.

1.4.1 High risk locations

Water agencies are recommended to investigate hazardous areas in their asset base in locations deemed high risk prior to a potential explosive event occurring.

This guideline defines a high-risk location as an asset which may have one or more of the following features:

- Be in a predominantly industrial area or convey predominantly industrial influent.
- Be the subject of odour complaints, especially where these complaints are of a nature **other than** "rotten egg" or "sulphur" smells e.g. "solvent" or "chemical" odour
- Have observed histories of oily sheen, chemical or unusual scum on the wastewater surface
- Have frequent confined space entries where greater atmospheric control is needed due to the 5% LFL limit being breached
- Have a monitoring history which demonstrates the need to change the zoning of the asset
- Have upstream conditions suitable for the generation of methane gas

Prioritisation of which existing assets to investigate for potential re-classification is best achieved with a risk assessment approach. We encourage water agencies to modify the suggested priorities to best suit the risks associated with explosive atmospheres in their asset base.

1.5 Areas not considered

To provide relevant and concise commentary, there are some areas which have a relationship with the management of potentially explosive atmospheres which are not covered by this guideline.

1.5.1 Toxicity

One aspect which may occur simultaneously with an explosive atmosphere is a toxic or harmful atmosphere. The working group noted an incident where several workers who were preparing for entry into a sewage pumping station wet well were hospitalised. This occurred due to the fumes of solvents, which had been discharged into the sewer, escaping into the atmosphere. There will be cases whereby the threshold value decided upon by a water agency for control or management of an explosive atmosphere will be insufficient to control harmful exposure to toxic or poisonous substances present in the atmosphere. This is particularly relevant in illegal discharges associated with illicit drug manufacture.

Exposure standards are published by the federal safe work authority, Safe Work Australia[10]. These are generally incorporated into law by the various state bodies, with any state-based changes being taken into account at this stage. A key example of a compound found in trace amounts in most gravity sewers in the country is gaseous hydrogen sulphide (H_2S). Due to the large amount of H_2S required to meet the LFL, it is unlikely to be a contaminant of concern with regards to its explosivity risk. However, with Workplace Exposure Standards (WES) mandating an 8-hour time weighted average of 10 ppmv[11], H_2S may become a contaminant of concern for the design of any ventilation system. It should not be assumed that control of explosive atmospheres is sufficient to control toxicity risks; these risks should be assessed independently for their impact on wastewater infrastructure design.

In line with the above, this guideline does not provide advice regarding procedures of safe work and the control of atmospheres. An example of this is entry into a gravity sewer for cleaning or de-silting, whereby gas monitoring and ventilation are required as part of minimum confined space practice. This is left to the individual agency to determine in accordance with their local legislative environment.

1.5.2 Chemical compatibility

An area which is not covered in this guideline is explosions or auto-ignition caused by chemical incompatibility and reaction.

There are many instances where chemicals coming into contact with each other can cause explosive reaction (such as flash vaporisation) or explosive compound formation and subsequent detonation. Two such examples of this are sodium hypochlorite and acids (flash

[10] **Workplace exposure standards for airborne contaminants (2019) – note most of these limits are under review and may change within the next 12 months.**

[11] **At time of writing, Safe Work Australia has nominated a reduction in this limit to 1ppmv**

vaporising and forming steam/chlorine gas), and mixture in air of sodium hypochlorite and ammonia (forming a UV sensitive high explosive, nitrogen trichloride).

These reactions and reaction products can be significant risks, causing injury or asset damage, from either one or both of an explosion or toxic atmosphere.

Storage and the use of chemicals should be checked by safety in design procedures prior to implementation. Other than the storage of flammable liquids and gases, and potential flammable atmosphere generation, chemical incompatibility or other aspects noted above are not covered in this guideline. Water agencies are however encouraged to consider these issues during normal safety in design protocols in design of such facilities. With robust safety in design procedures, the risk of this is low in a treatment plant environment. Although possible in a wastewater network environment, mixtures of this nature are generally not encountered in these settings due to the diluting effect of the wastewater.

1.5.3 Dust hazards

As part of standard hazardous area classification, and as per the definition of a hazardous area, the risk of a combustion due to dust generation should also be considered. This is of great importance in industries such as sugar processing, the likelihood of an explosive atmosphere forming due to dust concentrations is high.

In the conveyance of wastewater, combustible dusts are seldom encountered. In a wastewater treatment plant environment, there are a few areas where the potential for a hazardous area may exist. These are:

- Powdered polymer preparation areas
- Certain chemical areas, such as granular calcium hypochlorite
- Activated carbon installations, such as those in use for odour control systems (note that powdered activated carbon or granular activated carbon systems, such as those found in drinking water treatment, may also fall under this category)
- Sludge silos, where sludge has dried and is at risk of being aerosolised through dislodgement

These areas require special consideration and are often resolved in conjunction with a supplier, or with specific reference to the actual installation. For this reason, it is difficult to discuss combustible dust atmospheres in general, and even more difficult to make general recommendations. This guideline therefore does not apply to these areas, and water agencies and hazardous area professionals are encouraged to apply AS 60079.10.2 in classifying any areas which they believe may be susceptible to the build-up of combustible dusts.

1.5.4 Sources of ignition

There are many potential sources of ignition of a flammable atmosphere that can occur during normal or abnormal operation. These include, but are not limited to:

- Mechanical spark caused by installed equipment which is not inherently safe for the atmosphere in which it is used
- High ambient or process temperatures
- Mechanical spark caused by temporary equipment which is not safe for the atmosphere in which it is used e.g. tanker truck hose with aluminium camlock fitting
- Reactions such as the thermite reaction, which are created by striking an aluminium object with a rusted iron (iron oxide) object
- Pyrophoric sparks, which can occur when hydrogen sulphide and oxidised (rusted) iron react to create iron sulphide. Iron sulphide, when exposed to oxygen, rapidly releases large amounts of heat
- Electrostatic charge
- Ultrasonic and radar signals from instrumentation
- Nearby radio infrastructure and the associated inadvertent spark from their signals. Refer to PD CLC/TR 50427 – *Assessment of inadvertent ignition of flammable atmospheres by radio-frequency radiation - Guide for more information but long wave radio, radar communication and shipping communication represent the highest level of risk of radio frequency (RF) induced ignition*. In general, radio power below 5 W will not cause any issues.
- Work activities in and around the asset, such as:
    - Welding, including plastic welding
    - Grinding
    - Drilling
    - "Hot" cutting
    - The use of certain manual tools
- Smoking around assets
- Improper electrical installations or electrical failures, including degradation over time (e.g. due to long-term exposure to H_2S)

It should be noted that there can be other external factors that can lead to sources of ignition, such as embers in the air in bushfire affected areas or in campgrounds where fires are allowed, which the zoning of an area and the subsequent protections put in place will have no ability to impact.

The source of ignition does not impact the hazardous area assessment, as the assessment is based on the likelihood of a hazardous area occurring, not the likelihood of that atmosphere igniting. The zoning of a hazardous area, and the required equipment to be placed inside the zone as well as other administrative procedures, is intended to protect against the likelihood of a hazardous atmosphere igniting.

1.5.5 Prescription of hazardous areas

This guideline does not provide prescriptive, detailed design level advice for classification of hazardous areas. Although there are some reference zoning diagrams which can be used and adapted by water agencies, this guideline cannot replace the need for detailed design involvement by a qualified, competent design professional. The diagrams are intended as examples to assist hazardous area assessment and cannot be used in replacement of one.

2. FLAMMABLE ATMOSPHERES IN THE SEWERAGE SYSTEM

2.1 Contaminants of concern

2.1.1 Methane and hydrogen sulphide

2.1.1.1 Natural sources

Traditionally, analysis of explosive atmospheres in wastewater assets has covered the two major gaseous by-products of the natural organic material present in raw sewage. The first of these is H_2S. When sulphide has developed in a sewer, often due to long retention times and the impact of biomass in the pipework (particularly sulphate reducing bacteria (SRB) in the biofilm), some of that dissolved sulphide can be present in the form of H_2S. Molecular H_2S can then be released from the liquid phase into the gas phase. The relationship between different sulphide species in sewerage is described by Equation 1 and a conceptual view is provided in Figure 2-1.

Equation 1: $S^2 + 2H^+ \leftrightarrow H + HS \leftrightarrow H_2S$

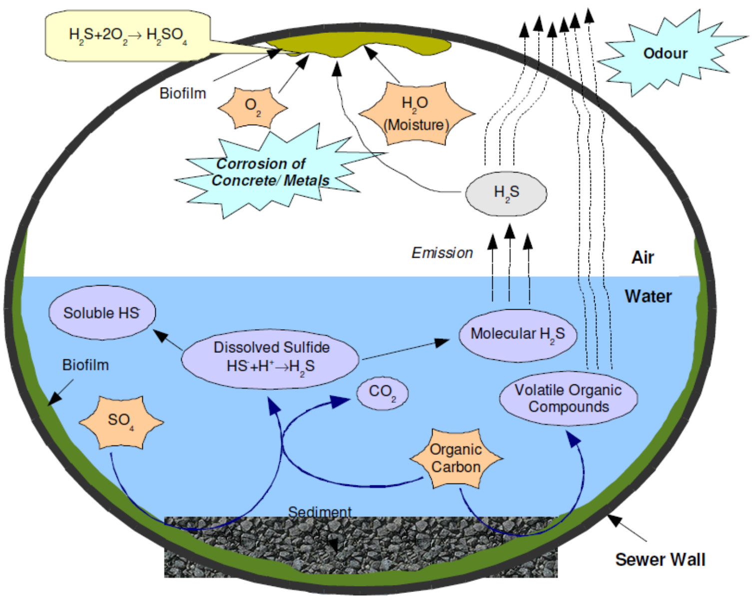

Figure 2-1: Showing the pathway by which sulphuric acid is created in wastewater networks (adapted from Capati et al, 2008)[12]

[12] **Capati B., Corrie, S., Sikder S., Hollingsworth A., 2008, H_2S Modelling – a step ahead to minimum odour and corrosion, MWH Australasian Water & Sewer System Modelling Seminar**

H_2S has a LFL of 4% by volume, corresponding to 40,000 ppmv. These concentrations are exceptionally rare in practice, with more common concentrations in the range of 1 to 1,000 ppmv depending on the hydraulic characteristics of the system. H_2S rarely becomes a contaminant of concern in the formation of explosive atmospheres in wastewater systems, although it remains a primary concern for water agencies due to its health and safety impacts, effect on corrosion (due to formation of sulphuric acid by thiobacillus) and odour emissions.

In competition with the SRBs for the hydrogen released by the organic matter in wastewater are methanogenic bacteria (MB). Gaseous methane production is positively correlated with, among other things, increasing hydraulic residence time (HRT) of wastewater in the sewerage system, as methane and sulphide are the final products of bacterial metabolism. A diagrammatic representation of the degradation pathways is presented in Figure 2-2[13].

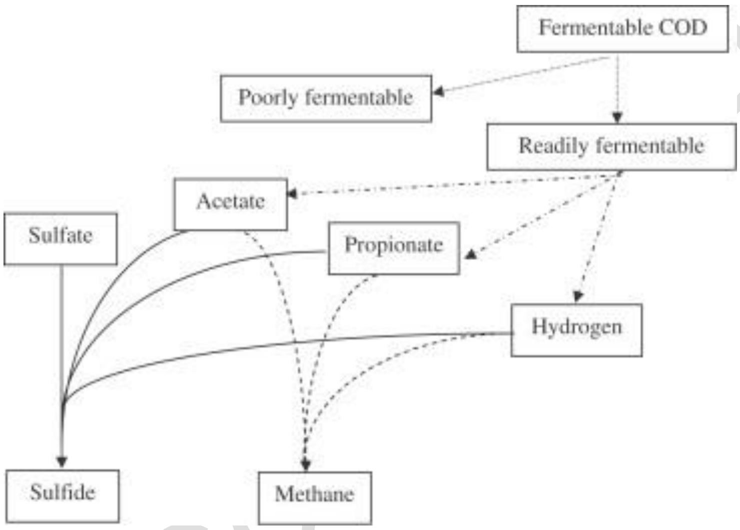

Figure 2-2: Generation of methane and sulphide in sewerage systems[14]. Solid lines indicate most common development pathway, dotted lines indicate less common pathway

Methane has a LFL of 5% by volume in air and is a contaminant of concern in wastewater treatment facilities, particularly in sludge storage and processing, as well in certain instances the sewerage network e.g. in structures with very high HRT.

Methane is lighter than air and therefore the gas will tend to rise and leave the structure from any leakage points or vent stacks. The weight of the substance is such that buoyancy induced movement may even dominate a ventilated space.

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[13] Guisasola, A., de Haas, D., Keller, J. and Yuan, Z. (2008). Methane formation in sewer systems. Water Research, 42(6-7), pp.1421–1430

[14] ibid

It is still common practice for hazardous area assessments of wastewater infrastructure to focus primarily on H_2S[15] and methane. The engineering basis of this has historically been that "normal operation" of the sewerage system is predominantly the transport of municipal wastewater, with minor contributions from industrial wastewater not contributing substantially due to the controls in place by the organisation's trade waste policy. If this is the case, the chemical reactions previously discussed lead primarily to these two contaminants of concern. In certain cases, such as an anaerobic sludge digester, this largely holds true.

In the experience of the working group however, other compounds which are encountered in wastewater networks such as volatile organic compounds (VOCs) can have a significantly greater effect.

2.1.1.2 Other sources of methane

Natural gas pipelines (either main carriers or reticulation pipes) can sometimes run near water related assets. Natural gas contains predominantly methane, given an odour by the addition of mercaptan at the processing plant. Ruptures of natural gas pipelines into water related assets is abnormal, however has been known to occur.

In addition to gas pipelines, sewer mains traversing geographical features such as coal pockets or proximity to landfills have been known to result in gas migrating into the underground pipe headspace (such an instance resulted in the Abbeystead explosion, which caused multiple fatalities at a valve house in 1984).

2.1.2 Hydrocarbons

Hydrocarbons are a group of chemicals which contain combinations of hydrogen and carbon. Although methane is a hydrocarbon, when referring to hydrocarbons common industry practice is to refer to substances introduced into the sewerage system either via trade waste discharge or other sources. This is distinct from methane, which can occur naturally in wastewater systems through fermentation and the influence of MB. Hydrocarbons are used in all facets of modern life, particularly in the form of fuels such as natural gas, petrol and diesel. A feature of natural gas and petrol is their combustibility at standard room temperature and pressure. This highly exothermic oxidation-reduction reaction produces carbon dioxide and water. Hydrocarbons generally do not dissolve in water; resulting in a large time spent in the sewerage system and a high risk of flammable vapour formation as they can settle on the surface layer of the wastewater yielding a high vapour pressure.

Petrol has a LFL of 1.4%, diesel fuel has a LFL of 0.6%[16] and natural gas has a similar LFL to that of methane, 4%. The specific hydrocarbon physical and chemical properties also affect

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[15] The LFL for H_2S is 40,000 ppm (4%). It is very rare for this level to occur in wastewater systems which are normally sulphur limited. The biological processes that generate H_2S are similar to those that generate methane, and it is more common for methane to reach the LFL well before H_2S does.

[16] Diesel is considered a combustible rather than a flammable liquid. Refer to AS/NZS 60079.10.1:2009 Ruling 1. Although diesel is a lower risk, there are still instances where it can be a contaminant of concern. Ignition of diesel can still occur through high temperature activities such as grinding or welding sparks.

the explosive atmosphere risk; diesel, with its higher auto-ignition temperature and flash point, is less of a risk than petrol in the same atmosphere[17].

A broader description of VOCs (of which hydrocarbons are a subset) is provided below.

2.1.3 Volatile Organic Compounds

VOCs can be generalised as organic compounds that have a high vapor pressure and low water solubility. VOCs are typically industrial solvents, such as trichloroethylene, fuel oxygenates, such as methyl tert-butyl ether (MTBE), or by-products produced by chlorination in water treatment, such as chloroform. They are often components of petroleum fuels, hydraulic fluids, paint thinners, and dry-cleaning agents. VOCs are common ground-water contaminants.

VOCs can contribute significantly, or solely be responsible for, an explosive atmosphere formation within a wastewater network or treatment plant. A selection of these is presented below.

2.1.3.1 Organic solvents

These chemicals are commonly used as surface preparation in certain coating or painting processes, and as cleaning products in industrial processes. Some examples include:

- Methyl-ethyl-ketone (MEK)
- Methylamine
- Acetone
- Toluene
- Chlorinated hydrocarbons, which although not generally flammable, may breakdown with other products in the sewerage system to produce flammable atmospheres

2.1.3.2 Organic industrial chemicals

These chemicals are present from manufacturing processes, for example in the production of PVC or PE, or in cosmetics or creams. Some examples include:

- Benzene
- Phenol
- Ethylene
- Styrene

[17] **Diesel is considered a combustible rather than a flammable liquid. Refer to AS/NZS 60079.10.1:2009 Ruling 1. Although diesel is a lower risk, there are still instances where it can be a contaminant of concern. Ignition of diesel can still occur through high temperature activities such as grinding or welding sparks.**

- Butadiene

2.1.3.3 Drug and pharmaceutical chemicals

These chemicals are used in pharmaceutical manufacture, and in the manufacturing of some illicit drugs. Some examples include:

- Methylamine
- Ethanol
- Ethyl ether
- Isopropanol
- Methanol (particularly in wastewater treatment where it is undiluted)
- Petroleum ether
- Phenol and 3- / 4-methylphenol
- Acetophenone

2.1.3.4 Industrial products

These are paints, thinners and other products used both by residential and commercial customers. Some examples include:

- Formaldehyde (varnishes)
- Xylene (paints)
- Alcohols (cleaning agents)
- Acetic acid (cleaning agents)

2.2 Likely sources

Apart from methane and hydrogen sulphide, which occur via natural pathways (methane migration is also an issue noted below), other compounds which are at high risk of generating flammable atmospheres can come from a variety of sources. An example of which are listed below:

- Trade waste discharge by licensed dischargers, either declared and regular, declared and irregular or undeclared and irregular
- Illegal dumping of material by members of the public or organisations
- Illegal manufacturing processes, such as from undeclared organisations or the manufacture of illegal drugs
- Infiltration of the stormwater system into the wastewater system, either through cross connection or through combined sewerage systems for transport of both stormwater and wastewater

- At the release point of rising mains at discharge manholes or gravity sections where a drop in pressure is accompanied by a drop in methane solubility causing a rapid release of entrained gas.
- Migration of explosive gasses / vapours from underground sources such as coal fields, gas fields (especially those generated by fracking) and landfills into underground pipes and other assets.

In wastewater treatment plants, there are several likely sources of generation, release, or accumulation of these substances:

- In areas where sludge is treated or stored, strongly correlated with Solids Residence Time (SRT)
- In inlet works, which receive the combined effluent of a network and thus have a similar risk profile to that of a network asset
- At the release point of rising mains at inlet works where a drop in pressure is accompanied by a drop in methane solubility causing a rapid release.
- In primary treatment areas, where an inlet works has not effectively removed contaminants
- Chemical areas, which can store flammable chemicals such as methanol for use in wastewater treatment processes

Table 2-1: Selected chemicals that can be found in the sewerage system, their LFL and some potential sources. Note this list is not exhaustive

Substance	LFL	Potential sources
Acetic acid	4%	Fungicide, household cleaner, industrial chemicals, food manufacture, hospitals
Acetone	2%	Solvent, fibreglass and plastics manufacture, pharmaceuticals, limited household products
Alcohols		Dependent on the substance
Benzene	1.2%	Petrol additive, solvent, plastics manufacture, printing industry, painting products
Butadiene	2%	Asphalt production, plastics manufacture, adhesive/sealant production
Diesel[18]	0.6%	Illegal dumping, accidental discharge, traces from sump wash out e.g. automotive industry, stormwater wash out at petrol stations

[18] **Diesel is considered a combustible rather than a flammable liquid. Refer to AS/NZS 60079.10.1:2009 Ruling 1. Although diesel is a lower risk, there are still instances where it can be a contaminant of concern. Ignition of diesel can still occur through high temperature activities such as grinding or welding sparks.**

Substance	LFL	Potential sources
Ethanol	3.5%	Brewery waste, hospitals and other areas using ethanol for sterilisation, pharmaceuticals, plastics manufacture, cosmetics, solvent in other processes
Ethyl ether	1.9%	Plastics manufacture, pharmaceuticals, gunpowder solvent, cosmetics and beauty, petrol additive, paint products
Ethylene	2.4%	Medical applications, metal fabrication, refrigerant, plastics manufacture, textiles manufacture,
Formaldehyde	7%	Disinfection, morgues and hospitals,
Isopropanol	2%	Solvent, electronics manufacture, coating manufacture, pharmaceutical, cosmetics, food manufacture
Methane	5%	Naturally occurring in sewers
Methanol	5.5%	Base chemical for acetic acid, formalin. Additive to natural gases, solvent, production of other chemicals e.g. chloromethane
Methylamine	4.3%	Chemical manufacture, tanning and dyeing processes, plastic manufacture, photography, solvent
Methyl-ethyl-ketone (MEK)	1.9%	Illegal drug manufacture, paint and similar products, fibreglass and plastic manufacture
Natural Gas	4%	Leakage of low/high pressure gas mains, buried natural gas deposits,
Petrol	1.4%	Illegal dumping, accidental discharge, traces from sump wash out e.g. automotive industry, stormwater wash out at petrol stations
Petroleum ether	1.1%	Solvent, laboratories, paints and coatings, pharmaceuticals
Acetophenone	1.1%	Solvents, drug manufacture, plastics manufacture, cosmetics, food manufacture
Phenol	1.7%	Plastics manufacture, pharmaceuticals, explosives
Styrene	1.2%	Plastics manufacture
Toluene	1.2%	Petrol additive, solvent, industrial paint products, plastics manufacture, chemical manufacture, beverage production
Xylene	0.9%	Automotive industry, paints, solvents, lubricants, printing, plastics manufacture, leather and tanning

2.3 Difficulty in measurement

The different sources of flammable substances listed above have varying challenges in quantification and measurement, described below and summarised in Table 2-2.

As there is a strong relationship between HRT (and other factors such as COD, temperature, pH and surface area to volume ratios) and the presence of methane in a sewer system, this allows a degree of predictability as to where methane will occur. Additionally, there are models which can predict the generation of methane in a sewer system. This makes sampling campaigns relatively easy to target and short in duration.

The review of land use and geological features near an asset will provide information on the risk of underground methane migration, again making sampling campaigns relatively easy to target and short in duration.

Explosive or flammable atmospheres are also likely to occur where the wastewater system has a large volume of industrial discharge relative to its residential connection (or where the industrial discharge is small in volume but from high risk sources) or is a combined catchment (i.e. sewers convey both wastewater and stormwater). This is readily observable by the experience of many members of the working group (and international water authorities in the case of combined systems), who report increased issues in these areas. Due to this relationship, selecting sampling locations for a monitoring campaign is more straightforward, although identifying an exact sample point can sometimes prove challenging. Discharge of contaminants of concern by trade waste customers may not always have malicious intent, as most licence to discharge agreements are limited to simple criteria such as flow, pH, temperature, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) or solids. Very few of these agreements prohibit discharge on the basis of flammability. For example, an industrial process may have fully defined their day-to-day discharge for the water agency but failed to consider their seasonal backwash with heavier concentrations of chemicals which may lead to an explosive atmosphere. This can make determining what to sample moderately difficult, as the typical discharges of the businesses connected to the network may not be wholly reflective of the contaminants of concern present over long periods of time. For this reason, sampling durations must be longer to capture seasonal processes.

In the case of illegal drugs or illegal dumping by members of the public, they are disposing of material which they are unwilling (in the case of the public) or unable (in the case of those manufacturing drugs) to dispose of through the proper channels. Certain factors may affect these discharges, such as a restriction of movement leading to increased residential discharge of residential quantities of paints, or a drug lab rotating around a certain residential area. These kinds of discharges are difficult to predict without very long term and constant monitoring and could be the source of a large variety of compounds.

In a treatment plant environment, process units are generally operated in a steady state fashion, with closely monitored inputs and outputs. This allows easier location selection and duration selection, as the plant staff or design engineers will be familiar with the cycles of the plant's operation. However, it can still be difficult to identify contaminants of concern, particularly in pre-treatment and primary treatment modules (which are highly reliant upon the feed network) or those which are not operated in a steady state manner (also such as inlet works or septage/tanker receival facilities).

Table 2-2: Likely source and sampling characteristics

	High hydraulic retention time catchments	Industrial catchments, combined systems	Cross connections, illegal dumping or drugs	Wastewater Treatment Plants
Sample Location Assessment	Easy	Easy/Moderate	Hard	Easy
Sampling Duration	Short	Moderate	Long	Short/Moderate
Sampling Difficulty	Easy	Moderate	Hard	Moderate

2.4 Examples of explosive atmospheres in wastewater/associated assets

Water agency experiences in Australia, as well as international experience, present numerous examples which demonstrate the occurrence and impact of flammable atmospheres being generated in wastewater network. The events listed below can be attributed to specific causes, however there are other events which have occurred which are still to have their root cause identified. Some instructive examples are listed below.

2.4.1 Fuel dumps

A water agency in Australia encountered a situation where waste diesel fuel was dumped into the wastewater system, via a pumping station located in a marina. The fuel subsequently worked its way through the entire wastewater network and receiving works preliminary treatment facility. The discharge was noticed when the treatment plant operator observed the organic layer on the secondary treatment process, together with a strong odour. The network transited by the diesel was considered non-hazardous. The incident caused a major review of all network assets: some of which were reclassified as Zone 1 or Zone 2 environments.

Another water agency had two customers complain of a hydrocarbon smell, resulting in a call out. It was found that a pumping station in the network had reached the LFL and a flammable atmosphere had formed. Hazardous area rated fans were brought in to ventilate, with the pumping station discharged to a holding tank at a treatment plant. The contaminated sewage was gradually introduced into the plant to avoid upset of biological process. Police and fire brigade were called, alerted and on standby.

2.4.2 Illegal drug manufacturing

A water authority in Australia encountered a high concentration of VOCs while monitoring for other contaminants in their network and managed to isolate the discharge source to a certain area. After analysis of the contaminants, it was concluded that the source was a mobile drug lab, moving around a local area and operating out of different locations.

The data recorded by the water agencies collection gas detection equipment (calibrated against isobutylene) over 9 days is shown in Figure 2-3, with the background levels reflective of a domestic catchment (0 to 10 ppm) for the first 3 days. The discharges of volatiles (shown by the 13 peaks) immediately reach the sensor maximum at 15,000 ppm and are thought to coincide with batch production of illicit drugs. These discharges not only cause a toxicity risk, but also a significant explosion risk. Given the recorded values, technology used, and calibration compound it is probable that these events exceeded 100% of the LFL. This water agency has since been working with relevant stakeholders to locate and mitigate these risks.

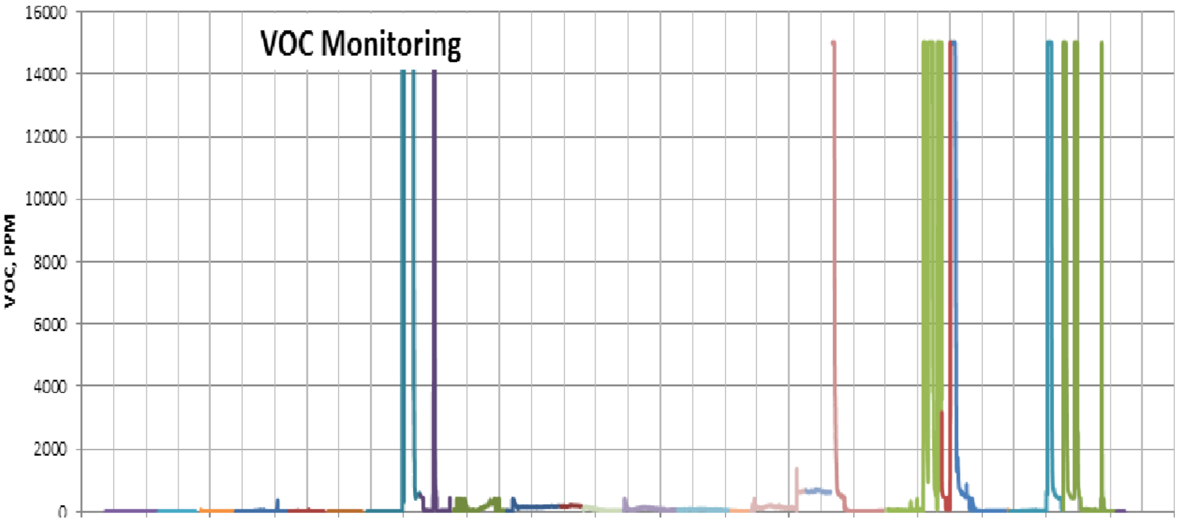

Figure 2-3: Example of VOC monitoring

2.4.3 Industrial catchment pumping station

A water agency in Australia owns and operates a pumping station in a heavily industrial catchment, with very little domestic flow contribution. Monitoring data for this pumping station reveal 294 days (of 1,468 total monitoring days) where the percentage LFL of the atmosphere was above 20%. Full data is shown in Table 2-3.

Table 2-3: Industrial pumping station - days above percentage LFL

LFL (%)	Number of days with a peak value above value nominated
20	64
30	59
40	54
50	39
60	22
70	18
80	17

LFL (%)	Number of days with a peak value above value nominated
90	13
100	8

Although occurring in the late 1980’s, another Australian water agency experienced an explosion of a pumping station so large that parts of the pumping station were forcefully ejected from the ground. This pumping station was a known receiver of heavy industrial trade waste.

2.4.4 Inverted siphon

A water agency in Australia operates an inverted siphon asset. Methane data was collected over a one month period. The methane levels measured in two of the connecting maintenance holes had a 90^{th} percentile value of 17% and 13.4% of the LFL respectively. Operators complain of odours, and access into the infrastructure is limited for safety reasons.

2.4.5 Sewer running alongside gas line

A major sewer in Taiwan ran parallel to a propene gas line. It is thought that propene gas leaked into the sewer. A spark within the sewer is believed to have caused the detonation of the atmosphere within the sewer which caused rupture of the gas pipe and further detonations. 32 people were killed and 321 people were seriously injured.[19]

2.4.6 Inlet works

A large wastewater treatment facility in Queensland has a number of industrial sub-catchments including a large military base. After a discussion with designers and a targeted sampling program, several of the plant areas had to re-zoned, even after mitigation measures were put in place.

The nature of the sub-catchments meant that there was a steady stream of flammable volatiles entering the facility which are generally controlled below 5% LFL by mechanical ventilation by the gas treatment facility (which is fitted with duty/standby fans).

Figure 2-4 shows how rapidly (within 90 minutes) the bulk headspace reaches 30% of LFL in a fan failure event. The flammable vapour concentration was still rising and would have likely reached 100% of the LFL within 3 hours had the fans not been brought back online.

Note that even with duty/standby fan redundancy, the mechanical ventilation still had a failure event leading to a potentially explosive atmosphere being developed.

[19] **https://en.wikipedia.org/wiki/2014_Kaohsiung_gas_explosions**

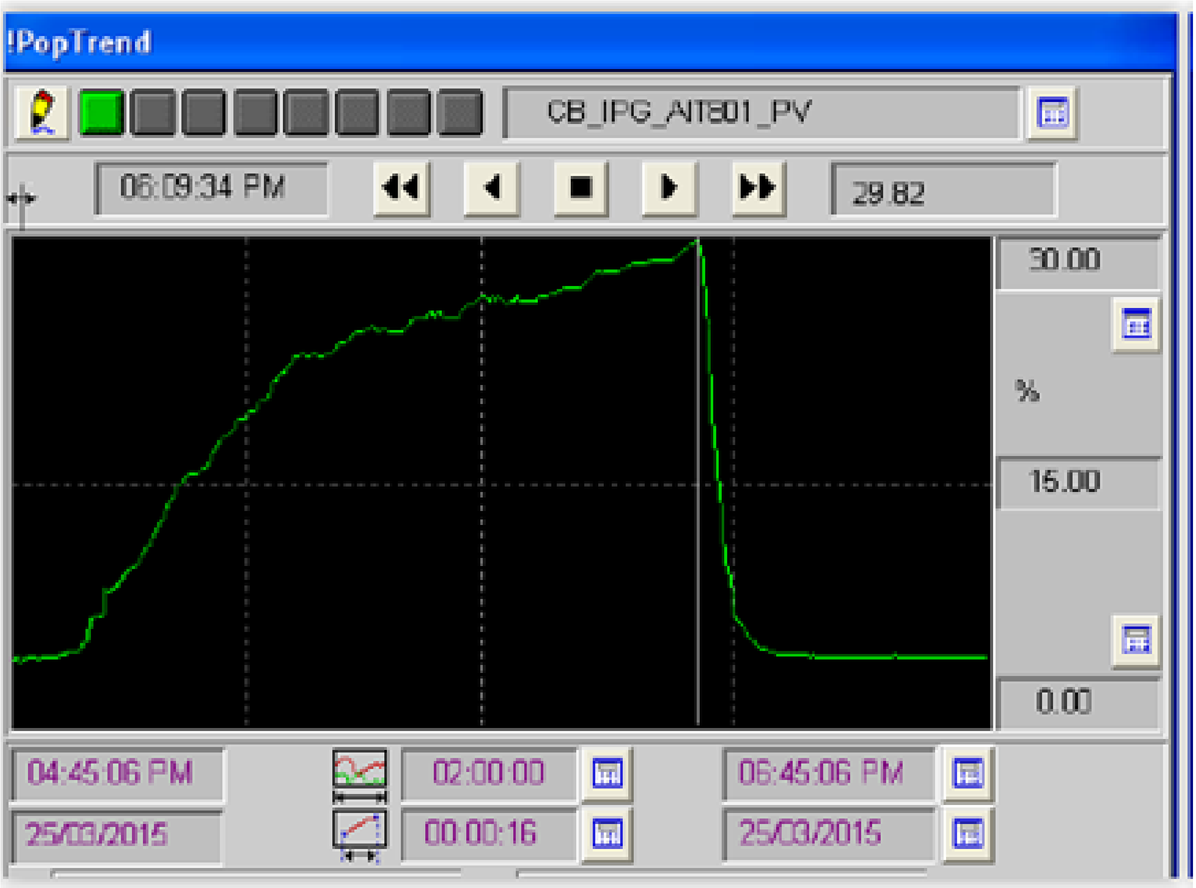

Figure 2-4: Percentage of LFL as recorded at a secondary screens pumping station after an extraction fan failure event, and subsequent re-start.

2.4.7 Sludge infrastructure explosions

A water agency had an injury to a worker who was maintaining a cogeneration engine, which was using biogas generated by anaerobic digestion to create power. Prior to this, hazardous areas were inconsistently applied across its asset base.

Figure 2-5: Ruptured silo at the facility showing the force of the explosion

Four workers were killed in a blast located at a biosolids facility withing a water recycling centre in December 2020. A fifth person was critically injured.

The blast occurred during maintenance work on conveyor feeding a biosolids silo. The investigation into the event is still (at the time of writing) ongoing, however there are (unconfirmed) reports that the workers were using disk grinders on the roof of the silo, a flame arrestor was not fitted to the silo[20] and the explosion was either caused by dust[21] (from dried biosolids) or methane gas.

2.4.8 Storage of flammable materials

In 2006 two workers were killed, and one seriously injured at a wastewater treatment plant in the USA. Workers were removing a steel canopy from the roof of a closed methanol storage tank. The workers were using a cutting torch that likely ignited methanol vapours from the tank and caused an explosion. The explosion led to the release of the total contents of the tank, approximately 11,000 litres of methanol.

[20] New details revealed about fatal Avonmouth explosion at Wessex Water plant

[21] Note that combustible dust atmospheres are not discussed in this guideline

3. MONITORING OF EXPLOSIVE ATMOSPHERES

In order to ascertain the likelihood of an explosive atmosphere forming, or the frequency or extent of this formation, there are a number of sampling and analysis techniques available. This section discusses some of those techniques used successfully for wastewater atmospheric monitoring applications.

Updated in 2016, AS/NZS 60079.29.2 provides a comprehensive discussion of the selection, installation, safe use and maintenance of flammable atmosphere detection equipment. Performance requirements for detection equipment are discussed in AS/NZS 60079.29.1 and in AS/NZS 60079.29.4. For those water agencies who require additional information on this topic, these standards are recommended. The intent of this section is to provide a general guide to instrument and measurement technique selection, such that equipment would be suitable for use in most wastewater monitoring applications.

Monitoring effectiveness is dependent upon a number of factors. These include whether continuous or spot sampling is required, whether the compounds need to be specifically quantified, or whether a specific compound (or group of compounds) is present in the gas phase that may constitute a hazard.

It is important to consider that instruments (even those with very similar specifications) can vary significantly in response time, calibration gas selection and sensitivity. When selecting an instrument for monitoring, discussion with the supplier in regard to the purpose of the monitoring is recommended to ensure that the supplied equipment is fit for purpose.

3.1 Purpose

The monitoring of atmospheres for compounds that may form explosive mixtures with air is generally undertaken for one or more of the following purposes:

1. detect the presence of a flammable atmosphere for shutdown of equipment to prevent or reduce the risk of ignition, or to isolate electrical equipment not rated for hazardous areas.
2. ascertain the likelihood, extent and duration of flammable atmospheres being present to inform decision making for classification of specific assets.
3. determine the specific type (or lack thereof) of flammable compound(s) present or identify specific contaminants of concern so that further action can be taken e.g., provide information to emergency responders, or reduction of risk through modified trade waste agreements.

The type of instrument and the testing used should be selected depending upon the intent and purpose of the monitoring.

3.2 Instrumentation

This section describes the main form of detectors available, their advantages and disadvantages and situations where they are suited. The information is current as of the date of publication of this guideline; over time, this may be subject to change as technologies are refined.

Each of these technologies can be configured to be stand-alone, such that local collection of data is required. Sampling assemblies can also be designed and constructed to output one or more analogue signals for use with a remote telemetry unit (RTU), or to provide a single output covering all assets through technologies such as Modbus over Ethernet or Profibus. Collaboration with the supplier of the equipment can provide a solution which suits the budget and the need of the water agency.

Table 3-1 provides a high-level summary of commonly used sampling technologies currently used by the working group to monitor hazardous areas. Further detail can be found in Appendix C. It is important to note that all online solutions require regular calibration and maintenance. This includes calibrating every month to every 6 months depending on the installation and the device manufacturer's requirements, with potential for additional calibrations in case of poisoning. For hire systems without automatic moisture management, it is often required to empty condensate collection traps, which remove moisture upstream of the sampling point for best accuracy and sensor life. The interval between emptying of traps can range to daily to weekly depending on the installation. Other maintenance may also be required may also be required, such as refilling of gas cylinders or cleaning of sampling points. This should be discussed with any vendor for hire or purchase of equipment.

Table 3-1: High level overview of different sampling technologies

Technology	Type of monitoring	Results	Suggested use:	Key challenges:
Pellistor/ catalytic oxidising	Continuous, logged	Online, 10 – 60 s	Monitoring of broad spectrum of contaminants	Can be poisoned by H_2S and other common compounds, requiring regular calibration
IR absorption	Continuous, logged	Online, 10 – 20 s	Monitoring of most hydrocarbons	Some compounds such as unsaturated VOCs not detected well, requiring prior knowledge of contaminants
PID/FID	Continuous, logged	Online, < 5 s	Monitoring wide range of low concentration VOCs	Can become overwhelmed by high concentrations, if methane monitoring needed a hydrogen cylinder is required
GC-MS	Spot sample	Discrete, 24 – 48 hours	Detailed and accurate breakdown of all contaminants in sample against search library	Sample transportation, discrete samples provide only a snapshot, expensive if multiple

3.3 Limitations and accuracy

It is important to understand the limitations of each technology summarised above. For instance, monitoring for methane emissions would rule out the use of a PID.

Unless a specialist lab is used with a GC-MS or similar technology, the accuracy of all the field instrument assemblies is reliant upon the following:

1. The correct selection of equipment
2. Correct calibration and calibration gas
3. Understanding the effects of humidity on the sensor
4. Understanding the cross-sensitivities and sensitivities of the gas being detected
5. Air movement at the sensor head
6. Particulate contamination or blockage at the sensor head filter
7. Many other factors which are not only technology dependant, but also manufacturer and maintenance dependant.

One of the major factors in determining the accuracy and relevance of any monitoring is the choice of measurement location. In an ideal situation, any contaminant of concern is well mixed within the entirety of the air volume of an asset. In practice, with infrastructure such as pipework and access platforms providing an impediment to the movement of air, there will be differing levels of contaminant at different points in the air space. This is also dependent on the contaminant. For example, petrol is heavier than air and is non-soluble, such that it will sit on a liquid surface and emit vapour. This means that the highest concentration is most likely to be present close to the wastewater surface. It is therefore important to consider both the air movement in the space, as well as the contaminants of concern, when selecting a sampling location.

It must be stressed that sampling campaigns and selecting equipment must be done in conjunction with a suitably qualified specialist or, if the knowledge is contained in-house, with the equipment manufacturer.

3.4 Sampling campaigns

A sampling campaign should be designed around establishing the risk of a flammable atmosphere occurring in an asset. It should therefore be of sufficient duration and breadth to ensure that a representative dataset has been collected.

Generally, assets can be split into two categories: those operating in steady state (where the quality and quantity of the inputs and outputs can be controlled and are relatively predictable) and those which have inputs are unpredictable in nature.

Predictable or steady state processes can be considered, for example, as assets at a wastewater treatment facility downstream of primary treatment, or in a sludge treatment facility with certain exceptions. In such processes technical knowledge of the process and its operation, associated standards and the use of industry standard safety techniques (such as hazard operability studies) can provide suitable hazardous area zoning. This can then be demonstrated or confirmed by relatively short sampling regimes.

Unpredictable processes i.e. those which are not steady state, where the inputs are outside of the control of the asset owner, are more complex and require longer sampling regimes. These generally include network assets, and preliminary and primary treatment assets.

In an ideal situation, the duration of sampling should cover all predictable normal and abnormal operating conditions if the risks associated with the contaminants of concern cannot be reasonably identified with high certainty.

It should be noted that the gaseous areas within chemical storage tanks, where the stored chemical is known, do not require sampling. Correct hazardous area zoning can be determined by simply knowing the tank contents, the storage variables and by the use of existing standards.

3.4.1 Methodologies

Sampling should not be utilised on its own for establishing zonal classification for equipment if the extent and duration of sampling does not cover the main likelihood factors as outlined in Section 5 or Section 6. It can, however, be used as an excellent tool to identify contaminants of concern (and thereby suitable mitigation measures), durations of events and likely responsible source.

In the event that an asset is proposed and not currently constructed and in use (rendering a sampling program impossible) feed infrastructure should be considered for a sampling program, if suitably similar. Where an existing asset is due for replacement, the existing asset can be sampled (for example, the upgrade of an undersized pumping station). Where any sampling is impossible, or the campaign would yield results which are not relevant to the asset under consideration, the use of results from similar assets in a water agency's network can be considered.

It should be noted that, in the event that the asset is being modified, replaced or if the upstream processes predicted to change, those factors should be considered in interpreting the data collected. The addition of an incoming long rising main, for example, to an existing pumping station from a new industrial catchment would increase the methane risk as well as flammable industrial discharge risk.

3.4.1.1 Selection of assets to sample

Linear assets

In linear assets, the risk of a flammable atmosphere being produced is dependent upon a large number of local factors. For example, consider several pumping stations in series. The inflow to each pumping station in the series is the discharge from the preceding pumping station with the addition of local inflows. This case has several scenarios:

i. One pumping station is monitored and recorded as having an atmospheric LFL measurement above the threshold value. This measurement in a single pumping station does not necessarily dictate that all or any of the others will have a flammable atmosphere. The local network inflow may be the cause. When diluted by other inflows, downstream pumping stations may not be likely to have explosive atmospheres.

ii. The last pumping station in the chain is monitored and recorded as having an atmospheric LFL measurement above the threshold value. This may be the only one in the chain to need a hazardous rating, as it is the first point at which the combination of flammables from the previous pumping stations reaches a level of concern.

iii. The pumping station at the beginning of the chain is in a high-risk catchment, susceptible to "dumping" or significant trade waste due to a high commercial/industrial discharger base or in an area with a history of unidentified illegal dumps, causing the entire downstream chain to have an increased likelihood of forming flammable atmospheres. In this example, re-direction of flows to limit the risk of hazardous areas forming downstream or addressing the discharges directly may be more economical than other forms of mitigation.

In a large network, the selection of assets to sample (e.g. pumping stations or trunk sewers) should be made on the basis of the features detailed in Section 5. An initial sampling of a number of pumping stations and/or sewers may then lead to further sampling being required if flammable atmospheres are identified, in order to trace the source or prevalence of a substance.

Treatment plants

On a treatment plant facility, every asset should be considered in a hazardous area assessment. Sampling is only required in those non-steady state processes that are not "standard", don't have examples available, or where the zoning cannot be selected with a high degree of certainty.

For example, anaerobic digestors, CHP engines, secondary digestors, flares, raw sludge processing and storage are all predictable, with zoning achievable without sampling. However sludge or wastewater import facilities, inlet works and primary treatment processes are unpredictable in that the asset owner has little to no control over what is received. Such processes should be sampled as part of a hazardous area assessment, or at least have the risk ascertained using the methodology described in Section 5.

3.4.1.2 Gas sampling locations within an asset

The gas sampling location for any asset should be selected to reflect the true headspace concentrations. Best practice is shown in Table 3-2 below for a number of common assets containing sewage, sludge or biosolids.

Note for sludge dryers, and downstream processes, there is a significant dust explosion risk. This risk is covered in other standards.

Table 3-2: Best practice sampling locations

Asset type	Covered or uncovered	Passive or Mechanical ventilation	Sample location(s) to be included	Reasoning
Tanks, vessels, preliminary & primary treatment processes, wet wells, pumping stations	Both	Passive only	Within tank, just above liquid level	Surface measurements for non-soluble hydrocarbons will be higher than the bulk gas levels due to a concentration gradient forming i.e. the emissions from the liquid layer will mean that there is higher concentration of contaminant at the surface. Covered tanks are at greater risk of forming flammable atmospheres due to lack of wind and limited air volume, slowing dispersion.
	Covered	Mechanical	Within tank, just above liquid level	Surface measurements for non-soluble hydrocarbons will be higher than the bulk gas levels due to a concentration gradient forming i.e. the emissions from the liquid layer will mean that there is higher concentration of contaminant at the surface
			In extraction duct	Measurement of bulk gas concentration to atmosphere or gas treatment. This applies for soluble contaminants or lighter than air gases, as these would be well mixed in the bulk gas phase.
Gravity main/storm sewer/MH	N/A	Passive	Within sewer headspace, above liquid level, at key points down the sewer (such as confluence of sub-mains)	Due to air movement down sewer driven by surface tension will generally cause good mixing and achieve maximum gas phase concentrations – unless the headspace is unusually high (> 1 m) bulk gas detection is sufficient.

Asset type	Covered or uncovered	Passive or Mechanical ventilation	Sample location(s) to be included	Reasoning
		Mechanical	Within sewer headspace, above liquid level, at key points down the sewer (such as confluence of sub-mains)	Due to air movement down sewer driven by surface tension will generally cause good mixing and achieve maximum gas phase concentrations – unless the headspace is unusually high (> 1 m) bulk gas detection is sufficient.
			At extraction fan inlet	Measurement of bulk gas concentration to atmosphere or gas treatment. This applies for soluble contaminants or lighter than air gases, as these would be well mixed in the bulk gas phase.
Buildings containing sewage and/or sludge processes	Enclosed Building	Passive	At low and high points within building – located close to equipment of concern, and away from grilles or other air passage devices.	Upper and lower level sample points to account for varying gas / vapour densities of varying substances. Sample point should be close to the equipment or process of concern, but away from fresh air sources that could dilute the sample and prevent true readings.
		Mechanical	Upper and lower points as per passive ventilation	As per passive ventilation

Asset type	Covered or uncovered	Passive or Mechanical ventilation	Sample location(s) to be included	Reasoning
			In extraction duct (in several key locations depending upon building size)	Measurement of general bulk gas concentration from building. For large buildings with varying use, several points in the ductwork system should be selected to establish if there are any local flammable gas risk areas. Measurement of bulk gas concentration locally in duct system and to atmosphere / gas treatment.

3.4.1.3 Type and duration of sampling needed

Once the assets to be included in the sampling program are selected, the duration of sampling should be such that it includes for all of the high risk normal and abnormal modes of operation. It is generally difficult to predict these periods in network assets, as well as pre-treatment, primary treatment processes and associated facilities. The duration of sampling should be based on an understanding of either the processes involved (at a treatment plant) or on the unique catchment features which dictate the composition and quantity of flows (at a network location). This understanding is a combination of asset owner experience, operator feedback and internal or external engineering advice. Some examples of the factors which can influence the duration of monitoring campaigns for different types of catchments are presented below.

In industrial discharge areas, knowledge of the industry and practices helps in understanding changes in discharges depending upon shift, shutdowns and other factors. For example, flammable liquids may only be used infrequently during seasonal shutdowns.

In residential areas, there may be a large transient population due to vacation areas or seasonal workers. For example, in periods of low flow, hazardous areas may form because of lack of dilution of trade vs domestic waste.

In residential areas with high vacancy, for example, due to mining turndowns) a higher risk of illicit drug manufacture and associated discharges is present due to the lack of population.

In the absence of any guiding factors to determine a monitoring period, the following is suggested as a minimum program per identified asset:

1. An initial 14 days of continuous sampling, with either a combined PID/pellistor type monitor or FID/pellistor type monitor.

   Continuous monitoring for at least this period of time is critical in identifying problem discharges, and to determine baseline levels and any flammable levels of concern. The figure below gives a clear example. A domestic network, with no licenced discharges was reported by operators to have a “solvent” odour every day, early in the morning. In one instance a personal detector was set off.

   7 days of monitoring via PID clearly demonstrated a discharge into the network at the same time each day, with the rapid increase/decrease of concentration reflective of a sudden dump of flammable liquid close to the asset being sampled. This is shown in Figure 3-1.

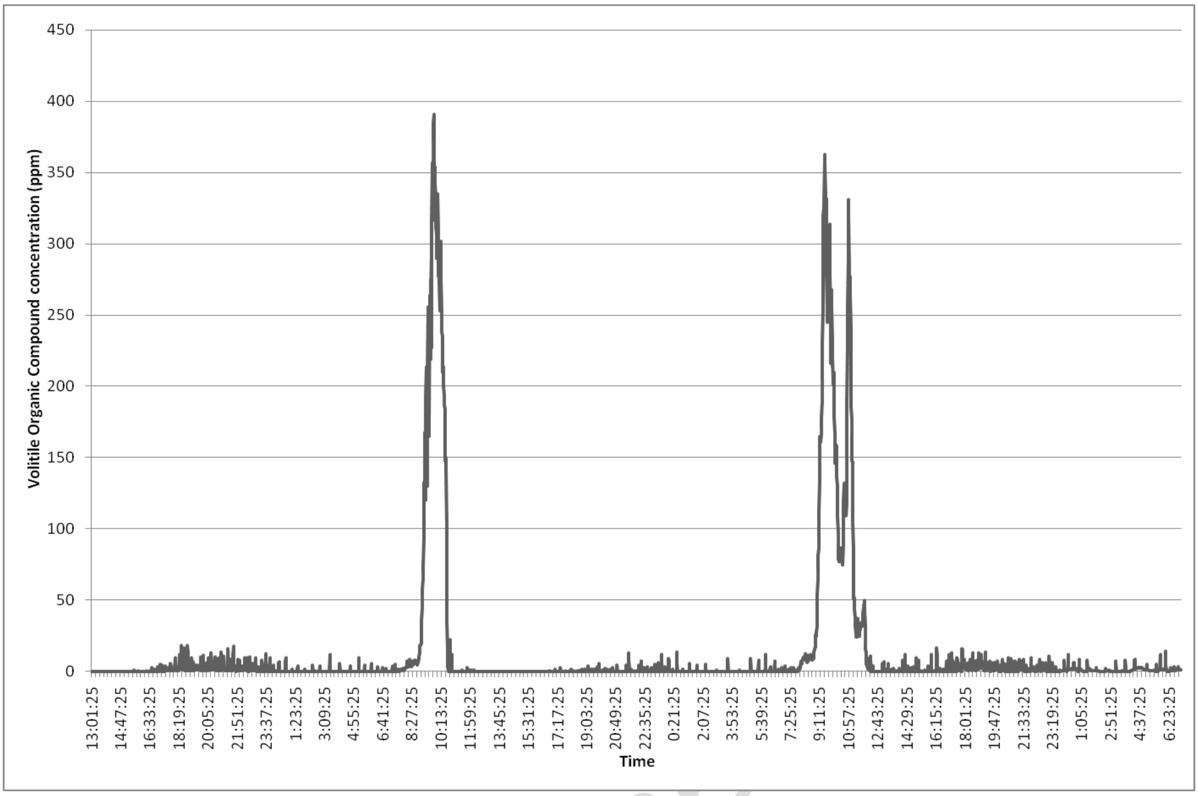

Figure 3-1: Example of Sporadic Industrial VOC Concentrations in Pumping Station Air due to Industrial Discharges into a Sewerage Network

Investigation into the relatively small catchment yielded the cause – a photographer disposing of waste developer fluid each morning. Spot sampling clearly would be unlikely to pick up such an event – thus the requirement for continuous logging.

2. After the first few days of continuous logging, the data should be reviewed to establish concentrations (ppmv or %LFL) of concern and any pattern. If no events occur, then the sampling period should be run to its conclusion, regularly checking the dataset for any events of concern. If any such events are established, do one of the following:
    a. If distinct discharges are evident, spot sample the gas at the peaks and undertake lab analysis to establish the compounds present. This can be costly, but worthwhile if further action can be taken to prevent the discharges or if the type of compound needs to be identified to aid in selecting mitigation technologies.
    b. If there are multiple high concentration events from multiple discharge events, the recorded data is usually sufficient to inform the hazardous area assessment and enable appropriate zoning[22], and required modifications for compliance, is appropriate.

    If no pattern is established after the first 14 days of sampling, continue sampling until a pattern is established or for 28 days, whichever occurs first.

[22] **Multiple peaks during the sample period would generally indicate a zoned area**

3. If the sampling yields conclusive data in line with the other factors identified, then further sampling is not required unless the asset use is changed in any way that changes the risk profile (such as a new rising main discharge being added to a maintenance hole).

Although a pellistor type instrument is referred to above, an IR instrument can also be used, as long as the user has considered the potential compounds present.

3.4.2 Limitations on use and interpretation of data

There are a number of factors which can affect the validity of data from the most comprehensive of sampling programs. Prior to the use of any data, the person charged with interpreting the data should understand how, when and where it was taken.

Initial testing should always be continuous – spot sampling alone can rarely be used to determine risk level. By establishing the pattern of discharge, the peak can then be sampled to identify the contaminants of concern at their worst.

Sampling must consider the intended use of the future or refurbished asset. One of the most common mistakes is measurement from an open structure, which is then used to inform the hazardous area selection in an upgrade which encloses that structure for health and safety, odour or other purposes. In such a circumstance, a temporary cover should be constructed to simulate the build-up of gasses that will occur in the upcoming modification.

Sampling should also consider the weather and flow conditions and the effect of these on the baseline measurement. Any asset which has wastewater flow as a variable will have dilution effects at high storm flows, but also may experience a "spike" in concentration at the start of the storm event due to flushing. Sampling should consider flow changes and storm events, and the potential changes to concentrations present. However, sampling after high flow and storm events will generally not be representative of the normal flow regime of the asset. As a rule of thumb, after the first flush from storm events is captured, sampling should be paused until 10 days have passed. At this point, any high flows have usually returned to normal. Some assets may have two normal conditions. For example, a regional town is a popular tourist destination, with significant additional flows between December and April. This means that there is a "peak season" baseline, and an "off-peak" baseline condition.

If the area of concern includes a combined system (a system which takes both wastewater and storm water) the first flush of a rain event is a critical event that can inform hazardous area assessments.

It is important to note that a sampling campaign may not adequately capture known peaks. Many peaks can be seasonal i.e. every three to four months or even long term, with only a few events per year. By knowing the contributing catchment well enough such that a campaign can be targeted towards suspected peak times (scheduled shutdowns of industrial emitters, off-peak seasons etc.), or by using multiple sampling campaigns at different times of the year, these peaks can be better captured. If doubt exists, assets should have their likelihood of forming explosive atmospheres checked using the methods in Section 5

3.4.2.1 Data confidence

As long as the principles herein are followed, the more data available, the better the outcome of the sampling campaign will be. It is important to ensure that the sampling campaign is fit for purpose. For example, classifying a rising main discharge point solely from data provided by PID would be improper selection of equipment, given the instrument cannot detect methane.

There have been instances where an initial sampling program has shown high VOCs and associated high LFL in the atmosphere. Asset owners can sometimes request additional sampling in the hope that this sampling will provide enough data to ignore the initial dataset, thus overruling the first set of samples taken. In such an instance the additional data does not overrule the risk demonstrated by the previous sampling, it only shows that the high levels do not occur frequently or on a regular basis. A second set of data showing low levels does not allow for a non-hazardous classification, unless the first set of sampling is proven to be in error – or effective mitigation measures (such as discharge enforcement) have been undertaken.

3.4.2.2 Likelihood assessment input

Once sufficient sampling data has been collected, this can be used as an input into the likelihood assessment process.

In some cases, the sampling data can be conclusive enough that a suitable classification can be derived immediately following the conclusion of an initial 28 day campaign, however some datasets are not as conclusive and require further assessment.

A dataset allowing immediate classification would show regular events above the threshold value of LFL in the atmosphere, with GC-MS analysis showing a compound such as petrol (octane and other isomers) being consistently present. Such a combination would be a “worst case” scenario, as petrol quickly forms a surface layer on water spreading out into a very thin film and evaporating. In this situation, at a location near to the liquid surface it is likely that an explosive atmosphere will exist. In such an instance mitigation measures such as ventilation (mechanical or passive) are insufficient to allow a non-hazardous rating to be used. The enclosed headspace and potentially even surrounding assets would require a Zone 1 or 2 classification depending upon frequency, duration and other factors (e.g. pressure).

4. INTERACTION WITH STANDARDS AND GUIDELINES

Having understood the types of contaminants and their likely sources and having discussed how to identify and monitor these contaminants, a strategy can be formulated for classification of wastewater networks and treatment plants. To provide agreement and compatibility with standard industry practice, a thorough review of national and international hazardous area standards was undertaken.

4.1 Relevant standards and guidelines

As part of the development of this guideline, a selection of guidelines and standards specifically addressing hazardous areas were reviewed, as well as other material for reference or background. These are discussed briefly below.

4.1.1 Australian standards and guidelines

4.1.1.1 Standards

As part of the work of this guideline, the following key Australian standards were reviewed:

- AS/NZS 60079.10.1
- AS/NZS 60079.13
- AS/NZS 60079.14

The foundation of area classification for flammable gases and vapour in Australia is AS/NZS 60079-10-1: *Classification of areas - Explosive gas atmospheres*. This standard, adopted from an International Electrotechnical Commission (IEC) 60079-10-1, contains methodologies by which areas can be classified. This is based on either one of the generalised methods or one of the ‘source of release’ methods accepted by the standard (or a combination of the two), with definitions available which define the discharge frequency of sources. There are also methods to ascertain availability of ventilation, appropriate safety factors for ventilation and the effect of ventilation on zoning.

A detailed set of annexes provides reference cases for use, with some specifically targeted at the water industry for areas of release at wastewater treatment plants such as valves, compressors, gas meters, filters and regulators in gas lines as well as areas around sludge digestion tanks. The examples note that the classifications are based on plants with inlet screens and clarifiers open to atmosphere and where they are enclosed (e.g. for odour control) further consideration will be necessary.

AS/NZS 60079.10.1 will be updated in 2022.To understand the forthcoming changes, the IEC standard upon which the majority of changes are based is reviewed in the international standards section below. This change will be both to the document’s structure and content.

AS/NZS 60079.13 covers rooms which are protected by pressurisation “p” or ventilation “v”. It specifies the requirements for ventilation or pressurisation equipment when it is contained in a hazardous area, as well as stipulating requirements for the design, control and documentation of areas served with pressurisation or ventilation. With some rare exceptions (e.g. underground treatment plants with hazardous areas), wastewater applications rarely have ventilation equipment within a zoned area, with only the ductwork internals being classified as a hazardous area. The standard also provides guidance on some general requirement for ventilations. which inform recommendations regarding ventilation outlined in Section 5.

AS/NZS 60079.14 is a standard for the design, installation and initial inspection of electrical equipment in hazardous areas (EEHA). It is a comprehensive resource for electrical designers to use in selecting equipment which is designed and constructed for use in hazardous areas. The standard is designed to be used after a classification has been completed and uses the classification and the intended application to assign an EPL to the required items of equipment. EPL is linked to types of protection (e.g. flameproof, non-sparking, enhanced safety etc.) and ancillary infrastructure is designed to provide this protection. Although critical to hazardous area design and construction, the standard is not of direct relevance to this guideline. It is however referred to by the guideline in one specific case discussed in Section 5, where an increased EPL is assigned to equipment in an area deemed non-hazardous.

4.1.1.2 Australian utility guidelines

The following Australian water utility guidance documents were reviewed in developing this guideline:

- SA Water, TS 0376 *Classification and Design for Electrical Equipment in Hazardous Areas*
- Sydney Water, *Technical Guidance Note TG502: Classification and management of flammable gas hazardous areas*
- Water Corporation, *HA-ST-02 - HA Classification Standard*
- Mackay Regional Council, *83501246-P-003 1 Mackay Sewerage Network Hazardous Zoning Final Report*

SA Water's guidance note provides specific guidance on design preferences but goes further by providing a baseline set of classifications for wastewater treatment plant assets, an overall philosophy for the classifying of wastewater networks, and specific commentary on the use of international standards as well as the details of AS/NZS 60079.10.1. It also covers detail design advice for hazardous areas and preferred parameters for dispersion modelling. Intended as a baseline from which design professionals can provide consistent zoning across their asset base, this guidance note has both prescriptive elements and recommendations.

Both the Sydney Water and Water Corporation standards provide specific guidance on preferences regarding the design process, including competence of personnel, but do not provide classification methodologies or minimum zoning advice. Both documents refer to the advice provided in AS/NZS 60079.10.1 for classification of assets.

As part of an exercise for Mackay Regional Council, in 2013 MWH (now Stantec) assisted Mackay Regional Council in creating a hazardous area classification system. This covered a review of available international standards and the formation of a system of classification with or without available monitoring data. A decision tree which could be used to classify areas was provided for use.

4.1.2 International standards and guidelines

The following international standards and guidelines were reviewed:

- IEC 60079-10-1: 2020, the latest version of the international code for the classification of hazardous areas where flammable gases exist
- (UK) United Utilities Code of Practice (COP) 1, named *Installations in Potentially Explosive Atmospheres* both i7 dated February 2013 and i9 dated March 2021
- (UK) Thames Water SPD E04, named *Zoning of Hazardous Areas*, dated May 2009
- (UK) Scottish Water Section 204, named *Guidance for the Assessment and Zoning of Hazardous Areas*, dated April 2006
- (UK) HSE Executive Dangerous Substance and Explosive Substances Regulation (DSEAR), a collection of WHS legislation from the UK providing guidance on hazardous areas introduced in December 2002
- (USA) National Fire Protection Association (NFPA) 820, named *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*, both the 2020 and the 2012 edition
- (DE) DIN EN 1127-1:2019-10, named *Explosion prevention and protection - Part 1: Basic concepts and methodology*; German version EN 1127-1:2019
- (INT) EI15, named *Area classification for installations handling flammable fluids*, dated June 2015

Due to the global harmonisation of the IEC codes, many countries around the world (EU countries such as Germany, as well as Asian countries such as Japan and China) use standards which are closely modelled on IEC 60079-10-1, as Australia does. For this reason and knowing that AS/NZS 60079.10.1 is soon to be updated with content from its newer IEC counterpart, this standard was reviewed.

The DSEAR regulations in the UK provide a regulatory framework in which the various UK water authority standards operate. The requirements are summarised in *Approved Code of Practice L138*, which sets out requirements for hazardous areas, as well as requirements for explosive dusts and toxic compounds. The fundamental basis of the regulations is a risk-based approach to the control of dangerous atmospheres, the responsibility of which lies with the "employer" or "dutyholder" (similar to Australia's PCBU). This includes requirements and guidance on design, storage, control and safe maintenance in affected areas.

Each of the guidelines from the UK water authorities (United Utilities, Thames Water and Scottish Water) provide guidance on the approach to be used with hazardous areas in wastewater environments. The i7 revision of COP1, and the current revision of SPD E04, are prescriptive in nature although there is a discussion about risk assessment and its application in SPD E04. For network assets, they describe different installation configurations and assign a zone rating based on availability of ventilation and the number of petrol stations and major petrol tanker routes in the asset's service catchment. For treatment plant assets, they provide comprehensive guidance on design, operation and maintenance of assets in hazardous areas and assign zoning classifications to common process units.

i9 of COP1 and Scottish Water’s Section 204 guidelines share a risk-based approach to classification, ventilation and other mitigation factors to assign a classification rating to both network and treatment plant assets. i9 of COP1 removes the prescriptive approach of earlier revisions and provides a framework for risk assessment, with some specifications regarding hazardous area installations and input data to use. Section 204 provides a tightly defined and comprehensive assessment methodology for assigning hazardous area zoning, along with prescriptive commentary on various unit processes as well as various inputs for further risk assessment.

In the aftermath of the Abbeystead explosion (where methane gas migrated into a water pumping station and exploded, killing 16 people) many UK water authorities introduced guidelines tightly prescribing zone ratings for network and treatment plant applications. After the DSEAR guidelines came into effect in the early 2000's, this approach began to shift towards the risk-based framework outlined by regulation, with inputs such as petrol stations in a catchment, degree of ventilation or methane production potential. This shift is clearly evident in the changing requirements of COP1, with Scottish Water's Section 204 providing a hybrid between pre- and post-DSEAR strategies for dealing with risk.

A highly prescriptive approach is evidenced by NFPA 820, which provides the exact zone rating for various network installations and unit processes for wastewater treatment plants. This is accompanied by a reduction in changed zoning requirements at the two different ventilation rates of six Air Changes per Hour (ACH) and 12 ACH, as well as mandatory minimum fire protection infrastructure such as alarms, interlocks and local fire fighting equipment. This provides a straightforward classification but is not flexible. Having reviewed two versions separated by eight years, this approach has not changed; rather, the number of installation cases has increased to provide more examples for design practitioners.

EN 1127-1 is a European Union guideline to the risk assessment process in regard to the management of explosions and explosive atmospheres, in accordance with the European standard for risk assessment and reduction in machinery (EN 120100:2010). The document specifies methods for the identification and assessment of hazardous situations leading to explosion and the design and construction measures appropriate for the required safety of equipment and machinery. Although its focus is on product design, it provides a generalised risk assessment framework which can apply to any system. The standard calls up the use of the EN 60079-10-1 for the classification of hazardous areas yet does not classify hazardous areas itself. By providing a generalised framework for risk classification, the standard provides a strong reference for risk assessments in the water industry, covering not only classification but other factors such as secondary guards, ventilation etc.

EI15 is a model code of practice, targeted primarily at the onshore oil and gas industry. It covers in depth ventilation and the control of contaminants of concern commonly found in oil and gas installations. It uses a method of classification similar to that of AS/NZS 60079.10.1: a point source method, with additional information on the use of a risk-based approach to determining point source sizing. There is also a direct example method, which provides common oil and gas installations and their zoning, which is not relevant to the water industry. The risk-based approach estimates a hole size for a secondary source of release, based on frequency of exposure of workers, probability of ignition and finally release frequency. The standard has guidelines for zoning around vents and stacks, based on air flow rate, pressure and stack size, which may be of use to the water industry. In addition, the ventilation guidelines described by the standard provide an alternative method of calculating ventilation when compared with AS/NZS 60079.10.1.

4.2 Guidance on use and interpretation of standards

Based on a review of national and international standards, as well as the experience of the working group, there are different approaches to the classification of explosive atmospheres in wastewater conveyance and treatment assets. This difference can be substantial and can lead to disagreements among hazardous area design professionals and water agencies.

This guideline proposes the following interpretations of common areas of divergence among the standards. The intent is to provide an agreed set of common principles which can be universally applied across the Australian water industry.

4.2.1 Prescriptive vs risk-based approach

Apart from suggested classifications for wastewater treatment plant unit process applications, this guideline does not recommend a prescriptive approach to the classification of assets in wastewater conveyance and treatment infrastructure. Prescriptive approaches to classification may provide significantly different effectiveness of outcome for the same asset in different contexts, and therefore cannot be relied upon to be universally applicable. For example, when ventilating at a rate nominated in NFPA 820 to achieve a zone rating, it is not possible to know if the rate of ventilation is sufficient to control the contaminants of concern for that installation. A prescriptive approach may also be overly cautious for the majority of installations of a certain asset type.

The approach favoured in this guideline aligns with both federal and state WHS approaches, whereby risks are assessed on a case-by-case basis depending on the situation at hand, and is common practice in design, construction and operation of wastewater assets. By utilising a risk-based approach, outcomes are more likely to be tailored to the installation, avoiding scenarios where prescribed designs are either overly conservative or unfit for purpose. Section 5 describes an approach whereby increased or lesser likelihood of explosive atmosphere is assessed.

4.2.2 Abnormal vs. catastrophic operating conditions

4.2.2.1 Catastrophic conditions

Baseline Australian industry for the classification of hazardous areas is based on AS/NZS 60079.10.1-2009. The standard states the following in Clause 1 d) as being a case where its guidance is not intended to apply:

> "*Catastrophic failures which are beyond the concept of abnormality dealt with in this standard*"

The following note is applied to this statement:

> "*Catastrophic failure in this context is applied, for example, to the rupture of a process vessel or pipeline and events that are not predictable*"

To provide further guidance on this for the water industry, this guideline recommends that the below events be considered examples of catastrophic failures:

- A lightning strike outside of the requirements stipulated in AS 1768
- A flood of magnitude greater than that which can be reasonably foreseen. A structure may have a life span of 50 years; in this case, the 2% (and in some cases, the 1% AEP) flood event can be reasonably expected (including consideration of potential changes to historical weather patterns). A process plant may have a 20-year design life; in this case, the 5% (and in some cases, the 2%) AEP flood event can be reasonably foreseen
- Cyclone or El Niño, outside of certain areas of the country where these can be reasonably foreseen
- Earthquake, of a magnitude and/or in a location where the risk cannot be reasonably foreseen
- Terrorism and intent to cause harm. While petty maliciousness (e.g. vandalism or purposeful carelessness) can be expected in certain installations, terrorism and intent to harm cannot be predicted. There are however certain instances where this should be considered; this is discussed in Section 5.

4.2.2.2 Abnormal conditions

Clause 3.15 of AS 60079.10.1: 2009 defines normal operation as the "situation when the equipment is operating within its designed parameters", with three explanatory notes as below:

> "*Note 1: Minor releases of flammable material may be a part of normal operation. For example, releases from seals which rely on wetting by the fluid which is being pumped are minor releases.*
>
> *Note 2: Failures (such as the breakdown of pump seals, flange gaskets or spillages causes by accidents) which involve urgent repair or shutdown are not considered to be a part of normal operation nor are they considered to be catastrophic*
>
> *Note 3: Normal operation includes start-up and shut down conditions*"

For a wastewater treatment plant, where there exists a relatively controlled, steady state process with defined and understood load cases, normal, abnormal or catastrophic conditions are more clearly defined. In a network environment, this becomes more difficult.

This is summarised well by EN 1127-1, which states in clause 6.1:

> *"In the planning of explosion prevention and protection measures, consideration shall be given to normal operation, which includes start-up and shut-down. Moreover, possible technical malfunctions as well as foreseeable misuse according to EN ISO 12100:2010 shall be taken into account*"

Based on review of the literature and the experience of the working group, this guideline outlines aspects of abnormal operation and foreseeable misuse considered necessary for consideration in both network and treatment plant applications. This list is below, and is further discussed in Section 5:

- Power failure and start-up on power return
- Asset failure
- Varying load cases
- Blockage or leakage
- Flood, with the selection of an appropriate AEP for design
- Foreseeable misuse. By its nature, the contents of the sewage system are not within the full control of the asset owner[23]. As such, material which is not standard municipal, or industrial (pre-treated) wastewater occasionally enters the sewerage system. This is the primary risk for the network. Some key examples include:
    - Illegal dumping of large quantities of material e.g. drug labs
    - Minor discharges of non-standard wastewater from residential houses
    - Undeclared discharges from trade waste dischargers
    - Stormwater ingress carrying material such as brake fluids, oils, fuels etc
    - Events which could occur due to insufficient operator training
    - Events which could occur due to a lack of concentration or carelessness
    - Other, similar failures which could occur due to human error
    - Trespass, putting members of the public at risk
    - Sabotage e.g. vandalism by members of the public

[23] Australian industry experience has shown that these events occur nationally, in both regional and major metropolitan areas. They are therefore a foreseeable misuse of the sewerage system. Due to their higher risks, their inclusion is critical to an understanding of hazardous areas in wastewater conveyance environments.

4.2.3 Controlled value of LFL

In accordance with clause 3.3. of AS/NZS 60079.10.1, a hazardous area is defined as:

> *"an area in which an explosive gas atmosphere is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment"*

As previously discussed, there are restrictions on this by WHS legislation in certain jurisdictions in Australia; for example, SafeWork NSW defines an area above 5% LFL as a hazardous atmosphere. In the standard, however, is the implicit intent that LFL should not be allowed to reach 100% without being controlled. This is further discussed in AS/NZS 60079.13 Clause 7.1.3.1, which requires ventilation control of an atmosphere to 25% of LFL as a maximum. [24]

This implicit assumption is made explicit in the international literature. From DSEAR 6.233:

> "*Ventilation for plant and machinery is normally considered adequate if it limits the average concentration of any dangerous substance that might potentially be present to no more than 25% of the LEL. However, an increase up to a maximum 50% LEL can be acceptable where additional safeguards are provided to prevent the formation of a hazardous explosive atmosphere*"

On this basis, this guideline is concerned with atmospheres which breach this control point, rather than reach the 100% LFL concentration. Called the threshold value, this will be dependent on various factors and is discussed further in Section 5.2.

4.2.4 Ventilation

As per AS/NZS 60079.10.1-2009, the degree of ventilation available influences the zoning of a space. For this reason, both natural and forced ventilation are fundamental tools in the control of hazardous areas. A discussion of the design of ventilation systems for mitigation of hazardous atmospheres is provided in Section 5.5.3.

There are cases in the application of the standard where the presence of ventilation can allow the use of non-hazardous equipment by reducing the volume of the zone to a negligible extent This approach has been used successfully industry wide. However, one aspect which can fail to be considered in hazardous area assessments is the effect of the abnormal operating condition (defined in 4.2.2.2). Three key clauses from the international literature, reproduced below, provide a summary of this intent:

> **SPD E04 A 2.2.3:** *"Failure of mechanical ventilation shall be considered and duty/standby extract fans may be prudent to improve the overall availability. This is*

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[24] **The standard considers concentrations above the UFL as hazardous, as there is a risk of the concentration dropping. Standard industry practice is also to allow a safety factor on the value above which an area is considered hazardous, meaning an area is considered hazardous from a value less than the LFL. This is not explicitly stated in the standard.**

particularly important when mechanical ventilation is being used as a means of controlling continuous and primary grades of release."

DSEAR Schedule 1 of Regulation 6(8): *"Ensuring that equipment and protective systems meet the following requirements –*

(a) where power failure can give rise to the spread of additional risk, equipment and protective systems must be able to be maintained in a safe state of operation independently of the rest of the plant in the event of power failure"

EI15, 2.5: *"The drawings and/or notes should indicate where the classification depends on the correct operation of a dedicated ventilation arrangement. It should consider and indicate the effect of failure of such an arrangement."*

In cases where the absence of ventilation can cause the probability of a hazardous atmosphere, this failure state should be considered as part of the classification exercise. Duty/standby ventilation may not be sufficient to provide this, as there are various reasons why standby equipment may not be immediately available (such as operator unavailability, failure of automatic change over, power failure etc). AS/NZS 60079.13 specifies that any equipment which must operate in case of ventilation failure must be rated for the latent (without ventilation) hazardous area.

The second aspect is that if the flammable liquid is insoluble, such that it forms a surface film, a concentration gradient will form. The concentration at the liquid film surface is then determined by the saturated vapour concentration. The concentration is lower as the distance from the liquid surface increases (much more rapidly for mechanical ventilation than passive), however there will always be a period of time and location just above the liquid surface where the LFL boundary is transited. In the instance of such a liquid being present the provision of mechanical ventilation does not prevent a flammable atmosphere from occurring; rather, it limits its spread to the bulk gas. This precludes the use of a non-hazardous classification rating as any spark which reaches the liquid surface at that time would cause an ignition/explosive event, regardless of controls.

For these reasons, ventilation or availability of ventilation does not means that the area served is always non-hazardous regardless of other factors.

4.2.5 Equipment protection level and classification

A hazardous area classification is undertaken without assessing the consequence of any potential explosion or ignition. The likelihood of the ignition is determined (by use of one or more methods outlined in AS/NZS 60079.10.1 or otherwise) and a zone is assigned. This zone is then used to determine an EPL for electrical equipment operating within the hazardous zone, as per Table 1 of AS/NZS 60079.14.

However, there may be situations where a water agency wishes to increase or decrease the default EPL of the equipment within the zone. This is summarised well in Clause 5.3 of AS/NZS 60079.14, and further discussed in Annex ZC of AS 60079.10.1: 2009 and Clause 4.4.1 of IEC 60079-10-1: 2020:

"As an alternative to the relationship given in Table 1 between EPLs and zones, EPLs can be determined on the basis of a risk, i.e. taking into account the

consequences of an ignition. This may, under certain circumstances, require a higher EPL or permit a lower EPL than that defined in Table 1. Refer to 60079-10-1 and 60079-10-2."

An example of this is where a water agency has assessed an asset as non-hazardous due to likelihood of potentially explosive atmosphere being low, yet consider the asset critical or high risk. In this case, where the potentially explosive atmosphere may be present for a period of time less than that required to classify the area (e.g. every three years for one hour), there may be a desire to specify an EPL for the equipment in the area such that it does not become a source of ignition. This can be done by selecting an EPL for any equipment in the non-hazardous area.

It is important to note that to maintain the EPL of the equipment, the equipment must be designed, installed and commissioned in accordance with AS/NZS 60079.14 (and in case of ventilation, AS/NZS 60079.13) and the manufacturer's instructions. It must also be maintained in accordance with AS/NZS 60079.17. An EPL cannot be claimed without these requirements being met.

4.3 Network specific interactions

4.3.1 Pumping station zoning

In Annex ZA of AS/NZS 60079.10.1, sewage pumping stations are addressed in the following two clauses:

> ZA.8.1: "*This section provides examples of area classification for areas associated with gas recovery, sewage treatment plants and sewage pumping plants. It is basically concerned with methane occurrences and can be extended to coal seam gas recovery and biodigestion of farm wastes.*"
>
> ZA.8.4: "*Generally, sewage pumping plants are non-hazardous (NH). However, where a pumping plant has a record of flammable liquids being passed through it, areas where the concentration of flammable vapour is likely to exceed the LEL should be classified in accordance with the relevant clauses of this Standard.*"

It is important to note that the international literature does not concur with either of these points. Many of the examples presented are from the US or UK, which have a longer urban history and therefore contain many more active combined sewerage/stormwater infrastructure. Perhaps due to the increased risk of chemical spill in these systems, there is a much stronger emphasis on hazardous area classification for network infrastructure in these countries with particular focus on non-methane substances.

With reference to ZA.8.1, this guideline does not recommend that hazardous area assessments of either sewage pumping stations or other conveyance infrastructure focus purely on the presence of methane. Australian industry experience has shown that there are other contaminants of concern which may be present in the municipal sewerage system, and in some instances these are the driver of the asset's classification. For further information, see Section 2.

With regard to ZA.8.4, it is true that many pumping stations nationally should be and are classified as non-hazardous. This is particularly true of areas with primarily municipal wastewater flows and few, short retention time assets upstream. It is not, however, always the case. Furthermore, there are recent examples of classification professionals and water agencies citing this clause as justification to enable sewage pumping station construction to occur without any hazardous area investigation. Without this investigation or any hazardous area risk assessment, it is difficult to establish if the site has or could have a history of flammable liquids (or flammable atmospheres). It is therefore prudent to allow for a hazardous area assessment when adding new linear assets (maintenance holes, vent shafts or pumping stations) to a network, or when building new unit processes at treatment plants. This applies to both brownfield and greenfield locations.

4.3.2 Generalised classification

A wastewater network of anything larger than a size encompassing a few homes is difficult to classify according to the source of release method. The large number of entry points for liquid wastewater makes it difficult to predict the exact quantities of any contaminant of concern present without long term monitoring at key locations. The risk of illegal or malicious activity is also difficult to quantitatively describe. For this reason, international examples of network classification have provided pre-set designs which have been developed in house by water authorities for their own common installation examples such as:

- Wet well and valve chamber (open between)
- Wet well and valve chamber (sealed between)
- Dry well and wet well
- Pump house/structure
- Sewer mains
- Odour Control Units (OCUs)

Prescriptions as to zoning of assets this way can be provided within the framework of AS/NZS 60079.10.1 using the generalised classification method. In clause 5.4.7 of the standard, this is described as follows:

> "*Where, through lack of detailed data or operating experience, it is not possible to identify and assess individual sources of release in a plant, a generalized method may be used.*
>
> *Generalized methods require judgements to be made, usually for quite large sections of the plant, on whether the overall hazard is high (Zone 0 or Zone 1) or low (Zone 2). The judgement is best made by reference to a set of criteria based on industry experience and appropriate to the particular plant.*"

Rather than provide pre-set installation cases, which may not be relevant nationally, this guideline seeks to provide a framework by which to make a risk-based assessment of the potential for hazardous atmosphere within linear infrastructure. This is achieved by using the generalised area method of AS/NZS 60079.10.1, which is similar to the pre-set installation cases of international standards. This is further discussed in Section 5.

4.4 Treatment plant specific interactions

As opposed to a network environment, in a treatment plant environment (with the exception of pre-treatment modules and other areas which have the characteristics of a network asset), the source of release method outlined by AS/NZS 60079.10.1 is an appropriate and practical method by which to classify treatment plants. Of particular note are the commonly used examples in the standard contained in Annex ZA.8.3, which provide a good reference for various sewage treatment processes. Although use of the examples is not mandatory, they represent common industry practices and this guideline will use them where possible. The international literature also contains opinion on the zoning of common wastewater unit processes. A set of recommendations for treatment plant hazardous area assessments and their use in general industry practice is provided in Section 6.

4.5 Current state of knowledge

The development of this guideline has been conducted based on the current state of knowledge from the working group’s experience and other guidelines and standards, both locally and internationally. Changes in key standards may warrant a review of these guidelines.

5. METHOD OF CLASSIFICATION FOR LINEAR INFRASTRUCTURE

5.1 Overview

AS/NZS 60079.10.1 provides alternatives to the method of area classification being:

1. Source of release method
2. Generalised methods
3. Combination of source of release and generalised methods

The source of release method requires a thorough understanding of the types of flammable materials and the release rates. These can generally be determined by thorough monitoring or a high level of knowledge of the particular situation. The level of monitoring in linear infrastructure required to be able to inform the source of release method is often difficult for most water agencies. A generalised method for linear infrastructure is provided in this guideline for those occasions when monitoring conducted is insufficient.

The generalised method for linear infrastructure in this guideline provides a risk-based classification methodology intended to be applied under the generalised classification approach of AS/NZS 60079.10.1. Its overview framework is presented in Figure 5-1.

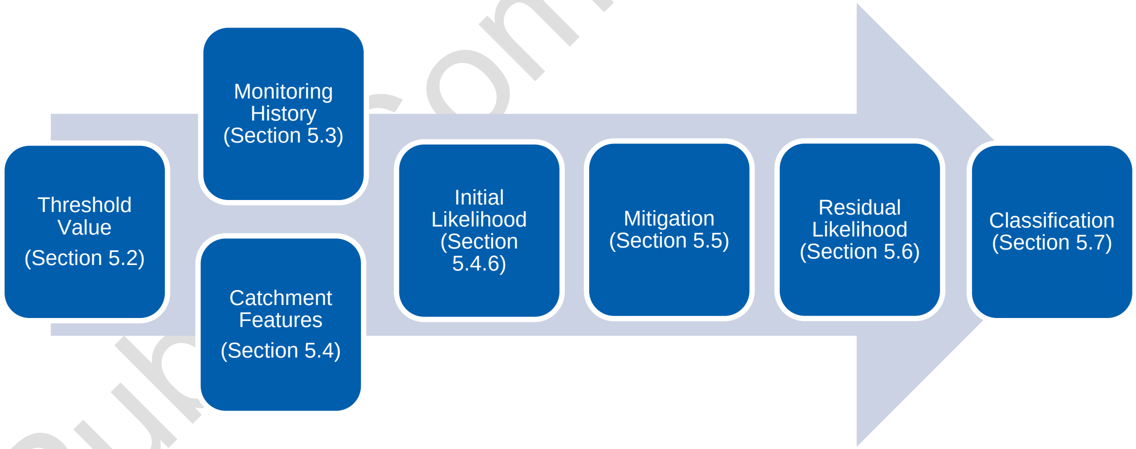

Figure 5-1: Overview of the linear infrastructure classification method

The process is a guided assessment of the likelihood of a flammable atmosphere occurring, with areas for consideration and tools to make informed decisions about likelihoods. The steps are as follows, with each step discussed in detail in following sections:

1. Set a threshold value; the value the water agency will use as the upper allowable limit of LFL for the contaminants of concern. This value must inform the design of any mitigation or controls, and will ultimately inform any classification
2. Available monitoring data.

a. If there is sufficient available monitoring data, use a 'Source of release' method defined in AS/NZS 60079.10.1. If there are gaps in this data, or the data is not considered representative enough for assessment, follow the generalised methods developed.

3. Generalised Method

a. Consider the following information and make informed judgements about their impact on the likelihood of an atmosphere containing contaminants above their threshold value.

    i. Hydraulic features

    ii. Catchment composition, such as stormwater infiltration and trade waste contribution to overall flow

    iii. Security features of the asset and how likely the asset is to be maliciously targeted e.g. by illegal dumping

    iv. Sources of ignition (from both installed equipment or operational activities)

    v. Abnormal operation, such as reports of hydrocarbon sheen or odour, or flow events which can influence trade waste discharge.

b. At the end of this process, collate risks from each category to provide an overall likelihood as provided in Table 5-6.

c. Assess mitigation measures (if any):

    i. Assess the effectiveness of monitoring in providing advanced warning of risk in the asset or system

    ii. Assess the effectiveness of ventilation in removing contaminants of concern from the asset or system

d. Re-assess the likelihood based on the benefits associated with the mitigation measures.

    i. Assess the consequences of an explosion occurring to influence the classification

e. Classify the area based on the residual risk likelihood and the threshold value. Note that this applies where the risk is being **controlled at the threshold value**. Refer to Table 5-18 for the relationship between risk assessed and threshold value.

5.2 Threshold value

As discussed in Section 4.2.3, to begin the process by which linear infrastructure can be zoned, a threshold value must be set. This is defined as the percentage LFL of the most significant contaminant of concern. It is intended that each water agency decide this value, taking into consideration their legislative environment, community expectation, response abilities, local emergency services capacity and other factors. Some examples may include:

- A water agency selects 5% LFL as the threshold value based on the legislative environment and legal advice regarding community exposure from their legal team
- A water agency decides that a threshold value of 20% LFL within the sewerage system ensures that any leakage or escape to atmosphere would likely be below their 5% LFL legislated value and have received legal advice that this logic is robust
- A water agency without a mandatory legislative environment decides that their threshold value will be 40% LFL, as this is the value at which their local fire department wishes to be informed of flammable atmospheres to inform their preparations

It is important to emphasise that this threshold value is for control of hazardous (i.e. flammable or explosive) atmosphere. Toxic substances can be hazardous to human health at very low LFL levels. For example, H_2S exposure at 1,000 ppm is lethal whereas its LFL is 40,000 ppm. This is highly dependent on the specific contaminant of concern. This guideline deals with hazardous atmospheres only, a separate assessment should be made for entries into areas which may have toxic atmospheres. Table 5-1 summarises the guidelines recommendations on threshold value. Although this guideline leaves the threshold value to the discretion of the water agency, a minimum of 5% LFL and a maximum of 40% LFL is recommended. Below 5% LFL, concentrations become difficult to measure accurately and it is therefore not recommended to target less than this value. At 40% LFL, Australian industry experience is that the fire department will require notification to begin tracking the event and it is therefore recommended that this is provided as a maximum threshold value.

Table 5-1: Guideline recommendations on threshold value

Threshold Level Recommendation	LFL of any single contaminant
Minimum	5%
Default (no legislation)	25%
Maximum	40%

In the absence of a legislated requirement and if in need of guidance, a threshold of 25% LFL is recommended. This is supported by the UK DSEAR guideline (clause 6.219), which advises controlling atmospheres with ventilation to 25% LFL. Further justification is as follows:

- Measurements of the kind described in Section 3 are from a single point. This point may not be reflective of the overall hazard, particularly if ventilation is low. Depending on asset geometry, pockets of higher concentrations may exist within a structure. Although measurement should occur from a conservative location, this is not always possible. As such it is possible that the measured value is insufficiently conservative
- Early indication of a high LFL event. If a high LFL event is occurring, notice and opportunity to take action should come well before the 100% LFL value. This is especially true of events which may begin slowly and become stronger over time (e.g. a malfunction of a high strength trade waste emitters pre-treatment processes)

- Time is required to respond to a high LFL situation. Emergency services may need notification, assets may need to be shut down, bypasses may need to be placed into service, back-up power may be required etc. All these activities require planning time which is less available should higher threshold values be used

There are significant implications associated with the choice of threshold value such as additional ventilation required to reduce concentration levels, or significant additional costs in maintenance ensuring equipment is suitably rated for the zoned environment. Careful consideration is advised.

5.3 Monitoring history

Prior to any qualitative risk assessment, data collection from any sampling should be assessed. Based on the guidance provided in Section 3, assess:

- If the data is of sufficient length in time to represent the asset's baseline operating condition
- If the data demonstrates abnormal operating conditions such that a judgement can be made confidently about abnormal operating conditions
- If the quality of the data is sufficient for it to be trustworthy

If all the above is true, discontinue the generalised method process evaluating likelihoods and use a source of release method either outlined in or in accordance with AS/NZS 60079.10.1.

If one or more of the statements is false, continue with the process. Use the data collected to inform decisions made in subsequent likelihood analysis.

A water agency is classifying a pumping station in a location of concern: an industrial catchment which receives primarily industrial effluent. The 28 day monitoring shows that peaks in flammable gases in the atmosphere are occurring, however there is no data to provide an indication of what compounds are causing the events. The generalised method is used in conjunction with the data to assess the likelihood of a flammable atmosphere based on potential contaminants, rather than the exact contaminants.

A water agency is classifying a gravity sewer main. A spot sample analysed with GC-MS shows that there are some species of VOC which could cause explosive atmospheres. The generalised method is used in conjunction with the known contaminants of concern, as the peaks of the contaminants are not known because the data was not continuous.

5.4 Catchment features

It is recognised that an asset within a wastewater network exists within a catchment, servicing a specific number of commercial and residential connections. When classifying an asset, a sensible boundary must be developed so that the classification exercise can be focussed. This may prove to be difficult, especially in large and complex networks. This guideline recommends focussing on a critical point (such as a maintenance hole or a pumping station) and applying the rating from this asset backwards to the entry points, until such time that data is available to distinguish which connections present the most risks and sub-classifying these as separate assets.

5.4.1 Hydraulic features

The type of asset in the linear infrastructure can lead to differences in methane generation risks. Methane generation predominantly occurs either in slime layers on sewers, or in accumulated sediment, under anaerobic conditions. Gravity systems with shallow slopes, or areas which can accumulate sediment (such as inverted siphons) are prone to sediment accumulation and have a higher risk of methane generation. Mains that have no, or small, gas-liquid interface, such as rising or undulating mains, are at greater risk of turning anaerobic than gravity mains and are therefore higher risk.

By design, the sewerage network conveys a large range of flows. Often, infrastructure is installed with future capacity available such that future flows can be conveyed within engineering tolerances. This provides a strong benefit, in that capital expenditure in the present can create a piece of infrastructure which is suitable for use in the future. The weakness of this approach is that it leads to longer hydraulic residence times (HRTs) of sewage in the system, which can then lead to methane generation and therefore increased likelihood of a hazardous atmosphere forming.

Assess the risk of methane generation using Table 5-2. Note that there is additional risk associated with rising or undulating mains compared to gravity mains leading to an increased likelihood of high concentrations.

Table 5-2: Hydraulic residence time likelihoods

Gravity main infrastructure (maintenance holes, wet wells, gravity vent shafts)		Rising main infrastructure (pipelines, air release valves, discharge maintenance holes, receiving wet wells)	
Residence Time	**Likelihood**	**Residence Time**	**Likelihood**
0 - 12 h	Low	0 - 6 h	Low
12 - 24 h	Medium	6 - 12 h	Medium
24 h +	High	12 h +	High

The likelihood of methane generation is further influenced by the following[25]:

[25] **Liu, Y, Ni, B-J, Sharma, KR & Yuan, Z 2015, 'Methane emission from sewers', Science of The Total Environment, vol. 524-525, pp. 40–51.**

- Surface area to volume ratio of pipelines (i.e. short and wide pipelines have a lower risk compared to long and thin pipelines with the same retention time)
- Slope of pipework in gravity systems; the shallower the system slope the greater risk of sedimentation and methane build-up
- Velocity of pipework; the greater the velocity the greater opportunity for sediment to be pushed further downstream
- COD; the greater the COD the faster methane generation will occur
- pH; above a sustained pH of approximately 8.5 - 9.0 methanogens will not produce methane
- Temperature; the greater the temperature, the faster methane generation will occur
- Turbulence; the greater the turbulence, the greater methane will be released to the headspace
- Transient populations; for areas such as holiday destinations or towns with seasonal industry, the flow will be low during significant periods of time leading to higher retention times in sewers

5.4.2 Catchment composition

One of the primary risks to consider in classifying a linear asset is the catchment composition. The amount and type of trade waste, as well as the susceptibility to stormwater flows carrying contaminants from the surface into the sewerage system, are discussed below.

5.4.2.1 Proportion of trade waste connections

The experience of the working group has found that assets which convey primarily commercial and industrial wastewater are at most risk of developing an explosive atmosphere. Although many water agencies carefully monitor the discharge of trade waste customers, their wastewater is not as predictable as that discharged by a municipal connection. Their own process upsets, foreseeable misuse or improper waste management can affect the wastewater system, even if much of the time their waste is predictable as per their trade waste agreement.

It is difficult to assign a boundary in terms of flow contribution from trade waste customers, as it is highly dependent on the contaminants of concern being discharged. A single high-risk discharge can significantly affect the catchment. Table 5-3 is therefore only a heuristic as to how to account for the strength and quantity of trade waste in a catchment. Where concerns about particularly high-risk trade waste exist, lower proportions of trade waste may also be considered medium or high risk.

Table 5-3: Risk classification based on catchment composition and risk of discharge

	Trade waste risk on explosive environments		
Percentage of flow from sources	Low risk trade waste quality	Medium risk trade waste quality	High risk trade waste quality
< 10% of flow from trade waste sources	Low	Low	Medium
10 - 25% of flow from trade waste sources	Low	Medium	High
25%+ of flow from trade waste sources	Low	High	High

Please note that the flow for the judgement of trade waste risk is the flow at the most critical time. Some examples of most critical time, based on actual examples from the working group:

- An asset experiences a large dumping of wastewater from a trade waste source between 2 - 4 AM daily. At this time, the trade waste discharge is >10% of incoming flows, and is therefore the most critical time
- An asset in an industrial area experiences a large spike in trade waste discharge on a Friday afternoon (2 - 4 PM) weekly, as the local businesses wash out and empty sumps in anticipation of the weekend. At this time, domestic flows are minimal this is therefore the most critical time
- An asset experiences a major spike in flow from a major trade waste emitter, corresponding to cleaning and descaling processes at their plant one day every quarter. This day each quarter is the most critical time for trade waste

If the proportion and quality of trade waste is unknown, it is recommended to assume a Medium trade waste risk until such time as more information is available.

Trade waste quality classification

To assist in risk classification of trade waste asset, this guideline provides a list of common commercial and industrial businesses, their likely contaminants of concern and a classification of the risk of these contaminants. Risk may vary from that mentioned in the table, depending on well individual businesses manage their waste processes. This table is in Appendix A.

5.4.2.2 Stormwater infiltration

Certain assets are at greater risk of stormwater infiltration than others. The stormwater system is a source of risk in heavily industrial areas, as run off from industrial spaces can carry with it various contaminants which can cause hazardous atmospheres to develop. Assess the likelihood of this infiltration. A guide is provided in Table 5-4. Low industry refers to areas where there are primarily residential dwellings and porous surfaces. High industry refers to areas of cities or towns where manufacturing, transport and handling of materials takes place e.g. a business park or precinct, with large, open and impervious areas.

Table 5-4: Likelihood of stormwater infiltration

Rate of measured or suspected infiltration	Catchment potentially contributing stormwater to asset		
	Low industry	Medium industry	High industry
No infiltration	Low	Low	Low
Low infiltration	Low	Low	Medium
Medium infiltration	Low	Low	High
High infiltration	Low	Medium	High
Combined system	Medium	High	High

5.4.2.3 Local ground conditions

As sewerage network infrastructure is generally buried under the ground, sometimes at great depths, there are various underground features which may affect the risks associated with the asset.

Nearby infrastructure can play a significant role in affecting the atmosphere of a network asset. Some examples are:

- Buried or above ground natural gas delivery infrastructure, such as mains or reticulation pipes. Leaks from these can enter the sewerage system, causing an explosive atmosphere. This is documented as occurring at several locations nationally over the previous 10 years.
- Nearby fracking or gas fields, which have the potential to cause gas migration, entering the sewerage system
- Buried infrastructure such as landfills. Where landfills are poorly lined or sealed, the methane generated by the decay of buried organic material can migrate through the surrounding earth. This gas can bubble to the surface, or enter nearby infrastructure

In addition to these man-made sources of risk, some examples of risk associated with naturally occurring underground features are:

- Contaminated groundwaters which may contain contaminants which influence the wastewater system
- Buried deposits of gas, which can migrate into nearby sewerage infrastructure

Assess the likelihood of the ground conditions contributing to an explosive atmosphere in the asset. If constructing a greenfield asset consider if location can be selected to reduce risk. The gas permeability of the local earth should also be considered: permeable sands are of higher risk than well compacted soils.

5.4.3 Security

Having established the likelihood of an explosive atmosphere associated with HRT and catchment composition, the location and operational considerations of the asset are evaluated for their contributions to the likelihood of the development of explosive atmospheres.

5.4.3.1 Location

Location can influence the risk associated with an explosive atmosphere being present within the asset. It can influence the likelihood of a hazardous atmosphere by:

- Being in such a place as to be difficult to access for illegal dumping purposes
- Being in a remote location, such that vandals are less likely to target it

Assess the risk of the assets location, and if constructing a greenfield asset consider if location can be selected to reduce risk.

5.4.3.2 Security of site

The security of the site can play a significant part in preventing foreseeable misuse. As discussed in Section 5.4.3.1, some sites are secure by virtue of their location being difficult to access. In this section, security is intended to discuss the barriers which may stop people or vehicles from entering. The following are examples of barriers for sites:

- Is the asset in a fenced compound? Is this fence sufficiently robust to stop people from entering? This can serve to prevent foreseeable misuse, reducing the likelihood of an explosive atmosphere being caused
- Does the asset have an open lid? Can the lid be opened easily by a member of the public? For example, a lockable lid or a heavy-duty cast-iron lid are not easily opened without multiple people and tools, making misuse much less likely and leading to a low security risk
- Is the asset monitored, for example by CCTV or patrolling security? Monitoring of this nature is more likely to discourage illegal activity and reduce the likelihood of explosive atmospheres being caused

Consider the security of the asset and adjust the likelihood based on how secure the asset is.

5.4.4 Abnormal operation

Having assessed the hydraulic features, the catchment composition and the security features associated with the asset, abnormal operating conditions and their effect on the potential for hazardous atmosphere should be considered. As discussed in Section 4.2.2.2, abnormal operating conditions form an important part of the hazardous area assessment. Assess the effect of the below factors on the overall risk profile of the asset.

5.4.4.1 Power failure

Consider the effect of power failure on the process. Loss of power in the network could mean:

- Loss of flow, leading to high residence times and methanogenesis in rising mains or accumulation of waste streams causing build-up of flammable atmosphere
- Loss of ventilation for control of hazardous atmospheres

- Loss of monitoring for hazardous area control

Assess the effect of power failure on the asset. This check primarily applies to pumping stations (both wet and dry/wet configurations) and odour control units (OCUs).

- Will power failure lead to an increased likelihood of hazardous atmosphere in my asset?
- How often is power failure occurring at the asset, and for how long? Refer to actual historical data
- How long until loss of power increases likelihood of hazardous atmosphere?
- Are there processes in place (e.g. back up generators, alternative power supplies, maintenance crew manual interventions) such that power can be restored sooner than the time frame which will lead to an increased likelihood of hazardous atmosphere? Refer to actual historical power failures and their time to re-energisation. If no data exists, consider that power cannot be restored in time.

If power failure can affect the explosivity of the atmosphere, and if power cannot be restored in time to prevent this effect, take this into consideration during the assessment.

When undertaking an assessment, the user should consider the upstream catchment and the potential for methane generation, and process specifics such as whether mechanical or passive ventilation is present. There are a number of factors which need to be considered, which will vary from area to area, and as such a “fault tree” analysis or other safety in design type assessment is recommended.

5.4.4.2 Plant/equipment failure

Plant/equipment failure in a network can cause:

- Loss of flow, leading to high residence times and methanogenesis in rising mains or accumulation of waste streams causing build-up of flammable atmosphere
- Loss of ventilation for control of hazardous atmospheres
- Loss of monitoring for hazardous area control

Assess the effect of plant/equipment failure. This check primarily applies to pumping stations (both wet and dry/wet configurations), air valves and their pits and OCUs.

- Will failure lead to an increased likelihood of hazardous atmosphere?
- How often is failure occurring, and for how long? Refer to actual historical data
- How long must the plant/equipment be offline until the likelihood of hazardous atmosphere increases?
- What is the time to the asset being placed back in service? Refer to actual historical data and experience. It is common practice that installed standby infrastructure can be left for long periods of time, especially for particularly bespoke assets (e.g. specialist fans requiring custom parts). If this data is not available, refer to Table 5-13 for an indication of the asset’s susceptibility to plant failure.

If plant/equipment failure can affect the explosivity of the atmosphere, and if the plant/equipment cannot have its service restored in time to prevent this, take this into consideration during the assessment.

5.4.4.3 Varying load cases

Differing loads on the sewerage system can have an effect on assets. For example, wet weather flow can lower methane production in discharge maintenance holes (DMHs) through the decrease of HRT. Wet weather flow can also contribute to sewer chokes, which may restrict movement of air in the system. It is recognised that connections to the sewerage system mean that these loads change over time. The forecast load to be used in the assessment should reflect the frequency that a hazardous assessment is reviewed. For example, if it is intended that the hazardous area assessment is reviewed every 4 years, the forecast load should consider expected variations across the next 4 years. In this assessment, the following should be considered:

- Will lowest dry weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will peak dry weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will wet weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will peak wet weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will these flows change significantly in the review period?

For example, a trade waste discharger with a known problematic wastewater stream discharges this stream in the middle of the night for their own process reasons. At this time, the wastewater forms a significant portion of the flow in the local sewerage system, leading to increased possibility of hazardous atmosphere occurring.

If changing flow to the asset causes a change of atmosphere, consider this in the assessment.

5.4.4.4 Blockage or leakage

Blockages (sometimes referred to as chokes) can increase the likelihood of a hazardous atmosphere occurring by:

- Restricting headspace and reducing volume, therefore creating an increased likelihood of an hazardous area forming in the downstream air space
- Higher pressure discharge in air movement pathways such as vent shafts leading to greater likelihood of hazardous atmospheres outside the asset
- Reduced liquid flows in pipelines, increasing HRT and (for rising mains) increasing pipeline pressures meaning the possibility of more methane being released

Leakage of pipework can increase the likelihood of a hazardous atmosphere by:

- Releasing flammable gases into unintended spaces
- Allowing migration of hazardous atmospheres into the sewerage system (such as that found from a nearby leaking gas main, or in-ground methane deposits)
- Insufficient control of an atmosphere (e.g. leaking OCU ductwork)

Assess the risk of blockage or leakage in pipework. Check the following:

- Will blockage or leakage lead to an increased likelihood of hazardous atmosphere?
- How often is blockage or leakage occurring? Refer to actual historical data
- How long is it taking for blockages or leaks to be repaired? Refer to actual historical data
- How long can a blockage or leak be in place until the likelihood of hazardous atmosphere increases?

If blockage or leakage in the asset increases the possibility of a change of atmosphere, consider this in the assessment.

5.4.4.5 Flood risk

The effect of a design flood should be considered on the hazardous atmosphere. Floods can:

- Reduce air spaces, leading to higher concentrations of flammable gases in the reduced volume if the source is an immiscible liquid (such as petrol)
- Disturb sediments, potentially releasing discharges
- Carry contaminated stormwater
- Degrade the quality of trade waste discharges

There may be cases where flooding decreases the likelihood of hazardous atmospheres occurring through infiltration diluting wastewater, leading to lower COD, temperature and retention times in sewers.

Consider the effect of a design flood in line with or of greater magnitude than the asset life. Common industry practice is to consider the 1% AEP for in ground structures; for mechanical equipment, with its lower design life, it is generally either the 5% or 2% AEP flood. If flooding increases the likelihood of hazardous atmosphere, take this into account in the assessment.

5.4.4.6 Foreseeable misuse

One of the highest risk abnormal conditions is that of foreseeable misuse of the sewerage system. Because of the open and unmonitored nature of the system, it is open to misuse in both malicious and unintentional ways. Some unintentional activities which can contribute to increased likelihood of hazardous atmosphere include:

- Undeclared discharges from trade waste dischargers e.g. from businesses whose process knowledge is low
- Minor discharges of a domestic nature. Although generally not a problem in isolation, an event such as a government mandated lockdown can lead to more prevalent discharging and contribute to hazardous atmospheres

- Operator error e.g. leaving valves in incorrect positions, wrong control sequences initiated
- Accidental discharge e.g. spills from tankers, which make their way into the sewerage system

Malicious intent would include:

- Businesses knowingly discharging trade waste not covered in quantity or concentration by their discharge agreements
- Purposeful dump of illegal material e.g. tanker emptying at pumping station
- Illegal material manufacture, such as drugs or unlicensed industry
- Vandalism, such as petty sabotage

Consider the possibility of these events in leading to a potentially explosive atmosphere, and assess the following for the asset:

- Is the current trade waste monitoring system robust enough to ensure that undeclared discharges are found and corrective action taken, deterring improper use? If not, how will these potential discharges affect hazardous atmospheres in the asset?
- Is the asset secure enough to prevent vandals from entering and illegal dumping?
- Are there combined systems, or known areas of cross connection, which may mean that an accidental discharge such as a fuel spill enters the system?
- Is there sufficient training and supervision to ensure that operator errors are minimised?
- Is there good community outreach to prevent illegal dumping by residential customers?

5.4.5 Catchment features summary

In the absence of good quality monitoring data, the catchment features should be assessed individually. The likelihood for each area can be summarised in Table 5-5 below by circling whether the likelihood is high, medium or low for each area. Each 'High' rating is given a score of 3, with each 'Medium' rating a score of 2 and 'Low' ratings a score of 1. Then number of ratings circled should then be summed and multiplied against the score for that rating type. The sum of this will provide an overall score.

Table 5-5: Summary of catchment features

Section	Area	Likelihood of atmosphere exceeding the chosen threshold value		
5.4.1	Hydraulic features Note 1	High	Medium	Low
5.4.2	Catchment composition risk			
5.4.2.1	Proportion of trade waste connections	High	Medium	Low
5.4.2.2	Stormwater infiltration	High	Medium	Low

Section	Area	Likelihood of atmosphere exceeding the chosen threshold value		
5.4.2.3	Local ground conditions	High	Medium	Low
5.4.3	Security and criticality risk			
5.4.3.1	Location	High	Medium	Low
5.4.3.2	Security risk of site	High	Medium	Low
5.4.4	Abnormal operation risk			
5.4.4.1	Power failure	High	Medium	Low
5.4.4.2	Plant/equipment failure	High	Medium	Low
5.4.4.3	Varying load cases	High	Medium	Low
5.4.4.4	Blockage or leakage	High	Medium	Low
5.4.4.5	Flood	High	Medium	Low
5.4.4.6	Foreseeable misuse	High	Medium	Low
A	Number of ratings circled			
B	Multiply by score	x3	x2	x1
C	Overall score = sum of A x B			

Note 1 – If the rising main retention time is >12 h on average, a minimum likelihood rating of 'Medium' should be used to reflect the high likelihood of methane present during low flow periods

The sum of scores can then be evaluated against Table 5-6 to determine an overall likelihood rating that can be used in lieu of monitoring data.

Table 5-6: Catchment features likelihood score

Overall score	Likelihood
11 – 14	Low
15 – 19	Medium
>20	High

An example of catchment feature risk is provided in Table 5-7.

Table 5-7: Example of filled in catchment features assessment

Section	Area	Likelihood of atmosphere exceeding the chosen threshold value		
5.4.1	Hydraulic features	High	Medium	Low
5.4.2	Catchment composition risk			
5.4.2.1	Proportion of trade waste connections	High	Medium	Low
5.4.2.2	Stormwater infiltration	High	Medium	Low
5.4.3	Security and criticality risk			
5.4.3.1	Location	High	Medium	Low
5.4.3.3	Security risk of site	High	Medium	Low
5.4.4	Abnormal operation risk			
5.4.4.1	Power failure	High	Medium	Low
5.4.4.2	Plant/equipment failure	High	Medium	Low
5.4.4.3	Varying load cases	High	Medium	Low
5.4.4.4	Blockage or leakage	High	Medium	Low
5.4.4.5	Flood	High	Medium	Low
5.4.4.6	Foreseeable misuse	High	Medium	Low
A	Number of ratings circled	1	3	7
B	Multiply by score	x3	x2	x1
C	Overall score = sum of A x B		16	
	Likelihood (from Table 5-6)		Medium	

The water agency may choose to add weightings that are applied to each of the above catchment features to take into account local issues that may impact hazardous atmospheres. If weightings are applied, the scoring should also be reviewed by the water agency to take into account the impact of weightings.

5.5 Mitigation Measures

After having considered the risks within the catchment either through monitoring or through an evaluation of the catchment features, a likelihood rating is assigned to the asset. In this section, the benefit associated with mitigating factors are considered and a final likelihood rating is applied to the asset.

These mitigation measures are intended to be provided over and above what this guideline would identify as standard industry practice. Standard industry is classified as:

- Regular service and maintenance in accordance with manufacturer's instructions
- A robust emergency response plan, in accordance with the suggestions of Section 7
- Safety management system to manage risks of exposure to hazardous atmospheres
- Confined space procedures in accordance with relevant state code of practice and Australian standards, for entry and into atmospheres which may be considered hazardous

Mitigation measures must be reasonable, effective and operational to enable the hazardous area classification to be reduced.

5.5.1 Monitoring and source control benefit

5.5.1.1 Monitoring

The presence of an online monitor in the asset can provide an early warning in case of an incident. A suitably calibrated instrument, providing a time history of contaminant concentration in the air space of the asset, can indicate if a potentially explosive atmosphere is substantial in magnitude or different enough from historical trend to warrant investigation. Depending on the asset, an emergency mode could be activated in case of high concentration in the space. For example, if a concentration of contaminant approaching the threshold value is detected ventilation could be increased automatically. Alternatively, if a high concentration of flammable contaminants is detected at a pumping station, a potable well washer could be called to run until the wet well reaches high-high level. This may assist in diluting the contaminants of concern. Other examples could include:

- Alarming operators to investigate, isolate and pump down the asset
- Alarming operators to co-ordinate an emergency response
- Interlocked to assets (e.g. pumps, fans etc.) to provide another kind of engineering control

If the asset being assessed has monitoring which is suitable for the environment and is linked to a method of responding more quickly to the risk of a hazardous area developing, the likelihood of an explosive atmosphere developing can be significantly reduced. The benefit that monitoring can provide is highly dependent on the chosen threshold value. Monitoring in an asset where the water agency's selected threshold value is at the lower end of the scale may provide only a limited benefit. An indication of this changing benefit effectiveness is provided in Table 5-8, noting that this will not apply in every circumstance.

Table 5-8: Benefit of monitoring on mitigation of hazardous atmosphere

Threshold value (LFL)	Monitoring effect

26 - 40%	High effect
15 - 26%	Moderate effect
5 - 14%	Low effect

For a linear asset, the monitoring of flammable concentrations in the asset headspace can be a cost-effective way to assist prevention of an explosive atmosphere if an action is automated to reduce the concentration based on the measurements. Consistent, long term monitoring can also establish enough data to make decisions about the classification of an asset when it is due for its next inspection period.

5.5.1.2 Source control

Monitoring is also of major benefit for use in source control. In certain assets, hazardous areas will be the result of a frequent trade waste license breacher, or from a customer who does not know that their waste is producing hazardous environments. In this case, monitoring provides exceptional utility in understanding patterns of flow, concentrations etc. such that breach of license or undeclared discharge can be identified and prevented at the source. In practice, this is a long process which can have mixed results.

For the purposes of this risk assessment, the effectiveness of any source control needs to be validated through monitoring.

Future source control cannot be relied upon as a mitigation. If source control is successful in the future, as deemed by monitoring, future consideration of the asset (such as a change of flow due to increased population) can consider the impact of this success on the contaminant profile and thus the risk.

5.5.2 Isolation and bypass benefit

In the event of an explosive atmosphere being discovered, the risk can be somewhat mitigated if there is both liquid and gas phase isolation and some way of bypassing the asset. In case of any event, the asset can be isolated in both liquid and gas phases and safely bypassed such that the threat is contained. The water agency can then contain the atmosphere to single location. This does not affect the likelihood of the risk, yet does affect the consequence.

Whilst theoretically possible, this type of mitigation measure is considered impractical in most linear assets throughout Australia and is therefore not considered further for linear assets.

5.5.3 Ventilation benefit

A common control for the mitigation of explosive atmospheres is ventilation. AS/NZS 60079.10.1 contains a method in Annex B by which to calculate the degree of ventilation and assign it a rating of high, medium, or low. This method is known to be flawed, and will be superseded in the next version of the standard, and thus should be used with caution. Ventilation is then further modified by its availability: good, fair or poor.

This section discusses ventilation best practice, international examples of suggested ventilation rates and specifies a method for determining the availability of ventilation and if the ventilation is good, fair or poor.

5.5.3.1 Cost/benefit considerations with ventilation

As per AS 60079.13 Table 7.1.6., if an area is classified as hazardous without ventilation, any equipment in the area which is required to be online during a failure of ventilation must have an EPL in line with the zonal requirements without ventilation. The ventilation system itself must always have the EPL of the baseline zone.

This means that there is a cost/benefit consideration to the use of artificial ventilation in controlling the formation of a hazardous atmosphere. For example, consider a pumping station classified as a Zone 2 hazardous area with an EPL of Gc. The use of ventilation in the wet well could provide the opportunity to use non-hazardous equipment. However, the asset owner would have to consider loss of ventilation and may find that all of the assets in the wet well (actuated valve, instrumentation, pumps etc.) are required to be operational even when ventilation has failed. In this case, these items must all have an EPL of Gc. If this is the case, the ventilation may not have a benefit. Another example is a primary sedimentation tank (PST) classified as a Zone 2 hazardous area. This may have equipment which can be isolated in case of power failure, and therefore the ventilation system would enable the installation of non-hazardous equipment. This may be more cost effective than the additional design, construction and maintenance requirements associated with EPL Gc equipment.

In practice, most wastewater assets have a need to be available at all times, regardless of ventilation status. However, many wastewater assets also have a need to be ventilated for reasons unrelated to hazardous area management e.g. odour and corrosion control. It may be cost effective to include the additional requirements of AS/NZS 60079.13 onto this ventilation system during installation and use it to provide the possible benefit of reduced EPLs. This may be especially relevant for installation in brownfield areas which are being re-classified as hazardous areas.

5.5.3.2 Ventilation best practice

To provide recommendations regarding ventilation, it is first important to define ventilation best practice. To provide guidance on ventilation, some aspects of ventilation best practice is discussed. Ventilation is used to control the formation of potentially explosive atmospheres in the asset by the introduction of (in most applications) clean air and the removal of contaminated air. For further information on ventilation requirements in hazardous areas, refer to AS/NZS 60079.10.1 and AS 60079.13.

Concentration gradient and local vs. bulk ventilation

Vapours which are discharged by immiscible flammable substances, as well as vapours which are discharged by flammable substances which have mixed with wastewater, will enter the headspace of an asset through different pathways.

Immiscible liquids will remain on the wastewater surface, creating an oily sheen or rainbow coloured effect which can be visible. These liquids will spread over the wastewater surface, creating a layer which will begin to directly discharge (or evaporate) into the space. As this evaporation occurs, there will remain a portion of the atmosphere immediately adjacent to the liquid surface where the air will be saturated with the flammable vapour. For flammable vapours such as petrol, this saturation concentration is higher than the LFL. It is important to note that even at exceptionally high rates of ventilation, it is very difficult if not impossible to avoid a concentration in the air space of at least 100% of the LFL at some small point in the pumping station. From this point, vapour is diffused through the bulk gas phase and the concentration in the atmosphere begins to increase at all points in the space. This leads to a concentration gradient, where the local concentration close to the wastewater surface can be significantly higher than a point distant from that surface.

Soluble liquids, which will dissolve in wastewater, are transferred from the liquid phase more slowly and are driven by the partial pressure of that substance above the liquid surface. This is defined by Henry's Law. In this case, the evaporation of the liquid substance into the vapour phase will generally be better mixed than an immiscible liquid in that the liquid in contact with the vapour contains a smaller concentration of the substance. Ventilation of the bulk gas phase is generally sufficient to manage the concentration of these substances. However, there will remain some difference between the concentration at the liquid surface and the uppermost part of the head space. This is particularly true when the substance, in the vapour phase, is significantly lighter or heavier than air.

To account for this, ventilation extraction points should be chosen to avoid localised concentrations. This could mean an extraction point close to the liquid surface (yet high enough that it will not be submerged during peak flow times), or for larger assets, multiple extraction points close to the water surface. In the case of an item of plant or equipment, the extraction point should be close to the source of release to minimise the diffusion of the local flammable atmosphere into the bulk air space. This will minimise the formation of local pockets of high concentration. In smaller spaces, or where contaminants are of a nature where diffusion to the bulk gas phase is more likely, ventilation of the bulk phase is often sufficient to control the formation of a hazardous atmosphere.

Relief or make up pathways

Although often neglected in ventilation design, the mechanism by which air is brought into or removed from a space which is being ventilated is an important ventilation consideration. If air is being supplied by the ventilation system, the air which then leaves the process unit is called relief air. If air is being extracted by the ventilation system, the air that first enters the process unit is called make up air.[26]

[26] In mining applications and some tunnelling applications, a positive pressure is often maintained in the asset to ensure fresh air is supplied for access, and that if a hazardous atmosphere develops, this atmosphere is dispersed through many gaps and not drawn to a single point where an electrical/mechanical asset (i.e. a fan) sits. In wastewater assets, if a positive pressure was developed, the continuous odour and toxicity impacts from H_2S inherent with foul air leaking through gaps at ground level overweighs the benefits from a hazardous atmosphere point of view. Wastewater assets tend to be operated under a negative pressure for these reasons.

Relief air or make up air is generally sourced from a dedicated item of equipment. In network applications, this is generally an inlet cowl or an air inlet. In wastewater treatment plant assets, this may be via a barometric air damper for a low-pressure application or flame arrested relief valve for a digester. It is important that the equipment contains a low pressure drop, such that air is encouraged to enter or exit through the intended pathway and not through uncontrolled leakage points such as gaps in covers.

The location of introduction of this make up or relief air is important, as it affects the path that air travels through the air space of an asset until it arrives at the extraction point (or vice versa). Best practice is to have multiple air relief or make up air openings, such that the air is not swept from a single point to the extraction point. Locations for relief valves should also be positioned to avoid short-circuiting, where the relief or make up point is too close to the extraction point and path of the air does not sweep through adequately. Best practice in ventilation design for covered assets also includes an allowance in the ventilation rate and extraction pressure to allow sufficient negative pressure under the covers. Sufficient points of low-pressure drop should be available such that fresh air is being reliably used to control the atmosphere in the space, rather than borrowed air from upstream of the extraction point.

Turbulence

Where evaporation is based heavily on the partial pressure of the vapour above the surface the turbulence of the wastewater is a significant factor in the quantity of flammable vapour which is emitted to the bulk gas phase. This is especially true for soluble liquids, yet also applies to immiscible liquids. A quiescent surface, such as the water level of a maintenance hole with submerged inlets and outlet, will not lead to an increase in emissions. The worst-case scenario is an asset with an exceptionally turbulent wastewater surface. This is readily evident in treatment plants where bellmouths in inlet works cause a waterfall event to occur.

A primary cause of surface turbulence in wastewater applications is the hydraulics of asset operation. Waterfalls (where wastewater falls from one height to another), free discharges or steep inclines all agitate the wastewater surface and can increase the release of any flammable substances.

Submerged inlets and outlets and low wastewater velocities, long radius bends and the minimisation of baffles are common best practice approaches used to ensure that wastewater surfaces are quiescent.

Impeding factors

Blockages to the movement of air can be a factor in increased local concentration of flammable vapour in a space. In an open environment such open process units at wastewater treatment plants, physical blockages such as walls or roofs can prevent horizontal air movement and decrease the effective ventilation of an installation. In a covered and ventilated space, blockages such as pipework, walls, stopboards or access platforms can cause a blockage between the area obstructed and the extraction point. The physical geometry of the asset itself can also cause this impedance. For example, a pumping station with an annular emergency storage tank which surrounds a wet well has very poor air movement between the tank and the wet well.

Best practice ventilation designs for open plant areas ensure that wind can access the structure from the most commonly occurring wind direction at the site, and with structures positioned away from key wind corridors to allow maximal natural ventilation. In the case of an enclosed structure, it may not always be possible to keep any internal structures or pipework minimal. In this case, additional extraction points are provided which allow for ventilation of areas impeded by the structures.

Contaminant features

The contaminant features can strongly influence the optimum ventilation strategy for an asset. For example, methane is lighter than air, meaning it will float and can often be released from gaps in covers of structures. Heavier than air contaminants will tend to accumulate near the wastewater surface. The striation in concentration gradients can alter quickly in dynamic systems such as if the water level significantly changes.

Ventilation rate based on control of contaminants

AS/NZS 60079.10.1 provides a method of calculating ventilation based on a known rate of release of hazardous material. If monitoring data is available to provide enough information to quantify the flammable material and the quantity of its release such that the methods of a recognised standard can be used, it is recommended that the ventilation requirement for the asset be calculated using one of the following recognised standards:

- AS/NZS 60079.10.1
- EI15
- Dispersion modelling software tools such as Computational Fluid Dynamics (CFD)
- Institution of Gas Engineers and Managers (IGEM)/SR/25, however this method should only be used where the contaminants of concern are exclusively biogas, methane or natural gas, which is unlikely

There is concern from the British Standards committee, as well as one of the water agencies of the working group, that the hypothetical volume method outlined in AS/NZS 60079.10.1 is overly conservative. This conservatism does not preclude its recommendation in this document. Water agencies should balance the initial costs of additional design work in the form of dispersion modelling/CFD against the construction and operation costs of larger ventilation infrastructure and the impact of this to the community e.g. through increased noise disturbance. This should only be done when there is high confidence in the data available.

Dispersion or discharge modelling using CFD is a tool which is growing in popularity as the costs of usage are reduced over time. There are commercially available packages tailored specifically towards hazardous areas, as well as standard CFD packages which can be used. CFD can provide strong evidence of the effectiveness, or lack thereof, of ventilation on hazardous areas, and when used correctly is one of the best available tools to understand the impacts of ventilation. United Utilities CoP 1 recommends IGEM25 and CIBSE B. CIBSE B has been reviewed and was deemed unsuitable for ventilation of linear assets. This is best used for habitable spaces such as buildings. IGEM25 is included but with a caveat which limits its applications to a very small set of cases.

Ventilation rate based upon headspace air change rate

In the absence of monitoring data, there is no alternative but to rely upon a heuristic approach to ventilation. These are air change rates, expressed in Air Changes per Hour (ACH), which when applied to the air volume of the space can provide a ventilation rate in cubic metres per hour.

For raw sewage applications, such as those found in network applications or inlet works 6 – 15 ACH is common in the water industry. These ventilation rates are often to ensure odours do not escape from the covered asset and are **not** designed to reduce the contaminants within the headspace of that asset below a certain concentration.

Many international guidelines specify ventilation rates for hazardous area control, although often no engineering basis is presented for review.

Using a specified air change rate can lead to either over or under design, as it does not address the requirements of the specific contaminant of concern. However, without knowledge of the specific contaminants of concern present in the asset, these heuristics are the only tool available. A range of international examples are discussed below.

5.5.3.3 International recommendations

Like AS/NZS 60079.10.1, EI15 does not provide any ventilation rates for use. Rather, it states that ventilation should contain the contaminant of concern in the space to 25% LFL. It also recommends localised ventilation close to the source of release, rather than space ventilation, to minimise the area. Although useful for a treatment plant environment, for the purposes of ventilation of network infrastructure it is difficult to apply without a good data basis.

In the review of the international standards and guidelines, prescribed figures are used by certain water agencies to provide an indication of sufficient ventilation. Examples include:

- NFPA820, containing two ventilation level recommendations which reduce the classification of the area with no guidance as to their recommended use:
  - 12 ACH
  - 6 ACH
- SPD E04, containing three recommended levels with guidance as to their usage:
  - 1 ACPH rate for digester air spaces and enclosed plant rooms to allow reduced zoning
  - 3 ACPH for enclosed plant rooms allowing further reduced zoning, wet wells and a lower limit for odour control
  - 6 ACPH as an upper limit on odour control
- COP1 i7 contains recommended levels with guidance as to their usage. The newer edition (i9) changes this to a recommendation to use a suitable standard such as IGEM25 (from the natural gas industry), Quadvent (a UK government developed tool for calculating gas release volumes for hazardous areas) or CIBSE B (a building services

industry ventilation code, somewhat equivalent to AS 1668.2). The i7 version recommended levels are:

- 5 ACPH for enclosed plant rooms
- A range of prescribed equations for different installation cases covering both network and treatment plant applications

These values are considered in the discussion of natural and forced ventilation below.

5.5.3.4 Forced ventilation

Basis of recommendations

Many of the international guidelines discussed provide ventilation rates for use, but do not demonstrate the basis behind these calculations. To provide an engineering basis, a method of approximating mass flow from a worst case contaminant was developed. This draws from experimentally validated equations for the evaporation of hydrocarbons in open, shallow containers. Although this will not be as accurate as CFD, it provides an indication of required ventilation. For the purposes of demonstration, a commonly encountered wastewater asset was used as a reference. This was selected as a 3 m diameter pumping station wet well, 7 m deep. This is a standard pre-cast concrete sized pumping station commonly available from vendors. Some characteristics of the pumping station are provided in Table 5-9.

Table 5-9: Parameters of a sample pumping station, for ventilation purposes

Parameter	Value	Symbol
Diameter (m)	3	D
Depth (m)	7	h
Minimum liquid depth (m)	2	h_{hs}
Air volume @ min. liquid depth (m^3)	35.3	V_{hs}
Surface area of liquid (m^2)	7.1	A_s

To provide an instructive example, a reference contaminant, petrol, is used as one of the worst contaminants of concern. There are some chemicals which have lower LFL values than petrol, such as cumene, diborane or diethyl benzene (or xylene), however, apart from xylene (found with toluene and benzene in industrial painting wastes such as from panel beaters), these tend to be products from the oil and gas industry which are not often encountered in the municipal sewerage system. Xylene is more soluble than petrol, meaning that its emission rate will be less than petrol for a given surface area as more of the compound will remain in the liquid phase. For this reason, octane (a hydrocarbon with similar chemical and physical properties to petrol) is used as the reference contaminant of concern for ventilation design.

When the liquid octane enters the pumping station (either from the lid or through the gravity inlet), it will settle on the wastewater surface, as it is not soluble, and begin evaporating. The following key assumptions are made in calculating this emission rate and subsequent ventilation rate:

- The air in the pumping station is 25°C, as is the liquid petrol and is at normal atmospheric pressure of 101,320 Pa
- The LFL of octane is 1% by volume (i.e. 10,000 ppm) at this temperature
- The emission rate of octane is constant. In reality, emission will slow down as concentration in the head space forms. A concentration gradient will form: air saturated with octane immediately adjacent to the liquid surface, and less saturated air at the furthest point from the surface. This concentration gradient is considered by use of the mixing factor and turbulence factor, detailed later
- Ventilation begins when the space is at 100% of the LFL. This provides a conservative approach
- That the wastewater surface, and thus the octane which sits upon it, is such that the wind speed is essentially zero. In reality, some limited air movement will occur during normal operation and there will be periods of high turbulence, the frequency of which will depend on the pumping station design. This is considered by use of the mixing and turbulences factors, ε and z, detailed later

A review of industry literature on the evaporation rates of a pool of liquid hydrocarbon concluded that Equation 2 adequately and conservatively described the assumptions used above, where E is the emission rate per unit area (kg/sm^2), M_i is the molecular weight (g/mol) and P_v is the vapour pressure (Pa) of octane[27]:

Equation 2: $E = 4.07 \times 10^{-11} M_i P_v$

For the reference asset, the relevant information is provided in Table 5-10.

Table 5-10: Chemical data for octane at the reference temperature

Parameter	Value at 25°C
Molecular weight (kg/kmol)	114.23[28]
Vapour pressure of octane in air (Pa)	1,880[29]

The calculated emission rate is as follows:

$$E = 4.07 \times 10^{-11} \times 114.23 \times 1880$$

$$= 8.74 \times 10^{-5} \frac{kg}{sm^2}$$

Using Equation 3 and multiplying surface area of the reference pumping station, provided in Table 5-9:

Equation 3: $E_{specific} = E \times A_S$

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[27] **Equation 13 in Mazzarotta B., Bubbico R., 2016, Predicting evaporation rates from pools, Chemical Engineering Transactions, 48, 49-54 DOI:10.3303/CET1648009**

[28] **https://pubchem.ncbi.nlm.nih.gov/compound/octane#section=Vapor-Pressure**

[29] **ibid**

$$= 8.74 \times 10^{-5} \times 7.1 = 0.618 \times 10^{-3}\,\frac{kg}{s}$$

The volumetric release of octane is based on the use of the ideal gas law where V_{oct} is the volumetric release of octane (L/s), R is the ideal gas constant for standard temperature and pressure (8,314 LPa/molK), $T_{surface}$ is the temperature at the liquid/gas interface (average of liquid and gas temperatures) (K) and P is the pressure (Pa). Using Equation 4:

Equation 4: $\dot{V}_{oct} = \left(\frac{E_{specific}}{M_i}\right) RT_{surface} \left(\frac{1}{P}\right)$

The calculated volumetric emission rate is as follows:

$$\dot{V}_{oct} = \left(\frac{0.618}{114.23}\right) \times 8314 \times 298.15 \times \left(\frac{1}{101{,}320}\right) = 0.132\,\frac{L}{s}$$

The maximum volume of octane which can be removed via ventilation is achieved when the air in the pumping station is saturated with octane vapour. Without ventilation, this will occur quickly. The saturation concentration is described by the saturated vapor concentration equation (Equation 5) where $Conc_{sat}$ is the saturation concentration (%) given by:

Equation 5: $Conc_{sat} = \frac{P_v}{P_{air}} = \frac{1{,}880}{101{,}320} = 1.86\%$

At this point, the selected ventilation threshold (VT) value is used to control the formation of the hazardous atmosphere with ventilation. This differs from the previously selected threshold value, as AS/NZS 60079.13 7.1.3.1 stipulates that forced ventilation should control atmosphere to a minimum of 25% LFL. For the purposes of this example, the default threshold value of 25% is used, however it should be adjusted for the selected threshold value as described in Section 5.2 with a maximum value being 25% as stipulated by AS/NZS 60079.

The turbulence factor, z, is used to provide an indication of the effect of surface turbulence of the asset. An assessment should be made of the worst-case surface agitation turbulence and a factor selected from the range outlined in Table 5-11.

Table 5-11: Turbulence factor, z. Note that values in between those in the table can be nominated also

Description	Turbulence factor (z)
Quiescent surface e.g. shallow gravity sewer, submerged discharge into MH	1
Significant turbulence e.g. waterfall into pumping station, steep gravity sewer	2
Severe turbulence e.g. constant waterfall into very small pumping station, rising main discharge MH where there is no submerged discharge	4

For the reference example, a z factor of 2 is selected as there is occasional waterfalling of sewage into the pumping station.

The mixing efficiency, ε, is a concept used in EI15 to describe the efficiency of mixing with an enclosed space. It provides a multiplier to rate of ventilation, by considering local confinement and congestion of the space. A range of possible values and their description is provided in Table 5-12.

Table 5-12: Efficiency of mixing factor for ventilation. Note that values in between those in the table can be nominated also

Description	Efficiency of mixing factor (ε)
Unconfined/non congested enclosures	1
Moderate level of confinement/congestion	2
Higher levels of confinement/congestion	3

In a quiescent MH, an ε value of 1 could be possible. For a pumping station or other asset with baffle walls, pipework, cable conduits, access steelwork etc. a moderate or higher level of congestion is more likely.

For the reference example, an ε factor of 2 is selected as there are large pipes, an access ladder with intermediate platform obstructing the free movement of air

The required amount of extraction air (V_{air} in L/s) is defined in Equation 6

Equation 6: $\dot{V}_{air} = z\epsilon\dot{V}_{oct}\left(\frac{100\%}{Conc_{sat}}\right)\left(\frac{100\%}{VT}\right)$

For our example, the final air flow rate is:

$$\dot{V}_{air} = z\epsilon\dot{V}_{oct}\left(\frac{100\%}{Conc_{sat}}\right)\left(\frac{100\%}{VT}\right)$$

$$= 2 \times 2 \times 0.132 \times \left(\frac{100}{1.86}\right) \times \left(\frac{100}{25}\right) = 114\ \frac{L}{s} = 411\,\frac{m^3}{h}$$

To find out how many air changes this is, Equation 7 divides the cubic metre per hour ventilation rate by the volume of the headspace (V_{hs}) to provide the ACH:

Equation 7: $ACPH = \frac{\dot{V}_{air}}{V_{hs}} = \frac{411}{35.3} = 11.6\ ACPH$

Recommendations

Based on ventilation best practice and the case study provided, and where no data exists to provide a conclusive indication of the contaminants of concern and their concentrations, the following procedure should be used:

1. Assess the geometry of the new or existing asset and worst case (maximum) surface area and worst case (minimum) air volume
2. Assume the entirety of the wastewater surface is covered in octane. Select a sewer liquid surface temperature and gas temperature as per the worst case.
3. Calculate emission rate and corresponding ventilation rate as per equations in basis of recommendations

4. Apply turbulence factor (z) and mixing effectiveness (ε) to ascertain the required ventilation

This method should only be used:

- In new constructions where similar data from previous sampling campaigns of similar assets is not available as a reference
- When assigning a classification to an existing asset or network where there is insufficient data from a sampling campaign available

In addition to these recommended ventilation rates, ventilation systems must comply with the following design requirements as well as all relevant clauses of AS/NZS 60079.13, AS/NZS 60079.14 and AS/NZS 60079.17:

- Be greater than the incoming air to the asset
- Be greater than the air displaced from water level changes in the asset
- Provide dedicated make up air pathway(s) e.g. inlet cowl, relief air vent. In large structures, there should be more than one. Air inlets should be designed in a manner to allow fresh air into the system without allowing foul air to be released.
- Be suitable for the life of asset in terms of selection of materials

The worst-case conditions for the equations described in this section are those with the largest ratio of surface area to volume i.e. maximum surface area with minimum volume of headspace. Ventilation can be classified as 'Good' if the ventilation rate meets the selected LFL threshold value in the worst-case conditions. For example, if the LFL threshold value is selected as 5% LFL and the ventilation rate keeps the LFL below this amount, the ventilation can be classified as 'Good'.

Ventilation can be classified as 'Fair' if the ventilation rate does not meet the selected LFL threshold value at the worst case conditions, however keeps the LFL below 25%.

All other cases should be considered as having a 'Low' ventilation rate.

Availability of ventilation

As discussed with regards to the power failure abnormal condition (Section 5.4.4.1), availability of ventilation is closely aligned with failure of machinery due to loss of power, as well as mechanical failure of fans. Clause B.6 of AS/NZS 60079.10.1 states:

> "*In assessing the reliability of artificial ventilation, the reliability of the equipment and the availability of, for example, standby blowers should be considered. Good availability will normally require, on failure, automatic start-up of standby blowers(s). However, if provision is made for preventing the release of flammable material when the ventilation has failed (for example, by automatically closing down the process), the classification determined with the ventilation operating need not be modified i.e. the availability may be assumed to be good*"

The availability of ventilation for linear asset classification should consider power failure, machinery failure and foreseeable misuse.

A relationship between industry practices and their availability is provided in Table 5-13. The table assumes a set of common principles for all rankings:

- Equipment is installed in accordance with manufacturer's written and verbal direction
- Equipment is maintained in accordance with manufacturer's instructions and at the intervals specified in the operation manual or according to the water agencies standard maintenance plan, whichever is more comprehensive
- Equipment is operated within its design envelope for its entire asset life

Table 5-13: Availability of ventilation mapped to common water industry installation practices

Installed ventilation infrastructure	Availability
Installed standby on separate power supply, uninterruptible power supply (UPS) or adequately sized battery supported auto change over via instruments, control system redundancy, critical spares in storage, fenced asset	Good
Installed standby on same power supply, UPS or adequately sized battery supported auto change over via instruments, backup generator installed with auto cut in, critical spares in storage, fenced asset	Good
Installed standby on same power supply, UPS or adequately sized battery supported auto change over via instruments, generator receiving infrastructure installed, critical spares in storage, fenced asset	Good
Installed standby on same power supply, UPS or adequately sized battery supported auto change over via instruments, fenced asset	Fair
Installed standby on same power supply, auto change over via instruments, fenced asset	Fair
Installed standby on same power supply, manual change over via alarm from instruments and operator intervention	Fair
Boxed or warehoused critical spare, manual change over, staffed asset	Poor
Boxed or warehoused critical spare, manual change over, unstaffed asset	Poor
No redundancy	Poor

Good ratings are those which produce a downtime for infrastructure of less than 15 minutes Fair conditions are generally those that will provide same day change over should there be no abnormal event occurring. Poor conditions are those which have unknown or long time between ventilation service resuming or those that can reasonably be expected to not result in same day change over when resources are strained (e.g. during abnormal conditions).

In addition to the above, to be considered fair or good, the following parameters require online monitoring:

- A method of knowing if the duty fan is running and effectively extracting air e.g. flow meter, flow switch, pressure transmitter etc. This can be in the common discharge, if there are automated dampers which switch duty and standby machines
- For larger, more critical machines there should be fault monitoring of the fan to enable planned maintenance or procurement of long lead time spares e.g. vibration monitoring, temperature monitoring of key bearings
- A method of preventing backflow between duty and standby machines

The nature of the online monitoring does not have to be sophisticated: it can be as simple as a text message to an operator, or as complex as differing levels of alarm and automatic work order generation via a SCADA system. Both achieve the same outcome in allowing down time to be notified immediately such that preventive action can be taken.

Selection of equipment

Selection of electrical equipment for use in hazardous areas is dependent on the contaminants of concern. Ideally, the contaminants of concern for an asset should be determined through sampling as per Section 3. This should be investigated first.

However, it is recognised that the methods outlined in this section enable classification of an asset without knowing the contaminants of concern (e.g. because the proposed asset has not yet been constructed), as it is a generalised classification method. If the contaminants of concern are not known, selection of equipment is not possible unless assumptions are made.

Table 5-14 suggests a minimum recommendation based upon historical evidence of compounds regularly present in the municipal sewerage system. As previously recommended, determination of contaminants of concern through sampling is always preferred.

Table 5-14: Suggested minimum hazardous area parameters for use when contaminants of concern and concentrations are not known

Suggested minimum parameter	Rating	Comment
Equipment Group	II	Best fit for wastewater applications
Subcategory	B (or B + H2, in the presence of hydrogen)	Based on the potential presence of common solvents such as MEK or isopropanol
Temperature Group	T4[30]	Based on the potential presence of ethyl ether (drug manufacture) or acetaldehyde (industrial discharge)

[30] **It is recognised that carbon disulphide is a T6 contaminant which may be present in the sewerage system. However, the LFL is 10,000 ppm, which is a level which is extremely unlikely to occur by illegal dumping, industrial discharge or otherwise due to its highly unstable and toxic nature. For this reason, it is not considered in assigning a suggested temperature group.**

From this point, electrical engineering professionals can make a suitable judgement on the required types of equipment.

5.5.3.5 Natural ventilation

Natural ventilation is commonly used throughout sewerage networks around the country to equalise pressure fluctuations associated with movement of liquid and air. As liquid levels inside the system rise, air is driven out of the system by the displacement effect of the water. If discharge points (e.g. a vent shaft) are not provided, the entrapped air can form pockets which inhibit flow. As the liquid levels fall, air will be drawn into the system to "make up" the lost volume of liquid and create an equilibrium with the pressure outside the network. This is generally done through induct points, such as cowls, valves or an open lid.

AS 60079.10.1 clauses B.6. states:

> "*For outdoor areas, the evaluation of ventilation needs to consider the local minimum wind speed and availability. If the minimum wind speed is 0.5 m/s and will be present virtually continuously, the availability of ventilation can be considered as good."*

In a sewer network context, these wind speeds are usually only applicable to vent shafts, air inlets and open top pumping stations. All other assets are generally buried below ground, such as dry wells, access pits, wet wells, air valve pits, maintenance holes etc. This means that the wind cannot be relied upon, and the asset cannot be considered to have good ventilation with natural ventilation as its only source of air movement.

Although natural ventilation is sufficient to allow the functioning of the sewerage network as a hydraulic system, this approach cannot be relied upon for the removal of the contaminants from the air space in the system for the following reasons:

- It is heavily climate dependent, relying on temperature differences, pressure differences and wind speeds (called micro-climatic conditions). This makes ventilation difficult to predict and therefore unable to be relied upon
- Open lids, which have better access to wind to drive the stack effect, are now less common in general industry practice due to current and future odour considerations
- It is highly susceptible to blockages and fouling, as the very low-pressure drops associated with natural air movement are more easily impeded than the induced negative pressure of a forced ventilation system. This applies both to the intake pathway (i.e. the air inlet point) as well as the air discharge point

To demonstrate this, the example pumping station from Section 5.5.3.4 is re-utilised. Common industry practice for the natural ventilation of pumping stations and other network assets is via the use of a vent shaft. Air flow through a vent shaft is based on the differences in temperature between air inside the asset and air outside the asset, with warmer and less dense rising to the top of the shaft. This is temperature induced buoyancy flow. A simple equation to model this effect is as follows:

$$Q = C_d A_{sq} \sqrt{2gh \frac{(T_i - T_o)}{T_i}}$$

Table 5-15 provides describes and assigns a value to of each of the parameters in the equation.

Table 5-15: Sample pumping station vent shaft variables

Parameter	Symbol	Value
Discharge coefficient	C_d	0.65
Shaft area	A_{sq}	For a DN150 and a DN300 shaft
Gravitational acceleration	g	9.8 m/s^2
Vent shaft height	h	9 m
Internal temperature	T_i	30°C
External temperature	T_o	Variable

The discharge co-efficient, stack height and stack sizes are typical of common wastewater industry practice. The temperature difference is the difference between the internal wet well temperature. For the purposes of example, the internal wet well temperature is fixed at 30 degrees. This was selected based on common for temperatures inside the sewerage system to be between 25 - 30 degrees.

The data is plotted, showing air flow and air changes per hours for each of the stack sizes, in Figure 5-2.

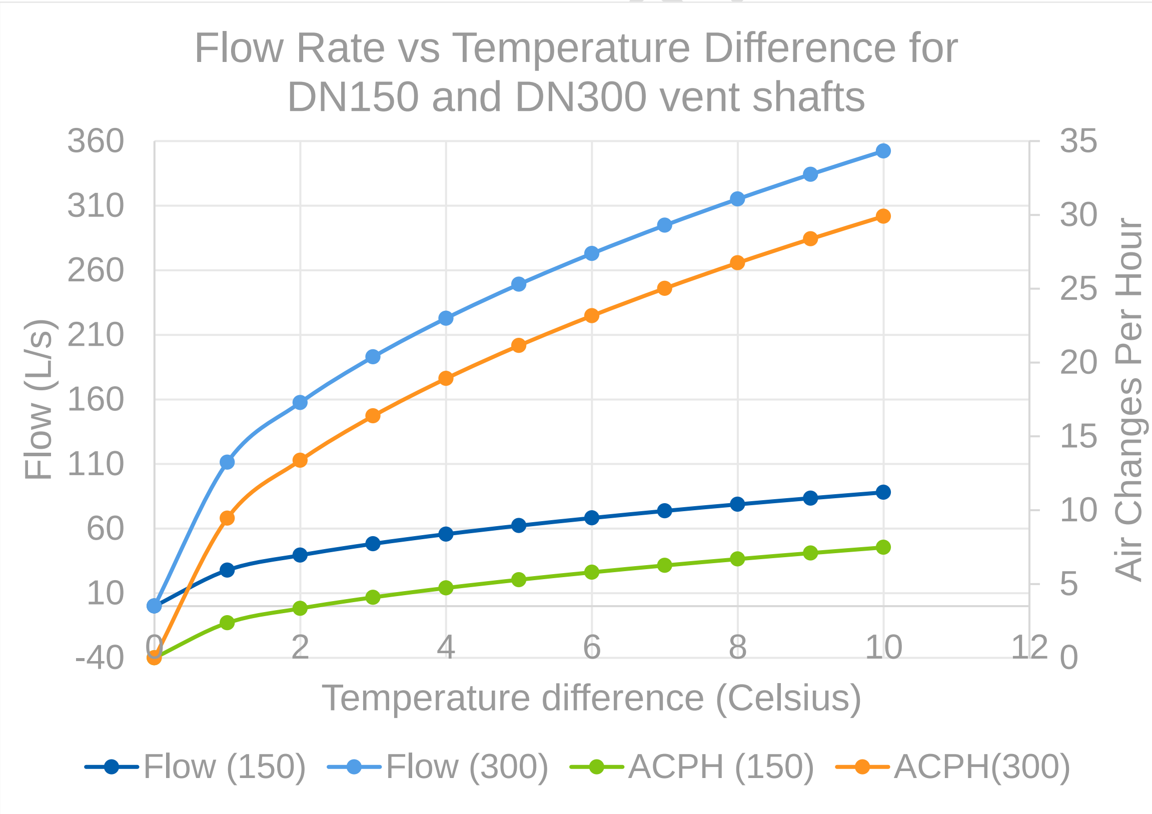

Figure 5-2: Two different vents shaft sizes and the effect on ventilation

At high temperature differences, the larger diameter shaft provides very high air flow and ACPH. In fact, for this sample asset, the larger shaft may provide sufficient ventilation to control the formation of an explosive atmosphere even with substantial concentrations of flammable material. However, the effect of wind on the ventilation rate has not been considered: this may assist or impede ventilation based on its direction and magnitude. Also not considered is the effect of increasingly warmer temperatures: when the external temperature is greater than or equal to the internal wet well temperature, ventilation will be substantially reduced.

This impediment is especially pronounced in the northern regions of Australia, such as far north Queensland. In these locations, the relative humidity and temperature differences between the sewerage network internals and the ambient conditions are such that vent shafts do not operate as intended. For the control of a hazardous atmosphere, if an asset only has natural ventilation, the asset can be considered as having a ‘Low’ degree of ventilation as per AS/NZS 60079.10.1. Its effectiveness in certain situations is offset by its poor reliability.

5.5.4 Summary of mitigation measures

Having considered the benefits associated with monitoring and source control, and the degree and availability of ventilation for the asset, the overall level of benefit can be determined in line with Table 5-16.

Table 5-16: Level of benefit through mitigation measures

Monitoring and source control	Ventilation						
	Degree						
	High			Medium			Low
	Availability						
	Good	Fair	Poor	Good	Fair	Poor	All
High	High	High	Medium	High	Medium	Low	Medium
Moderate	High	Medium	Medium	Medium	Medium	Low	Low
Low	Medium	Medium	Medium	Low	Low	Low	Low

5.5.5 Consequence

The above process has so far investigated the likelihood of an explosive atmosphere occurring which affects the classification requirements. Whilst the consequence of any explosion is often considered very high or catastrophic, there may be cases within linear assets where the consequence of an explosion is unacceptable to the water agency. For these locations, even if the likelihood of an explosive atmosphere developing is low, the water agency may choose to have a minimum classification level or to provide equipment protection without a formal zone. The types of consequences where this may occur are described below.

5.5.5.1 Asset criticality

Criticality requirements can influence the consequence of a hazardous atmosphere. For example, if a single pumping station having an ignition or explosion could shut down effective management of sewage for an entire city, the risk associated with the asset becomes much higher. Consider how important the asset is to the sewerage system and the operations of your organisation and modify the consequence field accordingly.

5.5.5.2 Location

The location can influence the consequence of an explosive atmosphere igniting by being:

- Within, adjacent or near to a location where an explosion could cause serious harm to people such as being located within a high density residential building or place of work
- Near to or within a high-risk site, such as a petrol refinery, such that an ignition or explosion causes follow on effects

5.6 Residual likelihood allocation

With a benefit identified, the likelihood identified through the catchment features can then be modified. This gives a residual likelihood allocation in line with Table 5-17.

Table 5-17: Residual likelihood allocation

Residual Likelihood	Benefit		
Original risk	**High**	**Medium**	**Low**
Low	Low	Low	Low
Medium	Low	Low	Medium
High	Medium	High	High

It can be seen that the use of good ventilation and monitoring, indicated by a ‘High’ degree of benefit, can reduce the original likelihood significantly. The degree to which benefits can reduce the likelihood of an explosive atmosphere developing depends on how high the likelihood is to begin with.

5.7 Classification

With the residual likelihood identified, the asset can be classified using the generalised method outlined in this guideline. The classifications are determined both by the residual likelihood level and the selected threshold values. The nominated classifications for each threshold value are provided in Table 5-18.

Table 5-18: Classification of area based on residual risk, adjusted for choice of controlled threshold value

Threshold Value	Residual Likelihood of exceeding the threshold value (after controls)	Zonal Classification
0 - 10% LFL	Low	Non-Hazardous [Note 1, 2]
	Medium	Minimum Zone 2 NE [Note 1, 2, 3]
	High	Minimum Zone 2 [Note 3]
11% to 20% LFL	Low	Non-Hazardous [Note 1, 2]
	Medium	Zone 2
	High	Minimum Zone 2 [Note 3]
21% to 30% LFL	Low	Non-Hazardous [Note 1, 2]
	Medium	Minimum Zone 2
	High	Zone 1 [Note 3]
31% to 40% LFL	Low	Non-Hazardous [Note 1, 2]
	Medium	Zone 1
	High	Minimum Zone 1 [Note 3]

Note 1 – If there is a confirmed history of flammable immiscible liquids being discharged into the asset, then the minimum classification should be Zone 2.

Note 2 – If the consequence of an explosion is considered too great by the water agency (see Section 5.5.5) the equipment installed may have EPL rating of Gc (see section 4.2.5), regardless of if the area is zoned as non-hazardous.

Note 3 – Any High residual likelihood (and Medium for 0-10% LFL) is recommended to perform a monitoring campaign. Zonal classification noted in the above table is recommended to be used until a monitoring campaign can be undertaken. Source of Release methods to be used based on results of monitoring campaign.

5.8 Documentation

To formalise this process, the hazardous areas must be fully documented as per the AS/NZS 60079 series. Due to the subjective nature of the likelihood assessment process, the outcomes of the assessment must be transparently recorded. There must also be sufficient detail such that any changes in personnel, or external third parties can clearly follow the logic of the assessment and the appending documentation. This is generally through the production of a hazardous area classification report.

Hazardous area zoning drawings, documented as per AS/NZS 60079.10.1 recommendations, should be produced for the asset. Some examples of this for linear assets are provided in Section 10.

Maintenance and engineering personnel (whether internal or external) should be sufficiently experienced in the requirements of working in hazardous areas. This is generally in the form of formal training as per the guidance provided in AS/NZS 60079.14 Clause 4.5 and Annex A, as well as AS 4761.1. This guidance varies depending on the role (such as a tradesperson or an engineer) and should be assessed at regular intervals to ensure competence is maintained, either through continuous familiarity with the work or refresher training. Training of personnel should be documented in an organisation's hazardous area training register, or along with other relevant training.

6. METHOD OF CLASSIFICATION FOR WASTEWATER TREATMENT PLANT ASSETS

Apart from the inlet works and pre-treatment modules or storage, which can have unknown inputs of a similar nature to a linear asset, wastewater treatment plants have processes which can be predicted. Due to this consistency, and with decades of practice and data, the use of one of the 'Source of release' methods, as described in AS/NZS 60079.10.1, becomes possible. Many facilities nationally are classified with the guidance provided in AS/NZS 60079.10.1. Despite this, many water agencies have observed that differences of opinion between classification professionals can lead to different outcomes in the classification of the same unit processes at different plants.

To provide the possibility of greater consistency for the industry, this section provides guidance on some aspects of the treatment plant classification process. In addition to this guidance, unit process classifications of common wastewater treatment modules are presented for industry reference. If classifications differ substantially from the reference, which may occur in practice, the reasoning behind this can be investigated.

As with linear assets, monitoring data of sufficient length to capture the range of abnormal operating conditions provides the best basis from which to make decisions about classifications of atmospheres. For the classification of new plants, monitoring from similar existing plants, if available, can be conducted. This data acquisition is encouraged first and foremost.

6.1 Considerations for treatment plant classification

To assist in consistency of classification, some commentary on the hazardous area classification process for the water industry is made below.

6.1.1 Threshold value for treatment plants

This is defined as the percentage LFL of the most significant contaminant of concern. As discussed in Section 4.2.3, in certain legislative environments it is necessary to control hazardous atmospheres below the level of the 100% LFL threshold. It is important to emphasise that this threshold value is for control of hazardous (i.e. flammable or explosive) atmosphere. Toxic substances can be hazardous to human health at very low LFL levels. For example, H_2S exposure at 1,000 ppm is lethal however its LFL is 40,000 ppm. This is highly dependent on the specific contaminant of concern.

Table 6-1 summarises the guidelines recommendations on threshold value. Although this guideline leaves the threshold value to the discretion of the water agency, a minimum of 5%

LFL and a maximum of 40% LFL is recommended. Below 5% LFL, concentrations become difficult to measure accurately and it is therefore not recommended to target less than this value. At 40% LFL, Australian industry experience is that the fire department will require notification to begin tracking the event and it is therefore recommended that this is provided as a maximum threshold value.

Table 6-1: Guideline recommendations on threshold value for treatment plants

Threshold Level Recommendation	LFL of most significant substance
Minimum	5%
Default (no legislation)	25%
Maximum	40%[31]

In the absence of a legislated requirement and if in need of guidance, a threshold of 25% LFL is recommended. This is supported by the UK DSEAR guideline (clause 6.219), which advises controlling atmospheres with ventilation to 25% LFL. This allows ample time to initiate a process shutdown (where applicable) or take any plant level rectification action. Further justification is as follows:

- Measurements of the kind described in Section 3 are point measurements, sampling from a single point. This point may not be reflective of the overall hazard. Depending on asset geometry, pockets of higher LFL may exist within a structure. Although measurement should occur from a conservative location, this is not always possible. As such it is possible that the measured value is insufficiently conservative
- Early indication of a high LFL event. If a high LFL event is occurring, notice and opportunity to take action should come well before the 100% LFL value. This is especially true of events which may begin slowly and become stronger over time, such as build-up of petrol in an inlet works structure
- Time is required to respond to a high LFL situation. Emergency services may need notification, assets may need to shut down, bypasses may need to be placed into service, back-up power may be required etc. All these activities require planning time which is less available should higher threshold values be used

There are significant implications associated with the choice of threshold value such as additional ventilation required to reduce concentration levels, or significant additional cost in ensuring equipment is suitably rated for the zoned environment. Careful consideration is advised.

[31] This threshold is set based on the value at which the fire department generally requires notification. For digesters at treatment plants it is acknowledged that these are often controlled to achieve <50% LFL in zoned areas. 50% LFL would be a suitable threshold for digester gases given historical designs and higher implications associated with digesters.

6.1.2 Security and criticality

6.1.2.1 Plant location and asset location

Location can influence the consequence associated with a hazardous atmosphere igniting at a wastewater treatment plant. This can occur external to the plant e.g. where a plant is in close proximity to many residences, or a process unit is close to the boundary associated with a member of the public. It can also occur internal to the plant, where the risk of a blast from an area such as a switch room can cause an ignition of the switch room. Consider proximity of assets to the boundary or to one another in classification at wastewater treatment plants. This will not affect the likelihood of a hazardous atmosphere occurring, however a water agency may wish to consider the consequence and apply a conservative view point.

6.1.2.2 Security

The security of the site can play a significant part in preventing foreseeable misuse. Some sites are secure by virtue of their location being difficult to access, meaning that potential saboteurs are discouraged from making the trip. Due to the dangers associated with interference from untrained members of the public, wastewater treatment plants are often fenced. However, this is not always the case. This risk is exacerbated by the often-dangerous chemicals which can be stored on the site. Consider the actual effectiveness of security systems in preventing vandals or thieves from entering the site when undertaking the hazardous area classification.

6.1.3 Abnormal operation

A significant difference of engineering opinion amongst hazardous area classifications is the definition of abnormal operation, and its effect on the zoning of the process module. The same features of abnormal operation discussed in Section 5.4.4 also apply to treatment plants; specific discussion is below.

6.1.3.1 Power failure

Consider the effect of power failure on the process. Loss of power at a treatment plant could mean:

- Loss of flow, mixing or process energy, leading to high residence times, foaming or causing environments which increase hazardous area risk
- Loss of ventilation for control of hazardous atmospheres
- Loss of monitoring for hazardous area control

Likelihood of power failure should be taken from plant operating data, or operator experience if this unavailable. Likewise, the effect of staffing should be taken into consideration e.g. if back up diesel generators are available, but operators are engaged with other issues which may occur during a power failure, the actual time to implementation should be considered.

6.1.3.2 Plant/equipment failure

Plant/equipment failure at a treatment plant can cause:

- Loss of flow, mixing or process energy, leading to high residence times, foaming or causing environments which increase hazardous area risk
- Loss of ventilation for control of hazardous atmospheres
- Loss of monitoring for hazardous area control

Likelihood of failure should come from water agency operational data for similar assets, or manufacturer's recommended Mean Time Between Failure (MTIF) rates.

6.1.3.3 Varying load cases

The forecast load to be used in the assessment should reflect the frequency that a hazardous assessment is reviewed. For example, if it is intended that the hazardous area assessment is conducted every 4 years, the forecast load should consider expected variations across the next 4 years. In this assessment, the following should be considered:

- Will lowest dry weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will peak dry weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will wet weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will peak wet weather flow affect the formation of hazardous atmospheres? If so, how frequently does this occur?
- Will these flows change significantly in the review period?

6.1.3.4 Blockage or leakage

Blockages and chokes can increase the likelihood of a hazardous atmosphere occurring by:

- Restricting headspace and reducing volume, therefore creating an increased risk of hazardous area in the downstream air space
- Ruptured or burst pipelines
- Damaging equipment, leading to plant failure

Leakage of pipework can increase the likelihood of a hazardous atmosphere by:

- Releasing hazardous atmospheres into unintended spaces
- Insufficient control of an atmosphere (e.g. leaking OCU ductwork)

If blockage or leakage in the asset causes a change of atmosphere, consider this in the classification.

6.1.3.5 Flood

The effect of a design flood should be considered on the hazardous atmosphere. Floods can:

- Reduce air spaces, leading to higher LFL in the reduced volume
- Disturb sediments, potentially releasing discharges
- Destroy above ground assets in sensitive areas

Consider the effect of a design flood in line with or of greater magnitude than the asset life. Common industry practice is to consider the 1% AEP for in ground structures; for mechanical equipment, with its lower design life, it is generally either the 5% or 2% AEP flood. If flooding increases the risk of hazardous atmosphere, take this into account in the risk assessment.

6.1.3.6 Foreseeable misuse

One of the highest risk abnormal conditions is that of foreseeable misuse of the sewerage system. Because of the open and unmonitored nature of the system, it is open to misuse in both malicious and unintentional ways. Some unintentional which can contribute to increased risk of hazardous atmosphere include:

- Operator error e.g. leaving valves in incorrect position, wrong control sequences initiated
- Vandalism
- Hacking of remote-control systems by malicious operators

For the secure environment of the treatment plant, the likelihood of foreseeable misuse is lower than encountered in the network environment. Consider the robustness of physical and digital security systems, effectiveness of training, presence of trained personnel on site and similar items in the classification of the unit process.

6.2 Unit process classifications

Some of the common unit processes present in wastewater treatment plants are discussed in this section. Any recommendations made are only suggestions as to possible minimum zoning requirements. Greater or lesser zoning may be required according to the individual circumstance, and each and every installation should be properly assessed in accordance with the source of release methods outlined in AS/NZS 60079.10.1.

6.2.1 Pre-treatment

Pre-treatment processes are used to remove large objects from the wastewater via screens (e.g. rags, wet wipes or other debris) and screenings processes, as well as removal of sand and other inert, insoluble fines material via grit removal processes and grit washing processes.

Inlet works, containing some or all of the pre-treatment stages, can frequently be situated at the end of a long chains of gravity mains and rising mains from the network, and the sewage may be very aged by the time it reaches the inlet works. This can lead to an increased risk of methane. In practice, observed levels of methane in inlet works have varied according to many different factors, similar to those described in Section 5.4.1.

Depending on the type of inlet conditions, screen and/or grit removal process, inlet works can be significant sources of turbulence. Methane generated throughout the upstream mains can be released readily at inlet works due to this turbulence. This should be considered in any classification exercise.

If there is no free discharge from the inlet works to subsequent stages such that immiscible liquids (such as petrol) can pool on the surface of the inlet works, this needs to be considered in any classification.

Inlet works at larger plants are most frequently covered to prevent the release of foul air and mitigate odour risks, although in smaller plants this is not always the case. As a frequently covered asset, with significant volumes of raw sewage, an inlet works/grit removal structure has much the same risk profile as a large network pumping station wet well. For this reason, it is recommended that an inlet works be treated as a network asset and have its risk classified in accordance with Section 5. Ventilation of inlet works is usually dictated by odour and corrosion control requirements due to the high concentration of H_2S and other odorants which can occur, rather than for control of hazardous atmospheres.

A suggested classification for an inlet works is Zone 2 unless there has been a suitable monitoring campaign to show otherwise.

6.2.1.1 Screen buildings

Some Australian plants have their inlet screens contained inside a building. In these cases, screens are often within a covered channel, with some element of the screen infrastructure sitting above the covers. As the buildings are considered working areas there is a requirement for ventilation. Some plants ventilate the building naturally using louvred openings whereas others use mechanical ventilation.

If the screens and screen channels are covered, with extraction taken outside the building, the building itself operates similarly to a network pumping station dry well, with connected or segregated atmosphere to its wet well depending on the building and cover arrangement. For this reason, it is recommended that screen buildings be treated as a network asset and have its risk classified in accordance with Section 5.

6.2.2 Primary treatment

After raw sewage has been screened and degritted, primary treatment commonly uses gravity (occasionally assisted with chemicals) to allow heavier particles to settle to the bottom of a tank and clearer water to overflow and continue for further treatment.

Primary treatment often has very strong odours associated and is often covered and ventilated to contain these odours. Some older plants, or plants in areas far away from sensitive receptors, are uncovered. As with inlet works, ventilation is usually dictated by odour and corrosion control requirements due to the high concentration of H_2S and other odorants which can occur.

It is common that primary treatment receives flow from an inlet works using a submerged inlet at the inlet works, and a submerged outlet at the primary treatment facility, to reduce turbulence of the water surface and therefore odorous gas release. If this is the case, immiscible liquid such as petrol is unlikely to travel to the primary treatment stage from the inlet works. Flammable substances dissolved in the wastewater may still be released into the gas phase or accumulated as sludge. This presents a risk when liquid levels are low, as there may be a build-up of flammable material in the solids at the base of the reactor.

If there is a free discharge from the inlet works to the primary treatment stages such that immiscible liquids can pool on the surface of the primary treatment process, this needs to be considered in any classification exercise.

A suggested classification for primary treatment is non-hazardous where uncovered, or Zone 2 when covered, particularly if the catchment has a high industrial load or if the processes on site are geared towards the production of methane and recycle streams are present in these covered areas, unless there has been a suitable monitoring campaign to show otherwise.

6.2.3 Secondary treatment

Secondary treatment consists of three general phases:

- Anaerobic zones, which allow the release of polyphosphate and the generation of acetate, improving biological phosphorus removal
- Anoxic zones, where denitrification occurs
- Aerobic zones, where nitrification occurs
- Selector zones, which can vary depending on process configuration

At this stage, any floating or immiscible layer of flammable substance has most likely been removed, either remaining in the inlet works or removed as scum from primary treatment. There remains a minor risk of dissolved flammable substances being released as gaseous vapour from the surface of the liquid, but this is unlikely unless there is a free discharge path for floating substances from the inlet works through to the secondary process.

Anaerobic zones are sometimes covered, receiving primary effluent, and have a very minor potential for methane due to their hydraulic retention times being in the scale of hours, rather than days. If covered, these zones are generally ventilated for control of odour and corrosion. If covered, these zones can be treated similarly as primary treatment processes in that they are often considered non-hazardous where uncovered, and sometimes Zone 2 when covered, particularly if the catchment has a high industrial load or if the processes on site are geared towards the production of methane and recycle streams are present in these covered areas. The same logic applies for anoxic zones.

Aerobic zones, having been treated prior and which receive large amounts of dissolved oxygen, are often uncovered as they are a very low odour risk. These zones are often classified as non-hazardous.

6.2.4 Solids treatment

In classification of solids treatment, it is important to distinguish between systems which are pre-stabilisation (pre-digestion or thermal treatment) or post-stabilisation (post-digestion or thermal treatment). Risks tend to be greater with solids prior to stabilisation, and within the stabilisation process, as their methane generating potential through the destruction of their volatile components is still present.

6.2.4.1 Aerobic digestion

Aerobic digestion uses dissolved oxygen, like that used in a bioreactor, to biologically stabilise contaminants and thus reduce the volume of sludges. Due to the stabilising effect of the dissolved oxygen, pathogens in the sludge are significantly reduced. It is suggested that aerobic digestion processes be considered non-hazardous when the aerobic process is operating. Any pre-storage holding and delivery, as well as conditions which occur during abnormal operation, should be assessed separately and are often classified as Zone 2 or Zone 1 depending on the availability of the aeration process and the solids retention times.

6.2.4.2 Anaerobic digestion

Anaerobic digestion is the process by which sludge is kept in an atmosphere without oxygen for long periods of time (usually between two and four weeks). This reduces the volatile content of sludges, produces methane (which is sometimes used for power and/or heating purposes) and destroys some biological pathogens. Anaerobic digestion, as well as associated gas delivery equipment and pipework, is well covered in the AS/NZS 60079 10.1. It is recommended that the guidance provided in AS/NZS 60079.10.1 Section ZA.8.3.2 be used as an industry standard example in the zoning of anaerobic digestion processes and ancillaries.

6.2.4.3 Cogeneration facilities

Cogeneration facilities draw upon the gas in the headspace of the digesters, treating these with various processes e.g. chillers, activated carbon scrubbers etc. The clean gas is then passed through a gas turbine engine. This can generate both heat for use in digester or site heating and power for return to the grid or local site use. These systems are generally low-pressure gas systems.

Given the methane content of the biogas stream (35 - 70% vol., well above the UFL) and the minimal expected oxygen (< 1%) the internal volume of the piping system is not expected to give rise to a flammable atmosphere under normal conditions. This approach is consistent with gas industry codes. This means that the internals of the gas piping is generally non-hazardous during normal operation. Stopping, starting and abnormal operation should be considered as part of the classification exercise.

Where pipework is susceptible to leakage, it is possible that methane could be released and diluted in ambient air to form concentrations between the LFL and UFL. The area classification here is ventilation dependent.

AS/NZS 60079.10.1 does not have any direct examples, but guidance is provided in section ZA 6. for commercial or consumer gas equipment. Section ZA 8.3.2 for digesters can be used to provide some indirect examples.

Manufacturer's proprietary equipment, designed and installed in accordance with commercial gas codes AS 3814 (for gas appliances) and AS 5601 (for gas installations), may also be non-hazardous internally. This should be confirmed on a case-by-case basis.

6.2.4.4 Thermal hydrolysis

Thermal hydrolysis is sometimes used as a pre-treatment prior to anaerobic digestion. Sludge is thickened, pulped and fed into hydrolysis tanks at high temperatures. Temperatures are then increased with steam and reacted for a length of time to induce hydrolysis. Hydrolysed sludge is then cooled to lower temperatures before being introduced to anaerobic digesters.

Thermal hydrolysis processes should be considered similar to pre-treatment stages in anaerobic digesters. The high temperatures involved act as sterilising agents and so methane is generally not produced in the hydrolyser itself, however it can improve methane generation during downstream anaerobic digestion. The high temperatures involved in the hydrolyser can also release entrained flammable substances that have made their way through the sludge lines of the plant.

A suggested classification for thermal hydrolysis processes, including venting processes, is Zone 2 unless there has been a suitable monitoring campaign to show otherwise.

The steam generation systems and conveyance pipework should be assessed separately to the thermal hydrolysis process.

6.2.4.5 Gas flaring

Gas flaring is used to combust and flare any excess biogas not used by the plant, or for certain plants not equipped with cogeneration facilities, to burn all digester gas accumulated.

Flares are usually designed to the gas industry codes that cover both gas fired industrial and gas fired consumer installations, namely AS 1375, AS/NZS 3814 (AG501) and AS/NZS 5601 (AG601). Zoning of these sorts of appliances are outlined in AS/NZS 60079.10.1 clause ZA.8.3.2.3 (f). In addition, consumer gas applications are generally classified as non-hazardous.

The exemption for gas appliances and equipment covered by gas industry codes is based on the premise that these codes provide an installation that produces a non-hazardous environment. The installer and operator need to ensure that the facility is installed in accordance with AS/NZS 5601.1 and AS 3814 to ensure that this premise is true in actual practice.

6.2.4.6 Storage

The risks associated with the storage of sludge are dependent on the source of the sludge being stored and the method which it is stored.

- Pre-stabilisation, there is a much higher chance of methane generation from the biological material (e.g. in a digester feed well, or a primary sludge holding tank)
    - Primary sludge has a greater risk of methane generation (and potentially having flammable contaminants entrained within the sludge) compared to waste activated sludge.
    - Waste activated sludge coming from an aeration process with a high sludge retention time has a low risk of methane generation
- Post-stabilisation, there remains a risk of methane generation however this risk is reduced when compared with the above case
- Anaerobically digested biosolids have a greater risk of continued methane generation or release compared to aerobically digested biosolids.
- Sludge/biosolids stored within an enclosed structure have a greater risk than those stored in the open (i.e. piles or sludge beds). This is due to factors such as:
    - Elevated temperatures within enclosed structures
    - Accumulation of gases in enclosed structures which are not free to disperse

Sampling and analysis of the source sludge will reveal the methane production, and this is the best way to understand the risk. If this is not available, then a suggested classification is

- Covered/enclosed storage of pre-stabilisation primary sludge: Zone 1
- Covered/enclosed storage of pre-stabilisation waste activated sludge: Zone 2 NE
- Covered/enclosed storage of post-anaerobically stablised sludge (i.e. biosolids): Zone 2
- Covered/enclosed storage of post-aerobically stablised sludge (i.e. biosolids): Zone 2 NE
- Storage of sludge/biosolids in uncovered drying beds: Non-hazardous

The specific processes within the sludge/biosolids treatment application should be considered in making the hazardous area assessment

Refer also to AS/NZS 60079.10.1, ZA 8.3.3.

6.2.4.7 Thickening/dewatering/conveyors

It is suggested that the internals of sludge conveyors (screw or belt), centrifuges, screw presses and the like should be classified as per AS/NZS 60079.10.1, ZA 8.3.3. The risks associated with this equipment are similar to those of sludge storage tanks, with the added risk of pressure and shear stresses forcing greater amounts of methane into solution, either within the equipment itself or for release at a later time.

6.2.4.8 Buildings

Biosolids buildings, both outloading buildings and infrastructure buildings housing equipment and closed storage tanks, are generally well ventilated to control methane build up. This occurs either with forced ventilation of a closed building, or with an open-sided building with natural ventilation.

Outloading enclosures, which experience transient odour due to truck movements, are generally non-hazardous. Closed outloading processes, where the truck arrives and doors close around it while it is filled, generally have forced ventilation to control the risk of driver exposure to H_2S or to control the risk of odour release. In this case, it is suggested that the outloading area can be considered Zone 2.

With biosolids building, the risk is again occupational exposure to hydrogen sulphide. If ventilation (either natural or forced) is sufficient to control this risk, then it is suggested a biosolids building can generally be considered non-hazardous. Where this is not provided, then a Zone 2 rating as per AS/NZS 60079.10.1, ZA 8.3.3 may be most applicable.

6.2.4.9 Lagoons

The classification of biosolids lagoons depends upon:

- The nature of the solids stored in the lagoon
- Their cover arrangement
- Their degree of ventilation

Biosolids lagoons that are open-topped and used for stabilisation are generally considered non-hazardous.

Anaerobic lagoons that are used for secondary treatment processes can have a higher degree of zoning due to the methane produced during treatment. These lagoons are often covered and the area within them is treated similarly to an anaerobic digester.

6.2.5 Tertiary treatment

By the time the bulk wastewater has reached the tertiary stage, most or all much of the contaminants of concern have typically been removed from both liquid and solid phases. Tertiary processes are often un-ventilated, as wastewater at this stage is not frequently odorous, but there are cases where ventilation is required e.g. a UV treatment module stored in a building which is ventilated for temperature control of proprietary control equipment.

Unless there is a specific risk with the tertiary treatment process itself (e.g. it requires a chemical of a type which could cause an explosive atmosphere), then tertiary treatment processes are generally considered non-hazardous.

6.2.6 Chemical storage

There are certain common chemical uses in the wastewater treatment environment which can cause flammable atmospheres. One key example is methanol, which, when dosed pre-secondary treatment, can provide additional readily biodegradable organic carbon for use by the biological processes present in the reactor.

Each chemical system should be assessed individually. Many common chemicals (sodium hydroxide, sodium hypochlorite, alum, ferrous/ferric chloride) are dangerous goods, but are not flammable in isolation. Chemicals such as ferrous chloride can react with metals to form hydrogen gas. Although outside the scope of this document, these risks must be managed.

Common coagulants and flocculants, often delivered in liquid emulsion form, are also generally non-hazardous. This should be confirmed in each individual case.

Liquid emulsion polymer is generally considered non-hazardous. On the other hand, powdered polymer can, in some instances, form combustible dust clouds[32]. This should be confirmed in each specific case. As outlined in the BASF Zetag® 8165 safety data sheet:

> "*This type of product has a tendency to create dust if roughly handled. The product does not burn readily but as with many organic powders, flammable dust clouds may be formed in air. The product is under certain conditions capable of dust explosion*."

This can lead to certain dry polymer powder areas being classified Zone 22 (for hazardous dusts). This should be considered in any assessment of polymer dosing areas.

6.2.7 Odour control facilities

Odour control plants are generally designed to serve multiple process areas, encompassing pre-treatment, primary treatment, sludge digestion and biosolids storage and treatment. Odour control ductwork is therefore often classified in accordance with the worst case zonal rating of the areas being served. This means that odour control ductwork can commonly range from non-hazardous to Zone 1. For a treatment plant environment, the most common zoning for odour control ductwork and vessel internals is Zone 2, consistent with common classifications of biosolids, pre-treatment and primary treatment systems. This is consistent with AS/NZS 60079.10.1 ZA 8.3.2.3. The internals of these vessels and ductwork are typically classified as Zone 1 or Zone 2. Classification of the internals of ducts downstream of odour control units should consider the cases of bypass around the treatment units. Vent shaft discharges of Zone 1 or Zone 2 odour control systems are typically Zone 2 for a 3 m radius around the discharge point.

[32] **Refer to AS/NZS 60079.10.2 for classification information regarding dust clouds, which are beyond the scope of this guideline**

7. ZONAL EXTENTS FOR LINEAR ASSETS

Due to the buried nature of sewers and other linear assets, the classifications are intended to be applied to the air volume of the asset only. Exceptions to this are where discharge to atmosphere occurs intentionally. These are as follows, applying where the classification is Zone 2 or Zone 1 for linear assets classified in accordance with Section 5:

- OCU discharge stacks
  - Apply a 3 m distance all around the discharge stack as Zone 2, as per Figure ZA.52 of AS/NZS 60079.10.1
- Vent shafts
  - Apply distance at the same rating as the zone all around the shaft, as per Table 7-1 adapted from EI15, Table 3.2
- For air valves/relief valves during their release function i.e. when operating in discharge, rather than vacuum break mode, based on advice in EI15 Clause 3.6.2.5
  - Apply a 1 m distance at the same rating as the zone all around discharge point if outdoors.
  - When inside a pit with a closed lid, the inside of the pit at the same rating as the air being discharged.
  - When an air valve is inside a pit with the lid open, a distance of 1 m at the same rating as the air being discharged.
- Leakage points above the ground transporting atmosphere from the zone e.g. ventilation ductwork and fans
  - Apply a 0.25 m distance all around these points, similar to AS/NZS 60079.10.1 Table ZA 8.3.2.2(2) for pressure less than 100 kPa
- Closed lids of wet well, dry well, MH etc
  - Apply a distance of 0.25 m all around the open penetration unless a sustained suction pressure of 15Pa is achieved under the covers (see Section 7.1)
- Open lids of wet wells, dry wells, MH etc.
  - Where there is insufficient or no active mechanical ventilation (i.e. pressure difference of -15 Pa is not achieved with lid open): 3 m minimum all around the open lid unless temporary active gas monitoring (such as the use of personal gas monitors) of the atmosphere around the release point is conducted. If gas monitoring shows a flammable atmosphere to be present, the zonal extant may need to be increased depending on the level.
  - Where there is sufficient active ventilation which ensures -15 Pa with the lid open: Apply a distance of 1.5 m all around the open penetration

Table 7-1: Clearance distance away from vent shaft tip. Adapted from EI15, Table 3.2 for a G(i) gas (similar to methane)

	Vent Shaft Diameter		
Discharge flow (m^3/hr)	**50 mm**	**100 mm**	**250 mm**
250	2 m	2 m	4 m
500	2 m	2 m	4 m
1000	3 m	3 m	4 m
2500	4 m	4 m	5 m

7.1 Importance of negative pressure in the contained environment

Provided that a sufficient negative pressure differential can be maintained between the covers and the external environment, effectiveness of capture due to ventilation is ensured. Many water agencies will specify an overarching differential pressure between 15 to 25 Pa to ensure less than 1% leakage.

The negative pressure required to reduce leakage is a function of cover size, type and wind loading. The magnitude of the negative pressure which can be sustained under covers is a function of:

- Negative pressure provided by the system fan at the extraction point
- Number of extraction points, and dispersal over the cover
- Type of cover, number of cover joints, penetrations and cover flexibility which define the leakage rate.
- Air inlet configuration, e.g. provision of weighted air inlet dampers or grills.
- Degree of interconnection of process areas under the covers allowing inter-process distribution of air.

If a design negative pressure of -150 Pa is assumed at the extraction point, then the negative pressure sustained is dependent upon the free area available for air ingress from the atmosphere (or other process area), and the gas flow rate through that space. As the free area is decreased, the gas velocity, and therefore pressure drop is increased, leading to a higher negative pressure sustained under the covers.

Figure 7-1 shows the approximate relationship between maximum negative pressure that can be achieved under covers versus air exchange rate, derived from standard head loss equations.

A hypothetical 10 m by 5 m rectangular covered structure with a 2 m headspace is considered, with one number 100 mm diameter air inlet. The covers are comprised of 10 No

1 m by 5 m panels. Achievable negative pressure is shown with varying gaps between the cover sections.

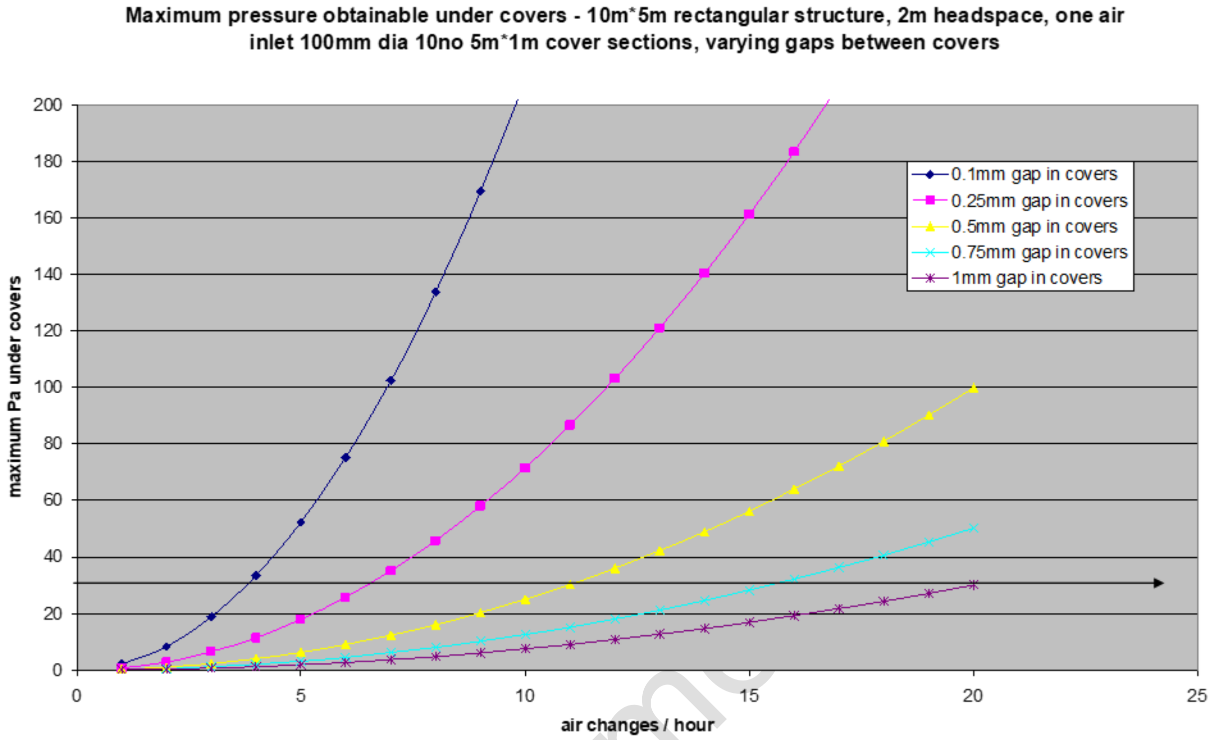

Figure 7-1: Example of Achievable Negative Pressure for Varying Air Exchange Rates

The achievable negative pressure is dependent upon both the ventilation rate and the gaps between the cover sections, with a high sensitivity to the gaps between the cover sections and the number of penetrations within the cover. The higher the free area between the atmosphere and the tank air space volume, the higher the extraction required.

Historically, to reduce the air infiltration to a level which enables a realistic extraction rate to be used (whilst still achieving > -25 Pa static pressure under the cover), the following is required:

- Foam or rubber gasket seals are required between covers and concrete tank walls (and the seal held under compression by suitable fixings).
- Penetration of any service must be carefully considered and be installed with effective collar seals.
- Covers not requiring removal should be gas-sealed with a flexible sealant (example given in Figure 7-2)
- Weighted air inlet dampers to maintain a constant negative pressure differential under the covers during varying flow conditions should be employed.

Figure 7-2: FRP Cover Sections Sealed with flexible, air tight sealant

8. EMERGENCY RESPONSE RECOMMENDATIONS

Where a high LFL has been detected, it is critical that a water agency has a plan in place for a series of responses. These responses will vary according to the water agencies individual circumstances, as they will be affected by geography, state based legislative environment, urban, regional or rural location (including time it generally takes for emergency services to arrive at the asset) and so on. Some considerations when developing the organisation's plans are provided below.

Common to all of these is the suggestion that water agencies develop a strong relationship with their local emergency services organisation.

In commercial construction, the fire department is responsible for inspecting each new residential building for emergency services access such as emergency exits, air movement in an emergency, path to Fire Indicating Panels (FIP) etc. They also provide commentary on air movement in underground car parks in case of emergency.

It is common practice for large construction sites (e.g. a large treatment plant upgrade) to show the local emergency services around the site, so that their familiarity can assist in the case of any event where they are required. This familiarity could be extended with a site visit when a site is finished, especially in the case of pumping stations and treatment plants.

When new treatment plants, or large pumping stations, are being designed, emergency services can make recommendations about where, for example, they may require a hydrant point for firefighting purposes, or where they require a larger turning circle for an emergency access vehicle. A hazardous zoning exercise as outlined in previous sections of this guideline, can assist the emergency services in making recommendations.

It is recognised these suggestions must fit within each water agencies safety management systems and thus may be substantially different. The suggestions outlined below do not form a complete plan and should not be used as such.

8.1 Linear infrastructure responses

8.1.1 Gas leak

Gas leaks are usually discovered by confined space entry crews, or by sudden spikes of fixed LFL monitors. The working group has had various experiences with nearby gas leaks creating flammable atmospheres in the sewerage network. The consensus is that gas utilities are not as concerned with loss of product, as they have some allowance for leakage in their business models, the leaking of gas is less of a source of concern. This makes dealing with the gas provider difficult as, unless the risk is major, their preference is not to actively leak detect. It can take multiple calls and firm pressure on the gas utility to have a technician attend site in a timely manner. Most gas utilities have a publicly advertised phone number to call to report a gas leak if the gas leak is before the meter to the property. If the gas leak is after the property meter, a licensed gasfitter is often recommended.

Some suggestions as to overall strategy are as follows:

- For each site, determine who the service provider is (consult Dial Before You Dig (DBYD) or nearby signage pits/junctions) and consult their website for the relevant phone number to report a leak. Record this number, along with relevant details, in the site's safety management plan.
- If a gas leak is determined either by smell or by a monitor reading above 40% of LFL, notify emergency services
- Report the leak to the relevant service provider in the area.
- Notify affected parties of the leak, and the associated risks, and try to temporarily ventilate the space to below the LFL with appropriately rated hazardous area rated ventilation
- Spend time with internal resources to try and locate the source of the leak without excavation if possible
- When reasonably confident, mobilise own teams to try and diagnose the leakage point prior to the arrival of the gas provider's representative
- Work with the representative from the gas authority to locate and repair the leak

8.1.2 Major trade waste discharge or illegal dump

A major trade waste discharge which significantly alters the flammability of the network's atmosphere should be notified by the discharger. If not, it may only be possible to detect this when it arrives at location such as a pumping station or treatment plant inlet works. A LFL monitor can assist in detecting this, but other indications, such as smells, oily sheens or different coloured wastewater, can also indicate the presence of a flammable atmosphere. An illegal dump has the same characteristics of a large discharge of trade waste. Realistically, it is exceptionally difficult to trace the source back on a single, isolated event. Some suggestions are as follows:

- As soon as aware of the change in atmosphere, notify all relevant parties
- Take a sample of the contaminated wastewater, or of the flammable atmosphere, as soon as it is safe to do so and using non-sparking equipment and tools. All operators taking samples should wear LFL appropriate hazardous area PPE (equivalent to confined space PPE, with non-sparking tools and including temporary ventilation suitable for a hazardous atmosphere if required) and work only where the atmosphere is being monitored online for increases in flammability. If having identified the substance in the network, try to sample it as it moves through and as it enter the inlet works. Have these samples lab tested as soon as reasonably practicable.
- Eventually, the discharge will arrive at a pumping station:
  - If the network receiving the discharge is serviced by a wet well style pumping station, the pump itself is rarely a risk. However, if the electrical connection to the wet well

pump is degraded over time, this can be a source of ignition along with others identified in Section **Error! Reference source not found.**

- If the pumping station has a hazardous area classified odour control or ventilation, this should run to help control the atmosphere. It may inhibit or damage biological systems and may saturate an activated carbon system necessitating a carbon change out. This should be investigated when the event is over[33]
- If it can be stored at a pumping station safely (no possibility of spark, ventilation in place), shut the pumps down and store the contaminated wastewater at that location. Mobilise a tanker truck (use a tanker truck suited to petrol, which should be set up to extract from hazardous areas) and extract the contaminated wastewater for disposal as hazardous liquid waste
- Depending on pumping station condition, pumping of the discharge is possible. This should be deferred until the downstream locations have been ventilated with temporary ventilation and are being monitored for possibility of sparks and LFL. Do not pump the contaminated wastewater if the atmosphere is above 50% of the LEL, unless the pumping station and the next pumping station in the network have equipment with an appropriate EPL
- At the treatment plant, try to re-direct the flow to a storage location (an old balance tank, a seldom used pumping station, a bypass tank etc.) for ventilation and monitoring prior to clean up. If sampling shows it is safe to do so, it can be reintroduced to the process for treatment by the plant, with discharge below the water level where possible. It may require some local treatment prior to this. Sampling should be assessed by a suitably qualified engineer for effect on processes.

8.1.3 Notification of authorities

According to the experiences of the working group, the fire department generally request to be notified of high LFL events in the sewerage system so that they can be ready and occasionally attend site. If there is a possibility of an atmosphere above 40% of the LFL occurring, this guideline recommends that planning with the fire department begin. It may be possible that in some jurisdictions, the fire department would expect contact either earlier or later; this should be confirmed for the conditions local to the asset.

Members of the working group also work with police; as police can get to know of locations where illegal dumping may be occurring e.g. by illegal drug labs. There has been some work

[33] **With activated carbon systems, many substances can have an exothermic reaction upon adsorption if in a high enough concentration. Certain substances, most commonly aldehydes and ketones, can adsorb onto activated carbon systems and, when ventilation is switched off, start breaking down with large heats releases causing bed smoulders or fires. If an activated carbon system experiences high concentrations of contaminants in its incoming stream, care should be exercised in turning off the ventilation through the carbon. Manual water sprays may be used prior to, or as the ventilation is turned off, to prevent smoulders. If an LFL is determined in a foul air stream, the activated carbon system should be bypassed where possible, either manually or automatically. This may not prevent a bed fire, but could prevent an explosion. Nitrogen purges are sometimes also used in industrial activated carbon installations to remove oxygen from the system and prevent bed fires.**

in a joint water agency and police effort to identify illegal drug labs. This helps keep the network safe, as well as assists police in their work. Such benefits are only clear with good communication between authorities and water agencies.

8.2 Treatment plant responses

8.2.1 Standard operating procedures

To capture the risks associated with a hazardous atmosphere, it is recommended that a Standard Operating Procedure (SOP) for each unit process (or the plant as a whole) be developed that has the operational steps which occur where changing atmosphere is detected. An SOP describes how a process is operated: rather than describing make and model of a valve, it instructs to open certain valves, close certain valves, notify certain parties or make certain operational changes.

Another appropriate place to describe the actions required to mitigate a hazardous atmosphere may be the Unit Process Guidelines (UPG) for a particular module. The UPG describes process performance parameters such as flows, removal rates, maximum levels etc. The SOP and UPG have some overlap, and many water agencies choose to have them incorporated as part as one overarching process manual. This is particularly true of smaller assets.

Some suggestions for inclusion in these documents are:

- Whom to raise an alarm with if the atmosphere is seen to be hazardous: supervisor, process controller, emergency services etc.
- Any mitigation actions e.g. flow isolation, bypass, redirection to different asset, powering down the site etc.
- Signs to look for which would indicate high LFL, if there is no online monitor installed, e.g. oily sheens, solvent or petrol smells or discoloration.
- Potential process impacts e.g. biological process die off, odour generation in case of flammable liquid/gas entry into the process
- Changes to operation in the event of an LFL being detected e.g. bypassing activated carbon processes

8.2.2 Emergency preparedness

Treatment plants are large, interconnected and often congested spaces. Their navigation can be difficult for new personnel. As such, a large part of effective response to flammable atmospheres is simply good emergency response practice. This includes:

- Fire infrastructure (hydrants etc.) maintained in good condition
- A plan in place for power failure or plant failure e.g. a generator hard stand for an in place or offsite generator and a procedure about where to source the power from, how to connect it and who to notify should it happen

- Items like temporary ventilation stored in an accessible and clean way, and regularly tested and tagged to ensure it is working
- Clear access roads with good access into areas where emergency services may need to attend
- Emergency equipment: torches, appropriate PPE etc., confined space entry gear in place for use. All equipment should be rated for the hazard condition expected.
- Regular emergency drills for the plant team

9. APPLYING THIS GUIDELINE

9.1 Pumping station

9.2 Siphon maintenance hole

9.3 Inlet works

9.4 Odour control unit on PS

9.5 Primary sedimentation tank

9.6 Biosolids upgrade

10. HAZARDOUS ZONE DRAWINGS

10.1 Linear infrastructure

10.1.1 Maintenance hole/scour pit

10.1.2 Wet well/dry well

10.1.3 Wet well/valve chamber

10.1.4 Emergency storage tank

10.1.5 Air valve pit/air valve

Appendix A: Trade waste risk categories

Industry	Contaminants of Concern	Risk Profile
Food processing and manufacture	Chlorinated hydrocarbons from disinfecting procedures, solvents from maintenance activities.	Medium – Low due to maintenance / disinfectant procedures
Abattoirs (red meat)	High BOD / COD waste can promote anaerobic activity and methane production – discharges with significant rising mains can have a high risk of methane generation	Medium to High due to methane generation
Poultry slaughter or processing		
Seafood processing and aquaculture		
Pet food manufacture		
Beverage processing and manufacture	Methanol, ethanol and other primary, secondary and tertiary alcohols. High BOD / COD waste can promote anaerobic activity and methane production – discharges with significant rising mains can have a high risk of methane generation	Medium - High
Tanning and textiles	Highly volatile solvents from processing and maintenance. Formaldehyde, Azo dyes, Chlorobenzene and other chlorinated hydrocarbons, glutaraldehyde	Medium
Petroleum-based activities	Highly volatile solvents, hydrocarbons, aromatic hydrocarbons	Very High
Pharmaceutical and cosmetic activities	Volatile solvents, phenolic compounds and ethers	Medium - High
Chemicals, plastics and surfactants	Many highly volatile flammable organics including: organic resins, organic acids, tetrahydric alcohol, pentaerythritol, formaldehyde, acetaldehyde, phenols, benzene & other aromatic hydrocarbons, aldehydes and ketones.	Medium - High
Metals and surface coatings	Acidic effluents, contaminated with solvents	Low - Medium
Paper, board, photographic and printing	Photography and printing utilise a number of solvents in the processing and in cleaning activities including nitrocellulose, maleic resins, vinyl acetate resin, Gilsonite, or natural resins in solvents, as xylol, toluol, and high-boiling mineral thinners	Medium
Cement, stone and abrasives	Mostly inorganic solids	Low
Waste and wastewater treatment	Methane, VOCs and substances from trade waste dischargers upstream	Medium to High

Industry	Contaminants of Concern	Risk Profile
Sewer mining and decentralised wastewater treatment	Methane, VOCs and substances from trade waste dischargers upstream	Medium to High
Retail food	Long chain organics (fat / grease). Some volatile solvents used in cleaning. High BOD / COD waste can promote anaerobic activity and methane production – discharges with significant rising mains can have a high risk of methane generation	Low - Medium
Restaurants, takeaway food outlets, function centres, hospital and nursing home kitchens, caterers, butchers, delicatessens and retail bakeries	Mostly volatile solvents / chlorinated hydrocarbons used in cleaning / sterilizing. High BOD / COD waste can promote anaerobic activity and methane production – discharges with significant rising mains can have a high risk of methane generation	Low - Medium
Automotive	Highly volatile solvents, organics, hydrocarbons such as octane (petrol) and other wastes	High
Service stations, panel beaters and spray painters, car detailers, car wash – hand wash and pressure spray, car wash <12 kL/day, mechanical workshops, auto recyclers, construction equipment hire		
Commercial laundries	Chlorinated hydrocarbons and other volatile solvents including tetrachloroethylene (perchloroethylene), known in the industry as "perc", 1-bromopropane and petroleum spirits amongst others	High if discharging to sewer
Laundromats, commercial laundries < 2 ML/year, and hospital, nursing home and hotel laundries		
Photographic	Many chemicals including; metol (monomethyl-p-aminophenol hemisulfate), phenidone (1-phenyl-3-pyrazolidinone), dimezone (4,4-dimethyl-1-phenylpyrazolidin-3-one), hydroquinone (benzene-1,4-diol), Aminophenol, Ethylene Glycol, Formaldehyde, Monoethanolamine, 1,1,1,-Trichloroethane, Triethanolamine	Medium
Hospitals	Organic disinfectants, detergents, pharmaceutical residues, solvents, X-ray contrast media, aromatic hydrocarbons and phenolics	Medium - High
Minilabs, medical facilities using X-rays,	See Photographic and Hospitals.	Medium

Industry	Contaminants of Concern	Risk Profile
graphic arts and professional photographic laboratories	Misc solvents, amines, alcohols, aldehydes, ketones, aromatic hydrocarbons and other volatile organics.	
Shopping centres with centralised pre-treatment	High BOD / COD waste can promote anerobic activity and methane production – discharges with significant rising mains can have a high risk of methane generation	Low – Medium
Shopping centres with shared pre-treatment other than grease traps	High BOD / COD waste can promote anerobic activity and methane production – discharges with significant rising mains can have a high risk of methane generation	Low – Medium

Appendix B: Supplementary information on the effects of explosions

Explosions can be broadly described as follows:

(i) A flammable substance is that which is capable of burning in the presence of oxygen between the upper and lower flammability limits (UFL/LFL) in a deflagration event (defined as combustion which propagates through a gas or across the surface of an explosive mixture at subsonic speeds, driven by the transfer of heat). Significant heat and modest overpressures are achieved – generally below 50 kilopascals (kPa).

(ii) An ignited flammable substance may also undergo Deflagration to Detonation Transition (DDT). This refers to a phenomenon in ignitable mixtures of a flammable vapour/gas and air (or oxygen) when a sudden transition takes place from a deflagration type of combustion to a detonation type of explosion.

(iii) A detonation is characterised by a flammable mixture of gas which has supersonic flame propagation velocities, and substantial overpressures (up to 2 megapascals (MPa). The mechanism of detonation propagation is a powerful pressure wave that compresses the unburnt gas ahead of the wave to a temperature above the autoignition temperature, rather than the conduction of heat.

Many compounds that can be found in wastewater systems are known to ignite in a deflagration event, but also detonate as a result of DDT. Both events can be characterised as an explosive event (accompanied by a heat and overpressure wave), however a detonation is a far more violent event, generally causing far more extreme damage. Having stated this, overpressures formed by deflagration event are more than enough to cause serious harm to personnel and damage to structures.

The human body can survive relatively modest blast overpressure without experiencing barotrauma (damage due to pressure changes). A 34 kPa blast overpressure will rupture eardrums in approximately 1% of subjects. The threshold for lung damage occurs at approximately 100 kPa (15 psi), with 380 – 450 kPa (55 to 65 psi) causing up to 99% fatalities. (Glasstone and Dolan, 1977; TM 5-1300, 1990).

The table below also shows the maximum wind speed associated with the given overpressure generated. In explosion events, it is the blast wind resulting from the blast overpressure that leads to most injuries and fatalities due to blunt force trauma or shrapnel.

Table 10-1: Department of Defence data from Glasstone and Dolan (1977) and Sartori (1983), effects of increasing blast pressure on various structures and the human body.

Peak overpressure	Max wind speed	Effect on structures	Effect on human body
7 kPa	61 km/h	Window glass shatters	Light injuries from fragments occur

Peak overpressure	Max wind speed	Effect on structures	Effect on human body
14 kPa	113 km/h	Moderate damage to houses (windows and doors blown out and severe damage to roofs)	People injured by flying glass or debris
21 kPa	164 km/h	Residential structures collapse	Serious injuries are common, fatalities may occur
35 kPa	262 km/h	Most buildings collapse	Injuries are universal, fatalities are widespread
69 kPa	473 km/h	Reinforced concrete buildings are severely damaged or demolished	Most people are killed
138 kPa	808 km/h	Heavily built concrete buildings are severely damaged or demolished	Fatalities approach 100%

Unfortunately, the full mechanism of DDT is not fully understood, with variables such as air turbulence, geometry and compound specifics at play. DDT can occur in closed and open spaces or in the open atmosphere, and is the basis of Fuel Air Explosives (FAE or thermobaric weapons). Within this document differentiation between deflagration and detonation events are not made; both cases are referred to as an “explosive event” caused by a flammable or explosive atmosphere.

Appendix C: Discussion of sampling technologies

The main types of detectors (other niche instruments are available) for the detection of explosive atmospheres or the VOCs that can form them are provided below. It is important to note that if the monitoring location is suspected of having a potentially explosive atmosphere (as per guidance in Section 1.4) the sampling assembly must be appropriately rated for the suspected hazardous area. Consult with the manufacturer to ensure that this is the case, and where doubt exists, refer to the requirements of AS/NZS 60079.29.1 and AS/NZS 60079.29.2.

Pellistor/catalytic oxidising type sensor

Type of monitoring: Continuous, logged

Results: Online, with response time noted

Response time: Dependent on gas being detected and the unit but generally 10 to 60 s

Ideal for: Determining percentage of LFL for a wide range of gases in an asset to inform classification of hazardous areas, or for shutting down equipment, especially when used in conjunction with a PID.

Main challenges: Regular calibration, response time and poisoning.

One of the most used combustible gas sensors, with operation dependent upon the oxidation of the target gas within the instrument. The flammable contaminant is oxidised on the surface of a pellet resistor (or “pellistor”) located within the sensor.

The unit contains two coils of fine platinum wire which are each coated with a ceramic/porous alumina material to form beads. One bead is “activated” by being coated with a catalyst (platinum of palladium), with the other “reference bead” being identical but uncoated. The two pellistors (active and reference) are wired into opposing arms of a balanced Wheatstone Bridge electrical circuit.

As long as there is oxygen present, combustion of the contaminant can occur on the active bead at concentrations far below the LFL. A sintered glass or similar protection is applied to the cell to allow diffusion of gas in, but prevention of flame propagating out.

A voltage is applied across both active and reference beads causing them to heat up. Note that the temperature of the active bead must be high enough for the gas to be oxidized, with the bead needing to be raised to 500ºC to detect methane (for example).

In uncontaminated air, the Wheatstone Bridge circuit is balanced with an output voltage of zero. If a combustible gas is present, oxidation heats the active bead further, however the temperature of the reference bead is unaffected. This difference in resistance caused by the temperature differential is than used by the detector to determine the gas concentration.

Historically such detectors have had limited battery life, however advances in battery technology and the repeatability size of the pellistors have mostly overcome this issue.

These gas sensors are unable to differentiate between different combustibles, simply providing a percentage of LFL of the combined gas, the accuracy of which is dependent upon the gas which the unit was calibrated against. They respond to a wide range of ignitable gases and are ideal for determining a baseline measurement of flammable compounds on a continuous basis.

As a general rule, the larger the molecule, the slower the response time. Some also have difficulty in adequately detecting heavy long chain molecules or the vapours from high flashpoint liquids such as turpentines, diesel fuel or jet fuel.

In order to ensure full coverage of potential compounds, a pellistor type detector can be used in combination with a photoionization detector (PID). There are detectors available that have both pellistors and PID sensors together, enabling monitoring for the presence of a wider range of vapours than possible with either one in isolation.

Pellistor type instruments can be ‘poisoned’ by hydrogen sulphide or many other common chemical vapours, with high concentrations of a gas or particularly corrosive gases being present both risk factors in this process. For some chemical vapours, this ‘poisoning’ can occur even at low concentrations. As such, they need to be calibrated on a regular basis.

IR absorption

Type of monitoring: Continuous, logged

Results: Online, with response time noted

Response time: Dependent on the unit but generally 10 to 20 s

Ideal for: Determining percentage of LFL for a range of hydrocarbons. More selective than pellistors in gas detection and require less calibration.

Main challenges: Poor/no detection of some flammables

Infrared (IR) detectors work on the principle of differing absorption of infrared radiation at specific wavelengths as it passes through a volume of gas, picked up by detectors. Two cells, a reference cell and a sample cell are used. If a gas intervenes between the source and the detector, the absorption is detected, and both the type of gas and its concentration can be identified.

Infrared gas detection is based upon the ability of the gases being detected to absorb IR radiation, with many hydrocarbons absorbing IR at a wavelength of approximately 3.4 microns.

Benefits of IR sensors include:

- Lower power consumption than catalytic sensors
- Ability to operate in oxygen deficient atmospheres
- Greater resistance to damage by exposure to silicones or other poisons which may effect catalytic sensors

IR detectors are excellent for the detection of common combustible gases such as methane and propane. As it is the chemical bonds in the molecules being measured that actually absorb the infrared light, larger molecules generally absorb more infrared. IR sensors are therefore generally more sensitive to larger combustible gas molecules like hexane, octane, and nonane.

Unfortunately, IR sensors cannot measure a gas unless the bonds in the molecules absorb IR at the measurement wavelengths. It should be noted that there are some hydrocarbons and other flammable substances (such as aromatics, acetylene, hydrogen and ammonia amongst others) that respond poorly or not at all to a general-purpose IR sensor. Depending on the manufacturer, they may or may not be able to detect benzene or other "unsaturated" VOC vapors i.e. those identified with one or more benzene rings or with chemical behavior similar to benzene. This can cause an issue in identifying specific contaminants when the potential contaminant is unknown. It is therefore important to verify that the IR LFL sensor is able to detect the gas(es) of interest before use.

PID/FID

Type of monitoring: Continuous, logged

Results: Online

Response time: Dependent on the unit but generally a few seconds

Ideal for: Determining the presence of a wide range of low concentration VOCs such as the case in wastewater networks – shown as ppm by volume

Main challenges: PID does not detect methane. FID requires hydrogen cylinder. High concentrations of contaminants (5,000 to 10,000ppm) will rapidly render a PID unit inoperative, usually requiring expensive repair.

Continuous VOC logging can be conducted using a photoionisation detector (PID) or Flame ionisation detector (FID), the difference being that FIDs include methane detection, whereas PIDs do not.

These units are generally handheld which include a moisture trap, a pump and some tubing to direct the sample to the detector. They generally sit outside the asset, with a sample tube extending into the asset. They tend to have an in-built battery life of 8 - 20 hours (depending on type) and the moisture trap needs changing every 1 - 2 days. When more than 8 hours sampling is needed, these units are often plugged into mains power, or can be installed with separate large batteries (for example, 1 weeks' worth of sampling requiring 3 car batteries in parallel to provide enough charge). PID units can be poisoned by large spike concentrations, whereas FID units are not susceptible to such damage.

PID units themselves are available from a number of suppliers and can be readily hired for short durations.

The PID sensors will be able to give an approximation of total VOCs (without methane). They will give a level in ppb or ppm, based on an assumption that all VOCs present are a reference substance to which the unit is calibrated, normally isobutylene. This type of analysis allows the user to identify a relative level of VOCs present, as well as a diurnal profile, but not what compounds constitute the VOCs. PIDs detect gases that ionise at the machine lamp voltage, with 10.6 eV being the most common lamp. As each VOC has different LFLs, high concentrations as indicated by a PID or FID may need further quantification using Gas Chromatography Mass Spectrometry (GC-MS, see below).

Where there is an unknown source of VOCs in the asset, PID/FID monitoring at one location can identify a diurnal profile. Subsequent monitoring at various upstream branches of the sewer can help narrow down which branch is carrying the VOC laden waste and help isolate a potential discharger.

Suitable Lab based technologies (GC-MS)

Type of monitoring: Spot sample only

Results: 24 to 48 hrs depending on the laboratory used and the distance the sample must travel to that laboratory

Response time: N/A – lab-based equipment

Ideal for: Determining all of the compounds present so that all flammables are identified (at the point in time the sample was taken) to allow risk to be determined or intervention to take place. Generally used in conjunction with pellistor or PID unit, with spot samples taken when high VOC load is detected.

Main challenges: Expensive with costs of approximately $800 per sample (inclusive of sampling and analysis) in a major metro area with a lab in the same city. Lab based analysis. Time consuming. Results only provide a snapshot of when sample was taken, and therefore may miss target discharges or peaks unless multiple samples are taken or the sample is targeted at a previously determined peak time (e.g. by use of online PID monitoring).

Previously discussed technologies that providing continuous monitoring are generally unable to specify the compounds present (with some IR exceptions, where compound recognition is limited).

Gas Chromatography (GC) – Mass Spectrometry (MS) can provide both concentration and detailed breakdown of contaminants. The units are large, generally lab based and require significant training to operate and maintain.

They cannot provide continuous monitoring (within normal economic restrictions), but instead rely upon a gas sample to be taken, transported to the lab, then analysed.

The GC determines the concentration of the compound, then the MS determines the compound species through comparing its mass spectra with a computer library.

Gas samples can be analysed for a certain set of analytes (such as through the USEPA TO-15 process[34]) or library matched for all known substances in a set larger library (more commonly conducted by universities). Testing for specific sets of analytes rather than library matching generally leads to misreporting, as gases in sewer headspaces can have differing components depending upon the catchment. Library matching is therefore considered best practice unless the specific components present are known.

[34] **The USEPA TO-15 (and more recently, TO-15a) method nominates 97 chemicals that can be analysed through this process. These 97 chemicals are from the list of 187 chemicals listed in the US Clean Air Act, which also includes non-flammable substances. Many labs will only offer analysis of a sub-set of the 97 chemicals listed in the USEPA TO-15 method due to the costs involved in calibrating the instruments for such a large number of substances.**

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