New Zealand Water and Wastes Association

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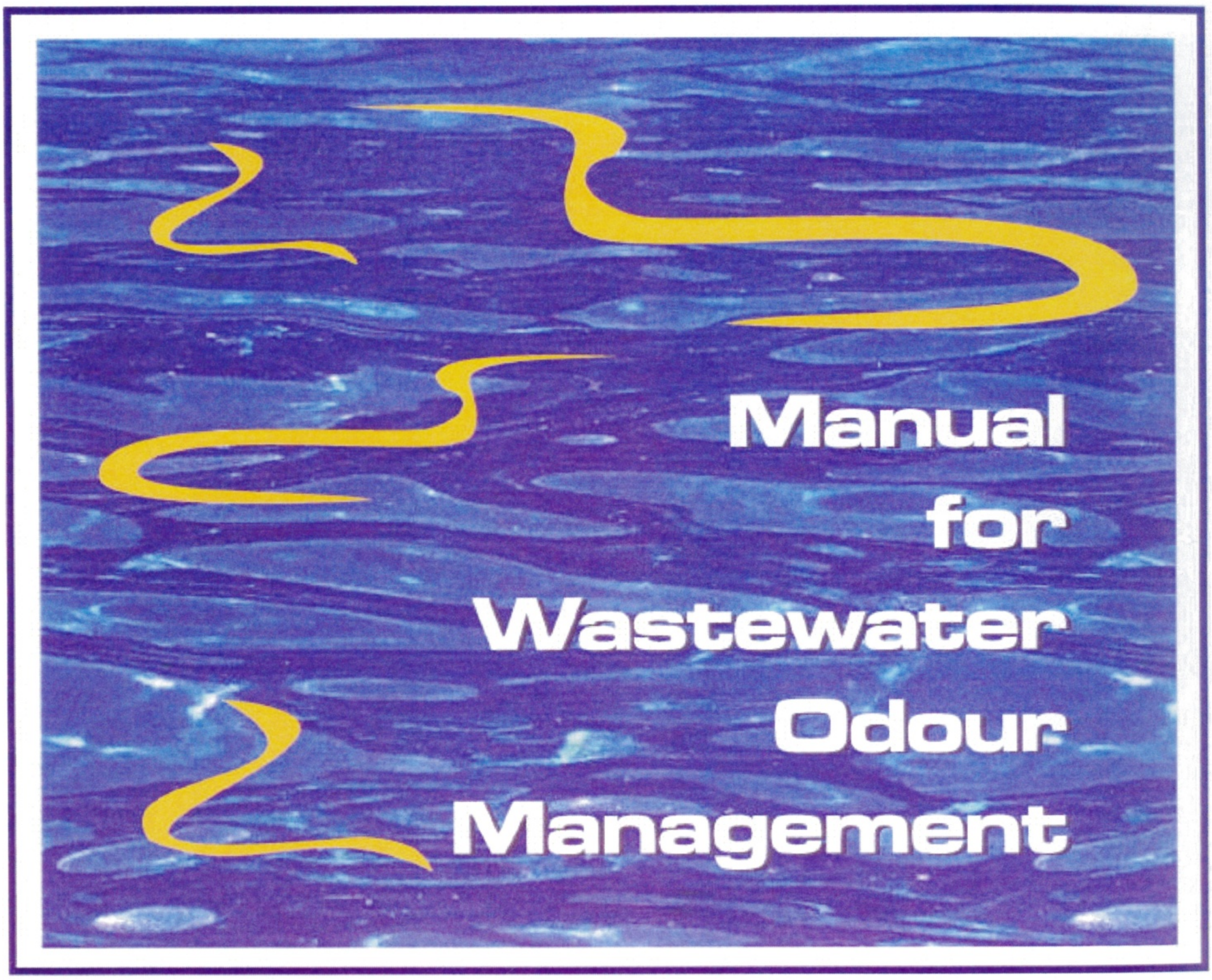
New Zealand Water & Wastes Association
Waiora Aotearoa



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MANUAL FOR WASTEWATER ODOUR MANAGEMENT

CHAPTER REVISION RELEASE NOTES, 19 SEPTEMBER 2000

Chapter	***Latest Version***
1. Definition and Measurement of Odour	First Edition, 1999
2. Regulatory and Legislative Issues	First Edition, 1999
3. Olfactometry Sampling and Analysis	Second Edition, 2000
4. Odour Evaluation Tools and Dispersion Modelling	Second Edition, 2000
5. Odour Control Technologies	First Edition, 1999
6. Collection Systems and Pumping Stations	First Edition, 1999
7. Case Studies	Second Edition, 2000
APPENDIX A: Guidelines for the Application of Dispersion Models to Odorous Sources in New Zealand	First Edition, 1999
APPENDIX B: Application of Biofilters to Control Odour	First Edition, 1999
APPENDIX C: Chemistry of Odour Generation	First Edition, 1999

FOREWORD

We all need water and we all help generate wastewater. By its very nature, the odour from that wastewater is an ever present component of our environment.

The New Zealand Water and Wastes Association (NZWWA) represents the people who design, operate, and manage the water and wastewater services. To assist the management of these services, we need to provide the tools to manage the odours generated in the process.

This manual has been prepared to bring together information on procedures and processes for the management of odour from wastewater facilities. Odour issues at wastewater treatment plants, pumping stations, and in reticulation systems are addressed. The manual covers the regulatory and legislative issues, methods of quantifying odour, dispersion modelling and standards, and techniques for assessing the potential for odour problems to occur. It outlines the methods of odour control - such as prevention, use of buffer zones, chemical scrubbers, biofilters, and others. Case studies and process guidelines offer examples for practical application to real situations.

Recent international experience has been incorporated where it is relevant to our conditions. Recognised practitioners, specialists, and wastewater system operators from around the country have contributed to the manual or have provided the peer review and additional comments. NZWWA hopes that broad use of the manual will lead to a better understanding of odour issues and to better management of this inevitable product from wastewater services.

Compilation of the manual has been made possible with the funding assistance of the Ministry for the Environment through the Sustainable Management Fund, and the Association gratefully acknowledges this contribution. The remaining funding was contributed by the Drainage Managers Group of the NZWWA, from a research fund composed of contributions from the territorial local authorities and drainage network utility operators of New Zealand.

I hope that you will find the information contained in this manual useful, relevant, and easy to understand, and I encourage you to register your copy with NZWWA so you can receive future updates to the manual as they become available.

Boyd Miller
President, NZWWA 1995-97

EDITOR'S PREFACE

This manual is a compilation of chapters and subchapters written by a number of odour management specialists around New Zealand. A draft manual was released in July 1998, and a variety of submissions were received from a range of parties including equipment suppliers, regional councils, private consultants, research organisations, and wastewater treatment plant owners/operators. Their comments and some additional chapters have been incorporated into this first edition.

The first edition of this manual has been bound in a ring binder so that any updates to chapters that may be necessary as the technology of odour management develops in New Zealand can be distributed without needing to reprint the whole manual. However, we will only be able to send updates to those people that have registered their copies with the NZWWA, which can be done by purchasing a copy from the NZWWA office in Wellington and returning the registration card inside the front cover. Please note that the cost of purchase has been set solely to cover the costs of printing and the maintenance of the register of manual holders. For these reasons, I encourage you to purchase a copy of the manual from the Association and to register your copy. However, as with all documents produced with funding from the Ministry for the Environment's Sustainable Management Fund, use and copying of the information for non-profit purposes is welcomed and allowed.

I would like to take this opportunity to thank all of those authors who responded to the invitation to contribute to the manual. By incorporating the viewpoints of a wide range of authors, the manual represents the majority viewpoint of practitioners in the field of odour management in New Zealand. The authors and their affiliations (at the time their contributions were written) are listed in the Acknowledgements section. Special thanks is owed to Boyd Miller, President of the NZWWA at the time the idea for the manual was conceived, for his enthusiasm, contributions, and comprehensive reviews throughout the development of the manual over the last two years.

I hope you will find the manual readable and informative, and if you have any comments or suggestions feel free to forward them to me or the NZWWA office at any time. If you would like to contribute some text to a future edition of the manual, either as a case study or maybe to present your own point of view about some aspect of odour management discussed in the manual, I would welcome your contribution and please don't hesitate to contact me.

Tracy Freeman
Editor

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- RDC Consultants
- Clean Air TechniQ Pty Ltd

CONTENTS

1. DEFINITION AND MEASUREMENT OF ODOUR

1.1 WHAT IS ODOUR?

1.1.1 Odour Sensation and Physiological Principles

Odour is a sensory experience. The human olfactory sense organs, along with that of taste, are generally considered to be the oldest ones in evolutionary development. The olfactory nerve cells are directly connected to the brain, and are highly sensitive instruments capable of detecting extremely low concentrations of certain chemicals.

Many contaminants discharged to air from both natural and anthropoegenic sources are immediately apparent because of their odorous properties. The human sense of smell is very sensitive to a wide range of odorous chemicals and will often result in a strong and immediate response in exposed populations. It is said that the human body can differentiate about 10,000 distinct odours (Amore *et al*. 1964). However, to date it has not been possible to predict an odour sensation solely due to the chemical structure of an odorant, nor to develop a machine to accurately duplicate the human sensory response.

The type of odour and amount (intensity) are both important in processing the signal sent to the brain. Certain chemicals are virtually non-odorous and cannot be detected at any level. Other chemicals are odorous but quickly desensitise the olfactory sense organs, resulting in a discontinued sensation of the odours. The individual components of an odour necessary to cause an adverse reaction in people are usually present in very low concentrations, far less than will cause adverse effects on physical health or impacts on any other part of the environment.

1.1.2 Odour Detection and Perception

The effects of odour are directly related to the subjective response of the individual exposed and their tolerance to the presence of a particular odour. When the level of odour exceeds the tolerance of an exposed population, nuisance is said to occur. Because it is carried in air, odour can be all pervasive and those affected often cannot escape its effects.

The annoyance reaction of a person whose nose senses an unpleasant odour is determined by non-sensory variables such as personality traits, attitude to the source, and environmental context. There are four major dimensions to the sensory perception of odorants:

(a) detectability
(b) intensity
(c) quality
(d) hedonic tone.

(a) Detectability

The odour detection threshold refers to the minimum concentration of an odorous substance that can produce an odour sensation in 50% of a panel of observers (see Chapter 3 for more details). It is important to note that these values are not fixed physiological facts or physical constants, but statistically represent the best estimate value from a group of individual responses.

(b) Intensity

The intensity of odour emissions is described using odour units (OU), ie, the number of times the odorous air must be diluted with odour-free air until the concentration of the odorous substance reaches the detection threshold (see (a) above), "Intensity' refers to the perceived strength of the odour sensation. The intensity is normally expressed as **odour units per cubic metre** (OU/m^3) of the original odorous sample.

(c) Quality

Odour quality is a qualitative measure, not quantitative. It describes the general character of the odour, or what the substance smells like. Odour quality is highly dependent on receptors and sensory neurons in the nasal cavity and the brain. The specific details of how the brain determines odour quality are complex and yet to be fully understood.

(d) Hedonic Tone

Like odour quality, the hedonic tone is a qualitative judgment of the pleasantness or offensiveness of the odour. For example, odours from perfumes and flowers are generally considered to be pleasant, whereas the odours from sewers and tanning factories are considered offensive. The perceived odour intensity is often influenced by both odour quality and hedonic tone, in addition to the concentration.

1.1.3 Odour Types and Sources

There are many types of odorous chemicals, such as:

- sulphur compounds — *eg. hydrogen sulphide, methyl mercaptan, sulphur dioxide*
- nitrogen compounds — *eg. ammonia, trimethyl amine, nitrobenzene*
- hydrocarbons — *eg. benzene, aliphatic hydrocarbons*
- oxygen compounds — *eg. ethanol, acetone, toluene*
- halogen compounds — *eg. allyl chloride, bromine, chlorine*
- selenium compounds — *eg. selenides*

The odours encountered in the ambient environment are generally due to mixtures of different compounds. For example, the odours associated with road transportation include vehicle exhaust gases as well as those generated from the tyres and road tar. Agricultural odours are often even more complex, consisting of various mixtures incorporating odorous compounds from decaying plant and animal matter, fruits, flowers, manure, cut grass, and silage.

Odours can come from virtually any source, and it only takes one nearby source to create a serious nuisance problem. Some of the more significant activities with the potential to cause odour in New Zealand are:

- wastewater reticulation and treatment systems
- landfills
- tanning industry
- agriculture
- food processing and servicing
- pulp and paper industry
- transportation
- petroleum industry
- fertiliser industry
- asphalt manufacture
- metal casting
- paint and varnish
- solvents and resins
- brewing industry

1.1.4 Odours in the Wastewater Industry

Processes involving the collection, treatment and disposal of wastewater have the potential to discharge a very wide range of contaminants to atmosphere. Many of these can have significant adverse effects over wide areas because of their odorous properties. Wastewater reticulation and treatment systems are the cause of many odour complaints, particularly in the urban environment where distances between the odour source and the impacted community are often limited.

Odours from wastewater are typically a mixture of compounds. Some of the key compounds associated with wastewater odours, and their descriptions, are as follows:

- hydrogen sulphide *egg, sulphide*
- mercaptans *earthy, pungent*
- ammonia *pungent*
- amines *fishy, pungent*
- skatole *faeces, coal-tar*
- iso-valeric acide *cigarette smoke*

Odour emissions from wastewater pumping stations and siphons along reticulation systems are highly vulnerable to localised discharges from industry as well as the general community. This has a significant impact on the type and intensity of odorous emissions. These emissions can be difficult to control and manage, primarily because some of the key factors responsible for the odours are beyond the control of the wastewater system operator.

On the other hand, odour emissions from wastewater treatment plants (WWTPs) can be controlled and managed with significantly greater success through the selection and operational control of treatment processes. Any adverse impact on odour emissions from localised discharges into the reticulation system are, to a large extent, diluted by the time they reach the WWTP. However, where the reticulation systems travel long distances before reaching the treatment plant, and have ventilation problems, the wastewater may become septic and cause elevated odour emissions at the WWTP.

1.1.5 Effects of Odour and Community Response

Impacts of odour on the community are most prevalent during the summer, especially at dawn, dusk, in the evenings, and in still conditions. In summer, windows and doors in residential homes are more likely to be left open, and people spend more time outdoors. The response from the community varies with:

(a) <u>frequency</u> of odour emissions
(b) <u>intensity</u> of odour
(c) <u>duration</u> of odour
(d) <u>offensiveness</u> of odour.

The likely impact of the odour emissions on the community is also dependent on the location of the source. These factors are generally abbreviated as the FIDO or FIDOL factors (Ministry for the Environment, 1995).

There are other human factors that also influence community response to odour emissions. These include:

(a) age of the person
(b) individual sensitivity to specific substance(s) in the odour
(c) health of the person
(d) community's perception of the odour control and management at the source.

When an adverse odour effect becomes significant, the community initially reacts with complaints to the regulatory agencies and/or to those responsible for the odour. In New Zealand, community complaints regarding odour problems are generally poorly documented and verified. Very little research has been done to relate odorous episodes to community health problems.

Although laboratory studies with animals have shown that some odorants can cause marked physiological and morphological changes in terms of cardiovascular and respiratory performances, there is very little information available about the toxic effects of odorous substances on humans.
However, it is known that prolonged exposure to offensive odours usually generates undesirable reactions in people such as unease, irritation, discomfort, anger, depression, nausea, headaches, or vomiting.

1.2 METHODS OF MEASURING ODOUR

1.2.1 Overview

The measurement of odour is based on two basic approaches: chemical analysis using an array of instruments; and sensory analysis using a human nose. Both types have their advantages and disadvantages in respect to the accuracy of estimation of odour concentration: they also differ in cost, detection limits and complexity. Apart from community odour surveys, most of the methods of odour measurement relate only to the quantification of odour strength (factor "I" of FIDO factors - see Chapter 1.1.5).

In chemical analysis, the concentration of the odorous compound is measured, and this is multiplied by a known odour detection threshold for that compound. There are several difficulties with this method.

(a) An odorous gas can be comprised of a cocktail of many odorous compounds. This fact presents a major challenge to the accurate measurement of odour due to the difficulty in identifying all compounds, and the synergistic relationship that may exist between the various compounds.

(b) The nuisance impact of an odorous compound is often perceived at extremely low concentrations (in the parts per billion range), making instrumental analysis difficult.

(c) Published odour thresholds may differ depending on the source of the information, as illustrated in Table 1.2.1. This is due to differences in sensory techniques used by laboratories in the past (this is becoming more standardised in the late 1990's).

Despite these difficulties, chemical analysis is still used as an odour measurement technique, and the methods are described in Chapter 1.2.3. Sensory evaluation is discussed briefly in Chapter 1.2,4, and then in Chapter 3 in greater detail.

TABLE 1.2.1: ODOUR DETECTION THRESHOLDS ACCORDING TO VARIOUS SOURCES

Compound	Reported detection thresholds (ppb)	Equivalent concentration (µg/m^3)	References (see notes below table)
Hydrogen sulphide	0.47 0.2 5	0.7 0.3 7	1, 3 4 2
Dimethyl Disulphide	0.7 0.03	2.7 0.1	4 3
Methyl mercaptan	0.02 0.1 2.1	0.04 0.2 4.2	2, 3 4 1, 5
Ethyl mercaptan	0.03 1	0.075 2.5	2, 3 1, 4, 5
Amonnia	470 38	330 26.6	1, 2 3

Notes:
1. Leonardo G, Kendall D, Barnard J. (1969) *J. Air. Poll. Control Ass.* 19,2: 91-95.
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1.2.2 Chemical Analysis

Instrumental Analysis

Gas chromatography using standards of known substances, or gas chromatography combined with mass spectrometry (GC-MS) when the composition of a gas sample is unknown, is an accurate and very sensitive method of chemical analysis of the nature of the gas (down to 0.1 ppb levels). Typically, odorous substances create nuisance at very low concentrations, while non-odorous components of the gas sample may be present at much higher concentrations, making interpretation of the chromatogram difficult. A sample may result in literally hundreds of peaks, with only a fraction of them formed by odorous substances. Odour threshold concentrations of most of them are not yet available.

Gas chromatography only gives an indication of the nature and concentration of chemical compounds in the sample, not their contributions to the overall odour of the mixture. An interesting modification was developed to overcome this shortcoming (Veijanen *et al* 1983). This combines instrumental and sensory analysis and is called chromatographic sniffing. The capillary column is equipped with an outlet leading to an odour observer. When a peak appears, the observer sniffs at the external sidestream and rates the odour intensity of that particular component. The system is highly sensitive and accurate for the determination of retention times of odorous compounds (Savenhed *et al*. 1985).

Even with the aid of chromatographic sniffing, chromatographic analysis of individual odorous compounds does not account for synergistic or antagonistic effects between odour components or for the hedonic nature of the odour.

Chemical Monitors

For an accurate measurement of some of the more significant individual odour components, electronic monitors with detection limits down to 1 ppb are used. These monitors are portable and offer the advantage of instantaneous readings in the field; however they are expensive. Examples of such instruments are given below.

- The TDL-1 toxic gas detector, manufactured by MDA Scientific (Brimble and Sharma, 1994), measures a selection of chemical species, among them H_2S in the range 1-90 ppb and 1-30 ppm, ammonia in the 2.6-75 ppm range and sulphur dioxide (SO_2) in the 0.2-6 ppm range. The parameter measured by the instrument depends on a specific interchangeable "key" inserted into the machine as needed. A tape called chemcasette is exposed to the target gas in the gas sampling head for 15 minutes. The chemcasette will change colour in proportion to the amount of gas present. The higher the concentration, the darker the stain.

  Each stain is read by the photo-optical system of the monitor, then compared to a standard curve programmed into the system. Each chemcasette is traceable to calibration to a primary reference. Calibration of the instrument is checked regularly using a calibration card containing standardised stains (secondary reference).

- The Jerome Analyser (Arizona Instruments) is used for the quantification of H_2S (Turner, 1992). The instrument belongs to a class of equipment based on electrochemical reactions. H_2S is selectively adsorbed onto the surface of a gold film microsensor, resulting in formation of gold sulphide which causes an increase in the sensor resistance. The resistance change is measured by a Wheatstone bridge circuit. The microsensor is regenerated by heat which catalyses oxidation of gold sulphide to gold and SO_2. The meter needs to be calibrated by an approved agent on an annual basis.

- Model 45 series analysers (Thermo Environmental) are used for the quantification of H_2S (Turner, 1992). These instruments catalytically convert H_2S to SO_2. The SO_2 is measured by the UV pulsed fluorescence, and a readout given as H_2S.

Gas Detection Tubes

These are commonly called Dräger tubes, but are also available from other manufacturers, eg, Gastec and Kitigawa in Japan. They are calibrated glass tubes filled with a chemical reagent which changes colour when in contact with the specific substance. The length of discolouration along the tube is a measure of the gas concentration in parts per million. For instantaneous gas concentration assessment short term exposure tubes are used, with a hand operated sampling pump (eg, bellows, piston or diaphragm pump) delivering a fixed volume of the sample, usually 100 cm^3 per stroke. Sample collection takes not more than 10 minutes.

The sensitivity of gas detection seldom reaches below 0.5 ppm. Readings are influenced by temperature and interfering substances, but reasonably repeatable results are obtained. Gas detection tubes present a simple and very inexpensive means to obtain an indication of the levels of odorous compounds in field conditions.

Electronic Odour Monitors

Contemporary state-of-the-art technologies in odour measurement include electronic equipment which is able to conduct complex chemical analysis and discriminate between items with different flavours. These instruments are known as “electronic noses”. Designed primarily for aroma analysis in the food industry, their range of application has developed into a broader scope of industrial and environmental applications, including water and wastewater odours. Electronic odour monitors are based on conducting polymer sensors, able to detect odour-causing chemical molecules in trace concentrations.

An example of such equipment is the Electronic Nose by Neotronics. The instrument profiles headspace volatiles over a sample tested. It produces a “fingerprint” of the volatile headspace. This is compared by the accompanying software to fingerprints of reference odours (eg, an odour fingerprint of stale peanuts is compared to the profile of a fresh batch). There is no identification of the components in the odour, and the analysis is not quantitative. The instrument is not a direct electronic equivalent to the human sense of smell but complements existing technology (sensory panels, GC/MS). Early trials with wastewater odours proved that the instrument can group samples collected from different stages of the treatment process. Further development is aimed at the application of this technology in pollution monitoring.

An example of simpler and less expensive electronic odour sensors is a Portable Odour Monitor by Sensidyne. It is small, rugged, versatile, and capable of measuring odorous emissions in a variety of industrial and environmental applications. It is however not recommended for use in the wastewater treatment field, as its sensors are vulnerable to H_2S poisoning.

Hydrogen Sulphide (H_2S) Monitoring in Ambient Air

Ambient Air Quality Guidelines in New Zealand specify the limit of H_2S in ambient air as 7 $\mu g/m^3$ (5 ppb) with 30 minute averaging time (Ministry for the Environment, 1994). The recommended method for measurement is Australian Standard AS 3580.8.1-1990. The method uses a field continuous gas chromatograph using an automatic intermittent sampling procedure. Measured portions of ambient air are delivered at regular intervals to a column separating H_2S from other sulphur compounds. The concentration of H_2S is measured with a flame photometry detector at a wavelength specific for sulphur. The instrument requires regular calibration.

1.2.3 Sensory Evaluation

Chemical techniques as described in Chapter 1.2.2 typically involve the analysis of a gas sample of the odour to determine the chemical compounds present and their concentrations. While this knowledge of the odorous constituents is frequently very useful in developing odour abatement or control strategies, it is difficult to fully utilise the data to assess the likely odour impact of a given sampler for the following reasons:

(a) odour threshold concentration data for most of the identified compounds are often not available, or vary according to the source of data; and

(b) synergistic effects between the compounds are impossible to predict, so that the chemical analysis results are rarely able to indicate the strength or character of an odour perceived by human assessors.

Sensory methods of odour measurement, on the other hand, avoid this problem by using the human nose as the sensor in the measurement process. "Olfactometry" is the science of odour measurement using sensory methods.

Because of the complex nature of odours, the human nose cannot be matched by any presently known instrument. Nor can an instrument measure the degree of unpleasantness of the odour. The disadvantages of the sensory analysis include the significant variability of human sensitivity and reaction to smells, and smell fatigue (where the human nose becomes desensitised to particular odours after a period of exposure).

Sensory analysis by humans can be used qualitatively and quantitatively (Turner, 1992).

- Qualitative surveys are performed at wastewater treatment facilities to estimate when odour levels at plant boundaries are exceeding acceptable standards. Both treatment plant personnel and the neighbouring communities can be involved in qualitative studies.

- Quantitative measurement is conducted using panels of trained individuals and controlled laboratory conditions to assess odour levels in collected samples by a sensory method called olfactometry. It measures odour strength in terms of the degree of dilution with odour-free air required to reduce a given sample to the level where its odour is barely perceptible.

Quantitative olfactometry will be described in more detail in Chapter 3 of this Manual.

1.2.4 Odour Indicators

Because of the time, costs and difficulties involved with dynamic dilution olfactometry, chemical analyses are often used in the place of olfactometry as indicators of odour. That is, one assumes that by measuring for the presence of a certain gas (such as H_2S), one can get an estimate of the amount of odour present.

Some researchers have reported success with this technique. For example, reasonable correlation between hydrogen sulphide concentration and odour concentration in sewer head spaces at drop structures in the Melbourne sewerage system has been reported by Chong *et al* (1997). The relationship was:

$OU = 42\ C^{0.543}$ *where* OU = *measured odour level in odour units, using an odour panel following Victorian EPA protocols (ie, Yes/No olfactometer (see Chapter 3.1.2))*

and C = *measured H_2S concentration in ppb.*

Note that the exponent in this equation is less than unity which implies progressive masking of odour potential as the H_2S concentration increases. While this relationship between H_2S and odour has been quoted as an example, it should not be applied to other systems without extreme caution as no two sewage streams are exactly the same.

Chong *et al* (1997) also reported that monitoring of the air in sewer drop structures (the "head space") confirmed that the combined contribution of other reduced sulphides (methyl mercaptan, ethyl mercaptan, dimethyl sulphide and dimethyl disulphide) to odour was small at 2 - 9% of that due to H_2S. However, there were two occasions after rain, when infiltration had significantly reduced sulphide levels, when the concentrations of methyl mercaptan were of the same order as those of H_2S giving a contribution to odour of from 50 to 100% compared to H_2S.

While H_2S may be an appropriate indicator for odour in sewer head spaces, at different stages of sewage treatment other reduced sulphides have been found to be the main odorant. Kaye et al (1994) found methyl mercaptan and dimethyl disulphide to outrank H_2S at aeration tanks and sludge thickeners. This finding was supported by odour monitoring studies at the Mangere WWTP in 1994 and 1995, which included both olfactometry and H_2S measurements of source emission rates. Comparison of the results from these two concentration parameters, as shown in Figure 1.2.1, led to the conclusion that H_2S was actually a poor indicator of WWTP odours. The Figure shows that for a number of sources at the WWTP, there was no consistent correlation between H_2S concentration and odour concentration.

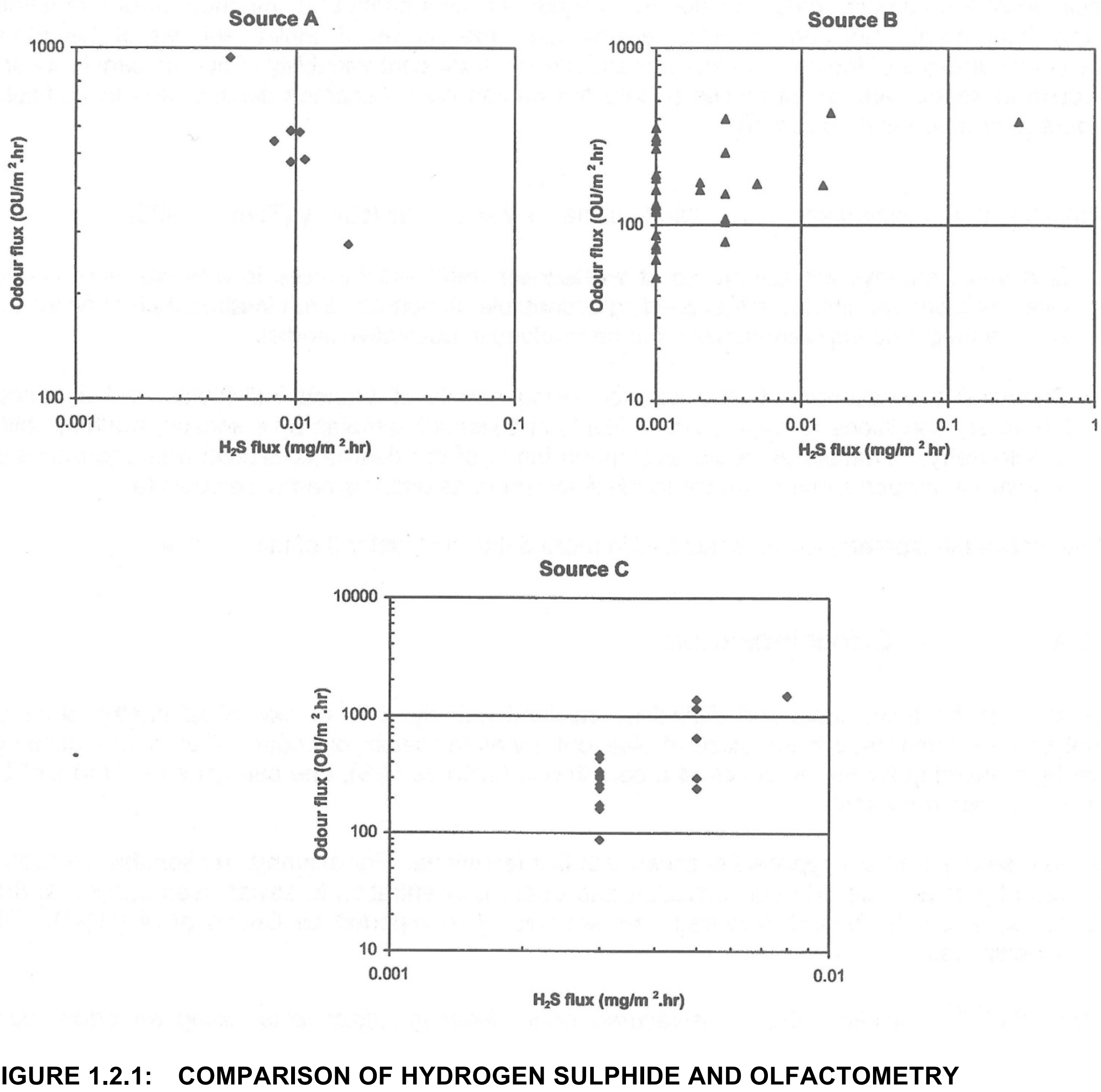

FIGURE 1.2.1: COMPARISON OF HYDROGEN SULPHIDE AND OLFACTOMETRY MEASUREMENTS FROM SOURCES AT THE MANGERE WWTP.

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2. REGULATORY AND LEGISLATIVE ISSUES

2.1 INTRODUCTION

Control and management of odorous activities present difficulties for regulators. One of the greatest difficulties is that, while highly technical evaluation is possible prior to an activity being established, the acceptability or otherwise of an odour will ultimately rely on a value judgment. Odour problems experienced by surrounding communities often prove intractable and result in considerable ongoing frustration to the regulator, those undertaking the activity and those affected by the odour. However, odour problems are often caused by a combination of poor land use planning, inappropriate controls and poor operating or management practices. Usually, the causes of odour are avoidable if appropriate evaluation of the activity is undertaken before it is established. This would include consideration of existing and potential future development of sensitive land uses in the vicinity of the proposed activity and the existing state of technical knowledge. It is far more difficult (and costly) to retrospectively solve odour problems from existing activities.

This chapter will examine the tools and methods available to regulators to control odorous activities, in particular under the Resource Management Act 1991 (RMA). Relevant aspects of the Health Act (1956) are also briefly covered. The mechanisms and requirements of the resource consent process will be evaluated and illustrated as they apply to odorous activities, in particular wastewater treatment. Finally, the issues of compliance and enforcement will be discussed with particular reference to the subjective nature of odour nuisance.

The RMA sets a framework for sustainable management and does not provide the detailed regulatory framework which is the role of regional air plans. Discussion of the actual provisions of regional air plans has been deliberately excluded from this manual, as the various plans around the country are in varying stages of development and any discussion would quickly become out of date.

Quotations from the RMA in this Chapter are current as of February 1999. However, clauses of the RMA are frequently updated, and the original legislation should be consulted if an exact, up-to-date wording is required.

The authors of this manual did not set out to provide a detailed analysis of legal opinion and interpretation of the RMA, nor a detailed discussion of Court precedent with respect to odour. Court precedent is constantly developing and the application of the law will vary depending on individual circumstances. In situations where application or interpretation of the law is required, the affected parties should seek a legal or planning opinion, and consult professional advice regarding the appropriate course of action.

2.2 LEGISLATIVE OVERVIEW

2.2.1 The Regulatory Environment

Prior to the enactment of the RMA, discharges to air were regulated under the Clean Air Act 1972 (CAA). This was primarily focused on control of industrial or trade processes through administration of clean air licences based on the "best practicable means" as defined in the CAA. The activities requiring licensing were described in the Second Schedule to the CAA. Administration of the licences was shared between the Department of Health and territorial authorities, depending on the nature and scale of the activity. An unusual feature of the CAA was that wastewater treatment processes did not require a clean air licence unless associated with another scheduled process. Therefore, discharges to air from many wastewater treatment processes were not specifically regulated.

With the enactment of the RMA in 1991, the CAA was repealed, although any existing clean air licences were transferred as resource consents for the term of the consent plus one year. This was to allow a smooth transition from the "process-based" CAA to the more "effects-based" resource management regime.

The Health Act was enacted in 1956 with the purpose of promoting and conserving public health. As part of its purpose, the Health Act sets out the functions and powers of local authorities in respect of public health, including the abatement of nuisances (such as odours) which are offensive or likely to be injurious to health. The Act also deals with the functions and powers of medical officers of health, including powers in relation to offensive trades, and enforcement mechanisms.

In matters of significant odour complaint from wastewater treatment plants (WWTPs), environmental health officers of the territorial local authority, or the health protection officers, as agents of the Ministry of Health, feature alongside officers of the regional council in dealing with complaints.

2.2.2 Key Provisions of the RMA

The essential sections of the RMA that apply to discharges to air are Sections 15, 20 and Section 418. Section 2 (*Interpretation*) provides useful definitions of both "discharge" and "contaminant". Discharge means "emit, deposit or allow to escape", and contaminant is defined as:

> *… any substance (including gases, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy or heat -*
> *(a) when discharged into water, changes or is likely to change the physical, chemical, or biological condition of water; or*
> *(b) when discharged onto or into land or into air, changes or is itheiy to change the physical, chemical, or biological condition of the land or air onto or into which it is discharged.*

Odour is therefore a contaminant under the RMA's definition.

Discharge of Contaminants into Environment (section 15)

Section 15 of the RMA *'Discharge of contaminants into environment'* restricts the discharge of contaminants to water, land or air unless the discharge is provided for in a regional plan, resource consent or regulations:

> *15. Discharge of contaminants into environment-*
>
> *(1) No person may discharge any-*
> *(a) contaminant or water into water; or*
> *(b) contaminant onto or into land in circumstances which may result in that contaminant (or any other contaminant emanating as 0 result of natural processes from that contaminant) entering water; or*
> *(c) contaminant from any industrial or trade premises into air: or*
> *(d) contaminant from any industrial or trade premises onto or into land-*
> *unless the discharge is expressly allowed by a rule in a regional plan and in any relevant proposed regional plan, a resource consent, or regulations.*
>
> *(2) No person may discharge any contaminant into the air, or into or onto land, from-*
> *(a) any place; or*
> *(b) any other source, whether moveable or not, -*

in a manner that contravenes a rule in a regional plan or proposed regional plan unless the discharge is expressly allowed by a resource consent, or regulations, or allowed by section 20 (certain existing lawful activities allowed).

(3) This Section shall not apply to anything to which section 15A (restrictions on dumping and incineration of waste or other matter in coastal marine area) or section 158 (discharge of harmful substances from ships or offshore installations) applies.

The critical distinction within Section 15 is in its treatment of discharges to air from industrial or trade premises, as separate from discharge from other activities. Section 15(1)(c) creates a presumption that no contaminant may be discharged to air from an industrial or trade premises, unless the discharge is expressly provided for by resource consent, a rule in a plan or regulations.

In contrast, for sources other than industrial or trade premises, discharges to air are permitted until restricted by a regional plan.

Existing Discharges (sections 20 and 418)

Section 20 '*Certain existing lawful activities allowed*' provides for the continuation of existing discharges, other than discharges from industrial or trade premises, until a rule in a regional plan that would otherwise require consent for the discharge becomes operative provided that:

- the activity was lawfully established before the proposed plan was notified;
- the activity has not been discontinued for a continuous period of more than six months since the proposed plan was notified;
- the effects of the activity are the same or similar in character, intensity and scale to those which existed before the proposed plan was notified.

However, regardless of the existing use status under section 20, the necessary consents must generally be applied for within six months of a rule in a proposed plan becoming operative.

The existing permitted discharge of contaminants from industrial and trade premises is provided for within Sections 418(1) and 418(1A) of the RMA.

This section effectively allows the status quo to continue from the CAA to RMA until a regional plan provides otherwise. Sections 418(1) and (1A) state:

418. Certain existing permitted uses may continue -

(1) For the purposes of this Act, section 15(1)(c) shall not apply in respect of any discharge from an industrial or trade premises that would not have required a licence or other authorisation under the Clean Air Act 1972, unless a regional plan provides otherwise.

(1A) Notwithstanding subsection (1), for the purposes of this Act, section 15(1)(c) shall apply to any discharges from industrial or trade premises used for the storage, transfer, treatment, or disposal of waste materials or other waste management purposes, or for composting organic material, commenced after the 1st day of October 1991.

The term "waste management purpose" is generally taken to mean any activity where waste management is the primary purpose of the process rather than a process with ancillary waste management facilities.

Section 418(1A) has the greatest implications for wastewater treatment processes. Given that all wastewater treatment processes discharge to air in some way, section 418 effectively requires an air discharge resource consent for any waste management process (including wastewater treatment processes) established after 1 October 1991. However, any process established before 1991 is able to continue operating without an air discharge resource consent until such time as a regional plan provides otherwise.

The regional air plans are the documents which determine the rules under which trade premises and other activities will operate. In the absence of a regional air plan, section 15(1)(c) of the RMA requires discharge permits (resource consents) for emissions to air from trade premises. It is also possible that district plans may have rules for activities which discharge to air and impact on amenity values. Requirements in regional plans are discussed further in Chapter 2.3.2.

In any individual case, it is important to contact the regional council for the relevant regional plan requirements. It may also be advisable to seek professional advice on how compliance is able to be achieved.

Duty to Avoid, Remedy or Mitigate Adverse Effects (section 17)

Compliance with the specific provisions of sections 15, 20 and 418 does not avoid the need to comply with the duty of section 17, in relation to avoiding, remedying or mitigating adverse effects. Section 17 also provides the framework for serving of enforcement orders and abatement notices as enforcement tools, and deals with those circumstances where the Environment Court may not institute or allow enforcement proceedings:

> *17. Duty to avoid, remedy, or mitigate adverse effects –*
>
> *(1) Every person has a duty to avoid, remedy or mitigate any adverse effects on the environment arising from an activity carried on by or on behalf of that person, whether or not the activity is in accordance with a rule in a plan, a resource consent, section 10 (certain existing uses in relation to land protected), section 10A (certain existing activities allowed) or section 20 (certain existing lawful activities allowed).*
>
> *(2) The duty referred to in subsection (1) is not of itself enforceable against any person, and no person is liable to any other person for a breach of that duty.*
>
> *(3) Notwithstanding subsection (2), an enforcement order or abatement notice may be made or served under Part XII to -*
> *(a) require a person to cease, or prohibit a person from commencing, anything that, in the opinion of the Environment Court or an enforcement officer, is or is likely to be noxious, dangerous, offensive, or objectionable to such an extent that it has or is likely to have an adverse effect on the environment; or*
> *(b) require a person to do something that, in the opinion of the Environment Court or an enforcement officer, is necessary in order to avoid, remedy, or mitigate any actual or likely adverse effect on the environment caused by, or on behalf of, that person.*
>
> *(4) Subsection (3) is subject to section 319(2) (which specifies when an Environment Court shall not make an enforcement order).*

Scope, application, and decisions on enforcement orders and abatement notices are covered in detail in sections 314-325 of the RMA. Of importance is section 319(2)(c), specifically mentioned in section 17(4), which makes it clear that no enforcement order can be issued for an adverse effect which was expressly recognised by the person that approved the plan or granted the resource consent unless circumstances have suitably changed:

319. Decision on application-

(2). The Court shall not make an enforcement order under paragraphs (a)(ii), (b)(ii), (c), (d)(iv), or (da) of Section 314(1) against a person who is active in accordance with-

(a) a rule in a plan

(b) a rule in a proposed plan to which section 19 applies (changes to plans which will allow activities): or

(c) a resource consent,-

if the adverse effects in respect of which the order is sought were expressly recognised by the person that approved the plan, or notified the proposed plan, or granted the resource consent, at the time of approval, notification, or granting unless, having regard to the time which has elapsed and any change in circumstances since the approval of the plan, the notification of the proposed plan, or the granting of the consent, the Court considers that it is appropriate to do so.

Implementation of enforcement proceedings is discussed further in Chapter 2.3.5 of this Manual.

In situations where enforcement proceedings are being considered or enacted, the affected activities should seek a legal or planning opinion and consult professional advice regarding the appropriate course of action.

2.2.3 Key Provisions of the Health Act

The essential sections of the Health Act that apply to air discharges and odours in particular are Sections 29 and 30. Section 30 outlines that any person who causes a nuisance as a result of their activities is committing an offence against the Health Act. Section 29 defines the term 'nuisance" in relation to the Health Act. This is defined below, with particular reference to odours arising from wastewater treatment activities:

29. Without limiting the meaning of the term "nuisance", a nuisance shall be deemed to be created in any of the following cases, that is to say:

(a) where any pool, ditch, gutter, watercourse, sanitary convenience, cesspool, drain, or vent pipe is in such a state or is so situated as to be offensive or likely to be injurious to health;

(b) where any accumulation or deposit is in such a state or is so situated as to be offensive or likely to be injurious to health;

(d) where any premises are so situated, or ... are in such a state, as to be offensive or likely to be injurious to health;

(g) where any factory, workroom, shop, officer warehouse or other place of trade or business is not kept in a clean state, and free from any smell or leakage from any drain or sanitary convenience;

(h) where any factory, workroom, shop, office, warehouse, or other place of trade or business is not provided with appliances so as to carry off in a harmless and inoffensive manner any fumes, gases, vapours, dust, or impurities generated therein;

(I) where any trade, business, manufacture, or other undertaking is so carried on as to be unnecessarily offensive or likely to be injurious to health;

(n) where the burning of any waste material, rubbish, or refuse in connection with any trade, business, manufacture, or other undertaking produces smoke in such quantity, or of such nature, or in such manner, as to be offensive or likely to be injurious to health.

Odour from wastewater treatment activities can therefore be defined as a nuisance under the Health Act as the odour that may arise from a wastewater treatment plant may be deemed offensive.

2.3 IMPLEMENTATION OF ODOUR POLICY

2.3.1 National Environmental Standards/ Guidelines

Section 43 of the RMA '*Regulations prescribing national environmental standards'* provides for the development of national air quality standards. No national environmental standards have been prepared under the RMA. However, in respect of odour, the Ministry for the Environment (MfE) has produced a guide on how to manage and measure odour entitled 'Odour Management Under the Resource Management Act 1991' (MfE, 1995). This guide has no legal status. It was prepared to assist councils and consultants in their resource management decision-making in relation to odour.

MfE has also produced Ambient Air Quality Guidelines' (MfE, 1994). This document sets out guideline levels for discharges to air. While the guidelines do not directly address "odour", the recommended guidelines consider the concentrations at which certain discharges become odorous.

Of most relevance to wastewater treatment is the guideline developed for hydrogen sulphide (H_2S). The MfE Ambient Air Quality Guidelines specify the guideline concentration for H_2S as 7µg/m^3 with a 30 minute averaging time. While this is above the known H_2S odour threshold (see Chapter 1.2.1), it is consistent with World Health Organisation Guideline (WHO - Air Quality Guidelines for Europe, 1987). The WHO Guideline recommends the 7µg/m^3 value to avoid complaints about odour annoyance.

The guidelines are not legally or statutorily binding, but may be used by Regional Councils in the development of regional rules and in assessing resource consent applications.

2.3.2 Policy Statements and Plans

Under the RMA sits a hierarchy of policies and plans. The purpose of these policies and plans is to promote the integrated and sustainable management of resources from a national, regional and district perspective. The policies and plans required under the RMA are shown in Figure 2.3.1, and briefly described below.

The purpose of a **national policy statement** is to state policies on matters of national significance that are relevant to achieving the sustainable management purpose, and will enable central government to retain a measure of control of the management of resources where required. National policy statements are not intended, in themselves, to bind individuals, and are not directly enforceable. However, regional and district policy and planning documents must be consistent with the national policy statement. At present the New Zealand Coastal Policy Statement (1994) is the only such example.

Every regional council must prepare a **regional policy statement**, having regard to any national policy statements. A regional policy statement provides an overview of the resource management issues of each region, and the policies and methods to achieve the integrated management of the natural and physical resources of the region.

Regional councils may prepare **regional plans** on any issues of regional importance, for example air discharges. Preparation of these plans is not compulsory, however, any person may request a regional council to prepare or change a regional plan in the manner set out in the first schedule of the RMA. The purpose of regional plans is to assist the regional council in carrying out any function for which it is responsible. The regional plan must also have regard to the regional policy statement.

The process for preparing or changing a plan is shown in Figure 2.3.2. An important stage is negotiation to avoid an appeal to the Environment Court.

Regional councils are responsible for the control of discharges of contaminants into air. Regional plans may contain rules relating to air discharges which set thresholds for managing the effects of activities on the environment, the discharge limits and the circumstances under which a resource consent is required for a particular activity.

The regional plan may refer to five types of activities: permitted; controlled; discretionary; non-complying; and prohibited. (Note; if the activity is made up of several parts, several rules and activity classifications may apply.)

(a) If an activity is permitted, it can be carried out provided it meets the conditions in the plan.

(b) If an activity is controlled, a discharge to air permit is needed. The council must grant the permit if the standards and terms of the plan are met. The council can also impose conditions on the consent, specified in the plan.

(c) If the activity is discretionary, an air discharge permit is needed, and the council will decide whether or not to grant the permit. This will usually depend on the nature of the effects of the activity and how well the proposal fits with the policies of the plan.

(d) If the activity is non-complying, ie, contravenes a rule in a plan or a proposed plan, a discharge to air consent is needed. The council cannot grant consent unless the effects of the activity are minor; or is not contrary to the objectives and policies of the plan. Even if these tests are satisfied the council retains the discretion to grant or refuse consent for the activity.

(e) If the activity is prohibited, the activity cannot proceed, and no discharge to air permit can be applied for. The only option available is to seek to have the plan changed.

If no explicit provision is made in a regional air plan for the particular odour discharge and the discharge is from an industrial or trade premises, then a discharge to air permit will be required in accordance with section 15(1)(c) of the RMA.

The differences between district council and regional council functions is well discussed in the MfE's guide “Odour Management Under the Resource Management Act 1991”. Relevant extracts from that discussion are as follows:

> *“... Section 30 (of the RMA) specifies the functions of regional councils. These include, at section 30(1)(f), ‘The control of discharges of contaminants into or onto land, air or water and discharges of water into water'.*
>
> *... Section 31 covers the functions of territorial authorities including "the control or any actual or potential effects of the use, development, or protection of land..." (section 31(b)). The emphasis is on the effects of the land user which are to be controlled.*
>
> *... The effects of council functions (sections 30 and 31) and sections 9 and 15 [of the RMA] are that regional councils need to grant resource consents for all odorous discharges from industrial and trade premises unless a plan provides otherwise... T erritorial authorities have no control over any land use which has the effect of producing odour, unless a district plan provides otherwise... The need for councils to ensure there is co-ordinated and integrated management is obvious ..."*

The MfE document should be referred to for full interpretation and discussion.

2.3.3 Consent Conditions for Odour Discharges

Most Regional Councils around New Zealand have released Draft, Proposed or Operative Regional Air Plans. Most of the plans do not contain any minimum odour standards but use the 'objectionable' and 'offensive' thresholds as criteria for assessing odorous discharges. Some regional plans provide for sewage treatment activities as permitted activities (no resource consent required) subject to strict conditions including:

> *"no objectionable or offensive odours beyond the boundary of the subject property."*

In general, if the above criteria cannot be met or there is a significant risk that odours will be offensive, then it is usual for these activities to be treated as discretionary activities (resource consent required).

The use of these qualitative, subjective standards poses problems for assessing compliance. What is 'objectionable' or 'offensive' will initially be determined by council officers, or their agents, whose odour sensitivity has been assessed by a recognised testing authority, according to recognised procedures.

However, the test in law is whether an odour would be offensive or objectionable to the ordinary reasonable person". An example of the application of this standard and assessment protocols is presented in Section 2.5,1 as a case study of the Watercare Wastewater Treatment Plant.

It should be noted that the condition of "no offensive or objectionable odours beyond the boundary" can and has been successfully argued against on a number of grounds and in a number of resource consents, particularly where the issue of "reverse sensitivity" applies. This is an important consideration in locations where residential areas and other sensitive land uses have been allowed to establish near odorous activities.

2.3.4 Best Practicable Option

By way of section 108 of the RMA, regional councils can impose a condition in respect of a resource consent, for the holder to adopt *"the best practicable option to prevent or minimise any actual or likely adverse effect on the environment"*.

Section 2 of the RMA sets out the definition of Best Practicable Option (BPO):

> *"… in relation to a discharge of a contaminant or an emission of noise, means the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to-*
>
> *(a) the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and*
> *(b) the financial implications, and the effects on the environment, of that option when compared with other options; and*
> *(c) the current state of technical knowledge and the likelihood that the option can be successfully applied."*

However, BPO applies only in certain cases, and is limited by section 70(2) of the RMA:

> *70. Rules about discharges*
>
> *(2) Before a regional council includes in a regional plan a rule requiring the adoption of the best practicable option to prevent or minimise any actual or likely adverse effect on the environment of any discharge of a contaminant, the regional council shall be satisfied that, having regard to-*
> *(a) the nature of the discharge and the receiving environment: and*

(b) other alternatives, including a rule requiring the observance of minimum standards of quality of the environment,-

the inclusion of that rule in the plan is the most efficient and effective means of preventing or minimising those adverse effects on the environment.

FIGURE 2.3.1: HIERARCHY OF POLICY STATEMENTS AND PLANS IN THE RMA (Adapted from RMA, Part V)

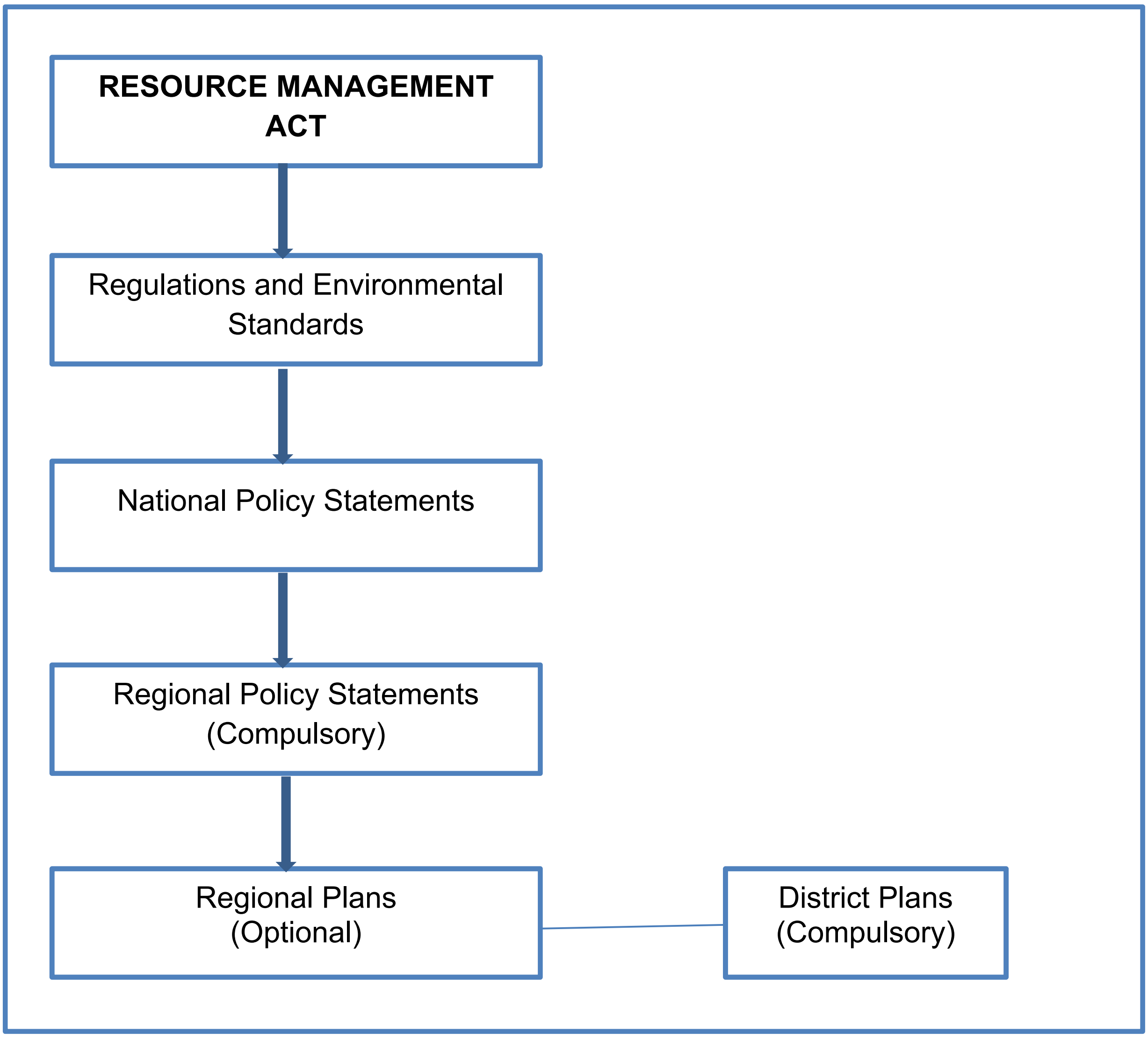
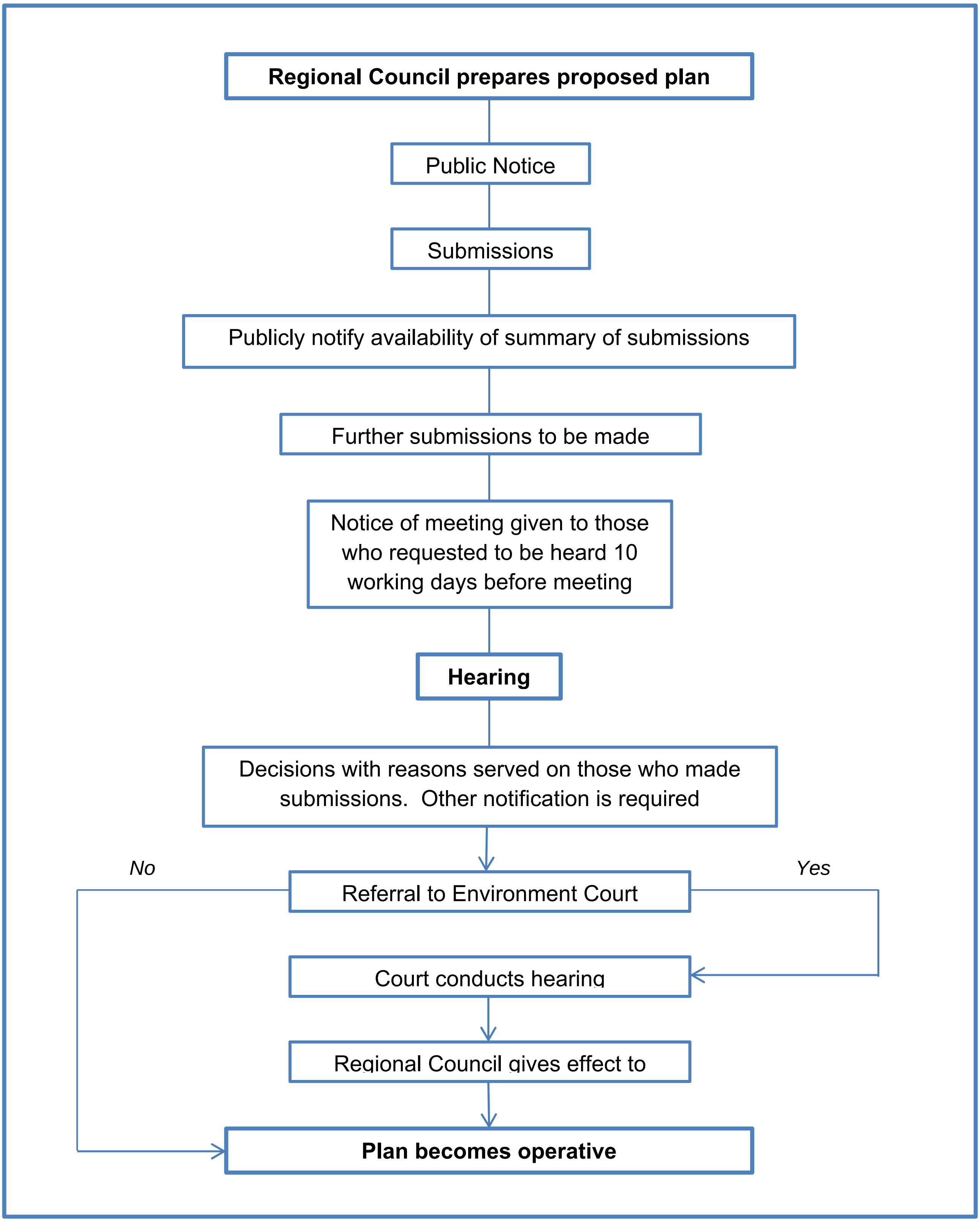


FIGURE 2.3.2: PROCESS FOR PREPARING OR CHANGING PLANS
(Adapted from RMA, Page A16-2 (last amended 4/12/98))



2.3.5 Enforcement

No resource management system is effective without an appropriate enforcement regime. The RMA contains a range of enforcement mechanisms, which can be used to manage odorous discharges. The key provisions in the RMA were outlined in Chapter 2.2.2. Abatement notices and enforcement orders are the most often used enforcement mechanisms. These mechanisms offer councils and, in some cases, the community, the ability to act on their own investigations or public complaints about the adverse effects of odorous discharges.

Abatement Notices

The abatement notice can be used by a Council where there is a contravention of the RMA that must stop, or that some positive action is required to rectify the contravention and/or to reduce the adverse effects on the environment. The abatement notice procedure is less onerous than an enforcement order, and can only be used by local authorities. Although the abatement notice is not directly enforceable, non-compliance with a nonce is an offence.

An abatement notice may be served on any person, by an Enforcement Officer of the local authority, although there must be reasonable grounds for doing so. Any person who has been served an abatement notice, must comply with the notice in the time specified (a minimum of seven days), and pay all costs and expenses associated with compliance. Any person who is served an abatement notice can appeal to the Environment Court, within seven days of receiving the notice.

Enforcement Orders

Enforcement orders are available to address non-compliance and/or adverse effects on the environment. Unlike abatement notices, an order may (subject to certain exceptions) be sought by a member of the public. Where the matter is of some urgency, an interim order may be obtained without the necessity of service or a hearing.

Amongst other things, an enforcement order (like an abatement notice) may prohibit or require cessation of an activity where it is:

> *"Likely to be noxious, dangerous, offensive, or objectionable to such an extent that it has or is likely to have an adverse effect on the environment" (Section 314(1)(a)(ii))*

An enforcement order may also require a person to do something that is necessary in order to:

> *"Avoid, remedy, or mitigate any actual or they adverse effects on the environment" (Section 314(1)(b))*

The enforcement order provisions of the RMA could therefore be used by any person to require those undertaking the activity to take certain actions to reduce an offensive or objectionable odour. An enforcement order can be made to enforce compliance in respect of a rule, regulation, heritage order or a resource consent.

An application for an enforcement order is made to the Environment Court, and must describe the nature, terms and conditions of any order sought. The Environment Court will then hear both the applicant and any person against whom the order is sought and who wishes to be heard. After considering the evidence of all parties, the Court will decide whether to issue the enforcement order or refuse the application.

2.4 RESOURCE CONSENTS

In accordance with section 15 of the RMA, any person may make an application to a Regional Council to discharge an odorous contaminant into the environment Section 88(4) of the RMA sets out the procedure for making a resource consent application and, in particular, refers to the type and level of information required by a local authority. Some issues associated with resource consent application and processing are discussed below.

2.4.1 Resource Consent Process

A Regional Council, on receipt of a resource consent application will determine whether further information is required to assess the application. If the Regional Council determines that further information is required, the resource consent application and timetable is effectively put on hold until the Council receives the additional information.

Once the Council is satisfied that adequate information has been provided, the RMA specifies timeframes within which applications are to be processed. As the initial step, the Council will determine whether the application can be considered on a non-notified basis or whether it must be publicly notified. There is often a strong desire by industry for applications to be dealt with on a non-notified basis, as the level of public involvement is minimal and the consent process shorter. However in order for applications to be considered on this basis, the application must satisfy the stringent tests of section 94 of the RMA. In particular the Regional Council must be satisfied that:

- the adverse effects on the environment are minor; and
- written approval has been obtained from every person whom, in the opinion of the consent authority, may be adversely affected by the granting of the consent unless, in the authority's opinion, it is unreasonable in the circumstances to require the obtaining of every such approval.

In the case of odour it is often difficult to identify those parties who may be adversely affected, and applications are likely to be publicly notified.

If a resource consent is to be publicly notified, and once all requests for information have been received, a regional council will serve, within 10 working days, a notice of the application on every person or organisation who is considered to be an affected party; and place a public notice in the newspaper and affixed to the site. Any person wishing to make a submission, in support of or in opposition to the proposal, may do so within 20 working days of the public notification.

Unless submitters concerns are satisfied or they do not wish to be heard, a hearing will be held. In some cases, where a proposal requires a number of different consents, the consent authorities involved may decide to hear all of the applications together. In any case, the hearing shall be scheduled no more than 25 working days after the closing date for submissions.

Notwithstanding these time limits, the Council can, pursuant to section 37, extend these, provided that the overall time-frame is not more than doubled.

The consent authority in determining the resource consent application shall, subject to Part II of the RMA, have regard to those matters outlined in section 104, and in particular section 104(3), which requires:

> *"(3) Where an application for a discharge permit to do something that would otherwise contravene section 15 (relating to discharge of contaminants), the consent authority shall, in having regard to the actual and potential effects on the environment of allowing the activity, have regard to-*

(a) the nature of the discharge and the sensitivity of the proposed receiving environment to adverse effects and the applicant's reason for making the proposed choice; and
(b) any possible alternative method of discharge, including discharge into another receiving environment."

The consent authority may grant a resource consent provided it meets the criteria specified in section 105 of the RMA. The consent authority also has the ability to place conditions on any consent granted, in accordance with section 108.

In any event, section 123 of the RMA allows a consent authority to limit the duration of a resource consent for a period specified in the consent and not exceeding 35 years from the date of granting.

A decision on the application must be released within 15 working days of the conclusion of the hearing.

Following receipt of the decision, the applicant, or any party who made submissions on the application, may appeal to the Environment Court in accordance with section 121 of the RMA, in regard to the decision or any part of the decision.

2.4.2 Assessment of Environmental Effects

All resource consent applications must be accompanied by an Assessment of the Environmental Effects (AEE) of the proposed activity. An AEE sets out to describe the proposal, the actual and potential effects on the environment, and the proposed mitigation measures. A resource consent application for odorous discharges must also describe the nature of the proposed discharge and address the sensitivity of the receiving environment. The assessment should also describe any other possible alternative methods or places of discharge, and measures to be taken to reduce the offensiveness of the odour.

The Fourth Schedule to the RMA sets out the criteria an AEE should satisfy. An AEE accompanying an application for a resource consent must include the following.

(a) A description of the proposal.

(b) Where it is likely that an activity will result in any significant adverse effect on the environment, a description of any possible alternative locations or methods for undertaking the activity.

(c) An assessment of the actual or potential effect on the environment of the proposed activity.

(d) Where the activity includes the use of hazardous substances and installations, an assessment of any risks to the environment which are likely to arise from such use.

(e) Where the activity includes the discharge of any contaminant, a description of:
   (i) the nature of the discharge and the sensitivity of the proposed receiving environment to adverse effects; and
   (ii) any possible alternative methods of discharge, including discharge into any other receiving environment.

(f) A description of the mitigation measures (safeguards and contingency plans where relevant) to be undertaken to help prevent or reduce the actual or potential effect.

(g) An identification of those persons interested in or affected by the proposal, the consultation undertaken, and any response to the views of those consulted.

(h) Where the scale or significance of the activity's effect are such that monitoring is required, a description of how, once the proposal is approved, effects will be monitored and by whom.

Subject to the provisions of any policy statement or plan, any person preparing an assessment of the effects on the environment should consider the following matters.

(a) Any effect on those in the neighbourhood and, where relevant, the wider community including any socio-economic and cultural effects.

(b) Any physical effect on the locality, including any landscape and visual effects.

(c) Any effect on ecosystems, including effects on plants or animals and any physical disturbance of habitats in the vicinity.

(d) Any effect on natural and physical resources having aesthetic, recreational, scientific, historical, spiritual, or cultural, or other special value for present or future generations.

(e) Any discharge of contaminants into the environment, including any unreasonable emission of noise and options for the treatment and disposal of contaminants.

(f) Any risk to the neighbourhood, the wider community, or the environment through natural hazards or the use of hazardous substances or hazardous installations.

The extent to which these matters need to be addressed will depend on the nature and scale of the activity. Within their Plans, regional councils will specify the information required to accompany the AEE, and can provide further advice on consent application requirements.

2.4.3 Consultation

Consultation is an integral part of the resource consent process. The AEE must record the consultation undertaken and the views of the parties consulted. While the RMA places some emphasis on consultation, it does not provide any guidance as to how to consult and what constitutes effective consultation.

However, the established case law has built up a good picture of effective consultation and how it should be undertaken. The most significant judgment on consultation (Wellington International Airport Ltd v Air NZ [1991] 1 NCCR 671 (Court of Appeal)) summarised what the Court viewed as the key elements of consultation in the RMA context.

These key elements were summarised as including, but not being limited to:

(a) the statement of a proposal not yet decided upon;

(b) listening to what others have to say and considering their responses;

(c) allowing sufficient time and making a genuine effort to listen to what others have to say and take their views into account;

(d) providing enough information for the participants to be adequately informed and to be able to make intelligent and useful responses;

(e) creating an intermediate situation involving meaningful discussion. Meetings being held by the party obliged to consult;

(f) relevant and further information being provided on request;

(g) allowing those consulted to clearly have their say before a decision is made.

Effective consultation can result in significant benefits to the parties involved including time savings and the development of strong relationships and trust between the parties, and in some circumstances cost savings.

Once an application has been submitted to a consent authority, the authority will then determine whether or not the application will be publicly notified, and from there whether a hearing will be required. If the consultation has been effective and the concerns of the consulted parties addressed, a hearing may not be required and considerable time savings achieved.

The RMA places particular emphasis on consultation with tangata whenua. In many cases, in addition to holding the same environmental concerns as the wider community, cultural and spiritual considerations will also be relevant. Given this, and the requirement of section 8 (which requires that the principles of the Treaty of Waitangi are taken into account), consultation with tangata whenua is an important consideration. Tangata whenua should be consulted when they are likely to be affected, whether directly or indirectly. The process may take place to provide and share information, identify tangata whenua concerns, and determine appropriate outcomes.

The nature of the consultation process and the most appropriate forum for discussions should be determined by those involved. It may be appropriate to take specialist advice on matters relating to tangata whenua. In any case, enough information should be provided to enable tangata whenua to participate fully and to make informed comments and decisions.

2.4.4 Resource Consent Conditions

Conditions that can be Imposed on a Consent (section 108)

Section 108 of the RMA '*Conditions of resource consents*', sets out the types of conditions which may be imposed on a resource consent and provides local authorities with the power to impose conditions that the consent authority considers appropriate. Conditions may be placed on a consent that:

- set discharge limits, either in respect of quantities of a contaminant that may be emitted or the effects authorised;
- require monitoring;
- require reporting to the consent authority.

In addition, conditions may also be imposed which include financial contributions, performance bonds, covenants and administrative charges. Conditions requiring the adoption of the Best Practicable Option (BPO) can be applied to resource consents and can require the holder of a resource consent to adopt the best practicable option to remove or reduce any adverse effect of the discharge on the environment. However, BPO conditions can only be applied in certain cases and are limited by section 70(2) of the RMA, as discussed in Chapter 2.3.4.

Request for a Change or Cancellation of Conditions of Consent by the Consent Holder (section 127)

Section 127 of the RMA allows for the consent holder to apply to the local authority to change or cancel a condition of consent provided that it meets the requirements set out in that section, unless the consent specifies that the consent holder may apply to change consent conditions and at what timeframes. Section 127 can only be utilised if it can be established that a “change in circumstances” has caused the condition to become inappropriate or unnecessary. The “change in circumstances” test has a very high threshold and should not be relied upon by the consent holder.

Review of Conditions of Consent by a Consent Authority (section 128)

It has been recognised that, from time to time, it may be necessary for a consent authority to revisit previously granted consent applications and review any conditions attached to it. Parliament has provided for this by way of section 128 of the RMA, the provisions of which ensure that conditions do not become out-dated, irrelevant or inadequate, whilst still allowing long term consents to be granted.

Monitoring Programmes

Monitoring is an essential part of the RMA regime for managing effects on the environment. Monitoring is necessary to determine the following:

- the ambient conditions of air to document the existing situation, to establish baseline values, and to use as a basis to measure the effects of activities;
- to ensure that the quality of the discharge is appropriate and that, in particular, resource consent conditions are being complied with;
- to ensure that levels of effects on the receiving environment are quantified and as expected from the consent process, and to monitor trends in the environment that may relate to the discharge.

2.5 REGULATORS VIEW OF THE RMA

2.5.1 The Resource Consent (Air Discharge Permit) Process

The resource consent process under the RMA can appear daunting to an applicant. However, many of the problems experienced by applicants can be avoided by approaching the consent authority well before the application is submitted and by obtaining appropriate technical advice from those experienced in this field. For new or proposed processes, early contact with consent authorities is essential to determine if a consent is required and, if so, what is the nature of the consent(s).

Any consent applicant is required to prepare an assessment of effects on the environment in accordance with the fourth schedule of the Act. This is discussed in Chapter 2.4.2. In addition, individual consent authorities will have specific requirements which should be discussed before the work commences on preparing the application, in particular the assessment of effects on the environment. If the application does not fully explain the process and its likely effects on the environment, a consent authority may request further information under section 92 of the Act. Such a request effectively suspends the time frames for consent processing provided for in the Act until the information is received. This can result in frustrating delays and additional costs for the applicant, delays which can largely be avoided through prior consultation with the regional council and obtaining appropriate advice on meeting the regional council requirements.

Once an application is made, the consent authority will evaluate the application to ensure that it is complete and meets the information requirements of Section 88, the Fourth Schedule of the RMA, and the relevant regional plan. If the application is for an existing activity, it is important to provide complete information on all potential emission sources and an evaluation of their likely effects. This is the area that will be subject to the greatest scrutiny by the consent authority and it is important that such an evaluation be done in accordance with commonly accepted standard procedures.

Most evaluations of actual or potential effects on the environment take measured emission data and predict likely maximum downwind concentrations using atmospheric dispersion modelling. This technique is described in Chapter 4 of this manual. Until very recently, techniques for determination of odour emission rates were not well developed and subject to considerable uncertainty. This meant that the model predictions were subject to considerable error and could not be applied with sufficient confidence to determine if the proposed activity would meet the requirements of the Act and any regional plan.

One technique to overcome the difficulties of measurement of odour is to use a single odorous chemical as an indicator of odour emissions (see Chapter 1.2.3 for more detail). For wastewater treatment processes, the most common indicator is hydrogen sulphide (H_2S), as it is relatively easy to measure and has a very low and well defined odour threshold. Unfortunately, experience has shown that the correlation between odour emission rates (as measured by dynamic dilution olfactometry) and H_2S emission rates can be very poor. This is in spite of H_2S being the predominant odorous species present. The reason for this is that odours from wastewater activities are very complex mixtures of a wide range of compounds. It is the mixture of chemical species that results in perception of odours and this is poorly represented by individual components of that mixture.
The recent development of more rigorous odour measurement techniques, odour modelling techniques and odour standards has meant that evaluations of wastewater treatment activities can now be carried out with far greater confidence. As more odour emission data of the components of treatment plants becomes available, it is also possible to predict the likely effects of proposed plants or plant upgrades using the same techniques.

In the past, consent authorities tended to rely on application of the best available control technology as the best approach to potential odour sources. Often this would be based on empirical results and experience elsewhere, and could result in costly mistakes through incorrect or inappropriate application of odour control techniques. However, it must be acknowledged that many odour control technologies are now well developed and, if correctly designed, installed and operated, will give reliable performance.

However, of equal importance is that the process operation and management minimises the generation of odour in the first place. There are two types of odour control techniques: control of odour through appropriate control equipment, and minimisation of the generation of odour through process management and operation. Attaining a satisfactory odour performance usually depends on a combination of both. Therefore, the consent authority will be interested in the procedures for ensuring the operation and management of the process is to a high standard. In particular, the likely causes, effects and methods of mitigation of process upsets need to be specified. This is best done through management plans that can be included in the consent application and even may be required as conditions of the consent.

Where there is a history of complaints associated with an activity, it is likely that the consent authority will require the circumstances causing the complaints to be addressed. As a result the consent authority, in granting consent, may impose particular conditions requiring modification to the structures and operation of the plant, mitigation and/or monitoring to reduce the risk of the offending circumstances occurring again.

Another key consideration in assessing potentially odorous activities is the location and the sensitivity of the surrounding receiving environment. Obviously, an activity adjacent to or surrounded by sensitive activities (eg, residential areas) is going to be subject to more stringent requirements than an activity in a non-sensitive location. Provision of adequate buffer zones may be desirable but, if this approach is adopted, the buffer zones need to be secured against future development. Frequently, wastewater treatment plants are constructed in greenfields areas but eventually experience problems due to encroachment of sensitive land uses. This is particularly the case in large urban areas where there is considerable pressure to allow development. Buffer zones are discussed in greater detail in Chapter 5.2.

Finally, the RMA regime requires a far greater level of consultation both before and during the consent process. Good RMA practice requires a far greater level of consultation than the CAA, both before and during the resource consent process. As one of the tests for determining whether to publicly notify a resource consent application, the council is required to assess whether the written approval has been obtained of every person considered by the council to be adversely affected. The council is also required to consider public submissions that may have arisen from the notification process, when hearing and evaluating the application.

Many applicants view the consultation process with considerable concern, preferring to deal primarily with the consent authority. However, consultation, if carried out well, can be a positive experience and may result in fewer submissions once the application has been notified. It is far better to address the concerns of those potentially affected by the application through the application than through the hearing process. Also, consultation can reduce the likelihood of the regional council's decision being appealed.

In summary, the consent authority in considering an application must consider (among other things): the actual and potential effects of the activity; the submissions received (if any); the matters contained within Part II (Purposes and Principles) of the RMA; and the objectives and policies of a plan or proposed plan. Activities that are likely to generate adverse effects will be required to demonstrate how those effects can be avoided, remedied or mitigated, in order to minimise the seventy of the effects on the environment, consistent with the promotion of sustainable management.

2.5.2 Monitoring, Enforcement and Standards

Monitoring the environmental performance of activities with the potential to generate odour can be a complex task. Often odour is generated from large diffuse sources that are not readily contained and require technically difficult sampling methodologies. The use of numerical modelling standards or maximum design ground level concentrations for odour are discussed in detail in Chapter 4. These are primarily evaluation tools. It is possible to set emission limits based on odour emission rates and dispersion modelling.

However, measuring compliance with such conditions, in particular from large area sources, is not straightforward and can be subject to considerable uncertainty. Also, modelling is a statistical exercise and, while being of considerable assistance in evaluating the likely effects of an activity, does not provide a guarantee that specified odour emission rates will not result in the occurrence of offensive odour downwind. For these reasons, emission limits based on odour emission rates are rarely used as compliance tools.

Other tools that may be used include community odour surveys, and odour diaries, although these tend not be implemented unless there is a history of odour complaints. Probably the most widespread tool for determining performance against odour standards is an officer of the consent authority actually experiencing any odours beyond the boundary of the premises.

Ultimately, the regulatory authority is dependent on complaints from the surrounding public to determine if the process is causing adverse effects. Because of the nature of odour, it is very important that an officer of the council attends the complaint as soon as possible. Most councils operate a 24 hour call out service for this reason. Thus the regulatory authority is able to satisfy itself that the complaint is valid and determine the source of the discharge responsible for the complaint. Council officers often have considerable experience with industrial and waste management activities and are able to discriminate between industries and sources within an individual industry.

Community liaison groups are another useful tool in determining if odour complaints are valid and for monitoring the on-going performance of a process. This establishes a formal process for dialogue to occur between the consent holder, the regulatory authority and the surrounding community. The presence of such a group may assist in preventing problems about which the consent holder is unaware from resulting in widespread complaint. However, there needs to be a commitment to such a process from all parties if it is to be successful.

The adoption of a "technical odour standard", presumably meaning a numerical standard of quality of the receiving environment, is often mooted as an appropriate measure of compliance for odour. However, the human nose is more sensitive than most measuring devices, particularly when presented with a complex mixture of contaminants. Most olfactory-based techniques are not sufficiently certain below 20 odour units to be used for enforcement purposes. However, ambient odours are clearly discernible down to about 5 odour units (or less). As discussed above, selection of individual indicator compounds does not provide a good measure of the likely perception of odour and can be very misleading.

Because of the subjective nature of odour, a more appropriate approach is to adopt a narrative standard for odour based on its "noxious, offensive or objectionable" properties. It is these that ultimately will determine the acceptability or otherwise of any odours that arise from a WWTP's operations, and the so-called FIDO factors (Chapter 1.1.5) will provide the basis of that assessment. As discussed in Chapter 2.3.3, many regional councils have adopted a narrative condition of consent for odorous, or potentially odorous activities. This standard will provide the "bottom-line" standard the operation in question must comply with. The standard is typically expressed in the following form;

> *That beyond the boundary of the Consent Holder's site, there shall be no odour caused by discharges from the site which, [in the opinion of an enforcement officer], is noxious, offensive or objectionable.*

In addition to this type of condition, many consents will include conditions relating to the management, operation and performance of individual process units and the plant as a whole. Recording and monitoring performance of the plant against these conditions will be an essential part of the evaluation and review process.

As with most activities that have the potential to cause nuisance, the acceptability or otherwise of any odour will ultimately depend on a value judgment rather than any specified technical standard. It could be argued that this does not provide any person undertaking an activity with sufficient certainty with regard to compliance and it is common for industry groups to object to such a condition. Often the main concern is that the activity in question could be either victimised through vexatious complaints or subject to pressures for other reasons. However, it should be noted that the Environment Court applies the test of what is objectionable to the average "reasonable" person.

To overcome this problem, it is useful to develop a protocol between the consent holder, the community and the consent authority setting out the procedures to be followed in determining the validity or otherwise of any complaint. This means that the consent holder can be assured that there will be a degree of objectivity and transparency in the consent authority's response to an odour complaint. An example of such a protocol is given in Chapter 2.6.1.

2.6 SUCCESSFUL CONSENT ACQUISITION

2.6.1 Case Study Examples

Outlined on the following pages are two case studies involving the successful acquisition of resource consents for odorous discharges to air. The outcomes of these two case studies and the experience gained provide some guidance as to the key elements of successful consent acquisition.

Watercare Wastewater Treatment Plant

CASE STUDY SUMMARY	
Location	Watercare WWTP, Mangere, Auckland
Subject	Resource Consenting – Discharges to Air from a WWTP
Application	Response to Enforcement Orders, AEEs, mitigation of existing effects, consent applications
Last Updated	January 1999
Further information contact	Phil Mitchell, Mitchell Partnerships Ltd Tracy Freeman, Beca Steven

Background

In 1996 Watercare Services Limited applied to the Auckland Regional Council for consent to discharge contaminants to air from its wastewater treatment plant at Island Road, Mangere.

The existing site had a history of odour nuisance. An odour control improvement process (OCI) commenced at the plant in 1993, as a consequence of an Enforcement Order and also as a result of the need to upgrade the facility. Following the Enforcement Order, considerable work was undertaken at the site to reduce the effects of odour. This involved improving the performance of several unit processes whilst also committing to a complete redesign of the plant. Integral to the process was the decision to decommission the extensive oxidation ponds, sludge lagoons and sludge drying beds. All of these, but especially the oxidation ponds, are significant sources of odour when unfavourable meteorological and/or process conditions prevail.

Odour Research

To determine the most appropriate mitigation measures and issues to be considered in the upgrade/replacement of the existing plant, considerable research was undertaken on the odour discharged from the site and the thresholds appropriate for continued operation of the plant. As a result, appropriate odour standards and buffer zones were decided upon.

In this case, dynamic dilution olfactometry was used to characterise odour sources and their odour thresholds. Having established this, dispersion modelling was used to assess compliance with the agreed odour standard, that being that there should be no offensive or objectionable odours beyond the odour boundary of the site (the “odour boundary” being an area enclosing the WWTP site plus land adjacent to the site designated as an odour buffer area).

Consent Conditions

The air discharge resource consent was granted by Auckland Regional Council in November 1996 and, after some amendments by the Environment Court, became operative in December 1997. A significant amendment that arose from the appeal was the removal of the assessment criteria "in the opinion of an enforcement officer" and the addition of protocols for determining consent compliance.

After the initial granting of the consent, the key condition for odour effects was:

> *“15. … there shall be no odour beyond the area designated as the "Odour Boundary" caused by discharges from activities undertaken on the site which, in the opinion of an enforcement officer, is noxious, offensive or objectionable.”*

This was replaced in the final determination of consent conditions by the following:

"15. … there shall be no odour which is noxious, offensive or objectionable beyond the area designated as the "Odour Boundary", caused by discharges from activities undertaken on the site.

Without limiting this condition or the methods and procedures that may be used to demonstrate non-compliance with this condition, the methods described in the protocol set out in Appendix 1 to this consent, may be used to determine whether any breach of this condition has occurred.

The Consent Holder shall do all things necessary to ensure that it complies with the procedures set out in the protocol."

The protocol referred to as Appendix 1 in the ultimate consent condition wording outlines procedures to be adopted in the event of a complaint about odour, dust and visible discharges being received by Watercare Services Ltd, the Auckland Regional Council, Manukau City Council, or the Neighbourhood Liaison Sub-group. The protocol was developed to provide for a consistent and objective approach to evaluating the adverse effects arising out of odour, dust and visible discharges from the Mangere WWTP.

The protocol itself is lengthy and detailed, and has not been reproduced in this manual. For a copy of the protocol, interested parties should contact Watercare Services Ltd or the Auckland Regional Council.

Tasman Pulp and Paper Mill

CASE STUDY SUMMARY	
Location	Tasman Pulp and Paper Mill, Kawerau
Subject	Resource Consenting – Discharges to Air from an industry
Application	AEEs, consultation, mitigation of existing effects, consent applications
Last Updated	April 1998
Further information contact	Phil Mitchell, Mitchell Partnerships Ltd

Tasman Pulp & Paper Co Ltd ("Tasman") obtained an air discharge resource consent under the provisions of the RMA in 1994. This consent provided for a review of compliance limits during 1997, and for the resource consent to finally expire in 2001. Details of the current consent, and in particular the results of the now completed 1997 review are set out below, followed by an initial assessment of possible future standards.

The original consent application attracted widespread opposition and in excess of 150 submissions in opposition were received. The hearing that was held before the Bay of Plenty Regional Council ("Environment BOP") was protracted and extremely confrontational. Nevertheless a resource consent was granted and this was not appealed by any of the parties.

A feature of the consent was that in addition to setting a range of emission limits for the various stacks, it required Tasman to undertake a variety of tasks/assessments, pending a review of conditions in 1997. These tasks included:

- install continuous Total Reduced Sulphur (TRS) monitors on various emission sources; assess and implementation of foul condensate stripping; assess the significance of Radon 222 in the geothermal stack;
- monitor the constituents in the foam from the effluent treatment ponds, and measure the trace element concentrations of soil and vegetation in the wider environment;

- undertake stack gas quality measurements, a programme of ambient TRS and particulate matter monitoring, and a detailed meteorological survey;
- undertake a detailed odour assessment that correlated TRS concentrations with resultant odour;
- assess all the above information, in combination with an evaluation of available odour reduction technologies.

The above assessments, and in particular the evaluations of meteorology, odour effects, and emission reduction options, were rigorous, and of a complexity not before undertaken in New Zealand or possibly internationally.

The assessments were undertaken with a close degree of co-operation between Tasman and Environment BOP and the end result was one of consensus between those parties. Although all the original submitters were contacted personally, and invited to make submissions in the review process, only three submissions were received. These were of little consequence and none of the submitters wished to be heard at a hearing. T hus, in contrast to the original hearing, the review hearing was informal, and resulted in the elected Councillors accepting, without substantive debate, the above-mentioned consensus.

The key outcomes of the review were to:

- update the original odour assessments by 31 March 2000 in preparation for subsequent resource consent applications;
- update the assessment of emission reduction options by 31 March 2000, and in particular include a detailed assessment of an approximately 150 metre tall stack option, which would discharge odorous emissions from significant odour sources above the inversion layer. The identification of odour sources which were feasible for connection to a tall stack was to be part of this assessment;
- reduce emission limits on existing plant to reflect their current performance improvements, which resulted from either an improved emission database or from improvements in operational performance.

As a result of the 1997 review of the air discharge resource consent, there appears to be a general acceptance by Environment BOP that:

- the current plant is achieving close to optimal performance in respect of emissions to air;
- the plant will never be "odour free";
- replacing the existing treatment machinery with technological improvements will improve the situation, but only to a relatively modest extent;
- the greatest potential for reducing the effects of odour may be to install a tall stack, thereby discharging above the inversion layer;
- a recognition that the costs would be high and the benefits questionable.

A particular feature of this process has been the substantial reduction in odour effects, together with a substantial reduction in community involvement (through submissions) in the statutory process.

Summary of Case Studies - Lessons Learned

A number of lessons have been learnt in the development and assessment of the resource consent applications described in the section above. The research effort has been exceptionally large and provides a sound technical basis for further research and development.

Given the research undertaken for the above and other similar studies, and the level of information and understanding developed, any further research for a project of a similar scale should build on the knowledge gained from the previous examples, rather than revisit the technical and process advances already obtained.

The key conclusions to be drawn from these and other case studies are as follows.

- Work alongside Regional Council staff and community interest groups in developing research protocols, identifying key issues and information requirements, and exploring mitigation options. Approach these parties at the beginning of the development process and prior to completing an AEE or lodging a resource consent application.

- It is essential that a resource consent application contains high quality information regarding all aspects of the proposed development. The consent authority has the ability within the RMA to request further information (section 92) relating to the application, and will do so if they consider the information received to be insufficient for them to adequately assess the proposal. If the proposal is complex in nature, it may be appropriate to obtain specialist advice in relation to resource management issues or technical matters before lodging the consent application.

- Because odour assessment is subjective, at least in part, community participation in developing thresholds and mitigation options is important. Community participation can have a pivotal role in ensuring that both the company and consent authority are aware of any odour problems, and the appropriate investigations are initiated.

- Review conditions are an appropriate mechanism for allowing consent conditions to be reassessed, while providing for longer term consents.

- A consent holder should seek explicit conditions allowing it to utilise section 127 to change the conditions, in order to not have to rely on the “change in circumstances” test.

- One of the most difficult aspects of assessing resource consent applications for odorous activities is determining the likely acceptability of any residual odours from the activity. Offensiveness is primarily a matter of perception, and it is important to remember the test under the RMA is not merely whether the odour is “noxious, dangerous, offensive or objectionable”, but whether odour effects can be “avoided, remedied or mitigated”. It is important to remember that odour effects are a subjective response, and that determination of the acceptability, or otherwise, of an odour will rely on subjective data to a large extent.

- The RMA does not require that activities do not have any adverse effects on the environment. In some circumstances it may be appropriate to allow an activity to occur provided that the effects are avoided, remedied or, where appropriate, mitigated, depending on the circumstances of the activity. Judge Kenderdine in Trio Holdings and Treble Tree v Marlborough District Council W103A/96 supports this view, in discussing 'mitigation' she comments:

  “The idea of 'mitigation' is to lessen the severity of effects. We have concluded that the inclusion of the word [mitigation] in s5(2)(c) of the Act contemplates that some adverse effects from developments may be acceptable, no matter what attributes the site might have. To what extent the adverse effects are acceptable is, however, a question of fact and degree.”

- It is likely that, in many circumstances, the investigations of the opportunities for remedying odorous discharges from existing plants and avoiding odorous discharges from proposed plants will be more appropriate than mitigation, which involves the enhancement of conditions in other areas.

2.6.2 Key Elements of Successful Consent Acquisition

Based on a large number of case studies, and the preparation of resource consent applications for other significant resource users, the key elements of successful consent acquisition require an applicant to:

- identify all of the relevant resource management issues;
- manage the resource consent process;
- ensure community perception of the potential odour effects is accurate;
- ensure that the resource consent application contains high quality information regarding all aspects of the proposed discharges;
- consider the potential odour effects and the use of buffer zones in the site selection process;
- continually undertake technological research, assessments of current performance, and plant enhancements that seek to reduce the adverse effects of discharges to the environment;
- investigate the potential for avoiding, remedying and where possible mitigating adverse effects on the environment;
- be clear as to what is necessary and achievable, and recognise community affordability;
- identify all of the potentially interested or affected parties;
- consult with all potentially interested and affected parties, including tangata whenua;
- obtain specialist advice on tangata whenua consultation;
- provide all of the consulted parties with a clear description of the project, the potential environmental effects, the proposed consultation programme and mitigation options;
- invite consulted parties to respond and provide feedback on the project, the potential environmental effects, the proposed mitigation and consultation programme;
- address the issues raised by the consulted parties and keep them informed of progress as the project evolves;
- consider the potential monitoring methods and address these in the resource consent application;
- Prepare draft consent conditions for council consideration.

In addition to the above, consideration of the following initiatives will also provide resource users with some pro-active involvement in the development of odour policy and the resource consent acquisition process:

- anticipate potential issues and address these before they arise;
- develop industry-specific codes of practice;
- participate in district and regional plan preparation processes;
- undertake ongoing evaluation of potential process modifications and technological change and the application of these to wastewater odour management;
- monitor resource consent conditions, record the results and use these to develop a clear understanding of the environmental effects of industry.

2.7 CHAPTER 2 REFERENCES

Auckland Regional Council Officers Report: 1996: "Application Number 9610850 by Watercare Services Limited for consent to discharge contaminants to air at Island Road, Mangere

Ministry for the Environment; 1994; "Ambient Air Quality Guidelines"; Wellington.

Ministry for the Environment: 1995: "Odour Management Under the Resource Management Act"; Wellington

Taranaki Regional Council; 1997; “Regional Air Quality Plan”.

World Health Organisation, 1987; “Air Quality Guidelines for Europe”

3. OLFACTOMETRY SAMPLING AND ANALYSIS

3.1 TECHNIQUE OF OLFACTOMETRY

3.1.1 Historical Development

The first olfactometer that used the principle of diluting odorous air with non-odorous air was built in the last decade of the 19th century. For nearly a century, olfactometry remained an academic pursuit, with physiologists and psychologists being the main interested parties. From the mid-seventies onwards, however, the techniques were dragged out of their academic realm and into the environmental arena.

A wide variety of techniques have been used. Odour test rooms, where the odour is released into a room of odour free air, and after equilibration people enter the room to determine if they can detect an odour, have been used by several researchers (Whisman *et al*., 1978; Hoshika *et al.*, 1991). Other techniques involve sniffing of an odour within a flask (Smith and Hochstettler, 1969), in the air above a dish containing an odorant in the liquid form, or squeeze bottles partially filled with a liquid odorant (Amoore, 1992).

3.1.2 Dynamic Dilution Olfactometry

The technique most commonly used today is dynamic dilution olfactometry. A sample of odorous gas from a source is collected and taken back to the olfactometer for analysis. The odour sample is diluted with odour free air and is presented to the odour panel (a selected group of people) via one or more sniffing ports.

The odour concentration of the sample is determined by first finding the odour threshold. The odour threshold is found by presenting the panel with a series of dilutions of the odour sample that cover the range from where none of the panel can detect the odour to where all the panel can detect the odour. The odour threshold is the concentration of the sample where 50% of the panel can detect the odour.

The unit of odour concentration is the odour unit (OU). By definition the odour threshold has an odour concentration of one odour unit per cubic metre of air (1 OU/m^3). The odour concentration of a sample is equal to the number of dilutions of the odour sample required to reach the odour threshold. For example, a sample requiring dilution by a factor of 1000 before reaching its odour threshold has an odour concentration of 1000 OU/m^3.

The "recognition threshold" of a substance or odour is also often found in the literature. The recognition threshold is the concentration at which the odour exhibits a recognisable "character", eg, "pig manure", to 50% of the test panel. Recognition thresholds are largely of only academic interest.

Australia/New Zealand Olfactometry Methodology Standard

Standards Australia has published a draft Australian/New Zealand Standard "Air Quality – Determination of odour concentration by dynamic olfactometry", code DR 99306 (July 1999). The Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EV/7, "Methods for Examination of Air". The Standard is based on a CEN (Comité Européen de Normalisation) pre-draft of the same title (CEN, 1995).

The objective of DR 99306 is to provide a method for the determination of the odour concentration of a gaseous sample using dynamic olfactometry with a panel of human assessors being the sensor. The draft Standard can be downloaded from the Standards Australia website, http://www.standards.com.au.

As outlined below, there are two methods for conducting dynamic dilution olfactometry; the Yes/No and Forced Choice methods. DR 99306 applies to both types of response method.

Yes/No Response

In this method each panelist has one sniffing port. When a test is run they must sniff the port and indicate if they can smell an odour. This would normally be done by the panelist pressing a button when they can smell an odour. This technique is the simplest to implement as only one sniffing port and one response button are needed per panelist.

This method was common in the early 1990's but is now being replaced by the more sensitive forced choice response method (see below). The Yes/No method is no longer used commercially in New Zealand but is still used by some Australian laboratories, and is still the regulatory-accepted standard in Victoria and South Australia.

Forced Choice Response

The forced choice technique differs from the simple yes/no technique in that each panelist has two or three sniffing ports. At any one time, one port will contain the diluted odour sample while the other(s) have clean air. The port containing the odour is randomly changed after each presentation. Panelists have no prior knowledge of which port contains the odour and are forced to guess if they cannot detect an odour from either port.

When indicating their choice of port the panelists also indicate if they were 'guessing', 'uncertain' or 'certain' about their choice. From these responses it is possible to arrive at two endpoints. The first is where the panelist is constantly correct in their choice of port without reference to guessing or certainty. This is often reported as simply the 'detection threshold' and is given the units OU_d/m^3. The second is where the panelist is constantly correct in their choice of port but is also certain about the choice. This is often reported as the 'certainty threshold' and can be given the units OU_c/m^3, although since the use of the certainty threshold is becoming standard practice, the subscript is usually dropped so the units are OU/m^3. The latter convention will be used throughout this manual. In theory, odour concentrations calculated using certainty thresholds are one half to one third of that calculated using detection thresholds, although in practice this ratio can be much greater. DR 99306 has standardised on the use of certainty thresholds.

Studies have demonstrated that in order to achieve improved repeatability and reproducibility (see Chapter 3.3.1), panel selection is an essential element. Prospective panelists are screened by testing their response to a reference gas, n-butanol. Panelist screening eliminates candidates with a very sensitive or insensitive sense of smell. Panelists are also screened in the same way every day before olfactometry testing begins. Those with unacceptable sensitivity on that particular day (eg, they may have had a cold which can affect nasal sensor response) are not allowed to take part on that day, or their responses are excluded from the calculations of odour concentration. In using a panel selection method based on a reference gas, it is necessary to abandon the notion that the panel reflects the sensory characteristic of the entire population (van Harrevald, 1994). Instead the panel is designed to be a reliable “composite sensor” representing an “average nose”.

Forced choice response is the most common technique used worldwide. Both commercial laboratories in New Zealand use this method (see Chapter 3.4).

3.1.3 Yes/No versus Forced Choice Response

Forced choice has the advantage of being more sensitive because the tendency of people to develop a conservative bias seen with yes/no olfactometry is eliminated. In the yes/no case, panelists, through a fear of giving a false result, are reluctant to indicate 'yes' when they are unsure about the presence of an odour in the port. They tend to wait until they are sure about the presence of an odour before responding positively. When a panelist is forced to give a response they must make their best estimate of which port contains the odour.

In addition, the human nose is more sensitive when able to compare an odorous environment with a non-odorous environment. Hence, forced-choice olfactometry methods will produce lower odour thresholds.

Overall, forced choice technique should give a lower threshold than the yes/no technique (Köster, 1985). However, results obtained using the yes/no technique are thought to be comparable to results using the forced choice, certainty threshold technique, provided that quality control and panel screening procedures are undertaken.

The overall change from yes/no to forced choice response, followed by using certainty thresholds for the forced choice response method, has been driven by the desire to standardise the technique and produce results with a higher degree of accuracy and repeatability.

When utilising odour concentration data published in the literature, or comparing old data (pre-1995) with that collected in recent years, it is essential to take account of the response method used and the data calculation procedures. The key variables are:

- whether or not panelist screening to the standard odorant n-butanol was undertaken;
- Yes/No or Forced Choice response; and
- forced choice response with or without the use of certainty criteria for panel selection and results reporting.

If data has been obtained using a method not utilising any form of panelist screening the results are unlikely to be comparable to more recent measurements.

If panel screening data is available it may be possible to further refine the conversion factor required to convert the data from yes/no response methods, so that it is comparable with that measured today using forced choice response and certainty criterion.

Prior to the publishing of the Draft European CEN Standard in March 1995, most forced choice response olfactometry was conducted without the use of certainty thresholds for panel selection and in reporting the results (see Chapter 3.1.2 for definition of certainty thresholds). Following the standard being published most laboratories have moved to using certainty thresholds.

3.1.4 Major Factors that Influence the Quality and Outcome of Odour Threshold Measurements

In the past years many factors have been discussed that were considered important to the outcome of odour threshold measurements. The major elements that can be distinguished are:

(a) **The sample holder**: usually a bag (of some polymer film) holding the sample. This storage in a bag can cause quite large effects, by absorption or transport of substance through the film.

(b) **The olfactometer**: the name implies that the instrument measures something; in fact it merely dilutes the sample with non-odorous gas.

(c) **The olfactometer/nose interface**: different types of cups and masks are used, each providing a certain way of getting the diluted sample into the nose of the panelist, allowing more or less normal 'sniffing behaviour'. The flow rate of the sample presented through the port is also important.

(d) **The panelists**: the noses of the panelists, collectively, form the sensor for the measurement. The brains of panelists process the stimulus and give a response in the form of yes/no perception or forced-choice results.

(e) **The odour room**: this provides the environment for the measurement, and thus conditions the reference level for the nose of the panelist.

(f) **Data processing method**: the calculation method obviously influences the outcome.

Standard parameters for all these variables are specified in the Standard DR 99306.

3.1.5 Limits of Detection of Olfactometric Measurement

The lower detection limit (LDL) of the odour measurement is the lowest detectable odour concentration that can be determined with 95% statistical confidence. It can be determined by filling an odour sampling bag with neutral gas, leaving the sample for the normal storage time and then analysing the sample using the normal procedure.

When an odour sample is taken by means of stack sampling equipment and pre-dilution equipment, this equipment becomes part of the system to determine the detection limit. In that case the sampling probe is offered neutral gas and the sample container filled with this gas is subsequently analysed for determining the detection limit of the system.

DR 99306 outlines a procedure by which the lower detection limit may be assessed. In practical terms it is often in the range of 10 - 25 OU/m^3, depending on the bag material and sampling apparatus used.

This has important implications in that weak ambient odours which may be capable of causing annoyance are not readily measurable by olfactometry.

3.1.6 Offensiveness Testing - Use and Restrictions

The offensiveness of an odour is a subjective rating of its unpleasantness (often called the "hedonic tone") at a standardised concentration above the threshold that is readily detectable to most people. For example, Lott (1992) reported on results showing that people typically rate odours from a wet feedlot as more offensive than those from a dry feedlot pad, when at the standardised concentration of 10 OU_d/m^3. So, although both these odours can be considered unpleasant, the wet feedlot odour has greater nuisance potential. Put another way, the dry feedlot odours would need to be present at greater concentration to elicit the same offensiveness response as the wet feedlot.

Considerable research has been carried out in Europe over the last 10 years to quantify the quality of an odour and to compare different odorants according to their hedonic tone. The methodology has been refined through experience over this time. In contrast to the similarity of perception of intensity between a variety of people, one finds that in the evaluation of odour offensiveness there are clear differences between test subjects, characterised through odour experiences, upbringing, and socio-economic status (Paduch *et al,* 1995). Therefore, the test population required for offensiveness testing is correspondingly large.

Another example of the use of offensiveness testing is the testing of gases entering and exiting a biofilter. The exit gas from a biofilter can have a measurable odour, typically due to soil and bark type odour picked up by the air during passage through the biofilter media. Therefore, consideration of the hedonic tone is important when interpreting dispersion modelling results, particularly when assessing the effectiveness of odour abatement processes such as biofilters and scrubbers. The quality of an odour is changed by most odour abatement procedures, and the resulting odour can be much more "pleasant" than the original crude gas. Therefore the annoyance potential may be lower than predicted from odour concentration measurements and modelling.

While offensiveness tests give a comparative indication of the relative unpleasantness of various odours, such values cannot be readily be extrapolated into the environment to predicted population annoyance to odours. This is because the laboratory-based offensiveness tests do not consider the frequency, duration and location of odour exposure. In addition, a person in the olfactometer is likely to be more sensitive to odours than in the real environment, as they are concentrating on detecting the odours and are isolated from normal, background household odours. Social surveys (see Chapter 4.1.2 and the case studies in Chapter 7) are a good method of measuring the level of annoyance in a community due to odour exposure.

3.2 METHODS OF SAMPLING

3.2.1 Odour Sampling

Samples are collected into special-purpose plastic bags made of teflon, tedlar, nalophane or mylar to minimise adsorption of the odour on the bag surface. To further minimise this, the bags should be flushed with the odour to be sampled prior to sampling.

The sample bags are usually housed in some form of plastic drum. To draw the sample into the bag the air within the drum is evacuated. This avoids the need to pass the sample through a pump, which may result in the odour being changed as a result of contact with lubricated pump surfaces.

Emission sources are comprised of:

- simple point sources (stacks, ducts)
- area sources with or without a positive gas release
- fugitive sources such as building vents or open doors
- ambient air.

Briefly, sampling methods are described below. Some sampling methods are discussed in DR 99308. However, there is still some debate amongst experts in the odour measurement industry regarding appropriate techniques, especially for sampling area sources. The Clean Air Society of Australia and New Zealand (CASANZ) Odour Special Interest Group is currently working through these issues and hopes to provide some answers in the next couple of years.

Stacks or ducts are easily sampled using a simple sampling probe. If the odours are strong a dynamic pre-dilution probe (see Chapter 3.2.3) may be used. Isokinetic sampling procedures are generally not required for odour sampling.

For area sources, such as sewage ponds with no positive air flow, a sampling hood must be used to collect the odours. Odour free air or nitrogen is introduced into the hood to provide an air flow. This may be conducted statically using a flux dome or dynamically using a flux hood or “wind tunnel”. A sample of the air exiting the dome or hood is collected in the sample bag.

When area sources have a positive outward air flow, such as pre-aeration tanks, biofilters, or force-ventilated compost piles, a simple sampling hood is all that is required to collect the emissions. The hoods are usually tapered arid have a small exit where the emissions escape. The odours are collected from within the hood.

Fugitive sources are any type of odour emission that cannot be readily quantified or defined, and usually refer to such sources as leaks in pipes, flanges, pump seals or structures, openings in buildings, floor spills, occasional sources such as uncovered truck loads or releases from pressure relief valves, and leaks in seals on covered tanks. Depending on type, fugitive odours can be very noticeable close to the source due to highly concentrated odour emissions, but if the rate of discharge is low then the odours will disperse rapidly and not be noticeable by the time the odours have travelled some distance downwind. However. if there are a large number of these sources, then the overall effect on odour discharges from the total site can be quite significant.

Determination of odour emission rates for fugitive sources is often difficult or impossible, and the reasons for needing to quantify the emission rate should be questioned. Fugitive sources can often be removed or reduced by inexpensive maintenance or changes in operating procedures. It may be sufficient to make a subjective judgment as to the significance of the fugitive source, and implement appropriate mitigation procedures without needing to go through the process of dispersion modelling assessment – ie, just “fix the leak”.

In ambient sampling, the sampling bag is simply flushed with the ambient odour, evacuated and then the sample collected. This can only be conducted for moderate to strong ambient odours as a result of the lowest limit of detection (see Chapter 3.1.5).

3.2.2 Information and Assistance often Required from the Site

The sampling team will often need information and/or assistance from the site being tested. Common requirements are detailed below.

Information

- Type and number of sources to be tested
- Sampling locations
- For stacks or ducts the dimensions, temperature and air flow rate
- Details regarding safe access to sampling locations
- Process parameters if applicable

It is preferable that this information be supplied to the testing agency prior to the sampling programme commencing.

Assistance

- Provision of personnel to assist with sampling (optional but reduces sampling cost)
- Access to a boat or punt for sampling effluent ponds
- Cherry picker lift to access stacks or ducts
- Handling of gas cylinders
- Provision of a clean area to store sampling equipment

3.2.3 Sample Pre-Dilution

For strong odour sources, pre-dilution of the odours while sampling, prior to be analysed by the olfactometer, is often necessary. Pre-dilution allows the odours to be on the scale of the olfactometer, makes them easier to analyse, and for moist or hot samples aids to preserve the sample.

Pre-dilution may be conducted statically or dynamically. Static pre-dilution involves pre-filling the sample bag with a known volume of odour free air or nitrogen before sampling the stream of odorous gases. DR 99306 recommends that this technique should not be used when a pre-dilution larger than a factor of nine is required. When sampling in a stack or duct, a dynamic pre-dilution probe may be used. This dynamically mixes a known flow of odour free air or nitrogen with a known flow of the odour being sampled. Pre-dilution factors of 4 to 400 may be achieved using such a probe.

3.2.4 Numbers of Samples

Variable Emission Rates

If a single sample is collected, analysed, and an odour emission rate determined, there can be considerable uncertainty in the result due to typical olfactometry errors, and a lack of confidence in whether this single sample is representative of either the whole source or the worst case emission conditions.

Odour sources will rarely discharge a constant odour emission rate, instead varying with time and also across the surface of sizeable area sources such as oxidation ponds, compost windrows, and landfills. The greater the number of samples collected, the better the confidence in the emission rates. This applies both to repeat measurements on a number of different occasions at the same position on the source, and also to sampling at different locations on the source over a short time period. The former quantifies the variability of the source over time, and the latter quantifies the variability over the surface of the source at a given time. Use of this data to select emission rates for dispersion modelling is discussed in Chapter 4.2.7.

In some circumstances, the necessity for any odour measurement at all must be questioned. If, for example, the main odour problem is known to be from occasional or "upset"' emission rates, is there any need to spend large sums of money quantifying the other odour emissions at the site, particularly if interpretation of odour diaries or complaints indicates that there is no adverse effect from odours under normal operations? Also, for sites with multiple odour sources, can the various sources be prioritised by subjective assessment odour complaint records, or even by initial dispersion modelling with guessed or "borrowed" emission rates before designing odour sampling programmes which target only the major sources?

Replicate Sampling

Replicate samples are useful to improve the accuracy of the olfactometry results. In van Doom and van Harreveld (1994), sampling strategies and statistical aspects for measuring odour emission rates are discussed. The research reported in that paper found that the best compromise between accuracy and expense was achieved when 3-4 replicate samples were collected. It must be stressed that the repeatabilities quoted by the Dutch authors refer to measurements carried out using the reference gas n-butanol. It is widely reported and accepted that the human nose responds better to mixtures of odorant compounds than to pure compounds. For this reason, the repeatability values obtained for results of testing of actual samples tend to be far lower than the values reported for n-butanol. Experience over several years in a large Australian olfactometry laboratory indicates that a repeatability equivalent to ±25% can be expected.

DR 99306 contains guidance on how to calculate the number of samples to be taken within a required precision of the odour concentration.

Odour samples cost approximately $500-$600 per sample in New Zealand, when the cost of collecting the samples is factored in with the costs per sample decreasing as the total number of samples increases, so a compromise between number of samples and cost is always required. For this reason, this Manual will not make any definite recommendations on numbers of replicate samples, as it is recognised that the budget available at an industry for odour measurement needs to be balanced between replicate measurements at one time, and repeated measurements at a number of different times and process conditions. However, some consideration of the likely error in the sampling determinations should be given when using the results in dispersion modelling, and when using the sampling measurements for compliance testing of source odour emission rates.

3.3 MEASUREMENT ACCURACY, REPEATABILITY AND REPRODUCIBILITY

3.3.1 Definitions

To be of use for practical odour management, the technique of olfactometry needs to have a defined accuracy, repeatability and reproducibility of the odour measurement data.

Accuracy is defined as the closeness of agreement between a test result and the accepted reference value of 40 ppb n-butanol.

Repeatability (precision) is the difference between two single measurements performed on the same testing material by the same laboratory under repeatable conditions.

Reproducibility is the difference between two measurements undertaken by different laboratories on the same material using the same method.

3.3.2 Quality Assurance and Quality Control

The terms “quality assurance” and “quality control” are sometimes used synonymously, but have different meanings. Quality assurance can be described as a definitive plan for laboratory operation that specifies the measures used to produce data of known precision and bias. Quality control, on the other hand, can be described as a set of measures within a sample analysis methodology to assure that the process is in control.

A laboratory quality assurance program is the orderly application of the practices necessary to remove, reduce or detect errors that may occur in any laboratory operation. Errors may be caused by personnel, equipment, supplies, sampling procedures, analytical methodology or a combination.

A good quality assurance programme will consist of three factors:

1. methods used will have been studied collaboratively and found acceptable, ie a “Standard Method”;
2. the routine analysis of control samples; and
3. the analysis of reference samples to confirm the ability of a laboratory to produce acceptable results.

The second factor is internal quality control while the third is external quality control or proficiency testing. In olfactometry, a measure of internal quality control is repeatability and a measure of external quality control is reproducibility (see Chapter 3.3.1 for definitions).

The quality of a result is reliant on the method or process as a whole, from the decision of where and when the sample is to be taken, how many samples should be collected, how it is to be collected, what other measurements required, right through to the measurement of a sample and reporting of the final result.

The Standard DR 99306 focuses on the quality requirements for olfactometry methodology and equipment.

3.3.3 Application of Quality Control to Methodology

It is important that a detailed methodology for quality control be available, which can be adhered to by samplers and olfactometer operators. The samplers and olfactometer operators also should be trained to a level where they are fully conversant with the methods to be used and areas which need special attention, as this will help ensure quality results.

Methodology should cover the areas of procedures relating to sampling, the operation of the olfactometer, odour assessors (panelists), and quality control samples.

Sampling

Sampling is critical if quality results are to be gained. If a quality sample is not gained then a quality result can never be determined, no matter how good the analysis procedures are. Some of the steps which help to ensure a quality sample is collected, that should be present in the sampling procedures, are:

- sound methodology for sampling of different sources (eg, point sources, area sources);
- regular calibration of sampling equipment (eg, dilution equipment, metered pumps);
- procedures to ensure the prevention and detection of contamination, which also specify steps to be taken if contamination is detected (this includes the use of materials resistant to odour for sampling, regular cleaning of equipment, avoiding the reuse of sampling equipment to collect other samples before it is cleaned, and checks that the equipment is odour free before use).

Operation

As with most analytical equipment, it is vital that the operator has an in depth knowledge in all aspects of its operation, limitations and methodology to be followed. Procedures relating to the operation of the olfactometer should cover the following areas:

- precise operation details (eg, equipment details, order of analysis of samples, number of panelists, number of presentations of the sample to the panelists);
- calibration, including frequency, accuracy and repeatability;
- maintenance to ensure the dilution gas (air or nitrogen) remains odour free, and checks to ensure the room environment is odour free;
- contamination (eg, steps for detection, repair, and prevention such as the use of odour resistant materials, flushing with odour free air and cleaning of parts with odour free cleaning products);
- measures to prevent bias in the analysis and procedures for detecting sources of bias (eg, physical differences in the gas streams presented to the assessors, such as flow rate, temperature, humidity).

Panelists

A very important part of the analysis is the panelists, who are in fact the detector for the olfactometric analysis. As with detectors on any analytical instrument, it is vital that the accuracy and stability of the detector be known and monitored continually.

Hence, it is important that the methodology include a section dealing with panelists, to cover areas such as:

- screening panelists for accuracy and variability (before a panelist is accepted and routinely whenever the panelist is used);
- code of practice for panelists (eg, not wearing perfume, no discussion of an odour during an assessment);
- number of panelists necessary for a valid measurement;
- duration of session to prevent smell fatigue;
- appropriate working environment, to ensure concentration on the assessment

Quality Control Samples

Measures that should also be covered in the methodology relating to quality control samples and standards include:

- calibrations are carried out using certified reference materials and measures are in place to validate these materials;
- analysis of externally supplied standards/samples as in proficiency testing. In 1997, New Zealand laboratories participated in an interlaboratory trial with laboratories in Australia and Asia;
- analysis of blank samples and control samples;
- analysis of duplicates;
- records of quality control results to assess the validity of related test results.

Finally, it is important that the person who receives the results or is making assessments based on the results, understands the method by which the analysis was carried out, how the results are expressed (eg, the units, and whether it is a detection or certainty threshold) and the degree of confidence that can be placed in the results. Confidence is based on a number of factors such as, that a representative accurate sample or number of samples were collected by suitably qualified personnel, that the sample(s) analysed were representative of those collected, ie did not change between sampling and analysis, and that they were analysed properly (suitably qualified personnel using sound equipment and methodology).

Checks can then be made on the methodology used, and any quality control measures carried out to assure the quality of the results.

3.4 NEW ZEALAND COMMERCIAL OLFACTOMETRY LABORATORIES

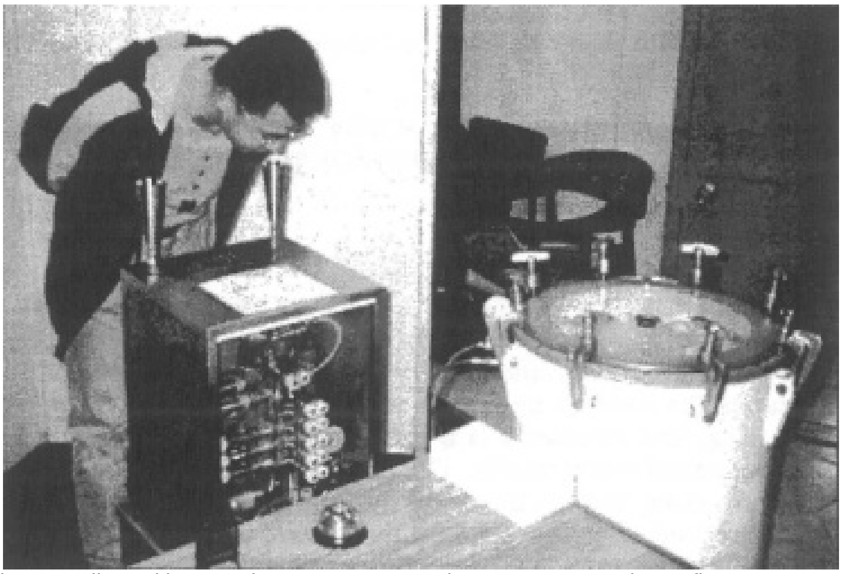
3.4.1 Watercare Services Olfactometry Laboratory

The Watercare Services Olfactometry Laboratory is a purpose-built facility located at Mangere, Auckland. The centre consists of a reception waiting area where panellists/odour assessors acclimatise, a laboratory where all analysis is carried out, and a preparation room where samples and equipment are prepared. The facility was constructed as far as possible with odour free materials. It has a separate air conditioning system specifically designed so as to provide clean odour free air as specified in the Draft European CEN Standard. A constant supply of high quality odourless air is critical in achieving quality results. For this purpose, a special oil-less compressor was imported which, when coupled with a filter, set supplies dry air, free of odour and oil.

The olfactometer used at the centre is a research grade, fully computer controlled Olfactomat® dynamic olfactometer custom built in the Netherlands. Several of these instruments are now in use in the Asia Pacific region. The olfactometer is able to accurately dilute an odorous sample with odour free air within the range of 4 to 60,000 times. Even greater dilutions are achieved by a two-step process using predilution.

Methodology followed at the facility is based on the Draft European CEN Standard and DR 99306 with manuals available for inspection. Odour measurements are generally expressed as a certainty threshold; however the guessing threshold is also readily calculated.

Fully trained staff are available to offer professional services in all aspects of sampling, analysis and advice. Sampling expertise covers all aspects of area and point sources, including aerated tanks, earth filters, compost heaps, stacks, ventilation outlets. The facility has a range of specialised equipment available, including predilution equipment. The assessors are permanent part-time employees who have been fully screened and are routinely monitored.



Odour panelist making an odour assessment at the Watercare Services Oflactometry Centre

Out of town samples are routinely handled and the facility has received samples from as far away as Wellington and Christchurch. Generally, samples are collected late in the afternoon and couriered overnight by road or air for receipt and analysis the next day. The centre recommends that samples be tested as soon as possible after sampling but no longer than 30 hours after sampling. Full on-site sampling by a member of staff is available or, for clients that have the expertise to collect samples, we are able to supply sampling equipment.

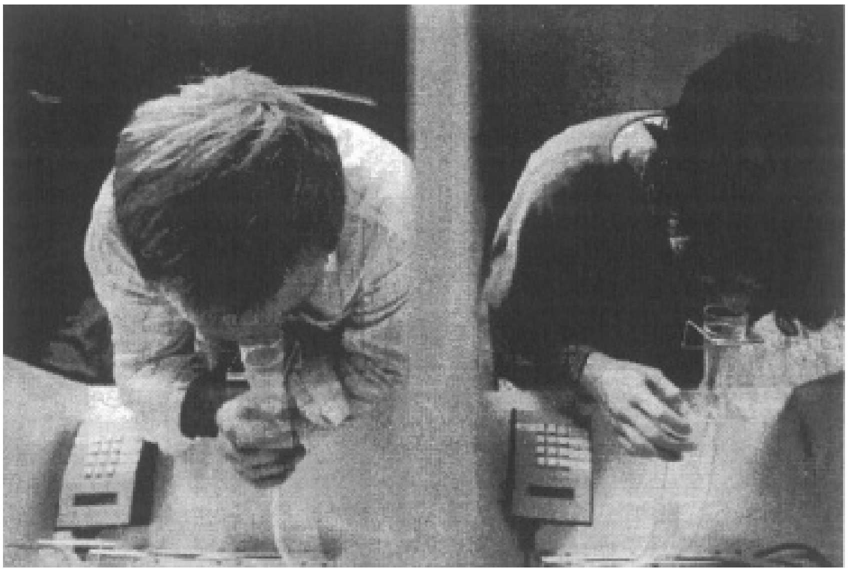
The centre caters for a range of clients with a variety with needs, from clients who may require one or two samples tested, to clients with programmes consisting of several hundred samples. The centre normally analyses up to 5 samples per day, but this can be increased to 8 samples by arrangement. A minimum of one week's notice is required by the centre in order to analyse samples so the odour assessors can be rostered for the day. However, with an increasing work load it is recommended that enquiries regarding testing be made as early as possible. Sample collection and other services offered by the unit also require adequate prior notice.

3.4.2 Lincoln Environmental Laboratory

Lincoln Environmental has been conducting commercial odour measurement since 1993 and has undertaken odour measurement projects at a number of WWTPs in the North and South Islands. The olfactometer is a state-of-the-art computerised three port forced choice dynamic dilution olfactometer. The olfactometer utilises eight calibrated odour panellists, who each have their own booth with sniffing ports. Unlike many other olfactometers, this eliminates the need for the panellists to proceed in single file past a single set of ports to assess the odour. As a result, samples may be analysed more rapidly.

The olfactometer is operated according to the Draft European CEN Standard and DR 99306. Odour samples are analysed by two repeat measurements, each involving a presentation series of 5-6 dilutions around the odour threshold. Tests for odour offensiveness, odour character, and performance assessment of emission control equipment can also be carried out. Up to 10 samples may be analysed per day.

The Lincoln Environmental olfactometer is completely self-contained, including air-conditioning and carbon filtered ventilation air. It is a mobile unit that can be transported by road to any location in New Zealand. Lincoln Environmental staff are experienced at collecting samples from a wide variety of odour sources and they are able to respond to requests for collecting odour samples from locations anywhere in New Zealand.



Odour panelists at work at the Lincoln Environmental Olfactometer

Odour samples may be collected by Lincoln Environmental staff or staff from the facility being tested (depending on the complexity of the sampling), and transported to the olfactometer at Lincoln for analysis within 30 hours (the maximum allowable time period according to DR 99306). Lincoln Environmental recommends that samples be tested as soon as possible after sampling but no longer than 30 hours after sampling.

For larger protects, it is often economic to freight the olfactometer to a location close to, but out of the influence of, the source being tested. In this case, panelists are selected from the local community. Similarly, in situations when samples require analysis within short (1-4 hour) time periods because of concern over sample degradation, or when a quick response to analysis results is required, it can be beneficial to locate the olfactometer close to the source being tested.

Over the last five years Lincoln Environmental has tested the odour detection thresholds of staff from WWTPs, district, city and regional councils. A person's sensitivity to odours is measured using Lincoln Environmental’s olfactometer. Having a nose that has been calibrated is becoming increasingly important for council regulatory staff involved in resolving complaints about odours.

3.5 CHAPTER 3 REFERENCES

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4. ODOUR EVALUATION TOOLS AND DISPERSION MODELLING

4.1 WHEN IS DISPERSION MODELLING AN APPROPRIATE TOOL TO USE?

The question of when dispersion modelling is indicated as an appropriate odour assessment tool was addressed in depth in the report "Analysis of Options for Odour Evaluation for Industrial or Trade Processes" prepared by CH2M Beca Ltd for Auckland Regional Council (1999). Some key discussions from this report are reproduced in the remainder of Chapter 4.1 below.

4.1.1 Evaluation versus Compliance

One of the greatest sources of confusion in regulation of air discharges, particularly odour, is the difference between evaluation and compliance. This most commonly arises in the resource consent process where an application is evaluated against appropriate criteria before a decision is made. If the consent is granted, the consent holder is then required to comply with (and be able to demonstrate compliance with) any conditions imposed as part of that consent. These two processes are quite separate and often the evaluation criteria are not the same as the guidelines imposed as conditions of consent.

4.1.2 Types of Application Techniques

Evaluation involves assessing the actual and potential effects of an activity in order to determine whether significant adverse environmental effects will occur. A number of evaluation techniques are available, including (WRC, 1998):

(a) history of complaints regarding the discharge;
(b) experiences of the Regional Council with the discharge;
(c) information from community consultation undertaken by the discharger;
(d) information from odour diaries and/or community surveys undertaken by the discharger;
(e) dynamic dilution olfactometry measurements and dispersion modelling results;
(f) whether the best practicable option (BPO) is being applied for the discharge;
(g) records of emission control improvements undertaken, and those proposed for the future;
(h) past experiences and knowledge of the Regional Council of the odour effects generated from existing sites of a similar nature and scale.

The techniques in this list form a "toolbox" of evaluation criteria at the regulator's disposal. Deciding which of these evaluation techniques is most appropriate will depend on the type of application, and on the particular industry or trade activity and location. Often a number of these techniques will be used in combination. Some comments on each technique are provided below.

(a) Complaints History - Factors Affecting Interpretation

- Complaint fatigue – are the complaints reflective of actual adverse effects or have people stopped complaining due to frustration about lack of action?
- Population density occupying land around the site.
- Local economy – is the activity concerned of major influence on the economy of the area where it is located, and does this affect complaints?
- Prevailing winds/changes – have complaints over a season been affected by unusual prevailing winds rather than activities on the site?
- History of plant activities and changes – how have these affected complaint frequency?

- Distinguish between "acute" and "chronic" effects – have the complaints been caused by normal or upset situations at the site?
- Complaints do not necessarily reflect the extent of adverse effects.

(b) Regional Council Experiences and Information

- This will vary from case to case.

(c) Community Consultation

- Must be genuine, with the community given the opportunity to express concerns.
- Can be difficult if there are many neighbours or potentially affected parties, or if there is tension between the community and the activity.

(d) Community Diaries and Surveys

- Diaries can be useful, especially if the duration is short-term, the events occur (say) early in the morning, or the site is in a location far from an urban base such that an investigating officer cannot verify complaints by a site visit.
- Diaries need discretion in assessment of usefulness, and validation of some entries by confirmed complaints, especially for records of strength and if there are possible background contributions to odour.
- Care is needed to interpret diaries from vindictive or sensitized neighbours that may exaggerate diary entries. Wide verification with a large number of neighbours participating is preferable.
- Surveys can be expensive to do well and in a statistically significant manner.
- Surveys require a large population base, which is often not available
- Both diaries and surveys can be used to develop an odour modelling guideline that is specific to the site, but care is needed in the setup of the model. Genuine odour emission rates are required.
- Participants must be selected to ensure fair coverage of the potentially affected area, and a control group outside of the affected area may be required.

(e) Odour Monitoring and Dispersion Modelling

- This is discussed in detail in Chapters 3, and 4.2-4.4 of this Manual.
- In any modelling exercise, it is very important to understand the applicability of the model to any particular situation and the limitations of modelling. Modelling on its own is not the absolute answer to an assessment of effects, and the errors and limitations in the modelling should not be underestimated. Other tools, such as process design parameters, performance measures and process management requirements, are often used by regulators in conjunction with dispersion modelling, to make sure that the actual and potential adverse effects are sufficiently controlled.

(f) Best Practicable Option

- Will vary from case to case.
- Performance standards can be applied to mitigation equipment, to bridge between evaluation and compliance.

(g) Improvements Undertaken and Proposed

- Will vary from case to case.

(h) Past Experiences and Knowledge of the Regional Council

- Care is needed with importing solutions from other sites.
- For example, with a wastewater treatment plant, each site can be different depending on the quality of the incoming wastewater, the type of liquid and solids handling processes used, operational aspects (such as open doorways and opportunities for fugitive releases) of any process-related buildings, and isolation of individual processes for ventilation and odour treatment.
- Industry Codes of Practice can be used as a guide, but one must be aware of what the objective of the Code of Practice is (eg, to protect neighbours from odour, noise, or health effects), what type of land use is anticipated at the boundary of the site or separation distance, what types of processes were envisaged in the Code of Practice (eg, could affect character and offensiveness of the odour – have recent changes in processes made the Code of Practice out of date?), degree of operator skill, and management practices required/anticipated by the Code of Practice.

4.1.3 Selection of Appropriate Evaluation Tools

Resource consent applications and odour assessments generally fall into the following three categories.

1. Renew existing activity.
2. Proposed modifications to an existing activity (mitigation or process change).
3. Proposed new activity.

Each category requires a different approach to evaluation for effects of odour discharges. The typical evaluation approach for each of these three categories is described below. For further detail, reference should be made to CH2M Beca (1999).

1. Existing Activity

In this type of application, the applicant seeks consent to continue with their current activity in the same manner, without any changes to the ways in which odours are generated and discharged. Odour monitoring and dispersion modelling is of little benefit in this case, as a model cannot prove the presence or absence of existing effects. Evaluation techniques that rely on assessing the degree of significant adverse effect experienced by people occupying land near the activity are more applicable.

If the regulator considers that actual or potential adverse effects cannot be suitably avoided, then the activity may be reclassified and evaluated as if it were a category (2) activity.

2. Proposed Modifications to an Existing Activity

Resource consent applications are rarely as straightforward as in category (1) above, and the regulator must often assess the likely actual and potential effects of proposed changes to existing activities, or evaluate whether proposed odour emission control measures will be adequate to avoid, remedy or mitigate existing adverse effects. Although performance standards and proven control technology requirements can be used to minimise odour release, a greater reliance must be placed on dispersion modelling to consider the actual and potential effects.

In many cases, the question of whether or not there is an adverse effect should be answered from the evidence of complaints, odour diaries, and consultation with neighbours. The dispersion model could then be "calibrated" to determine an appropriate odour modelling guideline for assessment of the results specific to the site. The role of dispersion modelling would then be to determine the degree of improvement offered by various mitigation options, rather than to prove the absence of an adverse effect.

If there are significant sources of background odour in the area around the site, then this approach may not be possible, and the dispersion modelling approach described for category {3) below may be required.

3. Proposed New Activity

This can be the most difficult type of application to evaluate. In this case there is no history of complaints nor plant performance from which to determine adverse effects, and the regulator must rely heavily on dispersion model results. The evaluation can be complicated if there is little information on which to select odour emission rates, and often a conservative approach to evaluation will be required.

4.2 INTERACTION OF ODOUR STANDARDS, DISPERSION MODELLING, AND PLANT DESIGN

Odour management for any odorous activity involves the inter-related processes in Figure 4.2.1. The following points describe these processes.

- The process begins with the **Odour Monitoring Standard** (Item ① in Figure 4.2.1), which is a qualitative standard set by the industry or the Regional Council. This standard should be the ultimate objective of odour management practices at the site. An example would be “no offensive or objectionable odours at the plant boundary”. Compliance with this standard would be a requirement of any air discharge consent, as “narrative” standards are often used for odour conditions rather than numerical standards.
- The **Odour Recognition Level** (Item ②) quantifies the odour monitoring standard. It sets a peak odour concentration, measured in odour units, that should be met at the plant boundary at all times to ensure that the Odour Monitoring Standard is met.
- Correction factors can be applied to the odour recognition level to yield the **Odour Modelling Standard** (Item ③) which can be compared with dispersion model results. The odour modelling standard converts the odour recognition level into model output, and therefore is dependent on the model averaging time used. The standard has both a numerical odour concentration and a percentage of meteorological conditions compliance factor. Odour modelling standards are discussed briefly in Chapter 4.4.1.
- **Dispersion Modelling** (Item ④) is then used as a tool, to predict how proposed treatment operations and layouts will perform against the overall odour objective. The odour model can also be used to “turn off” sources in turn to isolate the effects of individual sources. When combined with site specific meteorological data, dispersion modelling can be used to predict the frequency of nuisance odour events occurring over a long period of time. Dispersion modelling is discussed in Chapter 4.3.
- Obtaining **Monitoring Data** (Item ⑤) is needed to give input data for the dispersion model. A number of samples are generally needed from the major odour sources within the plant to ensure that the emission rates used in the model are statistically significant.

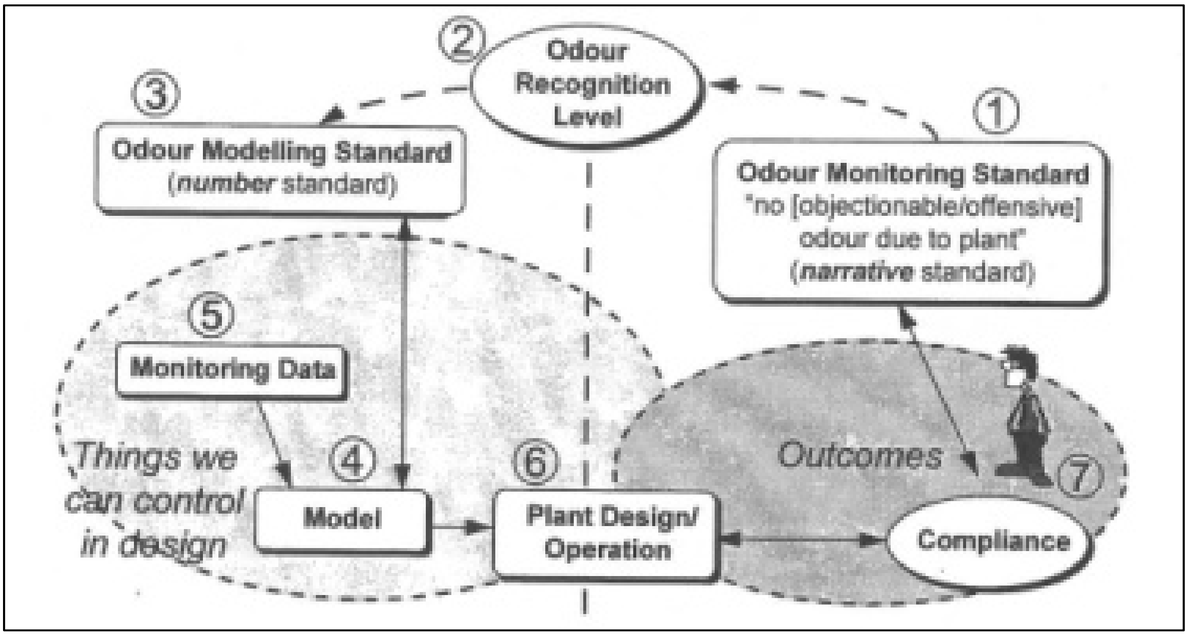


FIGURE 4.2.1: INTERACTION OF ODOUR STANDARDS, DISPERSION MODELLING, AND PLANT DESIGN

- From the modelling results the process operational changes and plant design modifications (Item ⑥) required to comply with the odour monitoring standard can be detailed. Therefore the plant design, and to some extent the way the plant will be operated, are determined primarily by the use of an atmospheric dispersion model using source odour emission information.

Evaluation of compliance (Item ⑦) is an ongoing exercise. Part of an ongoing odour management programme would involve reassessment of the various assumptions around the loop shown in Figure 4.2.1, as compliance data becomes available.

4.3 DISPERSION MODELLING

4.3.1 Introduction

This Section sets out to provide sound, practical advice on the application of air pollution dispersion models on modelling of odours in New Zealand. The text in this section is a summary of Appendix A, "Guide to Dispersion Modelling".

Atmospheric dispersion modelling is a statistical technique which builds up a quantitative model by predicting where emissions will go and at what concentration they will arrive. By predicting this concentration in terms of different atmospheric parameters, it is possible to predict the effect of worst possible conditions or even to simulate a full year of weather changes. Dispersion modelling is carried out using internationally recognised computer programs.

These models are generally a cost-effective replacement for direct field measurement of ambient air quality and, in the case of new installations or pollution control studies, are the only means of assessing the effects of air discharges on the environment. Effectively, individual sources of pollutants can be "switched off" to investigate the contribution of the remaining sources. For example, individual odour sources contributing to the overall odour emission from a WWTP can be ranked in terms of their odour effects on the surrounding environment. In this way, the best practical means of pollution control can be identified without extensive site trialling, and before capital works begin.

Air pollution dispersion modelling in New Zealand is frequently carried out by individuals without a strong background in air pollution meteorology, and therefore it is easy to apply and interpret model results inappropriately. Consequently, it is important that those applying dispersion models be aware of:

- the limitations of such models;
- the typical magnitudes and ranges of the model input parameters;
- the appropriate choices of model options; and
- conditions under which applications of particular models may be wholly inappropriate (for example, in hilly or coastal terrain).

4.3.2 Uses of Dispersion Modelling

The current regulatory guidelines in Australia and New Zealand (Chapter 4.4.1) are based on several assumptions:

- current dispersion models can sensibly estimate short term average concentrations under most atmospheric conditions in flat terrain;
- odours from different sources are generally assumed to combine in an additive fashion;
- because of olfactometry methodology, odour thresholds are usually tied to the median response of the population, not that of the most sensitive members.

Models are used to predict actual and potential effects of odour discharges, particularly for proposed activities. However, any amount of modelling is irrelevant if the public still complain of odour nuisance even though the model may predict compliance with the guidelines. This may happen if:

- the guideline is inadequate;
- some sources of odour have not been identified and modelled (such as occasional sources or leaks through covers);
- incorrect emission rates are used (such as poor measurement techniques or if odour measurements are taken during periods where the system is performing better than usual – eg, under low load or during a particular time of year);
- the sources have been characterised inadequately;
- the dispersion model is inappropriate for the meteorological conditions and surrounding terrain;
- the model results have been affected by the following sources of uncertainty -
  - ❖ errors due to the mathematical assumptions built into the model, and also associated with specification of emission rates and meteorological data inputs. The degree of error will depend on the complexity of the modelling situation, the number of sources (models assume that multiple sources are additive, but this is not the case with odour), surrounding terrain features, the quality of the meteorological data file, and the type downwind predictions required (for example, predictions at a precisely located receptor will have a greater error than predictions at a non-direction specific downwind distance (Turner, 1994))
  - ❖ modellers can often influence the selection of model input data to affect the modelling outcome, making the results either conservative or optimistic
  - ❖ in odour evaluation, there are a number of interrelating factors that determine whether an adverse effect will occur, commonly summarised as the FIDOL factors (frequency, intensity, duration, offensiveness, and location or land use). The interrelationship of

these factors is too complex in most instances to accurately incorporate into an odour criterion, although they can be accounted for in a basic manner.

Once a process has been established, the continued use of dispersion models and comparisons against standards may be of limited value, although still useful for the following types of investigations:

- to show the direction of plume paths, and where the greatest impacts are in the surrounding community;
- to show the frequency of occurrence of plume paths (if a period of real meteorology is available);
- to compare the relative effects of various sources;
- to test the sensitivity to upsets of individual sources;
- to compare the noticeable effects of mitigation options; and
- to compare existing versus future odour effects at a site.

4.3.3 Difficulties of Modelling Odour Sources

Compared to many other air contaminants (such as dust and chemical gases), the measurement of odour emission rates and prediction of ambient odours levels is complicated. There are several characteristics peculiar to odours which directly affect the modelling process. These are as follows.

- Odours are complex and subjective by nature and are difficult to quantify, ie, it is difficult to get realistic emission rates.
- Odours have various response rates and masking abilities and are perceived differently depending on the source, ie, area sources are perceived continuously whilst point sources may be perceived intermittently - this will effect concentrations, and may lead to either over- or under-predictions.
- Infrequent bursts of strong odour can be less of a nuisance than long exposures at a lower intensity, so there is confusion as to averaging times.
- Odorous sources are often characterised by a varied and often complicated network of structures, such as roof vents, stacks, large area sources and door leaks.
- Modelling of odours is complex. Some odours mask others, and other odours change in their intensity with distance and exposure to air and light. In some circumstances the effect of an odour mixture can be less or greater than the sum of its parts (called a synergistic" effect). Thus odours are not essentially additive, and it can be incorrect to model assuming they are so. However, there is no quantifiable alternative assumption that can be developed because each mixture of odorous compounds behaves differently. Therefore, the assumption that odours are additive must remain, at least for the present time.
- There is current debate over the standardisation of measurements of odour concentrations, and their relationship to background levels and perception of nuisance.

4.3.4 Types of Models

There are a multitude of dispersion models available. These can be broadly grouped into four classes.

1. Screening Gaussian models.
2. Full meteorology Gaussian models.
3. Puff models.

4. Other (specialist applications).

Briefly, these classes can be described as follows.

1. Screening Gaussian Models

The most commonly and easily used dispersion models are called “Gaussian” models, as the equations used to estimate the rate of dispersion assume that the spread of contaminants across wind and downwind can be described by the normal or “Gaussian” distribution, which is well known in statistics and can easily be described mathematically.

In a screening model, the model is run with a set of hypothetical meteorological conditions which are believed to include the worst case and cover a full range of dispersion (stability) conditions and mixed layer depths (NIWA. 1998). In models such as AUSPLUME and ISC3 (see Chapter 4.3.5), a screening input data file is provided. This model of operation of the models is called screening and is often the first step in a modelling exercise. Screening can be used to give an order of magnitude indication of where and under what conditions pollution problems may occur, where extra study is needed, where special factors might apply and to obtain an overall picture. Provided the screening meteorology covers the full range of possible meteorological conditions, that the choice of model options is conservative, and that the model's predictions are well below the odour criterion, no further modelling may be required. However, if these conditions cannot be satisfied, or if the odour criterion needs to consider a percentage compliance component (eg, exclude the highest 0.5% of predictions with a year of meteorological data), then a full meteorology Gaussian model will be required.

2. Full Meteorology Gaussian Models

In a full meteorology Gaussian model, the Gaussian model is run using a large data set of hourly meteorological records specific to the site being investigated. Gaussian models are by far the most commonly used types of models because of their simplicity and broad application.

3. Puff Models

These models are a significant advance on Gaussian models. However, they require significantly more computing resources and detailed input data, and are more complex to use. The models have a number of advanced features that make them more widely applicable. These include: space and time variations in the meteorological input fields, better turbulence representation, coastal effects are better handled, low wind speed and calm conditions can be handled, complex terrain is better handled, and upgraded treatment of building downwash.

Due to the difficulty in using these models, and the detailed input data required, these models are unlikely to replace the widespread use of Gaussian models, at least for some time into the future.

The AUSPUFF modelling system is now available from the Victorian EPA, and is seen by them as complementary to AUSPLUME and designed for use in many situations where AUSPLUME, and its planned upgrade, are not applicable.

4. Other (Specialist Applications)

There is also a series of very advanced models which can be used for dispersion modelling. These include LADM (Lagrangian Particle Dispersion Model from CSIRO, Australia), and RAMS/HYPACT (Regional Atmospheric Modelling System from USA). These require very substantial computing resources and expertise and are not recommended for general use. These models typically work at scales from a few kilometres to a few hundreds of kilometres, as opposed to the Gaussian models discussed above. If assessments are needed for distances beyond 10 km, then such mesocsale models are required, since the Gaussian approximations can be very misleading.

4.3.5 AUSPLUME and ISC3

AUSPLUME

AUSPLUME was developed by the Victoria Environment Protection Authority (VicEPA) in Australia, and is based on and similar to the United States Environment Protection Agency (USEPA) Industrial Source Complex Model (ISC). AUSPLUME has become the standard Gaussian model for use in New Zealand, particularly in smaller scale applications. It has been used extensively and performs well in most simple situations. This model is easy to use and the output is readily understood.

Provided that care is taken with input and interpretation of output, AUSPLUME is a good choice for most straightforward evaluations. In addition to the standard inputs detailing the source and emission characteristics, AUSPLUME can be run with real meteorology or the screening set provided with the model. It is recommended that it always be used with a year of local meteorology.

AUSPLUME is regularly updated, and the most recent version has an enhanced Windows graphical user interface (GUI). A major upgrade to the AUSPLUME model is underway with the VicEPA, and is expected to be released in late 2000.

AUSPLUME has several limitations which are most apparent in complex cases:

- cannot handle complex terrain and meteorological conditions;
- terrain effects are computed only for point and volume sources, (ie, neither area nor line sources);
- no spatial variation in meteorology (wind conditions assumed to be constant over the receptor field and over each hour);
- calm conditions are not handled (<0.5 m/s).

ISC

The USEPA Industrial Source Complex Model (ISC), originally developed over 20 years ago by the USEPA, is now in its third version (ISC3). There are two versions of ISC3, a short-term model (ISCST3) and a long-term model (ISCLT3). The models are used to predict pollutant concentrations from continuous point, area, volume and open pit sources. The models differ in the averaging times available for calculation, available terrain and deposition options, and the format of input meteorological data. In this Manual, when referring to ISC3, the short-term model is implied.

The ISC3 algorithm is regularly updated by the USEPA and can be obtained free via the Internet from the USEPA's website. Modellers should take care to ensure that the most up-to-date version of the ISC3 model is used.

ISC3 incorporates the USEPA's COMPLEX1 screening model algorithms for use with complex terrain (some or all receptors above final plume rise height) and intermediate terrain (terrain located between the release height and the plume height). When both simple and complex terrain algorithms are included in a model run, the model will select the higher impact from the two algorithms on an hour-by-hour, source-by-source, and receptor-by-receptor basis for receptors located on intermediate terrain.

The ISC3 model is not as easy for use as AUSPLUME, in terms of the user interface, but several software companies have produced programmes that incorporate the ISC3 model with a user-friendly GUI that simplifies the data entry and checking procedures. An example is the Breeze

Air ISC3 model by Trinity Consultants Inc. (USA), which is used by several modellers in New Zealand.

The ISC model has the same limitations as listed for AUSPLUME above. An added feature of ISC3 that is not in AUSPLUME is the characterisation of a new source type – "Open Pit Sources'", for modelling dry deposition of particulates from open pit sources. ISC3 also includes both state-of-the-science dry and wet deposition algorithms. A disadvantage of ISC3 is that it ignores the effect of partially penetrating plumes.

A further variant worthy of mention is ISC-PRIME. This is essentially the ISC3 model incorporating a new algorithm for building downwash. The PRIME building downwash algorithm is thought to be an improvement on the algorithms currently in AUSPLUME and ISC3, and may become widely used in future. It may also be incorporated into AUSPLUME during the upcoming review.

AUSPLUME versus ISC

Results from the AUSPLUME and ISC models are not directly comparable, due partly to minor variations in the handling of terrain, surface roughness and building downwash, but due mostly to the use of different numerical coefficients in the equations which describe the rate of dispersion (see Appendix A for explanation). In ISC, the coefficients are applied to a 1-hour averaging time. In AUSPLUME, the same coefficients are applied to a 3-minute averaging time, because the model's developers reviewed the initial field research which defined the coefficients and considered a 3-minute averaging time to be more applicable. Therefore, 1-hour average predictions in ISC are comparable to 3-minute average predictions in AUSPLUME. American researchers are now considering amending the coefficients in ISC as well, although any modification to the ISC model is not likely to occur without careful review.

The minimum averaging time in ISC is 1-hour, because the meteorological data is provided in the form of hourly averages, compared with 3-minutes for AUSPLUME. Averaging times of less than 1-hour in AUSPLUME are obtained by calculating the 1-hour averaging time, then converting the result using the following equation:

$$C_t = C_{60} \left[\frac{60}{t}\right]^{0.2}$$

where C_{60} = concentration for 1-hour average
t = averaging time, mins
C_t = concentration for averaging time of t minutes

Using this equation, the correction factors for various averaging times are as follows:

Averaging time, t (minutes)	*Factor to multiply 1-hour concentration (C_{60}) by to get concentration for averaging time of t minutes*
3	1.82
10	1.43
20	1.25
30	1.15

Research has shown this formula to be too simplistic and not entirely correct, particularly for some situations (Katestone Scientific, 1998). Future versions of AUSPLUME may incorporate the peak to mean ratios discussed in Chapter 4.4.2, rather than this simple conversion factor.

4.3.6 Limitations and Errors in Gaussian Dispersion Modelling

The Gaussian representation of dispersion is simplistic and applies only to a limited range of conditions. In particular, it applies to:

- continuous emissions from a point source;
- inert, almost weightless, pollutants (eg, gases and particles less that 20 μm in diameter);

- time periods greater than about 10 minutes;
- distances in the range from a few hundred metres to about 10 km; and
- relatively flat terrain.

Furthermore, the models often assume that:

- atmospheric conditions are not changing through time and distance (ie, the meteorology stays the same between the source and the receptor);
- there is no chemistry occurring within the plume (ie, chemical reactions between pollutants and with the air and light), although this can be allowed for in some models for simple chemical reactions; and
- there are no horizontal and vertical variations in turbulence, wind speed and wind direction within the boundary layer close to the earth's surface.

In Appendix A, a summary of the various sources of error in the use of Gaussian models is provided. Not only are errors associated with the representativeness of the model (ie, deficiencies arising from the assumptions described above), but also there are significant errors associated with specification of emissions and meteorological inputs. Given these assumptions and limitations, the best modellers can hope for with a Gaussian dispersion model is to predict concentrations within a factor of two of the actual case (ie, the ratio of the actual concentration to the predicted concentration is 2 or less). Greater errors would also be found if the task was to predict the concentration at a specific location downwind of a source. The largest error expected to occur during the process of modelling odours is in the correct quantification of odour emissions - both in quantity and fluctuation.

Despite considerable advancements in the user-interface (the appearance and ease of use of the models on desktop computers), Gaussian dispersion models have not changed fundamentally over the past two decades. The limitations and uncertainties described above remain. Instead: most improvements have sought to simply extend the range of conditions in which models can be used.

With the raft of uncertainties described above, and the crucial importance of correctly predicting ground level concentrations of pollutants, the following questions arise: *"why bother with modelling at all?"* and, furthermore, *"what models are out there? Are they better than the Gaussian models?"*

For all their deficiencies, Gaussian plume models represent a well understood and internationally standardised acceptable approach to modelling. Furthermore, they are simple to apply. These qualities are particularly important from a regulatory point of view where ease of application and consistency from application to application is imperative. Certainly there are more sophisticated approaches to dispersion modelling - such as advanced mesoscale models such as AUSMET/AUSPUFF, LADM and RAMS. However, unless one has better input parameters about the source characteristics and odour emissions, the use of a more sophisticated approach may not be really worthwhile. In Gaussian models at least the assumptions, errors and uncertainties are well-understood.

4.3.7 Selection of Emission Rates for Wastewater Treatment Plants (VIANTPs)

The basic mathematical equation which describes dispersion as used in Gaussian models is:

$C = Q \times fn$ (wind speed, downwind distance, and numerical dispersion coefficients),

where C = predicted concentration
and Q = pollutant emission rate

Therefore, the predicted concentration is directly proportional to the pollutant emission rate, and any errors in the emission rate in the model will translate directly into errors in the model output.

Emission rates determined by olfactometry are inherently erroneous, as described in Chapter 3.3. This must be kept in mind when selecting emission rates and interpreting dispersion modes results. Further issues which arise in odour modelling for WWTPs are the variability of WWTP odour sources, and dealing with the sheer number of sources involved. These issues are discussed below.

Odour sources at WWTPs exhibit significant variation in the rate of odour release on an hourly, daily and seasonal basis. An example of this is shown in Figure 4.3.1, which shows odour emission measurements over time from an actual WWTP odour source in New Zealand. Odour sources of large area, such as a lagoon, oxidation pond, or sedimentation tank, can also yield different odour emission rates at various locations on the surface at any one time. This is shown schematically in Figure 4.3.2.

For simple dispersion model scenarios, with only one or two sources, the maximum measured emission rate from the source is typically used for dispersion calculations. The results therefore represent the worst pollutant concentrations expected to occur.

However, in the case of WWTPs with a large number of sources, it is unrealistic to assume that all sources would discharge odour at the maximum rate over the whole surface at the same time. For example, a WWTP consisting of primary treatment could contain some or all of the following odour sources:

- Septage dump
- Grit/screenings storage
- Preaeration/grit removal
- Engine stack
- Sludge/biosolids stockpiles
- Flares
- Sludge lagoons
- Screening building fugitive emissions
- Biofilters/scrubbers (odour control devices)
- Sludge digesters (annular ring around lid)
- Primary sedimentation tanks – inlet, quiescent surface, and end weirs
- Sludge dewatering building ventilation, fugitive emissions, and batch tanks

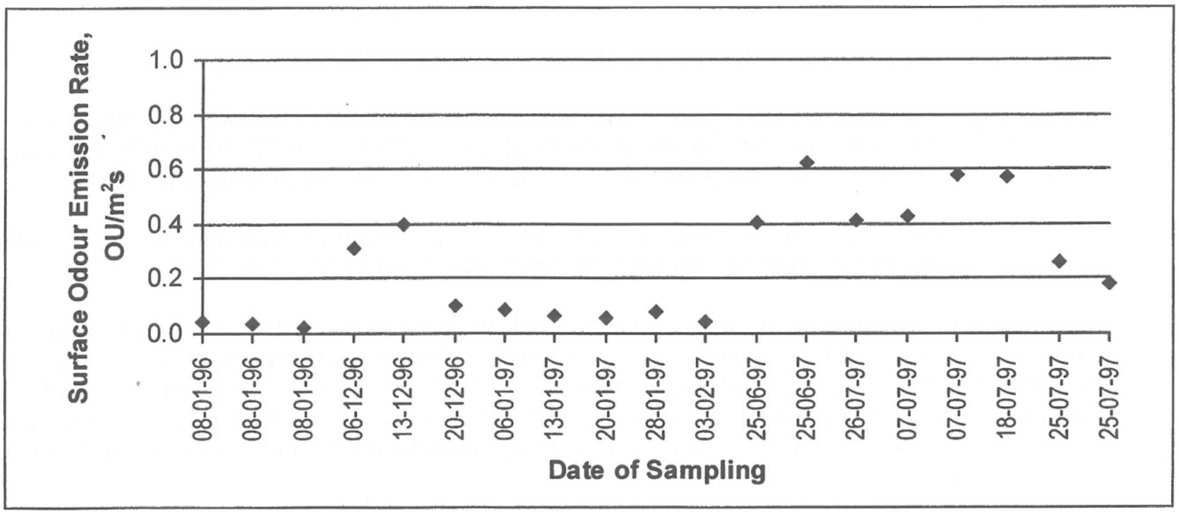
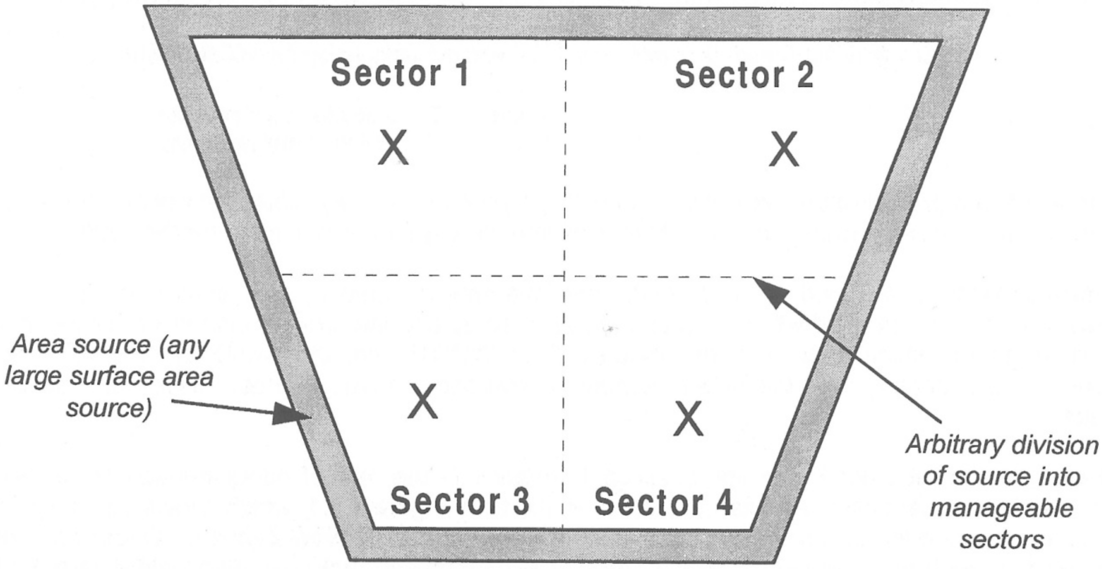


FIGURE 4.3.1: TIME VARIATION OF ODOUR EMISSION RATE FROM ACTUAL MEASUREMENTS OF A WWTP SOURCE



A = total area of source
$A_1 - A_4$ = area of sectors 1 to 4
$X_1 - X_4$ = sample location in each sector 1 to 4
$e_1 - e_4$ = emission rate of sample from each sector

Average emission rate: $\mu = e_1 \cdot \frac{A_1}{A} + e_2 \cdot \frac{A_2}{A} + e_3 \cdot \frac{A_3}{A} + e_4 \cdot \frac{A_4}{A}$

FIGURE 4.3.2: CALCULATION OF MEAN ODOUR EMISSION RATE FOR A LARGE SOURCE, FROM FOUR SAMPLES SPACED OVER THE SURFACE

If the dispersion model assumed that all of these sources were discharging odour at their peak rate at the same time, then the model results would be unrealistically high. So, what emission rates should be used? The following guideline is suggested.

(a) For a source with multiple measurements over a period of time (eg, a vent monitored on a number of occasions):

- if only a few data points are available, use the maximum measurement;
- if a number of data points are available, then a curve such as that shown in Figure 4.3.3 can be drawn, and a certain percentile (such as 50th percentile or 70th percentile) emission rate selected (percentile to be selected and justified at the discretion of the modeller).

Alternatively, the mean could be used, but this should be considered on a case-by-case basis, because one or two very high or very low data points can significantly skew the mean.

(b) For a source of large area, measurements should be taken at a number of locations over the surface in a short space of time, and a mean calculated which represents the average emission over the surface at that point in time, as shown in Figure 4.3.2. An example of where this may be appropriate is in a primary sedimentation tank, where the odour emission rate can vary along the surface, but the mean of the emission rates at the inlet and outlet ends could be assumed to apply along the full length of the tank.

(c) For a source which contains separate zones of different emission rates, such as a pond where the inlet end is mechanically aerated or a primary sedimentation tank with cascading outlet weirs, each zone should be modelled as a separate source.

Dispersion models using these “average” emission rates will show the performance of the WWTP under “normal average operating conditions”. However, modelling with some sources under upset conditions – either using the highest emission rates measured or some other estimate, will also be needed to demonstrate the sensitivity of the WWTP to odour variations on particular sources. For example, for an oxidation pond, a 50th percentile emission rate may represent “annual average” conditions, whereas an 80th percentile emission rate might represent peak summer conditions under low flows and high ambient temperatures.

As a further example, the 50th percentile emission rate may represent average conditions for a biofilter, but the maximum emission rate measured over a period of several years may represent poor operational conditions or short-circuiting of air flows through the media, and should also be modelled to demonstrate the priority that should be given to maintenance of that biofilter.

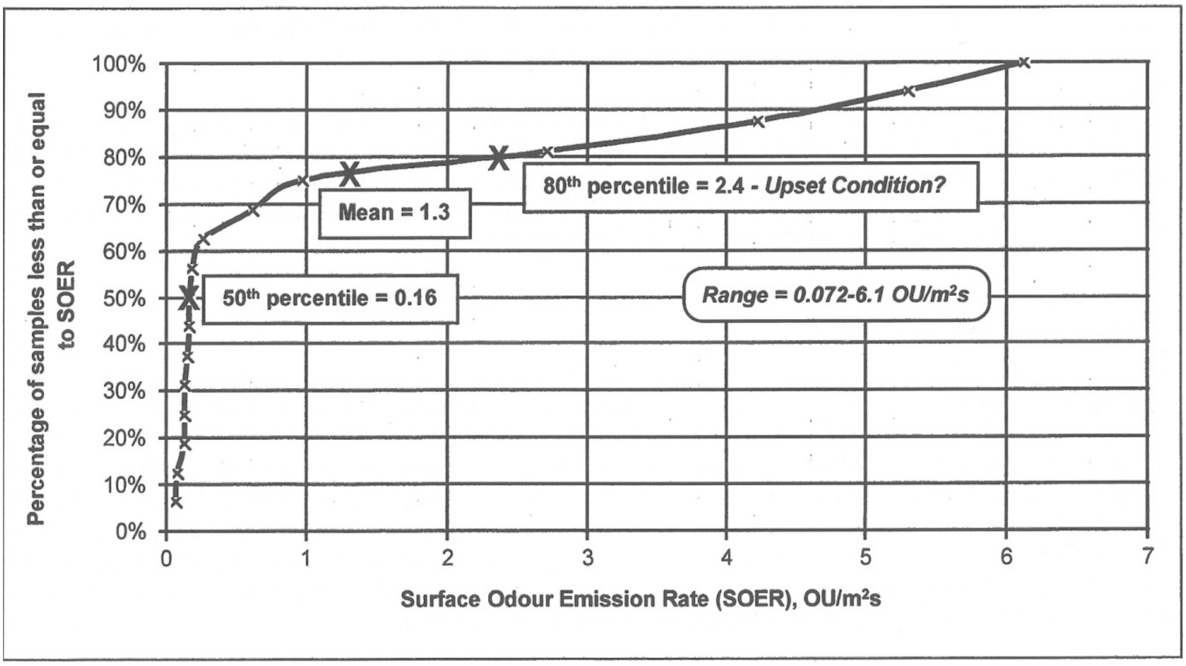


FIGURE 4.3.3: EXAMPLE PERCENTILE EMISSION RATES

4.4 MODELLING STANDARDS

4.4.1 Trends in New Zealand and Overseas

In Australia, standards are based upon "yes/no" or "forced choice" response olfactometry and the AUSPLUME (or equivalent) model. The standards, at or beyond the boundary of the activity, are in the order of 0.3 - 2.5 OU/m^3 for a 3 minute averaging time, although this is under review (Woodward-Clyde, 1997).

Most Regional Air Plans in New Zealand have not adopted specific numerical standards, instead using a narrative standard such as offensive or objectionable odour. However, numerical standards are still used in Assessments of Environmental Effects (AEEs).

In the Netherlands, standards are only applicable if domestic dwellings are present, while the Danish and US guidelines vary depending on the location of the source (Woodward-Clyde, 1997, and MfE, 1994). In Australia: none of the States presently take location into account, although this appears likely to change in future.

There has been considerable debate in Australia and New Zealand in the late 1990's regarding appropriate modelling standards and guidelines, and this is continuing (as at September 2000).

The debate includes methods for incorporating the offensiveness of the odour, and the nature of the receiving environment that experiences the odour. There is a large amount of discussion on these issues in the CH2M Beca report (1999), and this will be incorporated into the review of the New Zealand odour management guidelines scheduled for 2000/2001, which will be accompanied by a broad consultation programme.

An approach that is being explored by same policy makers in Australia, in particular in Western Australia, is to plot the odour concentration (ie, measured odour units) against intensity (EPA, 2000). This determines, for each odour source/character, the odour concentration which corresponds to a given “complaint” intensity using the scale “not perceptible”, “very weak”, “weak”, “distinct”, “strong”,. “very strong”, and “extremely strong”. The air quality target is determined by choosing the desired intensity rating such as “distinct”, and then choosing the odour modelling guideline to be the measured concentration that relates to this intensity.

This approach is proposed in Western Australia by the Environmental Protection Authority in the report entitled *“Draft Guidance for the Assessment of Environmental Factors – Assessment of Odour Impact”* released for public comment in April 2000.

A common failing in the interpretation of model results is that an activity will be considered to “pass” or “fail” the test for adverse effects depending on whether the results are higher or lower than the odour criterion. However, because of the sources of error described above, this is not the case. Therefore, if modelling results are close to the odour criterion, then a subjective assessment should be carried out to help determine whether adverse effects are likely to occur.

4.4.2 Peak to Mean Ratios

The shortest term predictions produced by Gaussian dispersion models are one hour averages. Within that interval, usually one hour, the actual odour concentration will fluctuate above and below the average concentration. Human response to odours is very quick, usually of the order of milliseconds or a maximum of a few seconds. The concentration of a pollutant in the air smelled by the nose over a few seconds can be significantly higher than the average over one hour. Hence, there needs to a factor incorporated in the “odour standard” to take into account what is called the Peak to Mean (P/M) ratio, that is, the ratio of that odour peak smelled by the nose over a very short period and the average result of a dispersion model over one hour.

A comparison between the odour model's predicted result for any particular hour, and what would typically happen during that hour in reality, is shown in Figure 4.4.1. The graph shows that although the model predicts that a concentration of 2 OU/m^3 would occur for the entire hour, this is not actually the case because of small changes in wind speed and direction from minute to minute. The actual ambient odour concentration could vary between, say, 0 and 5 OU/m^3 (depending on the P/M ratio for that source). The fluctuation could be even greater if the emission rate was varying as well. Therefore, the amount of time that people would be able to detect the odour is much less than the model results suggest.

With reference to Figure 4.2.1, to convert from the odour recognition level to the odour modelling standard, the PIM ratio is applied which converts an instantaneous peak concentration the odour recognition level) to a time-averaged model result (the odour modelling standard). This P/M ratio is also shown on Figure 4.4.1.

The value of the P/M ratio depends on the type of source, atmospheric stability and downwind distance. In Australia, guidelines have being established to define a set of P/M ratios for a variety of sources, range of stability conditions and several regimes of downwind distance (Katestone Scientific. 1998). The recommended range of P/M ratios is complicated, and therefore has not been reproduced in this Manual. Interested readers should refer to the document by Katestone Scientific, or the Environmental Protection Agency of New South Wales, for more information.

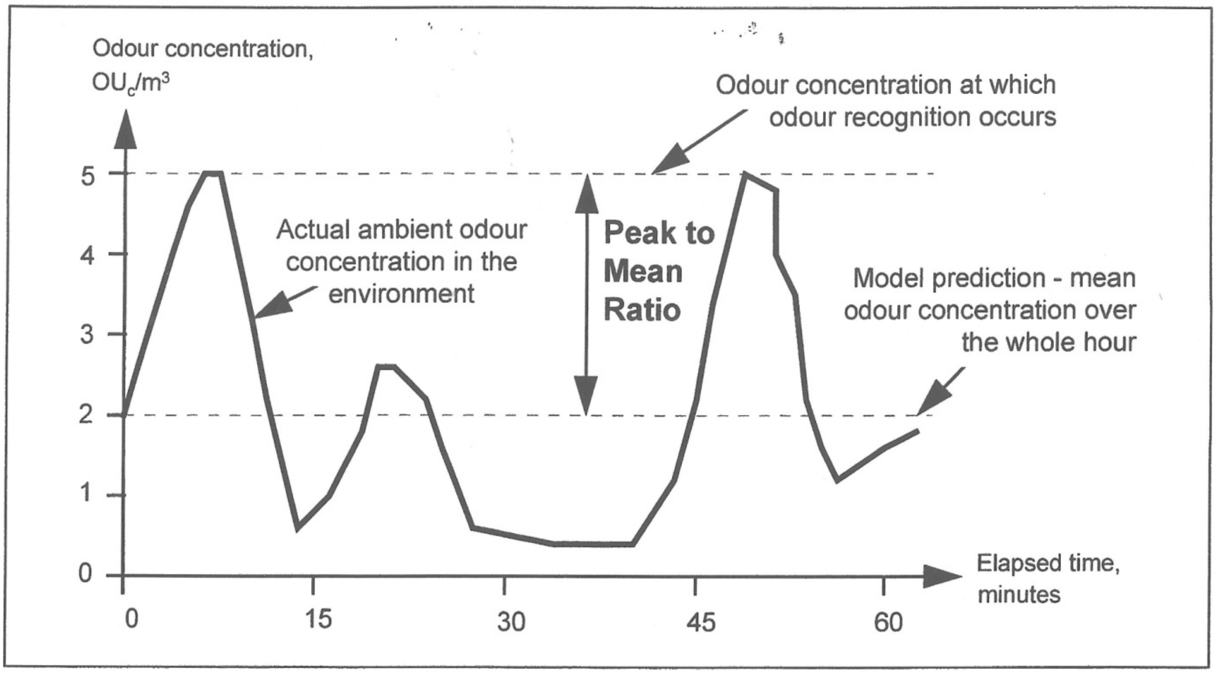


FIGURE 4.4.1: ODOUR DISPERSION MODEL PREDICTIONS COMPARED WITH REALITY

4.5 CHAPTER 4 REFERENCES

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5. ODOUR CONTROL TECHNOLOGIES

5.1 PREVENTATIVE APPROACH

5.1.1 Introduction

Prevention of odour emissions is a very important aspect of odour control, because if the generation and release of the odour can be prevented, then there is no potential for an odour problem to arise as a result. Depending on the circumstances, this may be more cost effective than capturing and treating the problem odours after they are generated. The preventative approach seeks to prevent the occurrence of conditions favourable to the generation and/or release of odours. Methods used include:

(a) process monitoring and good management;
(b) sewer design;
(c) oxygen transfer;
(d) chemical addition; and
(e) biological variation.

These five methods are discussed in Chapters 5.1.2 - 5.1.6.

5.1.2 Process Monitoring and Good Management

Many WWTP processes have the potential to generate significant odour if poorly designed or maintained. It is important to start off with the most suitable process designs for the treatment of the effluent and sludge residuals, and the odour treatment equipment. Once the equipment is commissioned, adequate process monitoring and maintenance is needed to ensure that the equipment operates at its optimum performance.

Minimising the generation of odours from a treatment plant is dependent on two related activities: <u>engineering design</u> of the plant and <u>operation and maintenance</u> practices. Engineering design considerations should include proper hydraulic design, providing the means for maintaining an adequate dissolved oxygen concentration to minimise sulphide generation, minimising turbulent conditions which cause odour release, and designing the plant to facilitate the cleaning of its various components. Proper operation and maintenance practices include a planned program for frequently removing odour-producing materials.

Good housekeeping is always essential to prevent odour generation. Many odours associated with effluent treatment operations can be controlled or eliminated by ensuring that process components are kept clean and free of accumulated grease, solids, and debris. This can be accomplished through a regular inspection and maintenance program involving the routine cleaning of tanks, unit process equipment, and hardware that come in contact with effluent or sludge. Such a program can typically be implemented at little cost, often with substantial reduction of odour generation.

Detailed description of suitable equipment design and maintenance for WWTP's is given the book "Odour Control in Wastewater Treatment Plants", Water Environment Federation (WEF) Manual of Practice No. 22 (1995). It is not the intention of this manual to reproduce the findings of that WEF publication. However, some comments on the potential for odour generation from various WWTP processes, based on the WEF document and NZ experience, is provided below.

Inlet Works and Preliminary Treatment

Raw wastewater may be septic and/or contain odorous trade effluents. The WWTP may also be a reception centre for septic tank liquors and cleanings from pumping station wet wells. The main odorous gas emitted at the inlet works is H_2S, which may be accompanied by other reduced sulphur compounds including mercaptans and dimethyl disulphide, but is usually the dominant species.

Turbulence induced by drops, flumes, aerated grit chambers, fine screens or similar structures will release the gases from solution. Septic wastewater at this point can give rise to odours throughout the WWTP and, as such, it may be an appropriate place to locate a dosing system for treatment of odours by addition of oxygen, chemicals, or biological agents to the wastewater (See Chapters 5.1.4 - 5.1.6).

Preliminary treatment works are potential sources of odour because they process raw effluent containing putrescible organics and debris. Accumulation of organic debris in influent channels, bar screens, comminutors, and fine screening devices can result in odour generation if regular cleaning and flushing is not practiced. Grit chambers and grit conveyance systems can also be sources of odours because of the organic coating on grit particles. This is especially true in smaller plants where grit may be stored for long periods of time before disposal.

Pre-Aeration Tanks and Lagoons

Pre-aeration tanks located upstream of primary clarifiers, and aeration lagoons treating raw wastewater, can be sources of considerable odour release as sulphides and other odorous compounds are stripped out of the liquid stream. The amount of odour released will vary with the quality of the influent wastewater, and may vary considerably throughout the year depending on flow and climatic conditions. It is not uncommon for such treatment processes to be covered to prevent odour release.

Settlement Tanks

Primary clarifiers are odour sources if improperly designed and maintained, Hydraulic underloading and hence increased retention times can encourage the formation of septic conditions, with the consequent generation of odours. If scum removal mechanisms are inadequate, resulting scum accumulation and subsequent putrefaction will result in odour generation. Infrequent or incomplete withdrawal of settled solids can result in septic conditions and generation of odorous gases. Discharge over the effluent weirs can release odorous gases dissolved in the primary effluent. When removed from service, primary settling tanks can become major sources of odour unless odour prevention procedures are followed. Quiescent surfaces appear in primary and secondary clarifiers. Emissions from such surfaces are increased by winds that generate waves on the surface. These emissions also increase with surface area. Emissions of odours from quiescent surfaces can be reduced by constructing wind barriers upwind of such surfaces.

The causes of odours in secondary clarifiers are similar to those for primary units except that odours can develop faster in secondary clarifiers because they contain more biologically active, settled mixed liquor. The two major sources of odours are scum and sludge removal systems. Without proper, daily housekeeping, accumulations of scum on clarifier water surfaces, sludge accumulations on walls, and organic matter on effluent weir troughs can produce odours.

Recycle Streams

Sidestream returns from solids-handling operations such as thickening, dewatering, and digestion are often significant sources of odour. Odour release from anaerobic sidestreams typically results from turbulence created when the sidestream enters the main plant flow. For this reason, sidestrearns should always be returned below the surface of the liquid. Adverse effects on primary clarification, such as septicity and odours, can be avoided by returning the sidestream to the biological process.

Activated Sludge Aeration Tanks

Biological aeration tanks must be aerobic to function efficiently. Keeping these units aerobic is one of the most important odour control considerations. An adequate concentration of dissolved oxygen must be maintained, especially at the point of fresh effluent entry, which requires a proportionately higher aeration air input. Activated sludge plants are less susceptible to odour emissions than biological trickling filters although surface aeration systems can have a "stripping" effect on malodorous wastewater. Inadequate oxygen supply can cause the formation of anaerobic pockets and the evolution of H_2S and other odours. Process upsets can occur if toxic elements in the influent such as may be discharged in trade wastes, disrupt the biological population in the activated sludge. Adequate process monitoring is required to identify and remedy potential problems quickly, and strict trade waste controls are also advisable (although not infallible).

Sludge Treatment

The more significant sources of odours at WWTPs are sludge treatment facilities. In addition to mechanical treatment and dewatering units, sludge lagoons and sludge drying beds can be particular offenders. Excessive turbulence should be avoided, and the combustion of digester gas should also be efficient in order to minimise odour emissions. The degree to which sludge handling facilities create an off-site odour impact depends on the nature of the material and the manner in which unit processes are operated. Numerous odour control alternatives are available for solids processing systems, ranging from operational adjustments to containing and treating emissions.

Facultative Ponds

Typically, facultative ponds require little odour control if they are designed and operated properly. However, odours from algae and the rising of accumulated bottom sludge may become offensive, particularly during hot weather or the spring and autumn turnovers of deep lagoons.

Algae, particularly the blue-green species, are the primary source of oxygen in unaerated, facultative ponds, but they also act as a food source for odour-producing actionmycetes. Odours will escape when aerobic conditions are not maintained. Odours can occur:

- during the spring and autumn overturn periods for deep ponds in cold climates;
- whenever conditions cause the death of algae;
- during overloading periods;
- when scum accumulates on pond surfaces; and
- when sludge removal is insufficient.

Excessive BOD loading on these types of WWTPs can create an overload on the existing oxygenation or aeration system. For facultative ponds, it is critical to maintain adequate surface layer oxygenation without stirring and mixing the lagoon.

Pond shorelines must be free of weeds to allow easy cleaning and prevent accumulations of scum, grease, and other organic material that may decay and become an odour source at the water's edge. This means providing stable, easily cleaned banks to protect against both wave action and weed growth.

Disinfection

The addition of excessive disinfection agent such as chlorine or ozone can cause residual odours along with employee health and safety concerns. Contact tanks require normal housekeeping procedures to prevent the build-up of odorous scum and slimes. Proper design and operation to achieve desired chlorine contact times will reduce solids deposition, floating sludge, and related odour problems.

WWTP Outfalls

Primary treated effluents still exhibit a significant biochemical oxygen respiration that can be as high as 10 mg/l/h, and septic conditions can arise in receiving waters such as rivers and estuaries. Discharges through ocean outfalls generally achieve greater initial dilution, are buffered by the sea water to maintain the dissolved oxygen content in the discharge plume, and have a degree of separation from the public, so are generally less of a problem. For primary WWTPs and industrial effluent plants, oxygenation of the partially treated effluent may be needed before discharge.

Outfall structures, if not cleaned and maintained, may become sources of odour, particularly those discharging into shallow water bodies such as a river. The cleaning of outfall lines and structures is often assigned a low priority and is ignored until the lines become odorous. When that happens, the adsorbed odorants typically continue to emit odours even after scrubbing and flushing. The point where the treated effluent enters the receiving waters should be turbulent so that any settleable solids remaining are well dispersed before they reach a sufficiently quiescent zone, where they settle to the bottom.

5.1.3 Sewer Design

The design of sewers is of critical importance in minimising potential odour nuisance. Long retention periods with inadequate transfer of oxygen at the exposed surface of the wastewater, insufficient ventilation, slime layers on sewer walls, and the accumulation of silt and other debris all contribute to H_2S formation. The odour very often forms along the sewerage system and can be noticed at breather pipes (vents which provide ventilation to the sewer). If the sewage is not provided with sufficient oxygen or other agents to maintain aerobic conditions in the pipes, H_2S will be conveyed to the WWTP, creating a similar nuisance there also.

An aim in sewer design is to utilise gravity flow wherever possible. This minimises operational costs, minimises sewage detention time, and provide the opportunity for aeration. However, pumping is required where topography makes gravity pipeline construction too expensive.

In a pumped rising main, peak flow velocity will be in the order of 2.5 to 3 m/sec. This means that to minimise sedimentation at normal flows, minimum velocity will be kept around 0.6 m/sec, and pumping will be intermittent. Thus the sewage may become anaerobic during the period of detention in a long rising main. Apart from odour issues, there will also be the potential for increased corrosion.

In achieving a balance between the cost of gravity sewer construction and rising main length, consequences of detention time in the rising main (and in the pumping station wet well) need to be considered. These matters are dealt with more fully in Chapter 5.

5.1.4 Oxygen Transfer

Oxygen transfer is the key to both natural and industrial aerobic biological purification processes. The self-purification capacity of a natural waterway depends on a delicate balance between the rate at which dissolved oxygen is used up in the breakdown of pollutants and the rate at which oxygen is absorbed from the atmosphere and produced by photosynthetic plants. In an aerobic industrial or municipal waste treatment system, dissolved oxygen must be made available at a rate equivalent to the oxygen demand loading exerted by the wastewater entering the WWTP. The rate at which dissolved oxygen can be made available determines the rate at which wastewater contaminants can be decomposed. If the rate is insufficient, the wastewater becomes anoxic, and anaerobic micro-organisms then proliferate and produce foul odours. Arguably the most noxious, troublesome and characteristic of these odours is hydrogen sulphide (H_2S).

Therefore, one method of preventative odour management is to bring oxygen, wastewater and a suitable microbial population into simultaneous contact to prevent the generation of foul odours. In general terms, this means bringing the wastewater into contact with oxygen, either by injection of compressed air or pure oxygen, transferring oxygen across the gas-liquid interface to dissolve in the liquid, and transferring the dissolved oxygen through the liquid to the micro-organisms. The chemistry of the transfer of oxygen into wastewater is described in Appendix C.

Compressed Air Injection

Injection of compressed air into rising mains is usually done with a small air compressor, 15-150 m^3/h capacity, running continuously. It has the advantage that, once installed, the only operating cost is the power required to deliver the air to the sewer.

Compressed air injection can cause many operating problems in rising mains, such as complete gas locking, loss of pump prime, and severe and damaging water hammer. The compressors themselves are prone to mechanical breakdown. In many cases, compressed air injection simply will not work. In those where it will work, the used air escaping from the main can be odorous, particularly when sulphide control is only partial, which is often the case. This foul air can require treatment to deodorise it.

Oxygen Injection

The principle behind the oxygen injection technique, as with the compressed air injection method, is the maintenance of aerobic conditions (ie, positive dissolved oxygen levels) in the sewers to prevent the development of conditions favourable to H_2S generation.

Pure oxygen dissolves 12 times more readily than air, and to five times the air solubility (see Appendix C for details). Only one dissolving station is needed instead of five for air with only a fraction of the power usage. Oxygen demand for odour control in the effluent can be calculated fairly accurately to enable the specification of an effective injection system.

Operating problems in oxygen injection systems are similar to those in compressed air injection systems, although generally not as severe in oxygen injection. If oxygen is injected in excess of the saturation limit, it is extremely unlikely that all the oxygen will dissolve. Large pockets of undissolved oxygen would represent a significant safety hazard. Specialised equipment is used for dissolving oxygen to eliminate this risk. Care should be taken with each installation to ensure that complete dissolving is occurring.

Three significant further benefits are obtainable through the adoption of an oxygen injection system and maintenance of the aerobic state in the wastewater. These are the prevention of corrosion by sulphuric acid, improved settleability, and the reduction of BOD by a kilogram for each kilogram of oxygen. The latter provides some pre-treatment of effluent and can be a deliberate part of the treatment system.

The success of oxygen injection depends upon numerous factors, not the least of which are the configuration, length and size of the pipe or pumping station. The pressure and retention time within the device are key parameters. Other influencing factors include the strength and nature of the effluent, whether H_2S is already present, the temperature, turbulence, pH and construction material in contact with the effluent.

Application Example - Sulphide Control by Direct Oxygen Injection

CASE STUDY SUMMARY	
Location	Canterbury Meat Packers, Ashburton
Subject	Control of Odours from Effluent Irrigation
Application	Direct Oxygen Injection
Last Updated	January 1998
Further information contact	Geoff Scrase, BOC Gases Ltd

Canterbury Meat Packers is a meat processing plant in Ashburton, with slaughtering, fellmongering and pelt house processing taking place on the same site. The two effluent streams are combined in a large balance tank in which aeration takes place. The sulphide load from the pelt processing operations is almost entirely oxidised through a conventional manganese oxide plant before mixing with meat effluent. As a result, initial sulphide levels in the effluent pumped from the balance tank to Briggs irrigators are 0-1 mg/l. However, because of the long retention time in the 17 kilometres of irrigation pipelines that extend out to paddocks, the effluent becomes anaerobic. H_2S is produced from bacteria and possible chemical reversion from thiosulphates to sulphide.

Extensive dispersion tests were conducted, measuring the release of H_2S and the effects of spray drift and wind on the neighbouring properties that suffered the noxious odours. A direct oxygen injection system was then installed on the 300 mm diameter main feeder. The amount of oxygen needed was calculated from estimated respiratory rates and the geometry of the pipeline. At a distance of 1.5 km from the injection point, dissolved oxygen levels as high as 15 mg/l were measured at high oxygen injection rates during the initial trials. Such high levels are not necessary and the oxygen flow rate was later reduced to an average flow rate that sustained aerobic conditions.

H_2S was the main offensive odour in this industrial wastewater stream and, since the effluent has been oxygenated, complaints from neighbours have all but ceased. Canterbury Meat Packers were later able to obtain consent to irrigate a greater area of paddocks.

As a further illustration of the use of the technology, the case study presented in Chapter 7.1 briefly outlines the experiences of Tauranga District Council with oxygen injection.

5.1.5 Chemical Addition

There are two groups of chemicals used as additions to wastewater for odour prevention or treatment.

(a) "Sterile" chemicals prevent all biological activity and thus stop odour generation. Chemicals in this group include chlorine, sodium hypochlorite, hydrogen peroxide, biocides, and Sewage Conditioner A. The use of these chemicals sterilises the sewage, and this is considered by same to be undesirable. Their use precludes all possibility of in-sewer treatment of wastewater by microbial activity.

(b) Other chemicals treat the odour while still in the wastestream after they are generated, preventing their release to the air, rather than preventing their generation. Chemicals used include oxygen, lime, ferric chloride and nitrate.

Chemicals used in the Sterile Approach Chlorine

The reaction between chlorine (Cl_2) and sulphide is usually represented by the following equations.

$$\left.\begin{array}{l} \underset{\text{chlorine}}{Cl_2} + \underset{\text{water}}{H_2O} \leftrightarrow \underset{\text{hypochlorite}}{HOCl} + \underset{\text{chloride}}{Cl} + \underset{\text{hydrogen}}{H^+} \\ HOCl + \underset{\text{hydrogen sulphide}}{H_2S} \rightarrow \underset{\text{sulphur (precipitated)}}{S\downarrow} + Cl + H^+ + H_2O \end{array}\right\} \quad (1)$$

$$H_2S + 4Cl_2 + 4H_2O \rightarrow \underset{\text{sulphate}}{SO_4^{2-}} + 8Cl + 10H^+ \quad \} \quad (2)$$

In equation (1) 2.2 mg of chlorine is required per mg of sulphide oxidised, while in equation (2) 6.8 mg of chlorine is required per mg of sulphide oxidised. Both of these reactions can proceed together, and whether (1) or (2) predominates depends on chlorine availability, pH and temperature. At pH's below 6.4 the formation of sulphate (equation (2)) is favoured, while at pH's of 9-10 the reactions could be of equal significance. In practice the reactions in wastewater are much more complex as a number of other compounds such as thiosulphate and sulphites are formed when the degree of oxidation is between sulphur and sulphate. The chlorine will also react with other constituents of wastewater and it is therefore impossible to predict the minimum chlorine dosage required for sulphide removal from purely theoretical calculations.

The complexity of the chemical reactions and the dependence on actual sulphide concentrations mean that field trials are the only reliable method of determining the chlorine dose rate in a specific situation. Suppliers recommend chlorine doses for sulphide control of sewage flow of 5 to 10 mg/l. Chlorine is applied using a chlorinator, a venturi device which dissolves the chlorine in clean water and then mixes this with the sewage.

Care must be taken in the use and storage of the chemical, as chlorine is considered dangerous and is very poisonous.

Sodium Hypochlorite

Where sodium hypochlorite (NaOC1) is available as a solution with 12.5% by weight chlorine equivalent, a minimum of 17.6 weights of solution are required per unit weight of sulphide. As in the case above, the chlorine also reacts with the other components of the sewage.

A storage tank and a metering pump to measure the solution into the sewage is required. In many cases, sodium hypochlorite is preferred to chlorine because, although it is more expensive and very caustic, it is much less dangerous and easier to use than chlorine.

Hydrogen Peroxide

Sulphide is oxidised to elemental sulphur with hydrogen peroxide by the following reaction:

$$\underset{\text{hydrogen sulphide}}{H_2S} + \underset{\text{peroxide}}{H_2O_2} \rightarrow \underset{\text{water}}{2H_2O} + \underset{\text{sulphur (precipitated)}}{S}$$

In other words, a minimum of one molecular weight of hydrogen peroxide is required to oxidise one molecular weight of sulphide. Suppliers recommend twice this amount, indicating that half the hydrogen peroxide reacts with other components of the sewage or is wasted in some other way. Hydrogen peroxide is normally applied after the sulphide has been formed. Generally, hydrogen peroxide doses for sulphide control are about 1.5 to 2.5 molecular weights of H_2O_2 per molecular weight of sulphide.

H_2O_2 is too expensive to be used as an oxygen source to prevent sulphide forming in the first instance, requiring two moles of peroxide compared to only one of pure oxygen:

$$\underset{\text{peroxide}}{2H_2O_2} \rightarrow \underset{\text{water}}{2H_2O} + \underset{\text{oxygen}}{O}$$

The rate at which hydrogen peroxide will oxidise H_2S in wastewater has been found to depend on the temperature, composition of the wastewater, the ratio of peroxide to sulphide used and the presence of a metal catalyst. The kinetics of the oxidation reaction is slow. Times of 20-80 minutes have been measured.

A storage tank and metering pump are used to apply the 50% or 30% concentrated solution of H_2O_2 to the sewage. Hydrogen peroxide is caustic and decomposes slowly when stored.

Biocide

Proprietary microbiocides are occasionally used. However, as they are intended to be used to reduce microbiological activity generally, not to sterilise the system, and as they have only limited activity against the sulphate reducers, they are not very effective at stopping the generation of H_2S.

Sewage Conditioner A

Sewage conditioner A is a mixture of ferric sulphate and nitric acid. H_2S is removed by precipitation to ferric sulphide. The chemical is metered into the sewage via a metering pump at the start of a rising main. The advantages of this treatment are that the running costs are low and that the problems are immediately eliminated. However, precise doses cannot be calculated theoretically, and a trial and error system is advised so that sufficient chemical is added to remove the H_2S with a 10% excess at the end of the sewer system.

The chemical is acidic and must be handled with care and stored in a well-ventilated area to eliminate fume problems. It is corrosive to most common metals, natural rubber, most thermosetting resins and concrete.

Chemicals used in the Treatment Approach

Oxygen Addition

If preventative injection is inappropriate, oxygen can be used to oxidise H_2S after formation. Sewage pipelines often permit sufficient reaction time (20 - 80 minutes) between oxygen and H_2S that has already formed, to effect its oxidation.

If odours have to be controlled at the WWTP using an oxygenation system, this can be done successfully provided the following factors are recognised.

- H2S oxidation is believed to be a relatively slow process. A rate of 2.5 mg/l total sulphide per hour has been quoted.
- If oxygenation is carried out in shallow channels or tanks, the dissolved oxygen concentration should be kept as low as possible (preferably less than 2 mg/l) to avoid poor dissolving efficiencies.
- Adequate oxygen is required to provide for sulphide oxidation (1 mg/l sulphide requires 1 to 1.5 mg/l of oxygen) and also normal respiration rates. If retention times are so long that the initial oxygen dose will be used up, then either the oxygen dose must be increased (at reduced efficiency) or several additional injection sites can be used, eg at the works inlet, primary tanks inlet and bid-flier distribution chamber.

Lime ($Ca(OH)_2$) or Caustic Soda

H_2S is an acidic gas and is more soluble in alkaline water than in pure water. If the pH of sewage is raised to about 8.5 or 9.0 with lime, most of the H_2S will be kept in solution (see Appendix C for details). This will control odours and corrosion because it is necessary for the

H_2S to come out of solution to create these problems. Lime addition also inhibits biological activity with alkaline conditions, and hence also creates sterile conditions in the sewage. Lime addition can also improve primary sedimentation treatment effectiveness.

In practice, given the large volumes of wastewater in question, large volumes of caustic are required to achieve the necessary level of control, and hence the operating costs are correspondingly high.

Ferric Chloride ($FeCl_3$)

Iron sulphides are insoluble. If ferric chloride is added to sewage containing sulphide a mixture of the iron sulphides is precipitated from solution so that sulphides cannot escape into the sewer air space.

The iron will also react with phosphates and other chelants present in wastewater and will seldom reduce the dissolved sulphides much below 1 to 2 mg/l. Iron salts may be useful in the treatment of very high sulphide industrial wastes. These salts are also effective oxidation catalysts for use with hydrogen peroxide. For preliminary design, about 5 mg $FeCl_3$ per mg of sulphide removed should be allowed.

Ferric chloride dosing can have high operating costs, depending on the availability of the ferric salt, and negative downstream treatment effects depending on the type of treatment processes utilised.

Nitrates

Sodium nitrate ($NaNO_3$) has been used as an oxygen source for sulphide control. Facultative and anaerobic bacteria, which are responsible for sulphate reduction and sulphide production prefer nitrate, when available, as an oxygen source over sulphate. When nitrate is present, bacteria will use it to the exclusion of sulphate. Normally, raw wastewater does not contain any nitrate so it must be added artificially. Doses vary from 10 to 30 mg nitrate per mg sulphide removed.

The various types of nitrate include, but are not limited to, calcium nitrate, sodium nitrate, potassium nitrate and ferric nitrate.

5.1.6 Biological Variation

Introduction

The use of cultured bacteria has been applied to the control of odour in wastewater treatment systems. Through the practise of bioaugmentation, the performance of indigenous bacterial populations can be enhanced by the addition of bacterial strains with specific degradative abilities. Bioaugmentatian can enhance the ability of an indigenous biomass to respond to process fluctuations or to degrade certain components of the waste stream resulting in improved treatment.

The main advantage is that odorous compounds can be selectively converted to non-odorous forms, eg amines to nitrates, sulphides to sulphate.

Principles of Technology

Bacterial isolates from contaminated sites and wastewater treatment systems tend to be dominated by vegetative, gram-negative type cells. The DNA of these types of cells most often contain the degradative abilities that are sought when addressing treatment difficulties associated with particular waste streams and organic compounds. Specifically cultured bacterial products can therefore be used to augment the natural degradation processes.

Bacterial strains are never found in isolation in the environment, but rather in complex interactive communities. Synergistic blending of individual strains results in final formulations that can outperform any single strain in the product. A specifically cultured bacterial product can rapidly neutralise odours without relying on the use of masking agents or hazardous chemical oxidisers. They can reduce or eliminate odour by degrading volatile amines and mercaptans. They can also enhance the activity of indigenous bacteria, resulting in higher rates of degradation.

Typical Applications

Cultured bacterial products are active against an array of nitrogen and sulphur containing compounds, classically associated with wastewater odour problems, including amines, ammonia, mercaptans and hydrogen sulphide. Factors that affect dosage include wastewater type, concentration, flow, the degree of mixing or aeration, and temperature.

Products are available in dry or liquid form. Typical wastewater processes where biodegradation is effective include:

- sludge thickening and drying bed operations;
- sludge hauling containers;
- landfills and composting;
- lagoons; and
- sewer lines.

Industry types where bioaugmentation can and has been applied include wastewater treatment (municipal and industrial), food processing, distillers, tanneries, pulp and paper, land application, wastewater hauling, spray irrigation, and anaerobic unit processes.

Application Example - Odour Control by Biological Augmentation

A building products company in the USA operates a large manufacturing facility which produces various building products, primarily wood panelling products. Wastewater generated by the manufacturing operations in the mill are discharged for solids removal and biological treatment to two large aerated lagoons. During the summer of 1993, the facility began having severe odour problems that emanated from its wastewater treatment facility. Some data indicated that sulphide concentrations in the lagoons were increasing.

Two potential courses of action were recommended by consultants.

1. Adjustment of the pH of the lagoon to 11 to tie up sulphide by making it less soluble. This was suggested because it worked before and it would be quick and simple. The downside of this procedure is that it would likely kill much of the biomass, not oxidise any chemical oxygen demand (COD) which serves to fuel the odour problem, and if odours are caused by substances other than sulphide (eg, butyric acid), pH adjustment may not help with these odours.

2. Convert the lagoons into a denitrifying reactor by adding nitrate and pre-acclimatised denitrifying microbes, ie, a bioaugmentation denitrification approach. As plant management had also indicated that time was critical in solving the odour problem, it was thus decided to add denitrifying micro-organisms supplied by a vendor. Adding the organisms would seed the lagoon and initiate the denitrification reaction more quickly.

The denitrification option was selected as the means to deal with the odour problem in the immediate short term. If oxygen were present in adequate amounts in the lagoon, sulphate would not be utilised as an electron acceptor (source of oxygen atoms). Nitrate also is a preferred electron acceptor over sulphate and hence sulphate production would be halted. The products of denitrification are nitrogen gas and carbon dioxide and neither is malodorous. If nitrate were added to the lagoon, COD would be metabolised using nitrate as an electron acceptor which would shut down odorous volatile acid and sulphide formation and consume excess COD.

The implementation of the bioaugmentation denitrification was achieved by adding nitrate, denitrifying microbes, and phosphorus. Less than 24 hours after initiation, odours out of the lagoon had stopped. Sulphide measurements in the high anaerobic activity area were around 10 mg/l before nitrate addition was started. The next day these levels were at 0. The programme was a huge success because odour production was halted so quickly and timely.

The bioaugmentation denitrification approach has the advantage of being able to be implemented relatively rapidly for addressing odour problems generated by unwanted anaerobic biological activity. Follow-on monitoring of this treatment situation also indicated that the nitrate and microbe addition only had to be added one other time until more aggressive aeration equipment was installed to provide a long-term solution. It appears that addition of the nitrate resulted in a relatively long-term disruption of sulphide production.

5.2 BUFFER ZONES

5.2.1 Introduction

This section examines the use of buffer areas as a land use management tool to separate incompatible land use activities. Essentially there are two types of buffer areas:

(a) transitional land uses between the WWTP and more sensitive activities; and

(b) physical separation distances between the actual plant and the plant boundaries.

In general, district plan provisions to control odour are based on the principle that there shall be no offensive or objectionable odour at the boundary of the site. Many WWTP facilities are unable to meet such a standard, despite employing "Best Practicable Option" (BPO) practices and undertaking expensive odour treatment works. Physical separation of the WWTP remains the best management tool for preventing or minimising odour nuisance effects on sensitive land uses.

Buffer distances may be necessary even where good odour control technologies and sound management practices are employed because equipment failure, accidents and unusual weather patterns can lead to odours affecting neighbouring properties. However, buffer distances may not be sufficient if the operators and designers do not get the technology and operation right, as odours can carry long distances.

The cost of control equipment can be prohibitively expensive, and can require significant areas of land. The more cost effective option is to identify, and purchase, odour buffer areas or to use a combination of less intensive treatment plus a buffer area. However, the solution for any individual site will be situation dependent.

Adequate buffer distances allow for uncontrolled events to dissipate without adverse effects on sensitive land uses. The use of buffer areas within the plant also has positive environmental effects in terms of providing opportunity to landscape and screen a WWTP and to locate non-odorous activities, such as offices and car parking, within an attractive open setting.

5.2.2 The Implications of Urban Encroachment

Remote or fringe locations to an urban area are naturally favoured for "nimby" (not-in-my-back-yard) activities such as WWTPs. Rural and industrial neighbours have traditionally been more tolerant of nuisances associated with treatment plants, and have acted as transitional areas between the WWTP and more sensitive land uses.

Until recently there has been a lack of explicit air quality considerations in land use planning which has, in some areas, resulted in sensitive land uses being located in close proximity or downwind of WWTPs. Such inappropriate planning and development practices continue in some districts. The development of housing and other people-intensive activities (eg, sports facilities and venues) in close proximity to WWTPs often causes conflict between the two activities. This can lead to controls being placed which constrain the WWTP operations or require the implementation of costly odour management programmes.

Good relationships should be built with local authority planners to make them aware of the implications for WWTPs of allowing sensitive land uses in close proximity to a WWTP. District plans need to ensure the integrated management of land uses. There will need to be a degree of tolerance, at a district level, of the generated effects of WWTP activities and constraints placed on the development of incompatible activities nearby. Provisions relating to separation distances when odorous activities are established should be considered when odorous activities are proposed.

Operators should adopt a cautious approach to intensifying land development around WWTPs and maintain a watching brief to proposed district plan reviews, resource consent applications and the like, to ensure they are not caught out by the establishment of more sensitive land uses nearby.

5.2.3 Establishing Appropriate Odour Buffers

Unless buffer zones are preserved by law or the land is owned by the operator, there is always the potential for buffer distances to erode over time. Acquiring adequate buffer areas at a later date can be fraught with difficulties. No land may be available or land purchase may be very expensive, particularly if land prices are high or inflated because of restrictive land practices, eg urban fringe areas. Lengthy and expensive appeals to the Environment Court are commonly required to expand WWTP boundaries.

In respect of internal buffer distances, no standard buffer areas are recommended as this will vary according to the method of treatment and disposal adopted, surrounding land use, and topographical and meteorological conditions. Many WWTPs around the country have relied on Department of Health guidelines to determine adequate buffer areas. However this is based on health effects, while odour buffer areas primarily address amenity effects to sensitive land uses. Every operator needs to be satisfied that proposed odour buffer areas are capable of preventing or minimising odour nuisance.

Where additional land cannot be purchased, common sense dictates that internal layout should locate all odorous or potentially odorous activities as far as practicable from sensitive boundaries.

5.2.4 What are Ideal Land Uses?

Rural, forestry and heavy industrial activities are often thought to be compatible with WWTPs. In general, rural activities are good neighbours for WWTPs. Occasional smells from farming practices are expected from time to time and there is a tolerance of low level odour nuisance from WWTPs as it is lost in the general background odour of the area. In addition, in rural areas the density of human population is much lower than urban areas, so the opportunity for odour nuisance to occur is lower. The distance from the odour sources at the WWTP to the sensitive receptors may be much greater than the distance to the WWTP boundary, creating a technical buffer distance.

However, the gradual encroachment of rural areas by rural/residential lifestyle properties introduces rural activities that are effectively urban in character. Hence there is no guarantee that larger lot sizes will reduce the incidence of nuisance complaint.

Industry is also a compatible land use adjacent to WWTPs. However, the encouragement of mixed business zoning by local authorities may intensify conflict as many reasonably sensitive land uses are now permitted as of right in industrial zones, eg, offices, travellers' accommodation, residential activities and food processing industries. In some circumstances, an advantage of industrial and commercial land use is that the density of human occupation is much greater during the day than at night. For odour sources close to the ground, such as most of those at WWTPs, meteorological conditions create poorer dispersion in the evenings and night-time due to the establishment of stable atmospheric conditions and inversion layers. Therefore, although at first interpretation the dispersion model results may indicate that offensive odours would occur, they may in fact not occur at a time of day when any person is occupying the land where the odour occurs. Therefore the potential for odour nuisance and adverse effects to occur is much reduced. This of course, would depend on the individual situation, and may not apply if industries are operating through the night, or there are any residences or accommodation facilities in the zone.

Passive parks, wetlands and bush areas are also less sensitive neighbours. This positive association can be reinforced by making a community aware that these areas also function as odour buffer areas.

Experience has found that recreational and sports parks do not always make for good neighbours with WWTPs. These activities expose large numbers of people to any odour nuisance from the WWTP and create conflict situations and complaints. As a general rule therefore, passive rather than active recreational facilities are more appropriate.

Residential areas are not considered to be compatible with WWTPs, although it is interesting to note the number of good quality homes developed in close proximity to existing WWTPs. People-intensive activities are also not compatible with WWTPs, eg, sports grounds, schools, commercial centres, tourism and entertainment venues.

5.2.5 Guidelines for Buffer Areas

The following is a 'starter' list of key parameters which should be considered for buffering WWTP facilities.

(a) During site selection for new or expanded WWTPs, carefully review the relevant district plan for surrounding land uses.

(b) Monitor statutory plan matters to ensure buffers are not eroded through applications for resource consents, or changes to plan policy or zones.

(c) Buffers should ideally be part of the WWTP site and if not owned by the operator, protected by designation or covenant to ensure their preservation.

(d) The buffer distance must be effective in reducing odour nuisance to a level that is commensurate with surrounding air quality and amenity.

(e) For buffer areas not owned as part of the WWTP, ideal land uses are heavy industry, general rural, forestry, passive recreation and open space.

(f) Active recreation, mixed use business areas, residential and people-intensive activities are generally not suitable as buffer areas.

5.3 BIOFILTRATION

5.3.1 Biofilter Application

Biological control of odour can be achieved by venting foul air containing biodegradable compounds in a gaseous or vapour phase, through a biologically active material. Biological odour control technologies have proven successful in many applications worldwide for controlling odorous and toxic volatile emissions. Biofiltration, the most common method of biological odour control, has become popular for treating odours from a range of industrial and municipal wastewater sources.

Due to comparatively low operating costs, this technology can provide a significant economic advantage over conventional air pollution control systems. Benefits include lower energy requirements, and the avoidance of hazardous waste generation and handling of corrosive chemicals.

Biofilters are the most cost-effective method of treating large volumes of foul air with relatively low concentrations of odorous compounds as are typically found at wastewater facilities. Gases of complex composition can be efficiently treated in biological systems. Biofiltration has also proved to be extremely effective in the control of odorous compounds commonly associated with sewer reticulation systems, most notably H_2S. Under optimum operating conditions, H_2S reduction rates as high as 99.9% are commonly achieved. This treatment method has moderate to high initial capital costs, but low running costs.

Biofilters typically consist of an air distribution system covered by a "bed" of filter media. Odorous air pumped into the air distribution network passes up through the biofilter media. The most common air distribution system consists of perforated PVC pipe. PVC pipe is readily available, has sufficient strength and is resistant to corrosion. Air for the bed is typically drawn from the odour source by one or more exhaust blowers with optional variable-speed controllers. Blower sizing should consider the volume of air flow to be treated, as well as the system's total pressure head loss. As the foul air passes through the bed, the organic material absorbs and biologically oxidises contaminants in the foul air. Compounds such as H_2S, organic sulphides and ammonia, are oxidised to carbon dioxide, water, and mineral salts.

A detailed discussion on the NZ experience of biofilters for odour control is given in Appendix B.

5.3.2 Biofilter Design Considerations

Biofilter design objectives should primarily seek to maximise the absorption/absorption of odorous compounds, and maximise microbial activity by producing favourable conditions for the survival and viability of the microorganisms. Design aspects are discussed briefly below. Further discussion can be found in WERF (1997), and Appendix B.

Biofilter Sizing

“Retention time” is calculated by dividing the influent air flow rate by the bed volume (this is not a true definition of retention time, where strictly the gross bed volume should be reduced by the actual volume of media material). Retention times typically range between 30 and 90 seconds based on gross media volume. Bed depth of early New Zealand biofilters was 300 mm, but more recent biofilters have depths of 600 mm to 1000 mm. The deeper biofilters, besides having a lower cost compared to shallow beds, appear to have better odour removal performance, presumably due to less risk of short circuit venting and the ability to form zones of differing pH with different biomass adapted to treatment of different compounds and intermediates. A depth of approximately 1 metre allows sufficient residence time while minimising biofilter land area requirements.

Types of Media

Selection of the biofilter active media is critical because the media supports the odour-treating microbial population. The medium must have the capacity to readily absorb water, while at the same time have a high pore space to minimise head loss. As these two characteristics tend to be mutually exclusive in most naturally occurring materials, blends of different materials may be mixed.

Several substrates may serve as a gas permeable filter matrix in a biofilter. Common media used in New Zealand are mixtures of scoria, bark chip, crushed shell, peat and loam topsoil.

Topsoil definition is difficult, but is seems that a free draining, friable, loam topsoil is superior to very sandy, or clay based topsail. Scoria or bark as a bulking agent enables the bed to drain water freely and conversely to allow upwards air flow. A dditional materials can be mixed in to increase porosity and to avoid compaction.

Biofilter Construction

Containment of the biofilter media can be either by walls (eg, a concrete block or timber wall) or compacted earth bund. The base of the biofilter should be lined with a membrane or clay barrier to prevent leachate entering groundwater. Foul air distribution is normally by a main header duct to one side of small biofilters, or in the centre for large biofilter units. Uniformity of media mixing and placement are also critical features. Grass cover is not recommended, as pilot trials have shown that odour removal efficiency is not increased. It is far easier to see if a short circuit vent has developed without grass cover.

The biofilter should be constructed as two or more sections which can be isolated from the air flow, so that the air can be turned off to one or more sections while the biofilter remains operational. Disconnection of the air flow is required for media maintenance or replacement, and also when watering, to allow the water to penetrate to the base of the media instead of being held up by opposing air flow stream.

It should be noted that biofilter underdrains produce a leachate with very low pH. Appropriate materials of construction, and treatment and discharge considerations, are required for leachate management.

5.3.3 Operating Considerations for Biofilters

Moisture content is one of the most critical operational parameters which must be controlled to maintain optimal filter performance. Odours have to be absorbed by moisture before bacteria can use these compounds as a food source. Optimal moisture content within biofilters ranges between 20 and 60 percent of saturation value on a weight basis depending on the media used. Necessary moisture within the biofilter is assured by direct application through a sprinkler system and/or by humidification of incoming air.

Both desiccation and excessive moisture are highly undesirable. Too little moisture has an adverse effect on the performance of a filter due to channelling and desiccation of micro-organisms, while too much moisture can cause increased back pressure and creation of anaerobic conditions. Moisture content should be checked at least weekly during dry periods.

Since biofilters function on the basis of microbial activity, the pH must be maintained at or near neutral to encourage maximum microbial activity and hence maximum odour treatment. Where H_2S is being treated, sulphuric acid will be produced. If a high loading of H_2S occurs over an extended period, acid build up may occur. In this instance, media replacement or pH adjustment will be required. Crushed shell or limestone chips may be included in the biofilter media to buffer and adjust the pH into the neutral range.

No matter how carefully a biofilter system is engineered, aging phenomena such as crusting of the biofilter surface, air short circuiting and acid build up can occur, resulting in reduced treatment efficiencies or increases in system back pressure. It is therefore desirable to allow for loosening or replacement of media when systems are designed.

5.3.4 Pitfalls and Tips for Biofilters

Some aspects of biofilter design and operation that should be observed include the following.

- The media needs to be kept loose and friable to minimise back pressure. Compaction increases back pressure, and when fan head capability is limited, failure to move air through the media will result in odour escape from the process areas.
- Media drying and cracking will cause short circuiting of foul air through the biofilter. It is necessary to provide an irrigation system and sometimes a pre-humidifier to maintain biofilter moisture. Caution is need in the supply of water to a pre-humidifier, because cold water sprays can cool a warm, humid air stream and actually remove moisture from the foul air if the water is cooler than the operating temperature of the biofilter.
- The biofilter bed must be designed to ensure foul air does not escape around the edges of the biofilter.
- Biofilter beds need to be dug over (cultivated) periodically if crusting or back pressure is a limiting factor. Cultivation intervals vary from 3 months to 5 years.
- Careful evaluation of geotextile fabrics for separation of the media from the gravel distribution layer is needed. Such fabrics can clog if the foul air is greasy or contains particulates. A blinding layer using pea gravel or bark chip is less prone to clogging.
- Methods of controlling acidification include: (1) blending crushed shell (CaCO3 source) into the filter mixture provides an alkalinity buffer; (2) blending iron filings promotes formation of iron sulphide then oxidation to elemental sulphur.
- Complete media replacement may be needed every 5 to 8 years, due to pH lowering, crusting, salt build-up or loss of porosity. Regular monitoring of these parameters is required. Biofilters treating high concentrations of odour may need more frequent media replacement.
- When setting air flow to a small biofilter, the speed of the fan can be adjusted to optimise the flow/head characteristics of the system using a small portable frequency controller, and then the motor and fan pulleys can be sized and fitted to match the fan speed required.

5.4 WET SCRUBBERS

5.4.1 Typical Applications

Wet scrubbers are used widely around the world for the control of odour compounds emitted from WWTPs. Some examples of relevant applications are given below.

Inlet Works

The main odorous gas emitted at the inlet works to WWTPs is H_2S. Wet scrubbers are able to remove 80% to 99.9% or more of the H_2S in an air stream. The milliscreen plant at the Green island WWTP (Dunedin City Council) uses a crossflow scrubber to remove in excess of 90% of H_2S.

Sludge Handling and Stabilisation Processes

Ammonia is evolved from sludge processes. The ammonia may be accompanied by other compounds such as amines and H_2S. Wet scrubbers are capable of removing 80% to 99% or more of the ammonia. Wet scrubbing involving several stages can be used to treat contaminated air. The North Shore WWTP uses a packed tower scrubber to remove ammonia from the ventilation air from its sludge stabilisation process.

As Pre-Treatment to Biofilter

Biofilters operate best and require minimum maintenance if there is a constant low to medium pollutant level load, the temperature of the air is below about 40°C, and if the air is well humidified. Wet scrubbers can be used to remove excess quantities of the odorous compounds, cool the air stream and humidify the air.

As Pre-Treatment to Carbon Bed Filter

Carbon bed filters can have a short and expensive bed life if the pollutant level is high. Wet scrubbers can be used ahead of carbon beds to prolong the life of the carbon bed by removing excess quantities of the odorous compounds. Special consideration needs to be given to the choice of the carbon as the gas leaving the wet scrubber and entering the carbon filter will be 100% saturated with water vapour.

5.4.2 Wet Scrubbing Principles

Introduction

The basic process involved in wet scrubbing is the contacting of a polluted gas stream with a scrubbing liquid, with the intention of transferring the pollutants from the air stream into the liquid stream. This is done by one or more of the following mechanisms:

- absorption of pollutant vapours into scrubbing liquid;
- chemical reaction of pollutant compounds in scrubbing liquid
- condensation of odorous vapours.

The process of absorption of vapours into the liquid is widely termed “mass transfer”.

Packed Tower Scrubbers

The most efficient scrubber design for gas absorption is the packed tower. Figure 5.4.1 illustrates one version of the packed tower scrubber, the vertical counter-current type. The packed tower scrubber contains a bed of packing irrigated with the scrubbing liquid. The gas flows through the packing where it contacts the liquid, then passes through an entrainment separator to prevent scrubbing solution carryover.

The bed of packing is usually a randomly dumped plastic moulding with the purpose of providing the most efficient contact between the scrubbing liquid and the gas. There are many different packings on the market with different configurations and different surface areas per unit volume. There are also a number of other styles of scrubbers that use a variety of methods to achieve a high liquid surface area that contacts the gaseous compounds and removes them.

The most important element is the packing's ability to generate fresh liquid surface area that is able to absorb the gaseous pollutants. This is achieved by providing not large, continuous surfaces, but a large number of small, discontinuous surfaces and hold up points such as relatively fine filaments and projections.

There are many variations of the packed tower scrubber including the spray tower. Instead of a plastic packing to provide mass transfer, the spray tower uses spray nozzles to generate very fine fogs or mists of scrubber liquid to achieve large surface areas for gas-liquid contact and mass transfer. Generally spray towers are not as efficient as packed towers and so are not widely used.

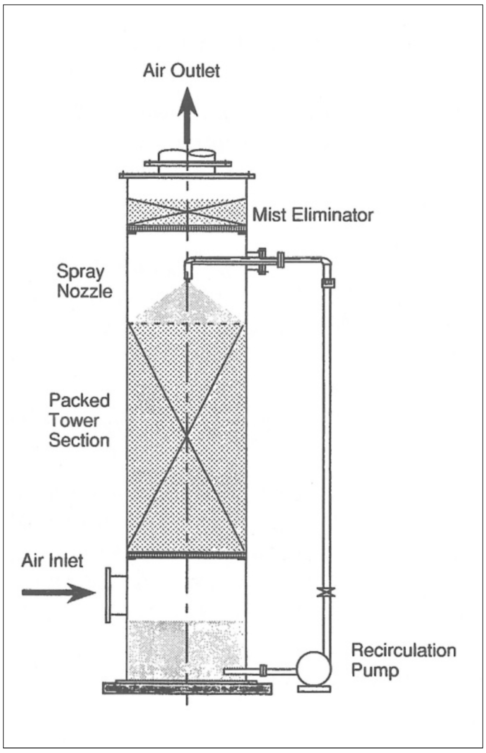

FIGURE 5.4.1: PACKED TOWER

5.4.3 Scrubber Selection

When a packed tower is to be designed for the scrubbing of a specific gas such as H_2S or ammonia, the following procedure is used to determine the appropriate scrubber configuration.

Scrubbing Liquid Choice

Water

Water can be used to scrub water-soluble gases. Generally, water would be used on a once through basis. The source of water could be treated wastewater, and the water would be pumped back to the inlet of the WWTP.

Caustic Solution

A scrubbing solution with a pH of between 9 and 12 is generally considered ideal to absorb H_2S and other odours from the air stream. The operation of scrubbers at a pH of between 9 and 12 requires the addition of sodium hydroxide (caustic) to adjust the pH of the make-up water and to maintain the scrubbing solution pH as H_2S and carbon dioxide are absorbed in the scrubber.

The following reaction applies:

H_2S	+	$2NaOH$	$\rightarrow$	Na_2S	+	$2H_2O$
hydrogen sulphide		sodium hydroxide		sodium sulphide		water

To minimise chemical consumption, most of the scrubbing solution is recirculated.

Packed towers using a caustic solution are able to achieve about 80% to 90% scrubbing efficiency with H_2S.

Caustic Solution with Oxidant

To achieve greater scrubbing of H_2S, an oxidant is used to oxidise Na_2S and stop it from hindering the absorption of further H_2S. A second oxidation stage can also be used to prevent the odorous (sulphur) compounds being released from the scrubber liquor upon a drop in pH, such as would occur if the blow-down water is discharged back to the sewer. Oxidants that can be used include sodium hypochlorite, hydrogen peroxide, potassium permanganate, and iron compounds. Catalytic oxidisers can also be used to enhance the oxidising capacity of the scrubbing liquid.

The amount of oxidant needed is high, being 3 to 4 times the molar amount of H_2S. Sodium hypochlorite is the most widely used oxidant. It has the ability to oxidise a large range of sulphur-based compounds and other water-soluble odorous compounds. Hydrogen peroxide has been considered more often in recent times as it eliminates the formation of chlorinated organic by-products and the chlorine odour commonly found in a hypochlorite scrubber. Potassium permanganate is not often used.

With the use of an oxidant, a packed tower can achieve efficiencies of over 97% in H_2S removal.

Catalytically Enhanced Scrubbing

For greater oxidation of a wider range of odorous compounds, catalytically enhanced scrubbing can be done with the Odorguard process. This is based on conventional alkaline bleach scrubbing with sodium hydroxide and sodium hypochlorite, and incorporates a catalytic reactor on the liquid recirculation stream that gives enhanced oxidation of a wide range of odorous compounds and low level volatile organic compounds captured by the scrubber. Installations at WWTPs in the United Kingdom and Ireland have achieved over 99% removal efficiencies for not only H_2S but also methyl mercaptan, dimethyl sulphide, and other sulphide compounds. The process also overcomes the disadvantages of conventional hypochlorite scrubbers described above, and reduces the consumption of hypochlorite.

Acid Solution

Gases such as ammonia and amines are more soluble in an acid solution. Efficiencies in excess of 97% are readily achieved.

Multiple Stages

When there are several pollutants requiring different scrubbing solutions or equipment, then it is necessary to have multiple stages of scrubbing.

Packed beds can be fouled with particulates, so if there are particulates plus a gas present, a venturi scrubber is placed ahead of the packed tower.

If, for example, both ammonia and H_2S gases are in the same stream and need scrubbing, then two stages of scrubbing are required. Typically the ammonia is scrubbed first in an acid stage, and then the H_2S is scrubbed in a caustic stage.

If very high scrubbing efficiencies in excess of 99.9% are required, then two stages of packed towers in series can be used.

Another example of multiple stages is to minimise chemical consumption of oxidant when scrubbing H_2S:

Stage 1	80% removal of H_2S using caustic only
Stage 2	97% removal of H_2S using caustic plus oxidant
TOTAL:	> 99% overall scrubbing efficiency for removal of H_2S

As oxidant is only used in stage 2, the oxidant can react with only 20% of H_2S, thus significantly reducing oxidant consumption costs.

5.4.4 Operational Notes

Automatic Chemical Dosing

For the most efficient use of chemicals, the addition of chemicals is automated. This ensures chemicals are added only on demand when there is a pollutant load. For caustic and acid scrubbing liquids, pH probes are used to activate and control the dosing pumps. Similarly an ORP (oxidation - reduction - potential) probe is used to control the dosing of the oxidant. The measuring points and dosing points in the system must be selected carefully to achieve a fast response time and minimise the escape of odorous compounds. Generally, dosing is best done into the circulating pump inlet with the probes in the scrubber liquid sump.

Carbon Dioxide Absorption

In an alkaline scrubber, carbon dioxide will also be absorbed if the pH is above about 9.5. If the scrubbing water makeup contains calcium irons, precipitation of calcium carbonate onto the packing can occur. If calcium carbonate deposits onto the packing a regular acid washing is needed to remove it. If the scrubber uses any chlorine-based oxidant, then great care must be taken to avoid the mixing of chlorine with acid as dangerous chlorine gas can be formed.

Ammonia and Chlorine

It is advisable not to put a stream containing ammonia through a chlorine-based scrubber as odorous chloramines can be formed that may be more odorous than the gases being scrubbed.

It is usually advisable to scrub the ammonia in a separate stage ahead of the chlorine-based scrubber.

Swimming Pool-Type Odours

A potential problem with chlorine-based scrubbers is the release of objectionable swimming pool-type odours. This happens especially when the sodium hypochlorite is overdosed. Particular attention must be given to the design of the instrumentation and dosing systems to avoid overdosing.

Materials of Construction

The combinations of H_2S, ammonia, sodium hypochlorite and high humidity levels make for a very corrosive environment. The preferred materials of construction are normally fibreglass and plastics which have proven themselves over many years. Fibreglass ducting is normally constructed from isophthalic polyester resin. Care must also be taken with electrical connections as H_2S in particular can cause problems here.

Scrubber Slowdown

To avoid build-up of salts in solution that may deposit out or interfere with absorption, a portion of the scrubber liquid must be blown down to waste. The actual blowdown is determined after installation and is normally in the range 0.5% to 5% of the scrubber recirculation rate. The blowdown must be disposed of in a place that does not cause the release of more odours. Disposal to the head works of the WWTP is a common practice.

Odour Removal

Due to the often complex combination of compounds which may contribute to the odour of an air stream, the odour removal capability of a scrubber cannot be calculated in terms of odour units. Where a specified reduction in odour units is required, then pilot plant work must be done.

There is a limit in reduction achievable, and generally a wet scrubber is not able to achieve an exit odour concentration of less than 300 to 500 OU/m^3. The use of catalytically enhanced scrubbing such as the Odorguard process can achieve a discharge with lower odour units.

Use Stack for Final Dispersion

A wet scrubber has an exit stream in a contained duct, so this can be directed up a suitably high stack to achieve maximum dispersion and the lowest odour concentrations outside the property boundary. Dispersion of the plume can be modelled using atmospheric dispersion models (Chapter 4) to optimise stack height.

5.5 CHEMICAL SPRAYS

5.5.1 Introduction

Odour problems can be treated at the source, or by treating the symptom. One method of "treating the symptom" is to use chemical sprays to combat odours in the ambient air, in WWTPs, pumping stations and other industrial wastewater facilities.

Generally, chemical sprays are grouped into four categories:

(a) masking agents
(b) counteractants (odour neutralising)
(c) reactants (gas phase chemical reaction)
(d) combined counteractant/reactant formulations.

Masking agents and counteractants are most effectively used in atomising systems to achieve good contact between the gas and the chemical; air-assisted and hydraulic systems are common. These may be low or high pressure systems. High pressure systems are normally more expensive in both installation and ongoing fluid costs. Both methods can be automated to reduce operating labour costs, and ongoing fluid costs.

None of these techniques should ever be used to cover or mask the presence of potentially dangerous gases, unless adequate gas detection equipment is installed and maintained on a permanent basis, especially indoors. These methods can be effective as an emergency or short-term solution, and where capital expenditure is limited. Generally, long-term control of the odour problem at its source will be necessary.

5.5.2 Masking Agents

Masking agents are sometimes used to cover or overpower the odorous compounds with another odour or odours perceived to be more pleasant. Though the total odour of the resultant mixture is greater than the original source, the resultant odour can be perceived as less objectionable. Without any chemical reaction occurring, the individual constituents of the odour remain unchanged.

The main advantages of masking agents are their low cost, and generally non-hazardous nature. However, material safety data sheets should be analysed before atomising masking agents into the air. A disadvantage is the tendency of masking agents to separate from the offensive odour downwind. The fragrance can be as offensive as the original odour. Applying high concentrations of masking agents for short periods of time can provide a simple method to track and identify a specific odour source in an affected area of the community.

The effectiveness of masking agents is difficult to predict because of varying odour characteristics, but performance has been acceptable in many cases. It is usually considered a short-term control method until more permanent and reliable measures are available.

5.5.3 Counteractants and Reactants

Odour counteractants add one odorous substance to another, so that the resulting mixture has little or no odour. Counteractants use a process that interacts with the offensive odour. Counteractants usually have a neutral pH, are easy and safe to handle, and are only slightly more expensive that masking agents. Counteractants work best on organic odorous compounds.

Terpenes, commonly called “essential oils” and found in trees, grasses, and flowers, are very potent in several types of neutralisation reactions. Because terpenes and terpenoids are highly reactive, simply exposing any gaseous stream to them will initiate many chemical reactions, so long as the following three criteria are met.

(a) The molecules must collide. This is accomplished by atomising the treatment solution into the air stream.

(b) The colliding molecules must be positioned for transition. A fine micron size is essential to maintain exposure and contact.

(c) The collision must have enough energy to form the transition state. This is accomplished by the atomising force, and a carrier such as isopropyl alcohol (IPA), and the energy of the highly reactive components themselves.

It has been established that scientifically blended essential ails have the capacity to neutralise families of offensive organic odours. They can be beneficial in that they are not as specific in their reactions as chemical treatments.

Counteractants blended with reactant chemicals also have the potential to make small pH adjustments, and to some extent, sufficiently reduce gas concentrations to affect the offensive odour concentration level.

5.5.4 Experiences with Application of Chemical Sprays

Example 1

High Tech Pure Air Corporation Limited commissioned Envirolab Geotest Limited to conduct laboratory evaluation of their odour neutralising aerosol named High Tech Pure Air (HTPA). An experimental apparatus was constructed in a form of 120 litre glass chamber fitted with a fan for adequate gas and aerosol mixing. Two ports were introduced: one for sample abstraction, and another for gas and HTPA dosing.

The gases tested were analytical grade hydrogen sulphide (H_2S) and ammonia (NH_3). The chamber was filled with the desired concentration of gas and after a delay allowing for dispersion, the initial gas concentration was measured with Gastec gas detection tubes. The chamber was then sprayed with 10 ml of 1:100 dilution of HTPA in deionised water. At the end of each run the chamber was cleaned and flushed with nitrogen gas to remove trace levels of the test gas.

Residual gas concentration on contact and after 5, 10, and 15 minutes was measured using Gastec tubes. The results indicated that the initial 50 ppmv H_2S concentration was halved at contact time, and reduced to below detection limit (0.5 ppmv) after 5 minutes of contact. Similarly, the ammonia concentration was reduced from 50 to 10 ppm immediately after the application of the masking agent, and removed below its detection limit (0.5 ppmv) after 5 minutes of contact.

A parallel experiment was conducted for sulphur dioxide (SO_2). At an initial SO_2 concentration of 50 ppmv, the gas could not be detected (< 0.5 ppm) on contact with 30 ml of HTPA diluted 1:1000 with water. At 100 ppm it was reduced to 10 ppmv on contact, and below detection limit after 5 minutes.

Example 2

Lincoln Environmental has conducted trials testing the effectiveness of three commonly available odour control chemicals in a sewage treatment context. The amount of odour reduction within a headwork's odour extraction duct and from the surface of oxidation ponds was measured using dynamic dilution olfactometry. The application of the chemicals did not result in any statistically significant reduction in the odour emissions in all cases.

Example 3

An “Air Repair” system was installed around the perimeter of an uncovered digested sludge thickening tank at the Hamilton WWTP. The Air Repair system is a system that sprays an odour-neutralising chemical into the air immediately above the surface of the tank, in theory neutralising any malodours at the point of release from the tank surface. To quantify the odour reduction in the ambient air as a result of the Air Repair system, ambient air samples were collected immediately downwind (less than 2m away) from the sludge thickening tank with the Air Repair system off and on, and tested by dynamic dilution olfactometry to determine the odour concentration.

The ambient odour concentrations measured downwind of the sludge thickening tank were close to the olfactometer's limit of detection, and there was no statistically significant difference between the two results. Two other reasons for the lack of difference between the samples could have been that the samples were collected too close to the source and the odour neutralising chemical had not had time to react sufficiently, or that the odour from the additives in the neutralising chemical itself was too strong so close to the spray nozzles. This illustrates the difficulty of quantifying effects of such applications in the field - the samples could not have been collected further downwind because natural dispersion would have diluted the odours too much for olfactometry, and there would be no guarantee that all of the samples were collected exactly downwind of the source in the centreline of the plume of odour.

The sampling was not able to distinguish between the odour effects with and without the Air Repair System in operation. However, WWTP operators and the sampling team reported the effectiveness of the Air Repair System as follows: "*noticeable when it came on, as there was an absence of the sludge smell, which returned when the Air Repair System pump was not operating*". Therefore, it could be concluded that the Air Repair system at least reduced the offensiveness of the odour discharge.

5.6 OTHER PROCESSES

5.6.1 Vapour - Solid Phase Adsorption

Gas adsorption is the process in which one or more components are removed from a gas through adherence to a solid surface. The attractive force holding the gas molecule at the surface may be either physical (physical adsorption) or chemical (chemisorption). Adsorption is widely used for odour control. Equilibrium relationships associated with gas-liquid adsorption, unlike those involved in absorption, lend themselves to the removal of low concentrations of contaminants. However, because of the complex mass transfer mechanisms involved and the great variability in adsorbent physical properties, adsorption is less suitable to generalised design from basic physical data than is absorption.

Adsorption is accomplished primarily on the surfaces of external passages within small porous particles. The three basic mass transfer processes occur as follows; mass transfer from the bulk gas to the particle surface, diffusion through the passages within the particle, and adsorption on the internal particle surfaces.

The most commonly used adsorbent material for odours is activated carbon. Activated carbon is able to effect and maximise gas-solid adsorption because it is a material with a large surface area contained in a small practical volume. Due to the non-polar nature of its surface, activated carbon has the ability to adsorb organic and some inorganic materials in preference to water vapour. The materials and amounts adsorbed depend on the physical and chemical characteristics of the specific compound. In general, organics having molecular weights over 45 and boiling points over 0°C will be adsorbed. Additional factors affecting carbon adsorption include: surface area of adsorbent; concentration of adsorbate in the gas phase; type of adsorbate; and contact time.

Activated alumina and silica gel can also be used as solid adsorbents. Chemically reactive adsorbents such as potassium permanganate and manganese dioxide are also used. Description and evaluation of adsorption methods are outlined below.

Activated Carbon

Activated carbon adsorption has been used extensively in wastewater treatment plants in the USA and Japan for odour control, and occasionally in New Zealand. In this process, odorous air passes through a bed of activated carbon. Odorous constituents adsorb to surfaces within the pore spaces of the carbon. Also, chemical oxidation or reduction of some compounds can occur. As these surfaces become occupied, efficiency degrades and the carbon has to be replaced or regenerated. Carbon is most effective on higher molecular weight polar molecules such as the organic sulphur compounds. Thus, carbon is often the technology of choice to follow chemical wet scrubbers that are typically less effective at removing these odours. Because of the cost of activated carbon, adsorption of H_2S in carbon adsorbers is expensive if there is any significant concentration of H_2S (above about 1 to 3 ppm). Activated carbon is also subject to saturation by excessive water vapour in the odorous air stream, and biological overgrowths.

Surface areas of commercial activated carbons vary from 1,000 to 1,400 m^2/g. Generally, the greater the surface area, the greater the adsorption capacity. Adsorption capacity increases as a function of pressure, concentration, molecular weight, and boiling point. On the other hand, the lower the temperature of the vapour stream, the higher the adsorption capacity. High relative humidity (greater than 60%) can reduce the adsorption of low molecular-weight, low boiling-point organics.

Activated carbon can be impregnated with caustic to promote a chemical reaction along with adsorption which will increase the rate at which H_2S is oxidised. However, caustic impregnated carbon is difficult to regenerate and has resulted in bed fires and explosions. As a result, this material is not recommended except in very specific applications.

Typically, adsorber vessels are made of fibreglass reinforced plastic (FRP); however, concrete and stainless steel can been used if adequately protected. Condensate from the adsorber can be highly acidic due to production of sulphuric acid from H_2S oxidation. Adsorbers operate at a higher air inlet pressure than chemical scrubbers due to the greater head loss through the carbon bed. While more carbon provides additional adsorption capacity, increased depth in the bed also increases air pressure requirements. In normal operation, the pressure drop through the bed may increase as contaminants are adsorbed onto the carbon particles. When odours begin to break through or the pressure drop becomes high, the carbon material can be regenerated or replaced. When unimpregnated carbon is used, regeneration is achieved by removing the carbon, regenerating by heat, and then reinstalling the carbon. Although complicated and cumbersome, regeneration can also be achieved in place using steam or hot air but has not been cost-effective due to energy usage and restrictions imposed on Air Permits for release of nuisance compounds.

To maximise the efficiency of the adsorption system, all the odorous gas must come in contact with the activated carbon. The efficiency of the odour removal will remain fairly constant until the carbon is completely saturated. Consequently, it may be necessary to monitor the gas leaving the adsorption bed.

Several manufacturers produce small tiller panels of activated carbon and other adsorbents that are suitable for use in air-handling units. These types of units are generally used in heating, ventilating, and air conditioning (HVAC) systems serving wastewater treatment plant control rooms and switch gear areas where small concentrations of H_2S can jeopardise sensitive electrical and electronic equipment. They are also appropriate in systems serving office areas, laboratories, and staff amenity areas. In this case, the incremental cost of the adsorbent filters is low relative to the equipment being protected. In addition, because H_2S concentrations are much lower in the HVAC intake than in process areas, the adsorbents are effective for longer periods of time.

Potassium Permanganate/Activated Alumina (PPAA)

PPAA is a solid, pelletised, oxidising system composed of activated alumina (Al_2O_3)impregnated with potassium permanganate ($KMnO_4$). In this form it is claimed that odours are initially both absorbed and adsorbed, then oxidised.

PPAA media consists of small spheres of activated alumina impregnated with permanganate. As the MnO_4 is reduced by odours, additional MnO_4 is leached from the interiors of the beads. In the life analysis, the oxidant (MnO_4 and MnO_2, which is intermediary in the reduction of MnO_4) is extracted and measured. The percentage life expended is typically determined from a standard graph furnished by the supplier. Experience has shown that the useful life of the material is less than would be predicted by the analysis, and full utilisation of the oxidant cannot be achieved. Therefore, it is likely that odour breakthroughs will occur before the oxidant is substantially consumed.

PPAA is effective in controlling a wide array of odorous compounds such as H_2S, methyl and butyl mercaptan, indole, and skatole. Unlike activated carbon adsorbers, the head loss through the beds is smaller because the air stream does not totally pass through the media. However, the adsorptive capacity is relatively low for many odorous compounds and therefore PPAA may not be economical when high concentrations of odorous compounds are present.

5.6.2 Ultra-Violet Light/Ozone

The current understanding of the destructive deodorisation of air is based on the principle that ozone is not directly formed from oxygen, but that radiant energy in the ultra-violet region of the spectrum would break the oxygen molecule into oxygen atoms which are extremely powerful oxidants. If the oxygen atoms come into contact with organic molecules in foul air, the atoms will attach to the organic molecules, oxidising and hence deodorising them. If, on the other hand, the air is free of organic molecules, the oxygen atoms (O) will join an oxygen molecule (O_2), forming ozone (O_3).

Since the life of an oxygen atom is in the order of microseconds, it must be an efficient oxidiser in the gaseous phase, and it must be generated "in-situ". Therefore, a foul air stream must pass through a radiation field of defined wavelengths and intensity, allowing for a certain residence time of the foul air in the radiation field, for the reactions to take place. If a smell of ozone is prevailing at the treatment discharge, it indicates that the odorous molecules have been oxidised, hence made odourless, and that there is a surplus of oxygen atoms.

The radiation field is produced by ultra-violet (UV) generators of the monokymatic (low pressure) mercury-discharge type in quartz tubes, designed to have a high output in short UV wavelengths which are particularly effective in the breaking up of oxygen molecules. The UV radiation field is contained within a chamber of specified dimensions allowing for the required irradiation/detention time. Manufacturers of UV light systems suggest a residence time of 7-10 seconds in the chamber.

Watercare Services' experiences with UV systems are outlined in the case study in Chapter 7.3.

5.6.3 Thermal Oxidation (Incineration)

Thermal oxidation has not been commonly used in wastewater treatment in New Zealand, and the main example is the incinerator at the Tahuna WWTP in Dunedin. This is also true of overseas experiences. However, thermal oxidation is used to a greater extent both here and overseas for treatment of odours from industrial processes such as rendering plants, printing presses, petroleum and chemical industries, and for disposal (and odour destruction) of landfill gas. The practice of flaring or burning digester gas at WWTPs also effects the thermal oxidation of the highly odorous gases. Other WWTP applications include routing strong four air streams, such as from a centrifuge in a sludge dewatering facility, to sludge furnaces for use as combustion air. In these cases, an afterburner is often required as well to achieve sufficient reduction of odours.

Principles and application of thermal oxidation are discussed in WEF Manual of Practice No. 22 (WEF, 1995). The discussion from that document has been summarised below.

Thermal oxidation is a broad term that describes the use of oxygen or air at high temperatures to destroy odorous compounds or volatile organic compounds (VOCs). This method of odour control has also been called afterburning, fume incineration, direct-flame oxidation, or other names that depict a special feature of the combustion or heat-recovery system. Examples of specialised thermal oxidation processes include catalytic converters, recuperative thermal oxidisers, and regenerative afterburners.

The destruction of odorous compounds by thermal oxidation is a complex combustion process that is dependent on many interacting chemical and physical phenomena. First, there must be sufficient concentrations of combustible reactants, typically hydrocarbons and oxygen, to sustain the combustion process. Except for digester gas, most odorous air streams in wastewater facilities do not contain sufficient concentrations of hydrocarbons to sustain combustion, so an external fuel such as fuel oil, natural gas, or LPG is required to supplement the combustion process. The amount of external fuel required will depend on the type and concentration of hydrocarbons in the odorous air, and the moisture content of the air stream. When additional fuel is added, it is important to make sure sufficient oxygen is available to sustain the combustion process, otherwise partially oxidised compounds such as carbon monoxide, aldehydes and ketones will form which can have strong odours.

The speed and efficiency of the combustion reaction increases as temperature increases. Heat produced during combustion of one molecule can increase the combustion speed and efficiency of the next molecule. Once the correct mix of fuel and oxygen is achieved, the efficiency of odour destruction is determined by the time, temperature, and turbulence of the reaction. If insufficient time is provided at a given temperature, the destruction efficiency will be less than 100%. Different odorants require different times and temperatures for destruction. Some examples are shown in Table 5.6.1.

Emissions from thermal oxidisers have a residual odour resulting from the small amount of uncombusted hydrocarbons and inorganic compounds, plus products of combustion. However, most thermal oxidisers reduce the odour of the untreated air stream by at least 90% and often by 99%. It is important to remember that there will be some residual odour, and that the correct type of thermal oxidiser is selected for the type and concentration of odorant.

TABLE 5.6.1: EXAMPLES OF THERMAL DESTRUCTION TEMPERATURES (DEGREES CELCIUS) (FROM WEF (1995))

Retention Time:	**0.5 seconds**		**1.0 seconds**		**2.0 seconds**	
Destruction Efficiency:	**95%**	**99%**	**95%**	**99%**	**95%**	**99%**
Compound						
Toluene	732	744	713	725	695	706
Xylene	1157	1180	1122	1143	1088	1108
Benzene	809	835	768	793	730	753
Glycol ethers	784	804	754	773	726	744

5.7 EVALUATION OF ODOUR CONTROL METHODS

The advantages and disadvantages of the most commonly used odour control technologies are summarised in Table 5.7.1. It should be noted that these evaluations are from American sources, where chemicals are cheaper and the use of scrubbers is more widespread than in New Zealand.

TABLE 5.7.1: ADVANTAGES AND DISADVANTAGES OF ODOROUS AIR TREATMENT SYSTEMS (FROM WEF (1995))	
Advantages	**Disadvantages**
RECIRCULATING LIQUID PACKED BED SCRUBBERS USING OXIDANTS	
• Wide-scale use of packed bed systems for gas transfer to liquid. • Ability to handle large gas flows in economical system size. • Ability to handle rapid increases in concentrations of H_2S and perhaps other odorous compounds. • High mass transfer efficiency with proper design and operation. • Well suited to removal of highly soluble compounds.	• Odorous compounds in solution are recycles and may be stripped into outlet gas stream. • Chemical blowdown can result in high chemical usage if not handled properly. • Chemical carry over in treated gas can occur. • Requires softened water to prevent scalding. • Required additional use of oxidant like hypochlorite to be effective on complex odours. • Need to handle hazardous chemicals. • Large vertical towers can be aesthetic problem. • Not well suited to low-solubility organic odorants. • Nozzle maintenance is often required as well as acid washing of packing media.
CAUSTIC ABSORPTION SCRUBBING	
• Highly efficient and reliable removal of H_2S from foul air can be accomplished. • High gas flow rates can be handled effectively. • Ability to handle widely fluctuating concentrations of H_2S. • Often used as the first stage of treatment where high H_2S levels occur.	• Proper handling of the sulphide-containing recycle stream is mandatory, because no "treatment" of H_2S occurs; H_2S is only transferred to the liquid phase. • High pH operation can cause formation of deposits on nozzled and other surfaces. • Process is typically not used on compounds other than H_2S.
BIOLOGICAL BULK MEDIA BASED SYSTEM (BIOFILTER)	
• Ability to treat wide variety of odorous compounds at low concentrations. • Simple operation. • No chemicals typically required. • Provides dispersed discharge. • Relatively low capital and operating costs. • Typically no sidestreams requiring treatment (except leachate run-off).	• Occupies space for units treating large gas flow rates. • Requires pressure (energy) to force foul air through the media. • Moisture and pH control is required. • Discharge at ground level restricts further dilution by vertical mixing. • Downtime for media replacement must be planned.
ACTIVATED CARBON ADSORPTION	
• Consistently reliable operation on many odorous compounds at low concentrations. • Simple operating for most systems. • Additive compounds can increase adsorbent material's treatment capability. • High gas flow rates can be accommodated in multiple units.	• Adsorbent used up rapidly at high inlet concentrations of odorous compounds. • Regeneration of adsorbent material can be costly, difficult, and time-consuming. • Caustic impregnated carbon systems must be handled cautiously due to extra reactively of the material. • Foul air streams containing particulate matter or high moisture content may plus the adsorbent material. • Disposal of spent material and regeneration fluids may be a problem.

Table cont'd overleaf

TABLE 5.7.1: ADVANTAGES AND DISADVANTAGES OF ODOROUS AIR TREATMENT SYSTEMS (FROM WEF (1995))	
Advantages	**Disadvantages**
THERMAL OXIDATION	
• Broad spectrum control for all types of odour regardless of the chemical characteristics of the odorants. • Performance is independent of inlet odour intensity. • Effective for treating air streams with variable odour levels. • Performance can be uniform and predictable. • Operator attention is typically low because control is typically provided by temperature adjustment. • Atmospheric dispersion is enhanced by warm exhaust.	• Can be high fuel usage and, therefore, high cost if modern techniques are not employed. • Requires different type of operator awareness and training (different from most wastewater processes). • High temperature and fuel use can produce NO_x and SO_x emissions. • Failures in mechanical equipment cause down time and maintenance problems. • Tall discharge stack.

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6. COLLECTION SYSTEMS AND PUMPING STATIONS

6.1 INTRODUCTION

In the past 5-10 years odour control associated with sewage reticulation has gained increasing public attention and decreasing public acceptance. As a result of urban development, pumping stations and sewers which were originally constructed, in undeveloped areas are now surrounded by residential or commercial development.

Sewerage systems are generally considered "closed" systems, with sewage and wastewater contained within pipes from the source to the point of treatment and/or discharge. If sewerage systems were truly "closed", the issue of odour treatment would be confined to the point of discharge and hence be reasonably manageable. Unfortunately, a truly "closed" system is not practicable. Sewerage systems generally utilise a combination of gravity and pumped sections, with the number and location of pumping stations dictated by distance and terrain. Pumping stations provide an "opening" in the system at which foul air can be released to the atmosphere. Similarly, manholes, of which thousands can exist in larger urban areas, are a necessary part of any buried piping system. These manholes present a potential point at which foul air can also be released to atmosphere. Siphon chambers also create a potentially major odour source, "blocking" the natural flow of air within a sewer and forcing an alternative air passage to be found. Therefore in practice, sewage collection systems contain large numbers of points at which foul air can be released to the atmosphere, whether by design or otherwise.

The main odour sources from the reticulation system are:

- pumping station wet well exhausts
- pumping station and sewer overflow pipes
- customer terminal vents
- manhole lids in pressurised sections of sewer
- reticulation vent pipes
- construction or repair works
- overflowed sewage.

In a sewer reticulation system, the requirements for odour management are very closely aligned with the process of sewer ventilation. In parallel with the generation of objectionable odours, the gases from the decomposition of sewage can be very corrosive to the sewer itself and all its manholes and other structures. In many situations, the odours which are discharged from the sewers at pumping stations and points of positive pressure are an indication that other aspects of sewer ventilation are not operating correctly.

6.2 ISSUES FACED BY SEWERAGE SYSTEM OPERATORS

Three main issues faced by sewerage system operators in relation to sewer gas are:

(a) corrosion of equipment and structures
(b) safety of personnel working within the wastewater system
(c) odour management.

These issues can be mitigated to a large degree by proper ventilation of the sewers, and are discussed briefly in subsections 6.2.1 - 6.2.3.

6.2.1 Corrosion

Corrosion within sewerage systems is a major problem. Hydrogen sulphide (H_2S) that is generated during the decomposition of sewage escapes as a gas from solution in a sewer, and may be oxidised on exposed surfaces.

If surfaces are kept dry through ventilation, free sulphur may be formed, but under moist conditions bacteria oxidise H_2S to sulphuric acid, with this acid leading to corrosion. Cementacious products (concrete, mortar, and asbestos cement), and most metals are rapidly corroded by the acid. In addition to bacteria, anaerobic conditions also lead to sulphide generation through the reduction of sulphate.

Under moist conditions, a slime layer builds up within sewer pipes and pumping station wet wells. This slime layer is the site of intense microbiological activity, and it is here that the anaerobic conditions necessary for sulphate reduction and sulphide generation occur.

While corrosion of sewers is generally a long term problem, often not given adequate priority, the associated costs are high when sewer replacement and/or refurbishment are the end result.

6.2.2 Safety

Many potentially toxic substances and/or gases can find their way into the sewerage system, as illustrated by the tragic deaths of three sewer workers in Auckland in February 1999. While some such as H_2S occur naturally, others such as toluene and xylene are sometimes dumped illegally.

While not the most toxic, H_2S is one of the most commonly occurring gases to be found in sewers. H_2S is detectable by the human sense of smell at very low concentrations (0.5 ppb), while concentrations higher than 10 ppm can cause health problems, and over 100 ppm be toxic. H_2S concentrations in sewers routinely exceed 10 ppm and if not adequately ventilated can also reach toxic levels. The dangers of H_2S exposure should not be underestimated. Other ventilation issues relate to oxygen depletion, carbon dioxide, and carbon monoxide (induced from traffic).

The minimisation of explosive gases is also an important issue, with many documented instances of explosions resulting from the build-up of explosive gases within confined sewage systems.

6.2.3 Odour

Uncontrolled odour discharge points can be minimised through forced ventilation. This process maintains the sewer at a slightly negative pressure, thus controlling the location of odour discharge points. Odour treatment can then be targeted at the designated foul air discharge points.

6.3 CONVEYANCE SYSTEMS AND VENTILATION

6.3.4 Effect of Conveyance System Design on Odour Evolution

At points of turbulence, such as entry to a pumping station wet well, a drop connection, or at a poorly designed junction, dissolved gases are driven out of solution. A prime source of damaging turbulence occurs where fast flowing water meets a slower flowing section. Sewage is often retained for a considerable time in a pumping station wet well and rising main, during which the decomposition processes continue. When this is discharged to the gravity sewer it is anaerobic, malodorous, and turbulent. The process of flushing a siphon also disturbs the anaerobic sludge that has been sitting in the siphon pipes.

Foul air accumulates at the inlet to the siphons, where the air flow in the gravity sewer is stopped by the full pipes of the siphon. These are often points of hydraulic turbulence where further gas is released from the water. If this air is not discharged from the system, the restriction to the air flow promotes condensation of the moist air, and corrosion by the gases dissolved in the moisture. The stationary air becomes particularly foul smelling.

If the moisture can be prevented from condensing on the surfaces in the pipes and manhole structures that are above the sewer flow, and the products from the decomposing sewage can be removed, then the detrimental impact of the sewage will be reduced. Both of these conditions can be achieved with proper ventilation.

In addition to the odours released from gravity sewers, there are specific facilities such as air release valves in rising mains which can be odour sources.

Odour generation in pumping stations can be minimised by reducing the accumulation of slime and solids. Attention to the shape of the wet well floor and the pump intakes can reduce sediment accumulation. The “fat bridge” that builds up at pump start water level can be minimised by having large fillets in any square corners of the wet well walls. If the whole wet well is painted with a light coloured high build epoxy paint, the walls are easily hosed down (and the light level in the wet well is improved).

6.3.2 Types of Ventilation

Depending on sewer size and wastewater flow rate, significant quantities of air will be carried naturally along a sewer. This air generally enters the system through the customer terminal vents.

This natural air flow is typically only marginally above atmospheric pressure which, while allowing passive venting to atmosphere, requires fan assistance to overcome the pressure drops associated with the majority of odour treatment options.

Passive ventilation (ie, without mechanical assistance) is therefore limited in practical terms to situations where no major odour source is present (and hence no treatment of the air stream is required) and/or where the foul air can be passively vented to atmosphere through a high stack to allow natural dispersion of the odour. Passive ventilation is discussed further in Chapter 6.4.

Forced ventilation is necessary where the foul air stream is to be passed through some form of odour treatment system, such as a chemical scrubber or biofilter.

6.3.3 Continuity of Air Flow

For sewer ventilation to be effective, the airflow has to be continuous through the sewer from single or multiple inlets, to the point where it is exhausted. However, the air flow through the gravity sewers is interrupted by inverted siphons where the pipe flows full, and by each pumping station. These are the two main facilities at which the effectiveness of ventilation can be controlled. The discharge from a rising main is often at the top end of a section of gravity sewer. This is a further control point, where there is a tendency for the flow to draw air into the system. These control points divide the overall sewer network into a number of largely independent ventilation sub-systems.

6.3.4 Ventilation Air Flow Rates

If sewer ventilation air flow rates are sufficient to counter the condensation and corrosion effects, they will usually be sufficient to manage odour issues, assuming that appropriate treatment of the air stream is provided before discharge to air.

Two suggested criteria for calculating the air flow rate to be extracted at a pumping station or siphon are given below, based on the experience of reticulation engineers at Watercare Services in Auckland.

(a) The air flow rate derived from multiplying the cross-sectional area of free space in the sewer at mean dry weather flow (say 80% of pipe area) by a mean air velocity of approximately 0.2 m/s.

(b) The air flow rate which produces a slightly negative pressure at, say, 1,000 pipe diameters upstream of the extraction site.

These methods do not take account of odour intensity or odour offensiveness, but they are reasonably practical to determine by calculation or by trial with variable extract air flow rates.

6.3.5 Drop Junctions

In larger sewers and in some other parts of combined sewer systems, drop junctions and drop manholes can induce a very large air flow, at a considerable pressure. The turbulence of a drop junction drives volatile products, H_2S, and some of the other odorous products out of solution. If this odorous air is not allowed out of the sewer it pressurises the downstream sewer system, and is likely to cause odour complaints at any leakage point or domestic vent.

From a major drop structure, it may be necessary to extract the pressurised air and treat it in a biofilter. This avoids the release of foul air to atmosphere.

6.3.6 Manhole Lids, Hatch Covers, and Overflow Pipes

Most manhole lids are not fully sealed, and this allows air movement into and out of the sewer. Where the sewer is under pressure, the gas emitted can be sufficient to cause complaints. Corrosion of a manhole lid is evidence of this problem. Where manholes are a reasonable distance from occupied premises there is rarely a problem. At the site of the most vocal complaints the manhole lid may be sealed, however this just transfers the problem to another manhole.

Leakage around the lid or through a keyhole allows low density volatile products to escape, thereby reducing any build-up which could reach explosive proportions. In other situations, the small amount of air entering the sewer through the keyhole maintains a small air flow in the manhole, limiting the corrosion and foul air accumulation.

Hatch covers on pumping station wet wells must have airtight seals which prevent odour emission at ground level.

To limit odour emission from pumping station overflows, the pipes should have a flap valve fitted wherever this is practicable. This also prevents air being sucked in to short-circuit the sewer ventilation system. Similarly, for a combined sewer overflow it may be necessary to provide baffles and a submerged discharge to contain the foul sewer air.

6.3.7 Pumping Station Wet Well and Dry Well Ventilation

In some larger and older pumping stations, the exhaust air from the dry welt (pumping room) is blown into the wet well. Because the wet well is a totally enclosed space, the only air outlet is up the sewer, against the air flow induced by the sewer flow. This has several particular disadvantages.

(a) The foul air is forced out the customer terminal vents, distributing the problems widely. At some point the air flow being driven down the sewer by the water surface friction encounters the air blown back from the station. The result is a section of sewer in which there is no air flow, giving rise to odour and corrosion problems.

(b) In the event of a power failure at the pumping station, the foul air driven by the sewer flow can penetrate through the fan into the pumping room and to the power and control equipment. This causes corrosion of equipment and raises the risk of volatile gases being ignited when the power comes back on.

(c) At times of maximum sewer flow there is very little air space available in the sewer. This is the time when the pumps and motors are generating maximum heat, and dry well ventilation is most necessary. Except in very large stations, this is unlikely to lead to overheating of the machinery, but does pressurise the building.

For effective and safe operation of pumping stations, ventilation of the electrical and pumping equipment (except submersible pumps) must be kept totally separate from the system which ventilates the sewer and wet well. A biofilter fan is likely to have some leakage from the fan shaft, so that it should not be in the dry well area.

6.4 MECHANISMS OF PASSIVE VENTILATION

Vent stacks at strategic places on the sewers, and the normal terminal vents on residential and commercial property, usually provide all the ventilation necessary in sanitary sewers.

Research has been carried out to investigate the factors which affect the natural, passive ventilation of sewerage systems (Pescod and Price, 1981). Five factors were identified:

(a) sewage drag;
(b) wind-across-vent extraction (or "educt suction");
(c) temperature differentials of sewer and surface air;
(d) sewage rise and fall; and
(e) Change in barometric pressure.

Sewage drag and changes in barometric pressure would be expected to induce horizontal transport of air in sewer systems while educt suction, temperature differentials and sewage rise and fall can induce vertical transport of sewer air to the surface and therefore vent the system. The effects of these five factors, as summarised from the paper by Pescod and Price (1981), are outlined below.

(a) Sewage Drag

"Sewage drag" is the frictional effect of the moving liquid surface resulting in movement of sewer air in the same direction. The mass air flow caused by sewage drag increases with increasing surface water velocity. Wall friction has a retarding effect on sewage drag, however the effects of wall friction are reduced at low proportional water depths and high surface water velocities.

(b) Wind-Across-Vent Extraction, or Educt Suction

The action of the wind passing across a vent stack (the "educt"), results in air being sucked out of the sewer. This phenomenon is called "educt suction". Assuming that a suitable inlet is provided elsewhere (the “induct”), this allows fresh air to replace the sewer air lost to the atmosphere. Educt suction is very important in passive ventilation as at times it can be the only natural phenomenon transporting sewer air to the atmosphere and allowing fresh air to enter the system.

Increasing the sewer length between the air inlet and outlet results in slightly increased head losses. However, reduction in the educt vent pipe diameter can considerably increase the head losses. In practice any aesthetic advantage of a reduction in vent stack diameter would have to be balanced against the increase in head loss through the system and its effect on passive ventilation at low wind speeds.

The combined effects of sewage drag and educt suction should also be considered. Significant air flow against the direction of liquid drag can occur when educt suction is greater than the mass air flow caused by liquid drag. When educt suction and liquid drag are acting in the same direction, the two effects are not additive.

(c) Relative Air Temperatures

During the summer months in the New Zealand climate, the sewer air tends to be at lower temperatures than surface air. This causes sewer air to be more dense than surface air and thus a temperature differential develops. In the winter months the opposite effect occurs. The temperature differential can be detrimental to sewer ventilation in the summer as the colder, denser sewer air resists the air flow caused by educt suction, causing a reduction in the rates of air flow. The influence of cold air resistance depends on the degree of the temperature differential. However, in a well-ventilated sewer system, the continual exchange of sewer air with fresh air from the surface reduces the incidence of a temperature differential occurring and therefore the effects of relative air temperatures are reduced.

(d) Rise and Fall of Sewage Levels

A diurnal variation in depth of sewage flow occurs in all domestic-based sewer systems resulting in an exchange of air between the sewer and the surface. The diurnal variation results in a net inflow of air from the surface as sewage depth decreases, and an expulsion of air from the sewer as sewage depth increases.

(e) Change in Barometric Pressure

Differences in barometric pressure can result in pressure gradients developing in various parts of the sewer system which result in sustained air flow. However, where large barometric pressure differences occur, unstable atmospheric conditions would be expected, causing significant surface wind velocities as well as the sustained air flow in the sewer caused by the pressure gradient. The resulting effects on a sewer system due to such a barometric pressure gradient depend on the magnitude and direction of the two air flows caused.

6.5 PREVENTION VERSUS TREATMENT

Where possible, prevention should be considered prior to treatment. Prevention needs to start with good design in the case of new facilities, and improved operation and maintenance in the case of existing facilities.

Good design practices should concentrate on:

(a) maintaining the smooth flow of sewage and minimising turbulence with no unnecessary "drops". H_2S levels can be decreased by up to 50% at source in this way;

(b) smooth finish to concrete structures for ease of cleaning and prevention of slime build up;

(c) strategically located fresh air inlet points.

Operational and maintenance factors recommended to minimise odour generation include:

(a) control pumps to maintain an air passage through sewers (ie, prevent the incoming sewer from flooding). Maintain regular cleaning of pumping station wet wells and sewers;

(b) minimise the ingress of salt water in low coastal sewers which can lead to odour generation;

(c) policing of catchment areas to minimise alleged dumping of odorous substances.

6.6 CHAPTER 6 REFERENCES

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7. CASE STUDIES

7.1 THE TAURANGA EXPERIENCE

CASE STUDY SUMMARY	
Location	Tauranga City WWTP, Tauranga
Subject	Control of odours from a WWTP
Application	Oxygenation, chemical sprays, chemical addition, and containment and ventilation to biofilters
Last Updated	May 2000
Further information contact	Wally Potts, Hamilton City Council

7.1.1 Background

The Tauranga City WWTP was built on reclaimed land adjacent to the Chapel Street causeway and commissioned in 1969. Chapel Street is a main roading link for Otumoetai to the city. The plant is situated about 800m from the central business district.

In the mid 1980's the WWTP had a severe odour problem. Residents complained of being unable to sleep at night with open windows. Passing the plant on Chapel Street was often very unpleasant. Some local residents feared for their health and many people had the impression that "*if it smells this bad, it must be creating tremendous pollution in the harbour*".

An in-house study began in late 1986 to identify the source of odours. The WWTP headworks was rapidly identified as the major problem area. The sludge area was also odorous. Raw sewage quality was visibly poor, and there were fine black particles in the raw sewage test settling cone, a sure sign of the reduction of the organic material. The study was then expanded to determine where the sewage was becoming anaerobic in the reticulation system. This work progressed through the summer of 1986/87 and covered the entire sewer system. Testing included total and dissolved sulphide, dissolved oxygen, pH, and redox potential.

The survey began at the WWTP and progressively moved out from the plant until fresh (aerobic) sewage was encountered. In some cases, wastewater flow was anaerobic all the way to the city boundary, especially in developing residential areas and a commercial area. The problem was a combination of high residence times and some high strength waste. The city had not reached design capacity for the sewers and the wastewater was sitting too long in some areas. In the case of the commercial area, situated about 10 km from the WWTP, a commercial bakery, meat-packer and meat by-products processor contributed a significant load to the WWTP at that time.

The main areas identified as contributing to odour were inverted siphons crossing the harbour, pumping station rising mains, and some wet wells. Siphons and rising mains produced a “slug of flow” that was very anaerobic and consequently had a high oxygen demand. This flow rapidly removed all the oxygen from any other wastewater it mixed with, creating a progressively larger anaerobic flow. The same effect was observed in the case of the commercial area, where the high strength waste depleted oxygen levers along its entire path to the WWTP.

Even though the odour source was the reticulation system, its effects were especially evident at the WWTP.

7.1.2 Trials

Options for treating the odour were assessed and trialled, including adding a masking agent to the inlet flow, spray systems at the WWTP and pumping stations, adding water at some points to reduce residence times, more frequent cleaning of some wet wells, and oxygenation of three rising mains.

In general terms the trials were not very promising. Some of the outcomes were:

(a) wet well sprays of water in some pumping stations were intended to re-dissolve odours and reduce residence times - no noticeable result;

(b) adding odour treatment agent (Epoleon) into the incoming flow at the WWTP was effective but very expensive, and therefore abandoned due to cost;

(c) there was some success with spray systems with chemical treatment at the WWTP and pumping stations, but each day there would be odour breakthrough from time to time;

(d) more frequent cleaning of wet wells provided no noticeable improvement but provided confidence that dirty wells were not a primary factor;

(e) Oxygenation of rising mains was attempted in-house without success.

Further technical assistance was required for oxygenation to be successful. Discussion followed with NZIG (now BOC Gases) and joint trials with NZIG looked promising. The initial trials were conducted at a moderate sized pumping station to prove the system and to enable final design for the two largest pumping stations.

Oxygenation

Over half the flow to the WWTP passed through two pumping stations. The flow to these two stations also contained the main sources of anaerobic sewage. It was considered more effective to treat the wastewater at these two sites than to attempt to treat all the flow at the WWTP.

The “Primox” system by NZIG worked well and resulted in a marked reduction in odours at the end of the rising mains and at the WWTP. However, there was an odour breakthrough (predominately in summer) at the WWTP at approximately 10.30am to 11.00arn each morning due to stale sewage being moved to the WWTP. The morning odour problem was generally confined to the area immediately around the WWTP but remained very noticeable within a 100m radius. To reduce the morning odour breakthrough, various trials were conducted adding chemical agents to the flow entering the headworks. Sodium hypochlorite was found to be effective and the least cost option.

Hypochlorite Dosing into Wastestream

In the 1988/89 summer a temporary tank for sodium hypochlorite and a flow proportional dose pump were installed and used with moderate success. The pre-chlorination facility was turned on at 8.00am and off at 8.00pm in summer. In winter the facility was used on an “as needed” basis and generally turned off earlier at 5.00pm.

This temporary arrangement lasted for several years and while generally successful was not without its problems. There were a few occasions when the pump overdosed, causing problems within the secondary treatment processes at the WWTP. There were one or two occasions early in the process when a venturi effect was created by the carriage water that resulted in a massive overdose of chlorine and killed the secondary process completely. A minor modification to the pump and pipework prevented this recurring. Pre-chlorination had some other benefits in addition to odour reduction: the primary sedimentation tanks remained cleaner, and fat was continuously removed from pipework to the primary sedimentation tanks.

7.1.3 Plant Upgrade

The WWTP was being completely upgraded in the early to mid-1990's. The first element installed was UV disinfection and it was found that pre-chlorination adversely affected UV transmissivity and at this point its use was limited to high odour events. Upgrading the WWTP headworks/pre-treatment was next on the programme and included fine screens, grit removal via pre-aeration and odour treatment of the headworks and pre-treatment building foul air. The commissioning of this facility was a major breakthrough in odour control.

Since 1993 foul air has been collected from the headworks and pre-treatment building and passed through a biofilter of 75% graded bark chip and 25% top soil with some shell fragments.

There were early problems with the bed drying out and cracking, and odours were very noticeable on these occasions. Minor adjustments were made to the biofilter following commissioning. The bed was doubled in depth and a spray nozzle installed in the air flow to help maintain moisture in the lower biofilter bed.

The biofilter has been operation for almost three years and is practically maintenance free. Occasional weeding and moisture checks are all that is required.

The pre-chlorination system was removed following biofilter commissioning and the oxygenation of the two pumping stations has now been discontinued.

The plant is now operating without creating a nuisance. Other areas of the plant that have been addressed include:

- sludge handling was poor with respect to odours and a new flow balancing tank was installed in 1995, covered for odour removal;
- in late 1996 a second biofilter was constructed to treat the foul air from the flow balance tank, centrifuges and dewatered sludge storage bin;
- the long term performance of the plant has shown no ongoing odour complaints.

7.2 RETICULATION SYSTEMS AND PUMPING STATIONS – THE CHRISTCHURCH EXPERIENCE

CASE STUDY SUMMARY	
Location	Christchurch City WWTP, Christchurch
Subject	Control of odours from the reticulation system
Application	Sewer design and biofilters
Last Updated	April 2000
Further information contact	Mike Bourke, Christchurch City Council

7.2.1 Introduction

Odour from the Christchurch reticulation system can be detected in many locations. Odour generation in the Christchurch system is exacerbated by large, long flat catchments with long retention times giving ample opportunity for the production of odour compounds in the wastewater. However, the opportunity for release of the odorous compounds is generally low in the Christchurch system with predominantly flat grades and few points of major turbulence.

The impacts of odour release are also less in the Christchurch system due to the high degree of ventilation. Every second manhole in the reticulation system is vented to the road surface. Some lengths of main sewer are vented at each manhole to a 4rn high vent pipe at the side of the road. Providing that bird nests can be kept out of the vents, these perform satisfactorily in that they distribute the odour over a wide area and by dilution, and are therefore not usually the source of complaint. One pumping station is vented to a tall stack quite remote from the pumping station site and as the public does not associate it with any sewer, it is not perceived to emit any odour.

7.2.2 Odour from Christchurch Reticulation

Sources of odour in the reticulation system include pumping stations, which have either a transient infrequent input or a persistent or repeated impact on residents. The transient infrequent impact occurs when a point source produces some noticeable odour infrequently or when a frequent point source of odour is noticed by people in a transient way, such as motorists or cyclists passing a manhole that is expelling foul air at the time. The persistent or repeated impact occurs from a source that frequently or constantly emits odours to the extent of causing continuous or frequent nuisance to local residents or businesses. These situations have been targeted by the Christchurch City Council in response to public complaint.

Thirteen sites on the Christchurch reticulation system have been identified as causing frequent complaint of odour and are all sites of significant turbulence, including the bottom of a cliff face pipe, the end of pressure mains, siphons and pumping stations. All of these sites have had biofilters installed which have been very successful in eliminating odours. One further site that emitted significant odour was remedied by changing pumping times so that under normal operating conditions the station only pumped between the hours of midnight and 6.00am; a very simple low cost solution. Odour emissions from a number of lower impact sites have been solved by making physical changes to pipework to substantially reduce turbulence and hence odour release. The best method of reducing odour impact is to ensure that it is not produced or released in the first place.

7.2.3 The Biofilter Solution

The 13 small biofilters operating on the reticulation system are all force-ventilated on the basis of 5 m^3/h for each square metre of biofilter area. The design is sometimes determined by available space for a biofilter but more usually by a desired air flow rate. Small cast iron centrifugal fans (Richardson Mill OD Exhaust Fans <1kW) are used and usually at quite high speeds (up to 3000rpm) in order to generate the required head to overcome biofilter back pressure.

The soil mixture found to be most successful has been a 50/50 mixture of topsoil and bark usually to a depth of 300mm, and at an air flow rate of about 5 m^3/m^2. The mixture produces a back pressure of between 15 and 50mm.

The air distribution system used is usually 150mm diameter Novaflow pipe connected to a distribution manifold, with the perforated Novaflow buried in a 300mm deep layer of graded round gravel between 14 and 20mm diameter. This air distribution system produces minimal headloss.

7.2.4 Summary

After eliminating all possible turbulence, if odour release is still at nuisance levels then the Christchurch experience is that small biofilters provide a simple low capital cost solution to the continuing release of odour. Any new reticulation systems with low flows or relatively long residence times in their pressure mains are now designed with a biofilter at the end of the pressure main or preferably a short distance downstream of the end of the pressure main, and the immediate downstream gravity piping is of non-corrodable materials. All large pumping station redevelopments will also include odour control facilities in future and, unless space is extremely limited, biofilters will be used.

7.3 RETICULATION SYSTEMS AND PUMPING STATIONS – THE WATERCARE EXPERIENCE

CASE STUDY SUMMARY	
Location	Watercare Services Ltd, Auckland
Subject	Control of odours from the reticulation system and pumping stations
Application	Chemical sprays, UV, ozone and biofilters
Last Updated	May 2000
Further information contact	Boyd Miller, Watercare Services Ltd

This case study describes observations from the operation of odour management facilities within the Watercare Services wastewater reticulation system in Auckland.

7.3.1 Drop Junctions

In Watercare's Branch 3C combined sewer in Newmarket, there are two manholes close together, each incorporating a drop of nearly 12 metres. Each drop comprises two parallel 450mm diameter pipes. The entry structure is shaped to direct most of the dry weather flow down one pipe, leaving the other empty. Downstream from the lower manhole, the air flow and the aerosol induced by the falling water used to escape into a wilderness area through a large opening which served as the combined sewer overflow. The odour from the escaping air reflected the major sources of the sewage, a brewery and a processor of vegetable oils - not particularly obnoxious, but definitely conspicuous. As development encroached on the area, odour complaints became more frequent, and the situation needed to be improved.

A large sealed flap gate, mounted on a sloping frame to assist closing, has been installed in the overflow weir opening. This pressurises the pipelines upstream and, under normal circumstances, this forces some of the air to recirculate back up the empty drop pipe, substantially reduced the foul air emission. Air is extracted from the sewer between the drop pipes and the flap gate, and is treated through a biofilter, so that there is now no air escaping directly from the sewer. In wet weather the overflow from this combined sewer escapes past the flap gate with minimal release of foul air.

7.3.2 Sewer Ventilation Biofiltration

As a general principle, the sewer upstream of a pumping station or siphon is vented by extracting and discharging the air from the sewer. Biofilters have been the most successful method of managing odorous emissions from the larger pumping stations and siphons in the Watercare system. In small stations with "fresh" sewage, a vent stack, with or without a fan, is usually sufficient. Many of the stations have some form of positive deodorising - seven pumping stations have biofilters, six have UV systems, and there are blotters at three other sites in the reticulation.

7.3.3 Biofiltration

In the earlier biofilters, the media comprised 70% SAP 7 scoria mixed with 30% topsoil. This was placed over a base layer of 300 to 400mm of 20/25mm scoria, in which the air distribution pipework was embedded. Media depths ranged from 600mm to 1 metre, most commonly 800mm. Typically, a layer of non-woven filter geotextile was placed between the base air distribution layer and the media. In some cases a similar fabric was placed on top of the filter, under approximately 50m of scoria, to prevent weed growth.

In several of the filters, the finer soil particles washed through the media and clogged the lower fabric layer, effectively blocking any air flow. At several sites the upper layer also tended to clog, restricting the air flow and lifting the scoria cover. Other biofilters performed badly at odour removal, probably because the media was not to specification, and contained too much fine material, which tended to form a solid clump with the scoria and allow “rat holes” to form.

The media in these filters has since been replaced. New and upgraded filters have a transition zone at the base of the media, comprising an open 3D erosion fabric under 70mm of 6-10mm scoria. The media is now 60% pumice and 40% bark, with a topping of 50mm of coarse bark over windstop fabric. This arrangement appears to be working very satisfactorily. The fan pressure on all the filters is being monitored periodically to gain an indication of performance and to highlight any tendency for the media to become clogged.

The basis of design has generally been to provide a total media volume equivalent to 90 seconds of air flow. Trials have been carried out with odour measurement in and out of the biofilters in an attempt to find a more logical basis for design. Results were inconclusive but they indicated that this formula might be useful:

$V_B = (O_I \times F_I) / L$, where

V_B = media volume, m^3
O_I = inlet odour concentration, OU/m^3
F_I = inflow air rate, m^3/s
L = 100 (derived experimentally)

Experiments are also underway with reduced media volume tending towards the recommendation of the Water Environment Research Foundation (WERF) of media volume equivalent to 70 seconds of air flow (WERF, 1997).

The airflow rate required to ventilate a pumping station wet well and/or the incoming sewer has been estimated as outlined in Chapter 6.3.4, or has been determined from trials with a variable discharge fan. As a general principle, the biofilter fan has not been located inside the pumping station dry well, because at a relatively high operating pressure, there is a certain amount of fan shaft leakage of foul air.

One biofilter was built with a turf topping, to provide cover similar to that on the earlier Mangere WWTP biofilters. Although the air pressure was sufficient to brow bubbles through the turf in wet weather, the grass cover grew to be so dense that it raised the back pressure to the point where insufficient flow was being achieved. A significant improvement was achieved by replacing the turf with a bark layer.

7.3.4 Chemical Neutralisation

In general, trials have shown that chemical neutralisation through the use of chemical sprays in the air is ineffective in reducing the effects of H_2S gas in foul air, when operated on a continuous air flow basis with short retention times. These chemicals may, however, provide a level of odour “masking”.

Automatic spray dispensers with conventional masking chemicals have been tried as an immediate response to complaints about pumping station smells, pending a more permanent solution. While the method is reasonably effective for masking fresh domestic sewage odours, it has not been so successful with stronger odours. The system is expensive both in chemical use and in the refilling and maintenance requirements. It is difficult to match the deodorising requirements closely enough when the odour load varies hourly, daily, or seasonally. However at some sites where there is not the space for anything better, the process has been effective enough to silence most of the complaints.

Chemical spray has been used to try and mask the skipfuls of “drained” material extracted from a combined sewer grit trap, while this is being carted to disposal. The process was not successful, because the vibration of the load during travel brought a foul liquid to the top surface and drowned the masking agent. The only successful method for this operation is to transport the material in a closed tanker.

7.3.5 Ultraviolet Light/Ozone

Ozone systems have been built into a number of stations in Auckland, with mixed results. It was originally anticipated that the deodorising effect could be enhanced by allowing the light to reflect around the contact chamber. The walls of the chamber were lined with reflective stainless sheet. It was expensive to construct, difficult to clean, and the operators could not see the corrosion behind the sheets. At one site, a white ceramic-type paint on the concrete walls has appeared to stand up to the ozone degradation, and is easier to clean. The reflective concept is however not likely to have been beneficial to the deodorising process.

At sites where there is turbulence in the sewer which brings an aerosol into the station, the lamps have required very frequent cleaning to maintain reasonable efficiency.

Odour control utilising UV light can be unreliable and generally ineffective. Matching of correct UV quantities to odour levels has proven difficult. Incorrect combinations can result in the production of ozone, which is undesirable for health, odour and environmental reasons.

At several pumping stations the UV lamps have been turned off and mesh bags of zeolite have been suspended in the air flow. The zeolite is replaced approximately once a month, and this appears to work surprisingly well.

7.3.6 Summary of Treatment Methods

Table 7.3.1 summarises Watercare Services' experience with various treatment technologies.

TABLE 7.3.1: EXPERIENCE OF WATERCARE SERVICES WITH TREATMENT OPTIONS FOR PUMPING STATIONS AND RETICULATION SYSTEMS

Parameter	Vent Stack	Biofilter	UV/Ozone	Chemical Scrubber
Best Applications	Works well for small pumping stations and fresh sewage, limited success for larger facilities	Effective for reduction of a wide range of odours and for changing odour load	May work well with constant low level odour load, limited flexibility	Worked well for H_2S, less effective with other odours
Flexibility	Some flexibility, may be natural draught or fan assisted	Flexible configuration, requires land space with maintenance access	Expensive to construct as part of the station	Complicated equipment, construction and ancillary services are expensive
Cost	Cheap to install and very cheap to operate	Expensive to build, low operating and maintenance costs, periodic maintenance required	Power, fan and lamp maintenance costs are high	Maintenance and chemical consumption is very expensive
Other	Resource consents for point discharge may be difficult to obtain	Moisture content must be maintained, can be poisoned but appears to recover	Difficult to control accurately to avoid ozone output, aggressive on facility	Corrosive chemical storage and handling facilities and skills required

7.4 RETICULATION SYSTEMS AND PUMPING STATIONS - MAIRANGI BAY PUMPING STATION - NORTH SHORE

CASE STUDY SUMMARY	
Location	Mairangi Bay Pumping Station, North Shore
Subject	Control of odours from a pumping station
Application	Biofilter
Last Updated	January 1998
Further information contact	Garry Macdonald, Beca Steven

7.4.1 Background

The Mairangi Bay Pumping Station is located on the northern shore of Auckland's larger metropolitan area. It is situated in a residential area, where two trunk sewers converge, one from the north (Browns Bay) and one from the south (Castor Bay) from where it pumps to the North Shore WWTP. The pumping station and reticulation is owned and operated by North Shore City Council (NSCC).

Nature of the Problem

Historically, the ventilation system at the Mairangi Bay Pumping Station was operated to draw air from the wet well area with discharge to the atmosphere (via a vent stack). Ventilation was necessary to meet Health and Safety requirements at the pumping station. Residents in the area had complained about odours from the pumping station which became worse during summer months due calm wind conditions.

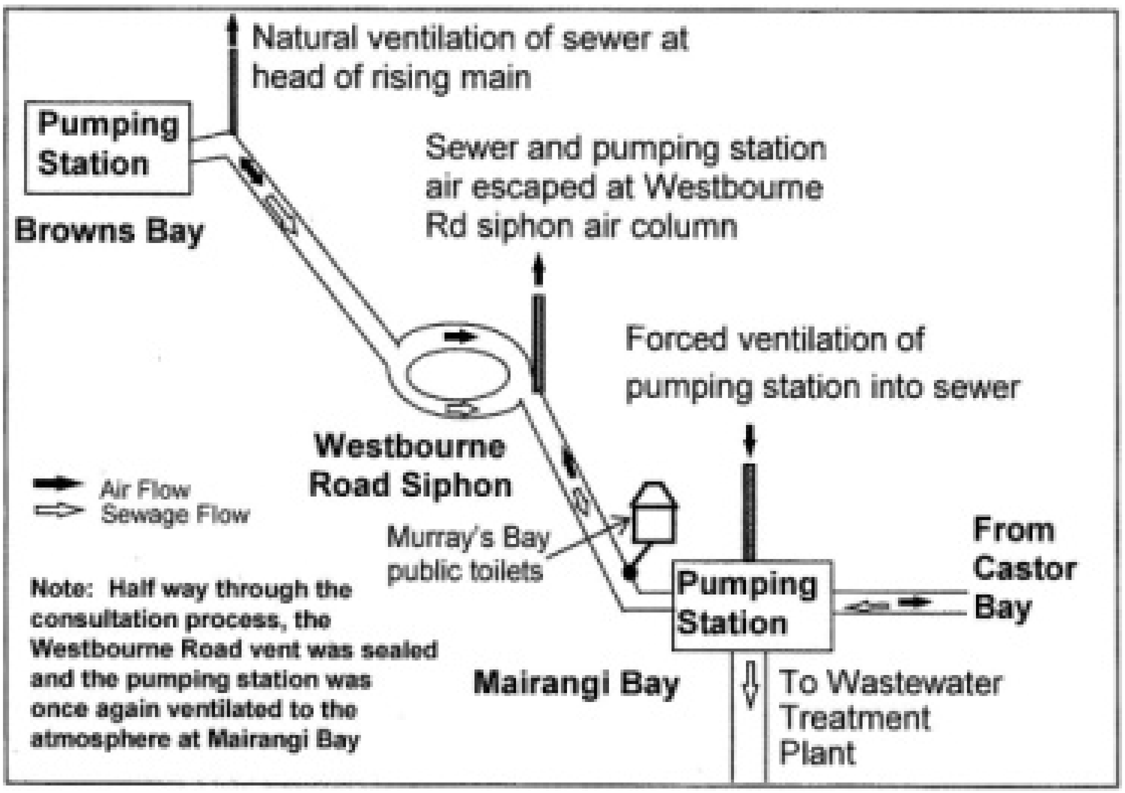

FIGURE 7.4.1: SCHEMATIC OF THE RETICULATION SYSTEM

Due to the complaints, an operational change at the pumping station resulted in the fan being reversed so that air was discharged into the sewer. Figure 7.4.1 shows a schematic of the reticulation and ventilation system in the area. As the section of sewer to the north of the pumping station was largely unventilated, odour was able to escape from the nearest exit points - a siphon vent and at the Murrays Bay public toilets. Odours were particularly bad at the vent associated with the siphon which allowed sewage to pass under a stream. The sewage in the siphon could become stagnant and odorous if held in the siphon for too long, particularly in dry summer months. There were numerous complaints from residents in these areas.

7.4.2 Consultation Process

NSCC wanted to involve the community in the process of selecting a solution to the problem. This was done by a series of community meetings which were attended by:

- representatives of the community including -
  - ➢ residents and a motel owner living near the pumping station
  - ➢ residents living near the siphon vent
  - ➢ members of the East Coast Bays Community Board
  - ➢ Murrays Bay Boating Club
  - ➢ Mairangi Bay Business Association
- NSCC staff
- technical consultants (Beca Steven).

Prior to the first meeting, the consultants produced a discussion document which was circulated to community representatives. The document identified the reasons for the problem and eight options for resolution of the problem. To aid in selection of a final option, several objectives were decided upon by the consultation group against which each option could be evaluated. These were to:

- solve the odour problem once and for all (no desire to shift the problem to another area)
- involve all stakeholders in the evaluation of options and in the decision making process
- apply for resource consents with the support of all stakeholders
- address health and safety issues at the pumping station
- select a “user friendly” solution with simple but flexible technology
- select an unobtrusive solution
- select a cost effective solution (in terms of both capital and operating costs).

7.4.3 Solution to the Problem

The option selected by the consultation group consisted of a biofilter located on a grassed area adjacent to the Mairangi Bay pumping station. Odours from the pumping station and the sewer were to be treated by passing them through the biofilter.

The intended works consisted of two components: the ventilation system and the biofilter bed. Design features included the following.

(a) Ventilation System

- Fan - air flow of 1000 l/s to the biofilter
- Ventilation rates - 12 air changes per hour in the pumping station (meeting Health and Safety requirements) and 5 air changes per hour in the sewer (preventing build-up of corrosive gases)

- Noise control - sound attenuator (muffler), arid system enclosed in a small room.

(b) Biofilter

- Embedded in the ground to a depth of 1.1 metres
- Area of 150 m2
- Media = topsoil and bark mix, 600 mm deep
- Retention time = 90 seconds
- Maintenance: the beds of the biofilter are scarified approximately every 2-3 months if required.

7.4.4 Consent Issues

The project required a land use consent, which was obtained by NSCC in late February 1997. An air discharge consent for the biofilter was not required as these works were considered to be part of an existing wastewater facility (and therefore covered under section 418(1A) of the RMA).

As the pumping station is located in a highly visible and frequently used recreational area, the aesthetics of the project were important in obtaining a land use consent. Considerations with regard to aesthetics included:

- the concrete block building to house the ventilation system was designed with a brick veneer, to blend with the existing brick building;
- the biofilter was configured to maximise the area of grassed recreational land remaining at the site, with particular care taken to avoid the drip-line of a mature Norfolk Pine;
- a condition of the consent was that a planting plan was provided. This allowed for a low thorny shrub border to be planted to deter people from walking across the biofilter.

7.4.5 Follow-Up

Consultation continued through to the end of the project where, prior to construction, a flyer was produced informing those involved in the consultation process when construction would begin, and for how long. In this project, the consultation process was effective in arriving at a solution that was accepted by all stakeholders. Construction was completed in October 1997.

The Mairangi biofilter is operating well and there have been no odour complaints for the past few years. No further modifications are planned at this stage.

Mairangi Bay Pumping Station, with the new biofilter, soon after construction, shown to the right.

7.5 ODOUR COMPLAINTS AND SURVEYS - MANGERE WWTP

CASE STUDY SUMMARY	
Location	Watercare Services Limited, Auckland
Subject	Odour complaints and surveys
Application	Analysis of complaint records, odour survey of resident
Last Updated	May 2000
Further information contact	Peter Rogers, Watercare Services Ltd

7.5.1 Introduction

Industries need to be seen as responsible members of the community if they are to have good relations with their neighbours. It is therefore important that when complaints about odour nuisance from a particular company/industry are received, that they be handled in the appropriate manner. At the Mangere Wastewater Treatment Plant (WWTP), Watercare Services Ltd has in place a procedure for dealing with complaints which includes the following steps:

- log complaint, obtain details from complainant
- acknowledge receipt of complaint within 3 days
- investigate complaint
- report on complaint
- respond to complainant.

Information gained from the complainant and further investigation is essential in determining if any odour nuisance has originated from the WWTP. This information includes:

- date
- description of odour
- wind direction
- time of day – morning, afternoon, evening, night
- duration – number of hours, constant or intermittent
- search for a specific source
- investigation into causes
- action taken
- follow-up
- comments

The recording of the above information means that the data can be used to analyse for trends related to the operation of the treatment plant. One such analysis is detailed below.

7.5.2 Analysis of Complaint Records

A review of resident complaints was carried out in July 1994 for complaints registered in the period July 1993 to May 1994. This period was prior to the major odour control improvements carried out at the Mangere WWTP.

For the 11 month period, complaints were registered on 99 days, which equates to complaints being registered on about 24% of the days. A total of 136 complaints were registered. Figure 7.5.1 presents a monthly summary of the residents' complaints, indicating a seasonal trend in odour nuisance.

The basic steps of analysis followed were to:

- collate complaints and details of subsequent investigations
- determine valid results for the purpose of the analysis
- general review of results
- sorting by possible cause of complaint and review for trends.

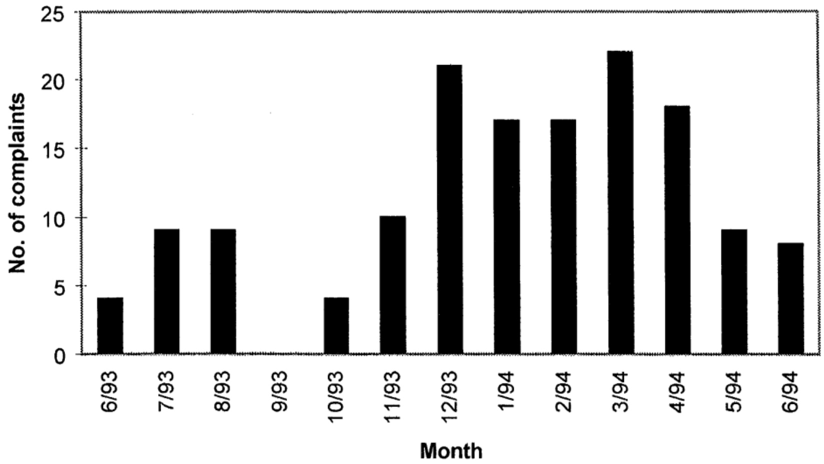

FIGURE 7.5.1: MONTHLY COMPLAINTS LOGGED AT MANGERE WWTP

Of the 136 complaints received during the period, 16 were regarded as invalid to the analysis. These complaints related to non-odour complaints or complaints attributed to sources other than the Mangere WWTP. The remaining 120 records (88%) were regarded as valid odour nuisance complaints. All of the complaints originated from the Mangere Bridge area, to the northeast of the plant.

Analysis of the data indicated that complaints were primarily generated with winds from the southwest direction, so any odour generated from the WWTP during these periods would be dispersed over the Mangere Bridge area. The complaints indicated that odour was detected in patches or irregular patterns, at differing intensities and at varying levels above ground. This is caused by the variations in wind speed, wind direction and atmospheric stability, combined with the effects of the terrain in the locality.

Complaints were triggered either by very strong odour even if lasting for a relatively short time (up to a few hours), or by odours of lower intensity which persisted continuously or intermittently for longer periods of time (few days to a few weeks). Evening, night and early morning complaints predominated. This coincides with the part of the day when most of the complainants are present in the area, and also the time of day when meteorological conditions tend to be more conducive to reduced air quality.

When sorted according to possible cause, the valid complaints showed that out of the 120 complaints, 8 had no determined specific source, and in 19 cases more than one probable source was assigned to a single complaint record. Two groups of sources were identified: regular and occasional.

Regular Sources

- 15 (12%) complaints connected an odour incident to the sludge lagoons, and particularly to periods when sludge was being discharged to a lagoon. This operation could take place several times during the day or night and might give rise to complaints of strong odours for a relatively short period.

- 49 complaints (41%) were related to odours emanating from the oxidation ponds. It appears that there are three main scenarios for odour generation from the ponds:

  (a) isolated incidents lasting for hours (typically midnight to 7.00am), related to sulphur-producing bacteria and diurnal changes in redox during warmer months (pond temperatures over 15°C)

(b) isolated incidents lasting for days or weeks at a time, related to algal and microbial composition changes. A reduction in the algal species which are essential for oxygen production has been identified as the main cause

(c) longer term background emissions, caused by the efforts to sustain a loading regime in order to prevent midge breeding. This results in relatively high loads which may cause odours.

- 37 complaints related to the primary treatment area, specifically the inlet works, primary sedimentation and odour control filter (a rock filter treating odorous air from the covered headworks and pre-aeration tanks). The odour nuisance problems were attributed to septic raw sewage. The problem appeared to have been aggravated by a period of low flow that resulted from the Auckland water shortage. The odour control filter was specifically noted as an odour source when primary effluent was applied as a spray instead of fresh water.

Occasional Sources

These are single occasion events that attributed odour nuisance to specific incidents, for example:

- digester No 2 - attributed to the short-term venting of gas to atmosphere from a safety valve
- effluent channels - indicated as a source, although no explanation available
- fixed growth reactors - noted as a source during periodical cleaning.

The primary treatment area sources have subsequently been addressed in the Mangere WWTP Odour Control Improvements Project. The project was concerned with reducing odour nuisance from WWTP odour sources excluding the ponds, sludge lagoons and sludge dewatering plant and was completed in February 1996. The latter sources were not included, as the future of the oxidation ponds and sludge handling processes were being dealt with separately under different projects. It has now been resolved that the oxidation ponds and sludge lagoons will be decommissioned before the year 2003.

7.5.3 Residents Survey

A survey of residents in the area adjacent to the WWTP was conducted in early 1994 to assess the effects of odour from the WWTP. Fifteen residents were asked to participate in regular odour monitoring. Data was collected over a period of 12 weeks between January and April 1994 and then analysed by CM Research. The results from this study are indicative only as the number of "reporters" was low, particularly when divided into regions. The surrounding neighbourhood was divided into 4 equal area sectors. The number of reporters in each region ranged from 1 to 9.

The reporters were asked to record when odours were observed during the day. The day was divided into three periods: morning (6arn to noon), afternoon (noon to 6pm) and night (6am to 6pm). They also had to indicate the strength of the odour using a rating scare from 0 (no smell) to 4 (very strong smell).

Over the 12 weeks, no odours were noted during any time of the day or night in any of the areas on only five days. On these days the wind direction was from the north-east for all but 3 hours. Under such conditions, odours from the WWTP would be carried away from the residential areas.

The results showed the following trends:

- the night period consistently resulted in the strongest odour;
- the panel response of “no odour detected” was recorded 77% of the time over the 12 week, all areas combined; and

- the periods in the day with the highest incidence of “no odours” responses were the morning and afternoon, ie, 78% of responses for each period.

It was concluded that, on average, the odorous emissions from the plant can be noticeable in the adjacent areas by one quarter of the population on a single day. However, wind direction at the report times was not compared to exclude other sources.

Among the reporters that noticed an odour, the average odour strength was 2.1 for the morning and afternoon periods, and 2.5 for the night time period. The percentage of respondents who rated the odour strong (3 or 4 on the scale) when detected was 6.5% in the morning, 7.5% in the afternoon and 12.5% at night.

The overall conclusion of the study was that odours, most likely originating from the WWTP, create nuisance to the surrounding residential areas. However, the sample number was quite small, and the period was restricted to four months and therefore not representative of the situation year round. The study was conducted over the summer/autumn period when odour release is considered to be more prevalent than in the winter months.

7.6 ODOUR COMPLAINTS AND SURVEYS - CHRISTCHURCH WWTP

CASE STUDY SUMMARY	
Location	Christchurch City WWTP, Christchurch
Subject	Design and analysis of an odour survey
Application	Odour survey
Last Updated	May 2000
Further information contact	Andrew Nichols, Christchurch City Council

7.6.1 First Survey, 1995-97

From September 1995 to July 1997, residents in the eastern suburbs of Christchurch who complained of odours from the Christchurch WWTP were invited to take part in a survey in which they were asked to record their observations of odours from the WWTP on supplied forms. Additional observers were recruited through notices in the local newspapers.

The purposes of this survey were to:

- tangibly demonstrate an interest by the Christchurch City Council in residents' complaints;
- gauge the spatial extent of any odour problem;
- determine the atmospheric conditions that generate most odour observations;
- gauge the impact of any future structural and process modifications at the WWTP; and
- form part of the community consultation process necessary for the gaining of an air discharge consent.

The survey was designed according to the objective principles described in MFE (1995). Information sought from the observers included:

- date
- wind direction
- wind strength
- time (that the odour was first noticed)
- duration of the odour (how long did the odour persist?)
- description and strength of odour

Information recorded for each of the observers included the location of their residence with respect to distance and compass direction from the WWTP.

Analysis of the first six months of returned forms showed that:

- the frequency of detection of odour events was greatest within 1000m of the WWTP;
- few odour events appeared to have been detected by more than one observer;
- almost all odour event detection occurred during conditions of little or no discernible airflow; and
- return of observation forms by most observers was erratic with only 15 observers out of 45 showing any sort of reliable commitment.

It was recognised that the selection of observers and the small sample of the population that they represented, rendered the survey results unsatisfactory from a statistical perspective. To address these concerns, a new survey commenced in November 1997. This involved many of the existing observers plus new people randomly selected in the area by a statistically valid grid method, as described in Young (1997).

7.6.2 Second Survey, Summer 1998

A new odour diary was set up for the period 1 November 1997 to 28 February 1998 that would:

- take into account the shortcomings of the first diary;
- deal with the identified shortcomings; and
- provide the Council with some baseline data for the assessment of the effectiveness of the programme of odour control and mitigation modifications to the WWTP.

Survey Design

The design of the survey incorporated the following steps.

(a) A 1.5km radius circle was drawn about the biosolids conditioning lagoons on a sheet from the Council mapbase showing all property boundaries.

(b) The residential areas were identified and the circle subdivided into compass quadrants.

(c) Using the map and the Council rating database, a total of three hundred residential addresses were chosen semi randomly from within these quadrants so that there was a reasonable geographic spread of prospective participants.

(d) The residents identified were invited to become odour observers. 100 residents were then chosen from those who responded.

(e) Observers were supplied with the same forms and reply paid envelopes as for the earlier diary and were asked to return a form once a month whether entries had been made or not.

Forty-eight observers provided returns over the summer period. The respondents were distributed mainly in twp clusters within the suburbs of Aranui and Bromley, which are situated to the north and west of the WWTP respectively.

Results

<u>Number of Returns</u>. 223 odour events were recorded during the summer evenly distributed in occurrence over the respondents and the period of the survey. Many of the respondents noted that there had been more odour events than in previous summers. This could well be the case as Council staff were called out to investigate many more odour complaints city wide than would be considered normal by staff over the same period.

<u>Airflow and Odour Event.</u> Given the findings of the previous diary, special attention was paid to analysis of the association of airflow with the occurrence of odour events. The main airflow features of the study period were:

- dominance of easterly and northeasterly airflow reinforced by the spatial distribution of observers
- low frequency of southerly and southwesterly airflow
- a high frequency of observed events associated with northwesterly airflow which is unusual in that wind from this direction would logically remove odour from the residential areas.

<u>Airflow Strength</u>. The analysis of the previous odour diary results concluded that the stronger the airflow, the lower the frequency of odour detection. The data from the 1998 summer would appear to confirm this with 75% of odour events being associated with minimal airflow. When it is relatively still, poor mixing occurs in the air column and so the odour remains concentrated and detectable by more observers close to the WWTP. Local thermal air currents override the synoptic airflow and seabreeze in influencing the track of the odour plume, especially during warm weather, such as occurs during northwesterly conditions. This is supported by an examination of the data for odour detection during northwesterly conditions which show that most of the observations come from the Bromley area closest to the WWTP, and that 55% of observations were made during conditions of little or no airflow. The data also show that most of the observations were strong, also a good indicator of poor mixing.

<u>Time of Observation and Duration of Event</u>. While significant numbers of observations were made at all times of the day (other than in the early hours of the morning), most odour events were made at either end of the day with a dip about noon. This is probably a reflection of the number of working people in the pool of observers, a population sampling problem faced by all those working in the field of odour diaries (MfE, 1995). If the observers were only retirees, or people who spent most of their waking hours at home, then this pattern might correlate with the diurnal vertical expansion of the atmospheric mixing layer. During mornings with little synoptic airflow, odours are of short duration and do not disperse well. As the sun climbs in the sky, the air heats from the ground up and odours are carried away horizontally and vertically. If people detect them at all, they have generally become much weaker. As the afternoon progresses towards the evening, the ground cools down and the process is reversed with odour observation shrinking to those areas close to the plant.

<u>Odour Strength</u>. There does not appear to be any relationship between odour strength with either atmospheric conditions or time of day. This implies that it is probably a function of WWTP performance and the warm weather phenomenon of decomposed raw wastewater arriving at the plant.

<u>23 - 24 January</u>. This was one of several events where the mix of WWTP performance and atmospheric conditions combined so that observers over almost the whole area experienced odours continuously for a day and more. The synoptic conditions involved a large stationary anticyclone centred over the middle of the South Island with the light and variable synoptic winds being dominated by local seabreeze and neighbourhood scale thermal aircurrents. The maximum air temperature recorded was 31 degrees on the 23rd and 30 degrees on the 24th. Minima did not drop below 18 degrees. No concurrent monitoring of the odour sources at the WWTP was conducted. The event concluded with the freshening of airflow associated with a passing cold front late on the 24th.

Conclusions

In common with the results of the earlier odour diary exercise, the results of the summer 1998 odour diary show that almost all odour event detection occurred during conditions of little or no discernible airflow when the atmospheric mixing layer is not extensive in height.

This means that emissions of odour from the sources at the WWTP are trapped close to the ground with little vertical mixing and disperse about the immediate neighbourhood of the WWTP on small scale thermal aircurrents. Intensity does not seem to decay with distance from the source. Such small events are localised phenomena only affecting a few observers.

However when still warm dry conditions and odour emissions persist, as happened during several weeks over the 1998 summer, far more observers pick it up.

The results provided the Council with a useful baseline of data to assess the impact of the WWTP modifications.

7.7 ODOUR MITIGATION – PARAPARAUMU WWTP

CASE STUDY SUMMARY	
Location	Paraparaumu WWTP, Kapiti Coast District Council
Subject	Control of odours from sludge consolidation/ stabilisation ponds
Application	Chemical sprays, covering, application of hay
Last Updated	April 2000
Further information contact	Ian Basrie, Wastewater Treatment Manager, Kapiti District Council

7.7.1 Summary

The Paraparaurnu Wastewater Treatment Plant (PWWTP) has been ponding waste activated sludge over a number of years. Some odour problems have resulted. Following the introduction of a dissolved air flotation unit in mid-1997, the odour problem became much worse. Odour neutralising chemical sprays were used between November 1997 and January 1998 to little or no effect. The problem was overcome temporarily by covering the offending pond and venting this through hay stacks built at each corner of the pond. More permanent means of sludge management and odour control are now being designed and installed.

7.7.2 Background

The PWWTP was commissioned in 1984 as an extended aeration activated sludge plant. In February 1995 extensions to the plant were commissioned which added biological nutrient reduction to the process. Waste activated sludge has been pumped to holding ponds for consolidation and stabilisation where it is held for more than two years before disposal to the landfill. Some odour has always been associated with this process.

The Kapiti Coast District Council has been considering for some time the best means of sludge disposal. The first part of this exercise was to retrofit a dissolved air flotation unit (DAF) into the old gravity thickener. It was anticipated that a DAF would be able to operate continuously and produce a sludge better than 3% dissolved solids, whereas the gravity thickener was achieving less than 1% dissolved solids as it was too small for the sludge quantities. Therefore, the DAF would reduce the volume required to be stored.

Because further sludge handling facilities were proposed, it was assumed that a temporary solution would be all that was required as the holding ponds would be decommissioned within a short period.

7.7.3 Odour Problems

Odour problems associated with the sludge ponds escalated when, in mid-1997, the DAF was commissioned. Although the DAF achieved a much thicker sludge (3.5 to 4% dry solids) this was full of air much like the consistency of a blancmange. Within days of this being placed in the ponds it produced a horrible stench, and the neighbours began to complain.

A firm specialising in odour control was called in, and in mid-November 1997 a high pressure deodorising spray unit was installed and commissioned. This consisted of a drum of concentrated odour neutralising solution, a mixing tank, a pressure pump with automatic timer controls, and 24 atomising nozzles strategically placed around the ponds. Many adjustments were made over the next two months including the concentration of the spray, the timing of spraying and whether intermittent or continuous, and the number of nozzles operating. Sometimes it seemed that the sprays were having an effect, at other times (especially during warm, relatively calm conditions) the smell seemed as bad as ever.

Community Survey

Before the spray equipment was commissioned, some of the affected neighbours were contacted and asked to report daily (morning and evening) on odour levels and note any significant odours at any time. The weekly returns confirmed that the deodorising equipment was having little or no effect.

Direct Spraying

Immediately before Christmas, it was recognised that something more drastic was needed. Again, on the advice of the 'experts', a quantity of the active solution was sprayed directly onto the surface of the pond. It was hoped that this would give some relief over the Christmas - New Year break, however this did not eventuate and the odours remained.

Pond Cover

During January 1998 the smell continued and “kiwi ingenuity” was applied to the problem. Plant operators considered that the only quick way to solve the problem was to completely cover the pond. Tarpaulin manufacturers were contacted and a large polyethylene cover ordered (55 metres square). In the meantime complaints continued, culminating in the issue of an abatement notice by the Wellington Regional Council on 27 January 1998. This notice allowed till 11 February to abate the nuisance.

The cover arrived on 3 February and was pulled over the pond the next day and the edges dug into a trench. This took considerable effort as the cover weighed just under 2 tonne and the position meant that only manpower could be used. Two 50mm PVC pipes were laid under the cover at each corner and these were terminated under hollow hay-stacks. The hay stacks were to act as a biofilter for any foul air released. Bales of hay were also used to stabilise and weigh down the cover.

The effect of the cover on the odour was immediate, and no more complaints were received after its installation.

Shortcomings of the Cover

Because it was assumed that the cover would be a temporary expedient only, a light weight material (14x14 polyethylene cloth) was used. This has proved not to be strong enough. The sludge enters the pond on one side and there is a substantial drag effect as it flows across. This drag placed the cover under considerable tension and at weak points this had split across the width of the pond. One worry was that having split, the cover could be destroyed by wind action. This was stabilised by placing hay bales on either side of the split. Hay was also spread over the exposed sludge and this appears to have suppressed any odours which may otherwise have been released.

Hay Covering as an Odour Control

Once the first pond covered was full, sludge had to be pumped to top up a pond used previously. Following the experience of using hay where the cover had split, the fresh sludge in this second pond was covered with a layer of hay 200-300mm thick. This was carried out in September 1998. Whereas immediately prior to placing the hay this pond was beginning to smell in the warmer weather, following the placing of the hay there was no nuisance odour. There is some smell from the hay itself but this is not objectionable.

7.7.4 Discussion and Conclusions

The failure of the deodorising chemical may have been due to a mismatch between the source of odour and the active chemical agent. Because the problem was serious and immediate, no attempt was made to analyse the gases being released from the sludge. It was evidently assumed by the suppliers of the chemical that the main odour-causing gas would be ammonia. As this is a biological nutrient reducing plant with a high level of nitrification/denitrification ammonia may not have been the problem at all. It is likely that hydrogen sulphide may have been more of a problem.

The fabric used was a 14x14 polyethylene cloth, which is described by the supplier as the highest grade 'cheap' material. If a more permanent solution is required, using fabric covers, then a heavier duty cloth would be needed for a pond of this size.

The following conclusions are drawn from the Kapiti Coast District Council experience.

- To have any hope of success, neutralising deodorant sprays need to be carefully matched to the actual odour being released.
- The experience suggests that neutralising chemical sprays have little or no effect where the odours are in an unconfined situation.
- Covering open sludge ponds with polyethylene cloth is a practical short term solution for the control of odours.
- Hay appears to be a useful odour absorbing agent acting as a medium tor odour reducing bacteria.

7.7.5 Update April 2000

Covering the ponds and using hay over any exposed sludge has proved to be an excellent short term measure. A similar polyethylene cover has subsequently been used on a second pond to good effect.

From December 1998 sludge from the Paraparaumu Plant has been further dewatered through a centrifuge. This has increased the dry solids content to between 15 and 18% and further reduced the storage requirement. The dewatered sludge has proved to be as volatile and odorous as the sludge directly from the DAF. Covering with polyethylene and hay have continued to be used as odour control measures with good success.

The Kapiti Coast District Council has now determined the final sludge handling facility for Paraparaumu, which will incorporate sludge vitrification through the Lemar process. This facility is now under construction and is due to be commissioned in July 2000, after which the sludge lagoons will be decommissioned and this source of odour eliminated.

7.8 CHAPTER 7 REFERENCES

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Young J.; 1997; "Surveying a Community's Perception of Odour"; Research Report No.97/02, Centre of Computing and Biometrics, Lincoln University.

APPENDIX A: GUIDELINES FOR THE APPLICATION OF DISPERSION MODELS TO ODOROUS SOURCES IN NEW ZEALAND

by Jenny Godfrey, National Institute for Water and Atmosphere Research (NIWA), Wellington (since moved to Earthtec, Wellington - 1998).

CONTENTS

1. THE PURPOSE OF THIS GUIDE

This guide sets out to provide sound, practical advice on the application of air pollution dispersion models on modelling of odours in New Zealand. This guide aims to offer a standardised modelling procedure and to describe the dispersion models most suitable for short to medium range odour dispersion.

The need for a document of this nature has been brought sharply into focus for the following reasons.

- Growing awareness that odours are one of the largest sources of complaints in industrial consents.
- The difficult nature of quantifying odours due to their subjective nature contributes toward ineffective “method based” and “legislative based” control strategies of odour nuisance.
- Complicated nature of odour measurement and control techniques.
- Lack of a simple yet effective, regulatory framework for an odour guideline.
- Recognition amongst experts that similar models can produce widely different results depending upon subtle differences in inputs and mode of application.
- Widespread availability of models with “user friendly” computer interfaces that encourage application by non-specialists.
- Rapid expansion of desktop computing power.
- Legislative changes that place the responsibility for airshed management on regional councils and territorial local authorities (the 1991 Resource Management Act changed the regime of air quality management from control of emissions at source to an effects-based approach).
- Growing awareness of the complicated dispersion characteristics at most New Zealand sites.

Air pollution dispersion modelling in New Zealand is most often carried out by individuals without a strong background in air pollution meteorology and furthermore, models are frequently applied and interpreted inappropriately. Consequently, it is also essential that those applying dispersion models be aware of the following:

- the limitations of such models;
- the typical magnitudes and ranges of the model input parameters;
- the appropriate choices of model options;
- conditions under which applications of particular models may be wholly inappropriate (for example, in hilly or coastal terrain).

There is a clear need for a common framework for modelling odour dispersion in New Zealand. This guide aims to provide an overall foundation for the application of modelling to odours by Councils and consultants, and thereby establishing a solid basis for the sound interpretation of model output. In so doing, it is hoped that the guidance provided will also be of benefit to those "end-users" whose task it is to make decisions on the basis of technical modelling reports.

The advice provided draws heavily upon the extensive experience of New Zealand scientists who have worked on the development and application of a wide range of air pollution models in a variety of New Zealand contexts. In recognition of the diverse backgrounds of readers, the guide is deliberately non-technical and attempts to provide sound practical advice designed to maximise reliability of predictions of ground level concentrations.

Typical issues addressed include:

- What are the advantages and disadvantages of the various models?
- Model pitfalls, especially terrain and coastal effects.
- Model limitations and model error, especially with regards to odour.
- Rules of thumb with regard to receptor spacing and terrain.
- Meteorological data.
- Model interpretation.

This study is separated into several sections. Chapter 2 acts as an introduction as well as highlighting the specific characteristics of odours and the problems likely to be experienced during modelling as well as typical sources of odours. Chapter 3 focuses on dispersion modelling and the modelling process, whilst Chapter 4 highlights modelling in New Zealand. Chapter 5 deals with the setup of model runs and Chapter 6 with special cases. Interpretation of model output results and conclusions terminate the document.

2. ODOURS AND THE MODELLING PROCESS

In general odour regulation, control and measurement is a major air quality concern in New Zealand. Industrial and trade processes are keenly awaiting a set of guidelines that will bring a degree of consistency around New Zealand to the control and measurement of odours.

Particular attention in this Chapter has been given to describing odour regulation in New Zealand and the role that atmospheric dispersion modelling plays in the regulatory process. Secondly, there is a focus on pointing out those areas which are likely to cause problems with modelling and interpretation of results. Thirdly, a comparison between odours and other common gases highlights the peculiar nature of odours which highlights the difficulties when conducting dispersion modelling.

2.1 ODOUR REGULATION

The most common form of odour regulation is source characterisation, allied with atmospheric dispersion modelling. Most international standards to odour regulation are based on the following progression:

(a) characterisation of the source, usually by forced-choice dynamic dilution olfactometry (DDO);

(b) use of standard dispersion model;

(c) comparison of the results to the appropriate national standard;

(d) determine appropriate emission standards.

The main impetus of international research in the last two decades has followed this direction of progression.

It is important to note that the current regulatory guidelines for odour modelling standards in Australia and New Zealand are based on several assumptions.

(a) Current dispersion models can sensibly estimate 3-minute average ground level concentrations (glcs) under most atmospheric conditions in flat terrain, and that the glcs profiles closely follow the ensemble mean.

(b) Odours from different sources are generally assumed to combine in an additive fashion.

(c) Because of olfactometry methodology, odour thresholds are usually tied to the median response of the population, not that of the most sensitive members.

It is also important to note that all of the guidelines mentioned above are irrelevant if the public still complain of odour nuisance even though the model predicts compliance with the guidelines. This may happen if the guideline is inadequate, some sources of odour have not been identified and modelled (such as occasional sources or leaks through covers), or if the dispersion model is inappropriate for the meteorological conditions and surrounding terrain. Therefore, once a process has been established, the continued use of dispersion models and comparisons against standards may be of limited value except to identify relative contributions of various sources.

In general, the international air quality regulatory community has been slow in developing more standardised procedures for carrying out odour surveys and determining overall community response to actual or perceived odour problems.

In New Zealand and Australia atmospheric dispersion modelling is still seen as an essential component of odour regulation and control despite the numerous potential problems inherent to quantifying and modelling of odours. This study attempts to address all those points which affect the modelling process.

2.2 DIFFICULTIES WITH MODELLING OF ODOUR SOURCES

Compared to many other air contaminants (such as dust and chemical gases), the measurement of odour emission rates and prediction of ambient odours revels is more complicated. Table A-1 lists some of the key significant differences between odours and other common gases. Each of these differences affect the modelling process in some way or another.

There are several characteristics peculiar to odours that directly affect the modelling process. These are as follows.

- Odours are complex and subjective by nature and are difficult to quantity, ie, it is difficult to get realistic emission rates.
- Odours have various response rates and masking abilities and are perceived differently depending on the source, ie, area sources are perceived continuously whilst point sources may be perceived intermittently - this will effect glcs, and may lead to either over or under predictions.
- Infrequent bursts of strong odour can be less of a nuisance than long exposures at a lower intensity - confusion as to averaging times.
- Odorous sources are often characterised by a varied and often complicated network of structures, such as roof vents, stacks, large area sources and door leaks.
- Modelling of odours is complex. Some odours mask others, other odours change in their intensity with distance and exposure to air and light. Thus odours are not essentially additive and it is conservative to model assuming they are so. However, no quantifiable alternative has yet been developed.
- Interpretation of the results - there is a rack of both theoretical knowledge and experimental observations which means there is no solid base on which to build worthwhile odour standards.

- There is current debate over the standardisation of measurements of odour concentrations and their relationship to background levels and perception of nuisance.
- Because of the intermittent nature of odours, a full year of meteorology is recommended as input into Gaussian models. This allows more accurate interpretation of the results, such as estimating frequencies of occurrence. However, this meteorological data may not be available.

TABLE A-1: UNIQUE BEHAVIOUR OF ODOURS COMPARED TO OTHER GASES

Characteristic	Odours	Most other gases, eg sulphur dioxide
Range of concentrations	Very short term concentrations since the range of response times of the nose is 0.1 - 1 seconds.	Concentration averages are typically over a period 10 - 60 minutes for adverse effects on health.
Intermittency	Irregular record of high peaks and periods of low concentration.	Regular record.
Source structure	Odour recognition differs according to source structure, ie odour detection is different depending on whether the source bean area or point source.	Gas effects on health remain the same regardless of the source structure.
Objective relationship between response and glc	Odour response is not linearly related to concentrations of odorous compound,	In most cases, response is linearly related to concentrations of pollutant.
Relationship between response and glc	Odour response is more related to the general characteristics of fluctuations of glcs away from the mean value, rather than the value of the peak glc.	Gas response is related to the value of the peak glc.
Main concerns	Annoyance and nuisance.	Health effects.
Human response	Can vary by factors of up to 100 between individuals.	No variance between individuals.
Most complaints	Mostly very stable night-time flows, with light winds and low turbulence.	Stable, unstable and neutral conditions.
Exposure limits	Desensitisation of the nose occurs after approximately 300s.	No desensitisation occurs regardless of time Wit.
Measurement	Normal monitor response times are too slow and insensitive at tow odour concentrations, so there no efficient and accurate means 10 determine short-term ambient odour levels.	Most pollutants are within the range of normal gas monitors.
Source characteristics	Variety.	Mostly point sources.
Met condition for max glcs	Transition from neutral to stable or stable boundary layer.	All conditions often unstable.

Notes to Table A-1:
1. Glc = ground level concentration predicted by the dispersion model

3. DISPERSION MODELS AND THE MODELLING PROCESS

Dispersion of pollutants released into the atmosphere is governed by turbulence at a wide range of scales. Near the surface of the earth turbulence is manifested in the small scale motions that pull smoke rings apart, in the "gustiness" of the wind, and in the upward motion of air forming cumulus clouds and "thermals". Much of the turbulence experienced near the surface of the earth is due either to the effect of air flowing over a rough surface (like water flowing in a rocky mountain stream) and/or the effect of heating of the earth's surface (like a boiling pot of water).

Unfortunately for those interested in dispersion of pollutants, turbulence is one of the great intractable problems in Atmospheric Science. It can only be represented in a statistical sense (ie, looking only at the average effects of turbulence). For this reason, it must be recognised at the outset of any modelling effort that there are likely to be significant errors associated with any prediction of odour units (hereafter referred to as OUs).

How do dispersion models deal with the "'chaotic" behaviour of the atmosphere? There are several approaches to modelling dispersion. The one most commonly used is to assume that for a plume of pollutants from a single elevated point source over a period of time (say 1 hour), the plume will fluctuate in direction horizontally, giving rise to a tell-shaped distribution of concentrations (see Figure A-1). Over the same time, the plume will also spread out in the vertical direction, also giving a bell-shaped distribution of concentrations around the centre line of the plume. T hese bell-shaped distributions of concentrations in both the horizontal and vertical are known in statistics as the normal or Gaussian distributions and can he easily described mathematically.

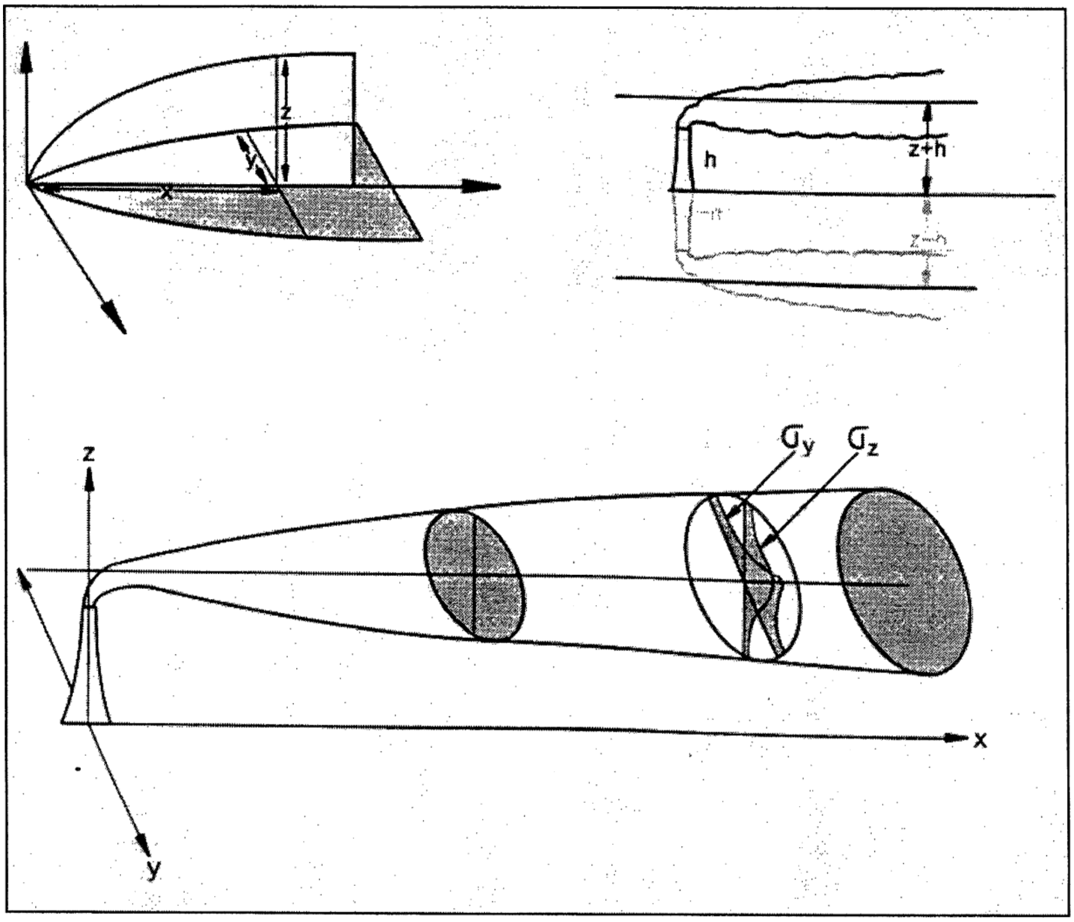

FIGURE A-1: A TYPICAL PLUME FROM AN ELEVATED POINT SOURCE ILLUSTRATING PLUME RISE, AND THE NORMAL (GAUSSIAN) DISTRIBUTION OF POLLUTANT CONCENTRATIONS IN THE HORIZONTAL AND VERTICAL. ALSO INCLUDES THE THREE-DIMENSIONAL CO-ORDINATE SYSTEM USED IN THE GAUSSIAN PLUME MODEL (FROM OKE, 1987).

It is this mathematical description that forms the basis of Gaussian dispersion models. On the basis of the mathematical model of the plume shown in Figure A-1, the glc of pollutants at some distance from an elevated source are dependent on the wind speed, and the dispersion parameters (σ_y, σ_z). These dispersion parameters represent the degree of plume spreading that occurs in the horizontal (σ_y) and in the vertical (σ_z), and are critical to any modelling approach. These two parameters will vary independently according to the state of the atmosphere (particularly the level of turbulence) and thereby dictate the shape of the plume and most importantly where it will impact the ground. Much of the difficulty in Gaussian dispersion modelling is associated with quantifying these parameters.

The Gaussian representation of dispersion described above is simplistic and, as such, it applies only to a limited range of conditions. In particular, it applies to:

- continuous emissions from a point source;
- inert almost weightless pollutants (eg, gases and particles less that 20 μm in diameter);
- time periods greater than about 10 minutes;
- distances in the range from a few hundred metres to about 10 km;
- relatively flat terrain.

Furthermore, the models often assume that:

- atmospheric conditions are not changing through time and distance (ie, the meteorology stays the same between the source and the receptor);
- there is no chemistry occurring within the plume (ie, chemical reactions, between pollutants and with the air and light);
- there are no horizontal and vertical variations in turbulence, wind speed and wind direction within the boundary layer.

In Table A-2, a summary of the various sources of error in the use of Gaussian models is provided. Not only are errors associated with the representativeness of the model (ie, deficiencies arising from the assumptions described above), but also there are significant errors associated with specification of emissions and meteorological inputs. The latter are discussed in detail in subsequent sections.

Given the assumptions and limitations described above, the best that modellers can hope for with a Gaussian dispersion model <u>is to predict concentrations within a factor of two</u> of the actual case (ie, the ratio of the actual concentration to the predicted concentration is two or less). The largest error expected to occur during the process of modelling odours is in the correct quantification of odour emissions - both in quantity and fluctuation (detailed in Chapter 2 of this Appendix). Therefore the error may be even higher with odours. Greater errors would also be found if the task was to predict the glc at a specific location downwind of a source.

Within this context, it is important to recognise that, despite considerable advancements in the user-interface (the appearance and ease of use of the models on desktop computers), Gaussian dispersion models have not changed fundamentally over the past two decades. The limitations and uncertainties described above remain. Instead, most improvements have sought to simply extend the range of conditions in which models can be used.

With the raft of uncertainties described above, and the crucial importance of correctly predicting ground level concentrations of pollutants, the following questions arise: "*why bother with modelling at all?*" and, furthermore, "*what models are out there? Are they better than the Gaussian models?*"

For all their deficiencies, Gaussian plume models represent a well understood and internationally standardised acceptable approach to modelling. Furthermore, they are simple to apply. These qualities are particularly important from a regulatory point of view where ease of application and consistency from application to application is imperative. Certainly there are more sophisticated approaches to dispersion modelling - such as advanced mesoscale models such as AUSMET/AUSPUFF, LADM and RAMS. However, unless one has better input parameters about the source characteristics and odour emissions, the use of a more sophisticated approach may not be really worthwhile. In Gaussian models at least the assumptions, errors and uncertainties are well-understood.

Within this framework, Gaussian models provide a valuable tool to:

- improve understanding of dispersion problems;
- give order of magnitude indications of potential air quality problems;
- indicate where further study is required (eg, the need for detailed field measurements in particular meteorological conditions);
- describe the impact of plant modifications and compare the noticeable effects of mitigation options;
- assist both regulatory bodies and proponents of emission sources to minimise environmental impacts. Models provide a quantitative and reviewable prediction of the potential effects of atmospheric emissions;
- show where the greatest impacts are in the surrounding community;
- compare the relative effects of various sources;
- test the sensitivity of individual sources to upsets;
- compare existing versus future odour effects.

Unfortunately, there exist many misconceptions about dispersion modelling. Although the ultimate aim of modelling is to produce a complete description of the process, this is never realised. Models are at best an aid to understanding. Model predictions give the illusion of both accuracy and precision, but in fact require skilled interpretation. Unless the underlying assumptions and model limitations are well understood, the interpretation of results can lead to erroneous conclusions.

TABLE A-2: SOME CAUSES OR ERROR DURING THE MODELLING PROCESS		
Error Type	**Error Source**	**Error Cause**
Emissions Data	Source strength / composition	Not known accurately enough
	Source location	Position and height not determined
	Variability in emission rates	Varies on short time scale
	Stack parameters	Not known accurately enough
	Plume rise after emission	Varying heat output
Meteorological Data	Wind direction	Not accurate, variations not determined, unrepresentative, varies over area of interest
	Wind speed	Not accurate, variations not determined, unrepresentative, varies over area of interest
	Dispersion parameters	Not known, estimated rather than measured, variable
	Mixing layer depth	Not known, variable
Model Representativeness	Plume behaviour not Gaussian	Special conditions apply; too close to source (<100m), too far from source (>10 km)
	Meteorological parameters not uniform in model domain	Curving wind directions, varying wind speed, presence of growing boundary layer
	Turbulence rates changing	Changes in surface roughness, changes in surface heat flux
	Point sources/area sources not representative of source	Models assume idealised sources
	Practical computational limitations	Calculations usually carried out for one hour segments, during which conditions can change
	Computational inaccuracies	Rounding errors, time averaging effects.
	Transformation and removal process	Chemical reactions, washout in rain

4. MODELLING IN NEW ZEALAND

Even a cursory examination of the assumptions and limitations implicit in Gaussian plume modelling reads to the conclusion that there may be serious difficulties in applying such models in the New Zealand context. Here, many odour emissions may be strongly influenced by either coastal effects (the meteorology varies markedly horizontally and vertically over water and land), topographic effects or both. Most places in New Zealand are within a few tens of kilometres of either the sea or significant hills. Thus, while simple Gaussian plume models developed for flat terrain applications can give an indication of potential pollution effects, their results can be misleading if not tempered by a good understanding of model limitations and a knowledge of the relevant factors which are not handled by the models.

The availability of meteorological data to run models is also a serious constraint in New Zealand. Because of the meteorological complexity of flow around the coasts and hills, which affects almost every site in New Zealand, measurements obtained at one site are rarely directly applicable to even nearby sites. Wind speeds and directions can be particularly misleading unless site investigations are undertaken well in advance of any modelling work. Data on other important quantities, such as stability and mixing height (see Chapter 6.2 for further discussion), often has to be estimated in a manner which leaves much to be desired.

The peculiar dispersion characteristics of New Zealand are summarised in Table A-3. Much of the remainder of this document deals with practical means by which these difficulties can be handled.

TABLE A-3: SPECIAL FEATURES OF NEW ZEALAND WHICH AFFECT DISPERSION MODELLING

Category	Feature	Effect on Dispersion Models
Topography	Mountainous terrain	models do not deal with steep terrain at all well, nor lee effects
	Coastal	Land-sea interactions not well handled
	Surface homogeneity	Many small scale surface features affecting the boundary layer
	Vegetation	Tall trees and dense bush affect roughness lengths and dispersion from sources located close to the ground
Meteorology	Winds	Strong and variable, strongly affected by terrain
	Spatial variability	Dramatic weather variations over just a few kilometres, representative measurements difficult to obtain
	Climate	Long term measurements not available in many locations
	Land-Sea interactions	Marine air moving over land is subject to boundary layer modifications for several tens of kilometres inland, difficult to incorporate in models.

5. MODEL CHOICE FOR ODOUR DISPERSION

The choice of an appropriate dispersion model to use is heavily dependent on the intended application. For some cases, more than one model may need to be applied. For others, none of the models listed below may be appropriate and special expertise may be needed (for example to run complex three dimensional wind and particle trajectory models). Ultimately, the choice of model will be based on a preliminary consideration of several important issues relating to:

- identification of potential contributors to pollutant concentrations in the region of concern, including the background concentration;
- the potential role of "site specific" effects. Of particular importance are coastal and terrain effects;
- the availability of reliable odour emissions data;
- the role of processes such as settling and photochemistry.
- the proposed site layout;
- the modelling domain, resolution and location of potentially sensitive sites. The need for, and availability of meteorological data;
- the sensitivity of the model results (ie, are they close to air quality guidelines).

Only after due consideration has been given to this range of issues can an appropriate model choice be made. This section briefly describes the models in current use in New Zealand, their characteristics, strengths and weaknesses.

AUSPLUME

AUSPLUME was developed by the Victoria Environment Protection Authority (VicEPA) in Australia, and is based on and similar to the United States Environment Protection Agency (USEPA) Industrial Source Complex Model (ISC). AUSPLUME has become the standard Gaussian model for use in New Zealand, particularly in smaller scale applications. It has been used extensively and performs well in most simple situations. This model is easy to use and the output is readily understood. Provided that care is taken with input and interpretation of output, AUSPLUME is a good choice for most simple evaluations. In addition to the standard inputs detailing the source and emission characteristics, AUSPLUME can be run with real meteorology or the screening set provided with the model. It is recommended that it always be used with a year of local meteorology. Outputs include a summary of important factors, statistics of the highest levels of pollutants and statistics of the occurrence of particular concentrations around the source. However, AUSPLUME does have several limitations which are most apparent in complex cases:

- cannot handle complex terrain and meteorological conditions;
- terrain effects are computed only for point and volume sources (ie, neither area not line sources);
- no spatial variation in meteorology;
- calm conditions are not handled (<0.5 m/s).

AUSPLUME is well supported and regularly updated, and the most recent version (4.0, mid-1997) has an enhanced Windows graphical user interface (GUI).

ISC

The USEPA Industrial Source Complex Model (ISC), originally developed over 20 years ago by the USEPA, is now in its third version (ISC3). There are two versions of ISC3, a short-term model (ISCST3) and a long-term model (ISCLT3). The models differ in the averaging times available for calculation, available terrain and deposition options, and the format of input meteorological data. In this Manual, when referring to ISC3, the short-term model is implied.

The models are used to predict pollutant concentrations from continuous point, area, volume and open pit sources. These versatile models are preferred by the USEPA because of the many features that enable the user to estimate concentrations from nearly any type of source emitting non-reactive pollutants.

ISC3 incorporates the USEPA's COMPLEX1 screening model algorithms for use with complex terrain (some or all receptors above final plume rise height) and intermediate terrain (terrain located between the release height and the plume height). When both simple and complex terrain algorithms are included in a Short Term model run, the model will select the higher impact from the two algorithms on an hour-by-hour, source-by-source, and receptor-by-receptor basis for receptors located on intermediate terrain.

The ISC3 model is not as easy for use as AUSPLUME, in terms of the user interface, but a couple of software companies have produced programmes that incorporate the ISC3 model with a user-friendly GUI that simplifies the data entry and checking procedures. An example is the Breeze Air ISC3 model, by Trinity Consultants Inc, (USA). This model is used by at least a couple of modellers in New Zealand.

The ISC model has advantages and disadvantages, as does AUSPLUME. An added feature of ISC3 that is not in AUSPLUME is the characterisation of a new source type – “Open Pit Sources”, for modelling dry deposition of particulates from open pit sources. ISC3 also includes both state of the science dry and wet deposition algorithms. A disadvantage of ISC3 is that it ignores the effect of partially penetrating plumes.

AUSPLUME versus ISC

Results from the AUSPLUME and ISC models are not directly comparable, due partly to minor variations in the handling of terrain and building downwash, but due mostly to the use of different values for the horizontal and vertical dispersion coefficients, σ_y and σ_z (see Sections 3 and 6.2 of this Appendix). In ISC, the coefficients are applied to a 1-hour averaging time. In AUSPLUME, the same coefficients are applied to a 3-minute averaging time, because the model's developers reviewed the initial field research which defined the coefficients and considered a 3-minute averaging time to be more applicable. Therefore, 1-hour average predictions in ISC are comparable to 3-minute average predictions in AUSPLUME.

The minimum averaging time in ISC is 1-hour, because the meteorological data is provided in the form of hourly averages, compared with 3-minutes for AUSPLUME. Averaging times of less than 1-hour in AUSPLUME are obtained by calculating the 1-hour averaging time, then converting the result using the following equation:

$$C_t = C_{60}\left[\frac{60}{t}\right]^{0.2}$$

where C_{60} = concentration for 1-hour average
t = averaging time, mins
C_t = concentration for averaging time of t minutes

CTDMPLUS

The Complex-Terrain Dispersion Model - Plus Unstable Simulation has proved particularly useful in New Zealand due to its ability to handle complex terrain. CTDMPLUS is a point-source, Gaussian-plume dispersion model developed recently in the USA under USEPA contract. It is specifically designed to predict hourly-averaged concentrations in complex terrain and is the best model currently available for this purpose. CTDMPLUS contains a number of features not found in other models, which enable a more physically realistic description of the processes occurring in hilly terrain to be made.

Specific limitations of CTDMPLUS include:

- inability to reliably model dispersion in the lee of hills;
- the model treats terrain features (hills) in isolation. Flow interaction between multiple hills is not represented;
- meteorological data is assumed to be representative of the whole area;
- some inputs have imposed minimum values. For example, winds less than 1 m/s are not considered;
- terrain is smooth to idealised shapes with no slopes exceeding 15 degrees;
- more difficult to use then AUSPLUME and ISC;
- no GUI, and terrain must be specially digitised using a digitising pad;
- specialised meteorological data is required, eg Monin-Obukhov length, friction velocity.

CTSCREEN

A screening version of CTDMPLUS, this has identical features and limitations to CTDMPLUS, but is specifically used only when no meteorological data are available. It is generally regarded as one of the more conservative models, and can be used as a final worst-case check of modelling results.

AUSPUFF

The developers of AUSPLUME have promoted the development of a new model for regulatory use in Australia and it will likely be used increasingly in the New Zealand context. The model represents a significant advance on AUSPLUME and incorporates many of the features on CTDMPLUS into a "puff" based model. However, it requires significantly more computing resources and detailed input data, and is more complex to use. The model has a number of advanced features that make it more widely applicable. These include:

- space and time variations in the meteorological input fields;

- better turbulence representations;
- coastal effects are better handled;
- low wind speed and calm conditions can be handled;
- better treatment of plume rise, inversion layers and plume breakup;
- variable emission rates on line and area sources;
- dry and wet deposition and simple chemistry;
- complex terrain is better handled;
- there is upgraded treatment of building downwash.

A major test and validation programme on AUSPUFF is currently underway in Australia and New Zealand. As more confidence is built up, and the capabilities of the model are explored, it is likely to be used in more applications. However this is a process which will take several years, and it is unlikely to completely displace the other commonly used models.

DISPMOD

Developed by CSIRO and the Environmental Protection Agency of Western Australia, this model has been optimised to account for shoreline fumigation. This is a common phenomenon in coastal locations, which is not handled in the standard Gaussian models. It is currently used in Australia, and is being developed further.

SCREEN

A simple screening model based on ISC, which is generally only used to check the case of fumigation (see Chapter 6.4.2 of this Appendix), which is not handled by many other models.

GASDIS

This is an older model, developed in New Zealand and still used occasionally. It is a straightforward implementation of the Gaussian dispersion algorithms and similar in performance to ISC and the simple options in AUSPLUME. Gasdis is adequate in many cases, but is not used extensively, since the input and output features are overly simplistic, and it does not incorporate some of the details needed in modern modelling approaches.

AERMOD

For several years now, a comprehensive overhaul of USEPA's regulatory models for air dispersion modelling has been underway. The AERMOD dispersion model is a result of this extensive overhaul and has undergone a number of enhancements and modifications since its initial development release. Initially, the AERMOD model was to provide a means of applying atmospheric dispersion algorithms that are state-of-the-science while maintaining the familiar ISC model input file structure. As the scientists developing the model made progress, their goal became more comprehensive. Not only was the model to better characterise the planetary boundary layer, but additional enhancements would be made to improve terrain handling and surface release representations.

As a result of this expanded goal, the final release date for a United States regulatory version of AERMOD is yet to be determined, but is expected sometime in 1998. The goal is for AERMOD to supersede ISC3. AERMOD will:

- adopt ISC3's input/output computer architecture;
- update, where practical, ISC3 model algorithms with newly developed or current state-of-the-science modelling techniques; and

- handle all processes presently modelled by ISC3.

The model will require high quality input meteorological and terrain data, such as surface and upper air sounding data, as well as site characteristics such as surface roughness and moisture availability.

Because of this comprehensive data requirement, which is similar to the CTDMPLUS and AUSPUFF models, AERMOD is not likely to replace the more commonly used models and will remain the tool of modelling and meteorological specialists.

MESOSCALE

There is also a series of very advanced models which can be used for dispersion modelling. These include LADM (Lagrangian Particle Dispersion Model from CSIRO, Australia), and RAMS/HYPACT (Regional Atmospheric Modelling System from USA). These require very substantial computing resources and expertise and are not recommended for general use. These models typically work at scales from a few kilometres to a few hundreds of kilometres, as opposed to the Gaussian models discussed above, if assessments are needed for distances beyond 10 km, then such mesoscale models are required, since the Gaussian approximations can be very misleading.

Table A-4 summarises some basic guidelines on appropriate choices of models for particular applications in New Zealand.

TABLE A-4: RECOMMENDED MODELS FOR A RANGE OF SITUATIONS

This table is a summary of potential model choices in various situations, and their strengths and weaknesses (see text for a full description)

Scope	**Condition**	**Stability**	**Recommendation**
Screening	Flat terrain	Stable Neutral Unstable	ISC, AUSPLUME, AUSPUFF or SCREEN3, but screening meteorology given by each is different.
	Complex terrain	Stable Neutral Unstable	CTSCREEN and AUSPUFF more realistic. AUSPLUME and ISC can give results but not likely to be accurate; ISC likely to be better than AUSPLUME due to inclusion of COMPLEX1 algorithm.
Full Meteorology	Flat terrain	Stable Neutral	All simple Gaussian and other dispersion model studies will perform well as long as the user is aware of each model's deficiencies.
		Unstable	Generally ISC or AUSPLUME. But the benefits of using full meteorology are captured better by a model more suited to unstable conditions such as AUSMET/AUSPUFF.
	Complex terrain	Stable Neutral Unstable	A specific complex terrain model such as CTDMPLUS, AUSMET/AUSPUFF is most suited or mesoscale models such as RAMS or LADM, see also comments above for "screening".
Building wake effects			Schulman-Scire algorithm recommended in all cases.
Special cases – shoreline or inversion break-up fumigation			SCREEN3, but only to examine these special case conditions. DISPMOD in some circumstances, but best treatment with mesoscale meteorological model such as AUSMET, LADM or RAMS.
Special cases – surface releases, eg odours, spills			Depends on the source characteristics, straightforward point, volume or area sources are equally well handled by AUSPLUME, ISC, AUSPUFF. No model is ideal for complex odour sources. Emergency spills, etc, which include dense gases, are best treated by models such as ALOHA, DEGADIS, GASDIS, SLAB.

Special cases – airshed, multiple sources			Challenge for standard models, but most are capable if used carefully. Preference for mesoscale models.
Limitations			None of the models can adequately handle all situations – such as concentrations in the lee of hills, very light winds, very complex meteorology and topography and complex sea breeze situations.

6. SET UP OF MODEL RUNS

Once an appropriate model(s) is chosen any air quality modelling assessment will involve several important steps. With each step, careful choices that will impact on the reliability of the modelling results are usually required. Major decisions and tasks that are typically entailed include:

- choice of modelling strategy - define the scope of an investigation;
- collection of input data;
- determination of receptor grid ;
- selection of appropriate model options;
- consideration of special cases;
- reporting of results and interpretation.

Many of these steps will be influenced by the scale and importance of the project, time constraints and the financial, computational and human resources available. Furthermore, constant re-evaluation is required. For example, the results of a simple screening analysis using a synthesised set of data representing a full range of meteorological conditions may dictate that further modelling, data collection and/or expertise may be needed.

In this section, the first three steps listed above are dealt with in detail. The final two steps are considered in subsequent sections. For odours the most important step is the collection and input of emission data and source characteristics.

The guidelines provided are generally not specific to particular models and therefore careful reading of model manuals is highly recommended.

6.1 MODELLING STRATEGY

Plume modelling is mostly conducted to determine whether glcs exceed some threshold level. Most emitters do not, or are not meant to, reach the threshold under any foreseeable conditions, and modelling is used to predict whether this is so. There are three basic methods by which models can be applied to particular problems.

Screening

In some cases it is satisfactory to run the model with a set of hypothetical meteorological conditions. Such a set should include the worst case and cover a full range of dispersion (stability) conditions and mixed layer depths. In models such as AUSPLUME and ISC3, a screening input data fit is provided. This mode of operation of the models is called screening and is often the first step in a modelling exercise. Screening can be used to give an order of magnitude indication of where and under what conditions pollution problems may occur, where extra study is needed, where special factors might apply and to obtain an overall picture. Provided the screening meteorology covers the full range of possible meteorological conditions, that the choice of model options is conservative, and highest glcs are well below regulatory guidelines, no further modelling may be required. However, some attention may need to be paid to any special effects (eg, the possibility of terrain effects or coastal fumigation). These effects and suggested ways of addressing them are discussed below.

Full Scale Investigation

If the screening exercise shows that potential air quality problems exist, a full scale modelling and observational programme may be required. This typically involves using the best, and most technically up-to-date, model that is appropriate and some form of extended data collection programme. The latter may involve an extensive period of standard meteorological observations as well as deployment of specialised instrumentation (eg, tower studies, vertical profiling with tethered balloons, acoustic sounders) to gather information on the vertical structure and stability of the atmosphere. Invariably, this approach requires a period of analysis and quality control, with perhaps a validation exercise, and full reporting and recommendations. This type of exercise can be both costly and time consuming.

Use of Routine Meteorological Data

An intermediate approach that is useful when routine hourly meteorological data is available, and a meteorological observation programme is not possible, is to run the models with at least one year of available meteorological data. This approach gives a more realistic assessment of the frequency with which particular conditions might occur. It is also likely to give a more realistic view of the site-specific conditions than reflected in a screening study. Problems with such an approach include:

- a year of data may not capture the worst case scenario;
- good hourly data from proposed sites as well as mixed layer depths are rarely available in New Zealand.

Methods of obtaining values of climatological variables (eg, mixed layer depths) are discussed above.

Cumulative Effects

For most cases, modelling is used as an input to an Assessment of Environmental Effects for some air emission. The Resource Management Act is very specific in requiring cumulative effects to be considered. The modelling predictions must be examined not only in relation to the effect of the particular discharge, but also with regard to how this might contribute to existing levels of contaminants.

Thus, a knowledge of existing contaminant levels is usually required at an early stage in the modelling process. In many cases this has to be derived from long term monitoring, which is often not available. Sometimes existing levels can be derived by modelling the other sources in the area, particularly if there are only a few easily identifiable sources. However in other cases it may be necessary to undertake specific new monitoring for this purpose.

Once existing levels are known or estimated, these must be added to model predictions to assess the true cumulative effects. This should be done for both peak values, and longer term averages.

6.2 INPUT DATA

Site and Emission Characteristics

Input data relating to the height and diameter of stacks, temperature and vertical exit velocities, site layout, and emission rates are usually provided by the proponent or owner of a particular emission source, and are assumed to be accurate. In reality, there may be several complex sources contributing to the overall odour problem such as leakages from door vents. In such cases, quantification of input sources, their emissions and source characteristics is highly subjective and difficult to objectively estimate. When considering a proposed source, it is important to recognise that the data may represent design criteria and may not necessarily reflect the true emissions. The emissions could vary according to fuel composition, combustion efficiency and production load. In some cases it will be necessary to check such emissions after the plant has been built, and if significantly different, re-do the modelling.

For the case of an existing source, data on the temporal variations in emission rates may need to be estimated. In both cases, the modeller should attempt to address the worst case scenario (ie, likely maximum emissions).

In cases where models cannot accommodate a source configuration with multiple stacks, models may treat emissions as a single source by simply adding the emissions from each stack and passing them through a single stack (provided the stack diameter and exit temperature is held the same as for a single stack). This gives the worst case scenario for when all individual plumes are aligned along the wind direction and superimposed on each other.

Meteorology

Generally, variations in air quality (ie, concentrations of pollutants at the ground) can be attributed almost wholly to changes in the state of the atmosphere (ie, dispersion characteristics). It is therefore essential that meteorological inputs are as accurate as possible, and their meaning well-understood. The variables most likely to affect concentrations at ground level are the wind speed, and the dispersion parameters σ_y and σ_z, (these are a measure of the propensity of the atmosphere to spread, or disperse, the plume horizontally and vertically). When pollutants are emitted into air that is passing over en emission source quickly, the pollutants are diluted more rapidly, resulting in lower concentrations. Some measure of the depth of the atmosphere, through which a plume can be expected to mix, is also required.

Stability

The stability of the atmosphere is a measure of the propensity for vertical motion (the likelihood that a volume of air will rise or sink in the atmosphere), and is an important indicator of the likely magnitude of dispersion. The extent to which vertical motion occurs in the atmosphere is largely a function of the vertical profile of temperature in the atmosphere. For example, during warm sunny days the surface of the earth is strongly heated and in turn heats the layers closest to the surface this is typically an **unstable** atmosphere. Conversely, at night, the earth surface cools quickly by emitting long wave radiation (much more than the atmosphere). Consequently, temperature will decrease less rapidly with height than in the daytime case, and may even increase with height (an inversion). Such conditions are called **stable**.

The effect of stability and different turbulent intensities is represented in Gaussian plume models by the dispersion parameters (σ_y and σ_z). Unfortunately these parameters are not easily or routinely measured. Several schemes have been developed for calculating the dispersion parameters. Most typical are the Pasquill - Gifford stability classes which assess stability on the basis of the routinely measured variables of wind speed, cloud cover and solar radiation (Turner, 1992).

Mixed Layer

The mixed layer is the layer of air (usually below an inversion base) within which pollutants are mixed by turbulence. It is sometimes called the well-mixed layer or convective mixed layer to reflect that fact that mixing generally produces a uniform distribution of moisture heat and pollutants in the vertical.

Nocturnal Stable Layer

At night the daytime convective mixed layer is typically replaced by a shallow stable layer (typically 10 - 200 m). In this layer, turbulence is considerably reduced and is produced predominantly by mechanical effects (rather than buoyancy effects caused by heating).

σ_q

This is the standard deviation of wind direction. This can be obtained from wind vane data and is an optional method for specifying plume spread in a model.

6.3 RECEPTOR GRID

All dispersion models require specification of a grid of receptors at which ground level concentrations are predicted by the model. The spacing of receptors is an important consideration. Inappropriate choice of receptor grid may result in the maximum glcs not being "captured" by the grid. Simple approaches to optimise the receptor grid include the following.

- Run the model repeatedly, each time halving the grid spacing and checking for differences in model output. The resolution can be accepted when the maximum glc differ between runs by a desired tolerance (recommended 10% or less).
- If a polar receptor grid is used, round off all wind directions in the meteorological data so that they align with the rays of the polar grid.

With odours, it is likely that for the areas of interest will be limited to within the first few hundred metres to perhaps the first few kilometres of the source. An extremely dense receptor grid around the source in all wind directions is then required. In some instances, especially for odours that are emitted from tall stack sources, odours may be carried above the surface of the earth for a considerable distance before coming to ground. An appropriate receptor network is then required. However, odours do change in their intensity and smell with distance: and receptors at far locations may over-predict glcs.

6.4 DEALING WITH SPECIAL CASES

In most models, it is relatively simple to deal with basic problems of dispersion from elevated point sources, which occur in relatively flat terrain away from large obstructions (eg, buildings) and water bodies. However, as described in Chapter 4, such straightforward application of a model is rarely possible in the New Zealand context. Often, the situations in New Zealand when air quality is likely to be seriously degraded are exactly those when the Gaussian plume assumptions do not apply. Attention must therefore be given to the effects of processes which are not well-handled by the Gaussian plume approach on dispersion. It may be that these effects are crucial to the correct assessment of the air pollution impacts from a potential emitter.

6.4.1 Terrain Effects

Under certain conditions (particularly at night when the atmosphere is stable), plumes may impinge directly on hills giving rise to high glcs. Such problems are commonly observed in New Zealand and require careful analysis. Determination of when it is appropriate and necessary to consider terrain effects and what model to use is not always easy. Questions invariably arise of the type: "*is it acceptable to ignore a 100 rn high hill located 2 km from a stack, and if not, what model should be used?".*

The most basic way of treating terrain in models is to ignore the effects of the terrain on wind speed and direction and to simply adjust the height of the plume centre-line above ground-level. Simply stated, this means that the plume centre-line travels horizontally and may directly impact on and at the same elevation as the centre-line. This simple option is offered in ISC3. A slightly more realistic approach (the modified Egan halt height method) is also available in AUSPLUME and permits the plume centre-line to be lifted over elevated terrain to an extent that varies with stability. This is also applied in the COMPLEX1 algorithm used in ISC3 for complex terrain. A considerably more sophisticated approach that permits the plume to flow both around and over terrain obstacles according to stability is used by CTDMPLUS and CALPUFF.

In the steep complex terrain often encountered at sites in New Zealand, use of CTDMPLUS or CALPUFF is usually necessary. However, if local terrain is not significant and a decision has been made to use AUSPLUME or I3C3, sensitivity studies suggest that:

- terrain which is more than 10% of stack height and in the range 5 - 50m should not be ignored;
- for terrain heights smaller than 10% of stack heights, a 10% underestimate in peak concentration will occur.

It should be noted that for both AUSPLUME and ISC3, terrain effects are only computed for point sources and volume sources (ie, neither area nor line sources).

6.4.2 Coastal Effects

The meteorology of coastal areas can have a significant impact on dispersion characteristics. It may also make it unreasonable to represent the meteorology of a coastal site on the basis of meteorological observations (eg, wind speed and direction or mixing depth) from some relatively close inland site. A number of situations may arise in coastal locations that call into serious question the applicability of the Gaussian plume modelling approach. These include sea breezes and fumigation.

Sea Breeze Development

Daytime sea breezes frequently develop around coastlines (including lake shores) during summer anti-cyclonic conditions in New Zealand. These occur when there is maximum solar heating and when large scale winds are light. Often at night in these conditions, winds reverse along coastlines to produce light offshore winds, the "land" breeze. These coastal winds can significantly affect dispersion processes and must be taken into consideration when assessing dispersion from sources near coasts. With respect to their effect on dispersion parameters sea breezes can:

- produce a steady breeze (typically 4 - 5 m/s) where winds would otherwise be light;
- transport emissions inland when they might otherwise head seaward and be of no consequence;
- greatly reduce the mixing depth;
- exhibit low horizontal turbulence (particularly within a few kilometres of the coast);
- create the potential for recirculation of pollutants (sea breezes may have a "return flow" aloft forming a closed cell circulation).

The development of sea breezes around coastlines in Australasia means that very unstable conditions (ie, class A in the Pasquill - Gifford stability scheme) rarely occur. That is, conditions which would give rise to strong convection elsewhere instead generate a sea breeze where wind speeds are too high and turbulence intensities too low to create strong instability.

Potential for Fumigation

A second very important phenomenon in coastal areas is associated with the effect on turbulence levels of air that passes from over water to over land or vice versa. Most commonly, higher than expected glcs may occur from coastal emission sources when pollutants travelling initially in stable, non-turbulent onshore flow are intercepted by a growing surface based turbulent layer caused by solar heating of the land surface. This may cause pollutants to mix rapidly downward, the so-called "fumigation" process, at some distance from the source. This process is illustrated in Figure A-2. Note how pollutants may also be recirculated aloft in the sea breeze circulation.

The fumigation phenomenon is not handled by Gaussian plume models, but should always be considered for coastal sites. The possibility exists (particularly in winter) for over-water fumigation to occur when polluted air passes across cool land and then over relatively warm water (eg, air from a point source transported in stable conditions over an estuary). This has been observed in New Zealand and should be considered when examining potential coastal effects. Unfortunately, there are no well-established relationships describing the growth of an unstable layer over water.

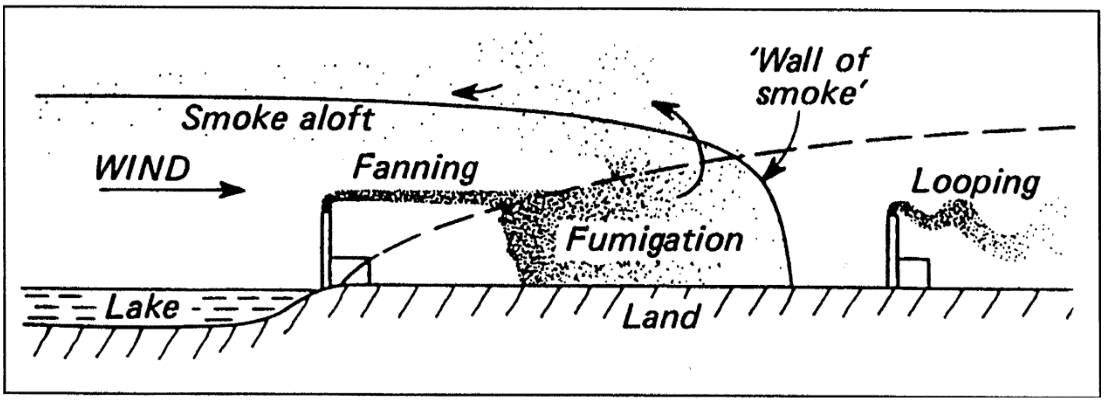

FIGURE A-2: PLUME BEHAVIOUR IN THE VICINITY OF A COAST ON A FINE SPRING DAY (FROM OKE, 1987). THE DASHED LINE IS THE THERMAL INTERNAL BOUNDARY LAYER.

6.4.3 Building Wake Effects

Air flow around buildings is often very complicated and may create zones of strong turbulence and downward mixing. In such cases, the entrainment of exhaust gases released by short stacks or rooftop vents into the wakes of buildings can result in very high glcs and the contamination of fresh air intakes. It is often difficult at the project proposal stage to accurately determine the likely heights, shapes and positions of building associated with an industrial complex, and the way in which flows around these buildings may interact. As a general rule, the stack outlet should be at least 2.5 times the height of neighbouring flow obstacles (ie, buildings) for downwash of pollutants around buildings to be insignificant. This simple rule permits an estimate to be made of the likelihood of significant building effects (and perhaps a recommendation for a higher stack). If wake effects are likely, models such as ISC3 and AUSPLUME permit a simple treatment of the effect on glcs. However, conventional diffusion approaches employed in such models can be misleading in such complex flow situations. Consequently, where significant interactions between several flow obstacles are likely, recourse to either wind tunnel simulations or models designed to estimate minimum atmospheric dilution near buildings (eg, Georakis, Smith et al. 1995) may be necessary.

6.4.4 Partial Plume Penetration into Inversions

A buoyant plume emitted into an unstable boundary layer may sometimes rise to the height of the capping inversion and then partially penetrate into the inversion and be trapped there. If the plume becomes trapped in an elevated inversion then clearly glcs will be significantly reduced.

Models attempt to account for this process by calculating the plume centreline height and the fraction of the plume which penetrates the inversion. However, in treating partial plume rise, the models generally ignore the rising part of the plume. This may lead to a significant underestimate of peak concentrations.

It is recommended that when there is a suspicion that partial penetration of elevated inversions is important (eg, when mixing heights are low and the stack is very high and/or the plume is buoyant) three model runs should be undertaken:

- gradual plume rise and no partial penetration;
- final plume rise and no partial penetration;
- partial penetration and no gradual plume rise.

This approach should give some indication of how important the two phenomena are. In keeping with one of the basic tenets of plume modelling (be conservative), it is recommended that the highest glcs that result should form the basis of the air quality assessment.

6.5 REPORTING AND INTERPRETATION OF RESULTS

Be cautious when interpreting any model's results. **Remember that the results are only as good as the input data. They reflect the amount of guesswork that went into the input**.

Plumes are discontinuous and 'patchy', moved about by winds which fluctuate in strength and direction. A snap shot of a plume at one moment can look quite different from another one taken a minute later.

Gaussian plume models **cannot** represent these fluctuations. Instead, they provide smoothed-out representations, obtained using combinations of two subtly different kinds of averaging, time averaging and ensemble averaging.

The first kind is **time averaging**. This depends on the time chosen; a small averaging time gives a snap shot while a long exposure gives a smoothed out image which is more smooth. The longer the averaging time, the greater the likely variations in wind direction and hence the image of the plume becomes broader and less concentrated around the centreline.

The other kind of averaging is **ensemble averaging**. The objective of an ensemble average is to capture a typical image from the ensemble of photographs, without the time-average's tendency to broaden the image and reduce the concentration about the centreline. The ensemble average has a peak concentration which is also in the middle equivalent of a snapshot for each averaging period. The differences between snapshots decrease as their averaging time increases.

Most models' predictions are interpreted as ensemble averages of a large series of Images, all with a particular averaging time.

In other words, they are intended to depict the "average" trajectory, the "average" rate of spread and the "average" centreline concentrations appropriate for the chosen averaging time, even though the image is smoothed out compared to reality.

It is important not to forget that the ensemble average represents the middle-of-the-range concentrations. At any one instant, concentrations on the centreline could be higher or lower than predicted. This is particularly important when considering odours which fluctuate considerably.

It is recommended that a year of on-site meteorology be used when modelling odours. This way a more accurate 99.9 percentile (or other percentiles such as 99.5) value can be determined which is more realistic of the higher glcs than the absolute maximum. By modelling with a lengthy record or real meteorology it also means that the hours of exceedence of a particular odour level can be determined. The frequency of occurrences of a certain odour level gives more realistic and meaningful information than the maximum glc as it reflects more honestly the actual meteorology. The results are often plotted as contour plots or two dimensional xy graphs and typically show the dominant direction of plume paths and where and how often the plume impacts on the surrounding community.

Consider Table A-5, which compares the interpretation of modelled results for odours versus common gases. Odours typically have very short response times; and are highly variable. Other gases tend to have much longer response times, are not intermittent and their response is related to the peak glc. There are two commonly used ways to interpret odour model results:

(a) peak to mean ratios; and

(b) comparison of model output, OUs, with the rate of annoyance of a community. However, for common gases, either the peak glc or the 99.9 percentile is considered sufficient.

TABLE A-5: INTERPRETATION OF MODELLING RESULTS, ODOURS VS COMMON GASES

Characteristic	Odours	Interpretation of odour model results	Most other gases, eg SO_2	Interpretation of model results
Range of glcs	Very short term glcs since the range of response times of the nose is 0.1-1 seconds	Interpretation of odour modelling should be toward an assessment of odour fluctuation, by: 1. assessing the peak to mean ratio; and 2. compare 99.9% model output glcs or 99.5% with annoyance of community	Glc averages are typically over a period of 10-60 minutes, or even up to 1 year, for adverse effects on health.	The ensemble average given by simple dispersion models on an averaging time gives a reasonably accurate representation. Interpret results by assessing maximum and percentile glcs
Intermittency	Irregular record of high peaks and periods of low glcs	Model output as ensemble averaging is not adequate as fluctuations in glcs are not represented	Regular record	
Relationship between response and glc	Odour response is related to the general characteristics of fluctuations away from the mean value, rather than the value of the peak glc		Gas response if related to the peak glc	Gas response if mostly related to the values of the peak glcs.
Interpretation of results	Assess hours of exceedance above a certain OU level		Assess maximum glcs, hours of exceedance	

There are a couple of different ways to interpret odour dispersion model results. The first is using “peak to mean” (P/M) ratios and the second to use a system employed from the Netherlands which defines the "percentage of population annoyed" and then establishes percentile odour concentration contours known as “Cp” contours. These would allow the use of odour dose-response functions (developed in Netherlands) for predicting actual levels of population annoyance. The latter method has been employed in New Zealand.

Peak to Mean Ratios

The aim of developing a “peak to mean” ratio is to characterise the concentration fluctuations downwind of sources. The interpretation of the results of odour modelling should be **an assessment of the odour fluctuation rather than mean concentration.** Perceived odour is not linearly related to the concentrations of the odorous compound. Odour response is more related to the general characteristics of fluctuations of concentrations away from the mean value rather than the value of the peak concentration.

In order to make an assessment of odour fluctuations, a procedure is available to estimate peak concentrations from predictions of mean concentrations. "Peak to mean (P/M) ratios" will depend on the type of source, atmospheric stability and downwind distance. Once a suitable P/M ratio has been applied to the modelled values, the "new" results are then compared to some odour guideline. P/M ratios are discussed further in Chapter 4.3.2 of this manual. More information on P/M ratios can be obtained from the Environmental Protection Agency of New South Wales (EPANSW).

Netherlands - Odour Dose-Response Functions

Another method for interpreting results is to compare the model outputs to levels of annoyance in the community. In general, the odour dose-response functions show the experimentally determined relationship between odour annoyance in a community and the extent of odour exposure. The exposure is defined as a "Cp" value, which is the odour glc (OU/m^3) which is exceeded for (100-P)% of a total year.

The experimental procedure for developing dose-response functions involves conducting a social survey to measure the level of annoyance to odours in a community. The "predicted" odour exposure level is then correlated to the level of measured annoyance. Source quantification of odour emissions using olfactometry and dispersion models is used to calculate odour exposure levels.

Of the two methods of model interpretation above, neither method can be recommended over the other, they both have their advantages and disadvantages. Both methods need to be periodically reviewed in the light of new experimental and theoretical results.

Necessary Elements

From all that has been described above, a cynic might argue that air pollution dispersion modelling is "more of an art than a science". Certainly, there are tremendous uncertainties inherent in any predictions of glcs from such models, thereby creating the opportunity for criticism and alternative interpretation of model results. Such problems can be minimised in a well written report that systematically addresses the various elements of the modelling process. In particular, the reporting of modelling results should include the following key elements:

- a discussion of uncertainties: it would be grossly unfair to the end-user of the results of a dispersion study (and indeed potentially damaging to the modeller) if the level of uncertainty in model predictions was not made abundantly clear;
- a detailed justification of the choice of model used, the modelling strategy used (“screening” or full scale investigation') and the model options chosen;
- a comprehensive discussion and, if necessary, treatment of any special effects (eg, coastal fumigation, plume impingement on terrain);

- a detailed description of all parameters used in modelling runs (to permit repetition of runs for review purposes, or when new models become available). This material may be relegated to an appendix;
- in cases where the results are likely to be reviewed, it is also desirable to include model output tables as an appendix, although this tends to make the report bulky;
- recommendations for further investigation; is further modelling and/or data collection required;
- any recommended strategies to aid in the reduction of further OUs, eg, higher stack heights, efflux velocities, or higher temperatures of flue gases;
- specification of the reduction in emissions required, and if appropriate, control equipment performance features; and
- an executive summary of key findings at the beginning of the report.

7. CONCLUSIONS

This Appendix has set out to provide sound, practical advice on the application of air pollution dispersion models to odorous sources in the New Zealand context. The central message implicit in the detailed discussion is that even when applied appropriately in relatively simple situations, model results contain significant uncertainties and should be interpreted with considerable caution. In the complex coastal terrain of New Zealand, where the assumptions implicit in Gaussian plume models are invariably violated, there is an even greater burden on the dispersion modeller to make difficult choices as to the most appropriate model and model options to use. As illustrated above, such decisions can have a significant impact on the quality of the modelling study, and most importantly, on the validity of results and recommendations made. With so much at stake, expert advice should be sought wherever possible, particularly with respect to the potential effects of local meteorology and terrain on the dispersion problem.

In summary, the framework provided herein is designed to minimise the possibility of models being applied incorrectly. If a well-chosen model is used appropriately, and its limitations are well understood, then the model results can be a cost-effective decision tool. However in the final analysis, wise application of models and interpretation of their results is a question of experience. Hopefully these guidelines provide a solid foundation on which to build that experience.

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APPENDIX B: APPLICATION OF BIOFILTERS TO CONTROL ODOUR

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CONTENTS

1. INTRODUCTION

Odour pollution of the atmosphere is a common environmental problem. The Resource Management Act (1991) requires that discharges of contaminants to air, including odours, be controlled to avoid adverse effects. Odour management is an increasingly important challenge in the reticulation and treatment of wastewater.

Conventional techniques for controlling odours include incineration, adsorption, chemical oxidation and condensation. Over the last few decades, biofilters have become a popular means of odour control, particularly where large volumes of gas require treatment.

Although biofilters are a relatively recent technology for air pollution control, they are now widely used for treating a variety of odorous emissions, mostly from waste treatment systems and primary processing industries. Several reviews of the technology have been published (van Lith *et al* 1990; Leson and Winer, 1991; Archer and Fullerton, 1992: Bohn, 1992; Mills, 1995, Edwards and Nirmalakhandan, 1996 and Bliss *et al*., 1997). Generally, biofilter capital and operating costs are lower than those associated with chemical scrubbing or incineration systems. The economics of biofilters have been discussed in a number of references (Prokop and Bohn, 1985; Bohn and Bohn, 1988; Leson and Winer, 1991 and Brennan *et al*., 1996).

Although biofilters are an efficient, practical and simple technology for gas cleaning and can reduce odours to acceptable levels, their design and operational parameters are not well defined. Most biofilter designs are based on blanket "rule of thumb" criteria. As a result, the performance of biofilter systems is sometimes unreliable and systems are not always operated at suitable conditions to achieve the desired odour control.

This Appendix provides an overview of basic design, operation and maintenance criteria for biofilters to control odours.

2. PRINCIPLE OF BIOFILTRATION

Biofiltration is a biological process in which bacteria, actinomycetes, and fungi convert odorous gases into carbon dioxide, water, minerals and biomass (Bohn and Bohn, 1988). Two basic odour removal mechanisms are believed to occur simultaneously in a biofilter: adsorption/absorption and bio-oxidation (Williams and Miller, 1992). As the gas stream passes through the biofilter medium, odorous compounds are adsorbed onto the surface of the medium particles and/or are absorbed into the moisture film surrounding the particles. Most gaseous compounds sorbed in the biofilter are then removed biologically by micro-organisms, which use them for carbon and energy sources. These micro-organisms are present in a slime or biolayer on the surface of medium particles (Ottengraf and van den Oever, 1983), and it is here that the biodegradable organic and inorganic compounds are oxidised. It is believed that this bio-oxidation continuously regenerates the biofilter's ability to sorb and remove more odorous compounds. If biofilters are overloaded, sorption sites are filled faster than they are regenerated by bio-oxidation, resulting in odorous compounds passing through the biofilter into the atmosphere (Bohn and Bohn, 1988).

In MIRINZ studies, we have found that, in most cases, biofilters perform well immediately on start-up, suggesting the importance of sorption mechanisms in odour removal (Luo and van Oostrom, 1997a). The relative importance of sorption and bio-oxidation processes in biofilters is currently being investigated in a MIRINZ study funded by the New Zealand Foundation for Research, Science and Technology. In this work, we are comparing the performance of sterilised and biologically active media for treating specific odorous compounds. Preliminary findings confirm the importance of sorption as a primary removal mechanism, and the need for an active microbial population to sustain the removal performance.

Because microbial degradation of odorous compounds in biofilters is necessary to sustain odour-removal, good odour control depends on providing suitable conditions (including pH, moisture content, temperature, oxygen, and nutrients) for microbial growth. The benefits that may be gained by optimising environmental conditions for microbial growth in a biofilter will depend on the substrate loading, and the ability of the filter medium to physically sorb the odour. In the common situation where the substrate loading is very low, good odour removal efficiencies can be achieved when environmental conditions in the biofilter are well outside the range normally thought to be optimal for microbial activity. In this situation, sorption processes limit the biofilter performance. An understanding of such bottlenecks is important in the design and maintenance of biofilters.

3. BIOFILTER DESIGN AND CONSTRUCTION

A biofilter system consists of a gas distribution system and a biologically active filter medium, through which odorous gases pass and odours are removed. A schematic of a typical biofilter for treating odour emissions is shown in Figure B-1. Individual aspects of the overall design are discussed in the following subsections.

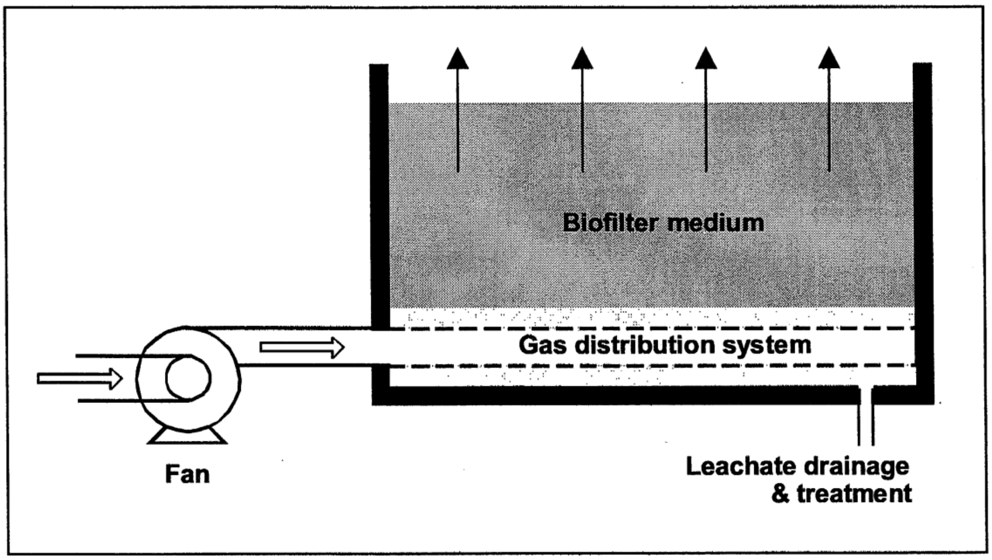

FIGURE B-1: BIOFILTER SCHEMATIC

3.1 GAS PRE-TREATMENT AND DELIVERY

The biofilter influent gas should ideally be moisture-saturated to avoid or minimise moisture loss from the biofilter. It is usually necessary to humidify the gaseous emissions from wastewater reticulation and treatment systems if these gas streams are to be treated by biofiltration. This can be achieved by a fine water spray in the influent ducting (with appropriate drainage), or by a packed-bed water scrubber.

Typically, one or more exhaust fans draw odorous gas from the odour source, for delivery to the biofilter. The fans should be sized based on the gas flow volume to be treated, as well as the total pressure head loss in the system. Stainless steel or PVC pipes are generally used to direct the gas stream to the biofilter.

The pressure drop across a biofilter generally increases over time as the biofilter medium decomposes and settles. Also, short-term increases in pressure drop may occur following watering or rainfall. An appropriately sized variable speed fan can be used to maintain a constant flow rate to the biofilter when the pressure drop changes.

3.2 GAS DISTRIBUTION SYSTEM

The design of the gas distribution system must ensure a homogeneous gas flow throughout the biofilter medium and therefore avoid any short-circuiting of the gas flow. The most commonly used distribution system is a network of perforated (slotted) pipes laid in a 300-500 mm deep bed of coarse gravel. The gravel base ensures uniform lateral distribution of the gas, and allows excess water to drain easily from the biofilter medium. Alternatively, the influent gases can be distributed through a plenum and perforated floor under the biofilter medium (eg, Werner *et al*,. 1986).

Some biofilters contain one or more intermediate layers of porous material, such as fine gravel or bark, between the gas distribution base and the filter medium. These layers reduce the potential for the medium particles to fall into the base. A porous geotextile fabric is widely used in biofilters for this purpose, but in our experience, this material can clog with particles and restrict drainage, causing high back-pressure and uneven gas flow. Careful evaluation of a geotextile fabric is therefore necessary to ensure the fabric will remain porous in the biofilter. A fabric layer is generally unsuitable for biofilters treating gas streams that contain volatilised fats or greasy particles.

The presence of intermediate bark or gravel layer(s) will also help to protect the gas distribution base during loosening and replacement of the biofilter medium, operations that may need to be undertaken several times during the lifetime of a biofilter.

An important limitation of conventional biofilter gas-distribution systems (such as those consisting of a network of perforated pipes) is that they can be easily damaged during moving or loosening of the medium. For large biofilters in particular, heavy machinery may need to drive over the gas distribution base during medium loosening. Therefore, the base of such biofilters must be designed to withstand heavy machinery loadings.

3.3 LEACHATE COLLECTION SYSTEM

The design of the gas distribution base should allow excess liquid to freely drain from both the biofilter medium and the pipework/plenum. Although the mass loading of pollutants in the leachate from biofilters is generally low, the base of the biofilter should be lined with a water-impermeable barrier, to prevent leachate from entering the groundwater. The drainage system should have an appropriate seal (such as a water trap) to prevent the escape of untreated gases. A water seal can be easily created by discharging the leachate at an appropriate depth below the liquid surface in a sump. From the sump, the leachate can drain or be pumped to a wastewater treatment system.

3.4 SELECTION OF MEDIUM

The odour removal performance and operating costs of a biofilter depend primarily on the medium selected; thus medium selection is critical.

The medium should have a large active particle surface area (ie, in general, small particles should be used) to sorb gases, attach microorganisms, and effect good water holding. The medium, however, must be sufficiently porous to maintain a low pressure drop and provide good drainage. A key challenge is therefore to select a medium with an appropriate balance between odour removal efficiency and porosity.

Also, the medium should have chemical characteristics that help to support and sustain the growth of micro-organisms. These characteristics include nutrient content, pH, and buffering capacity.

Biofilter media include soil, compost, sand, bark, peat, scoria or a mixture of these and other materials (Rands *et al*., 1981: Pomeroy, 1982: Furusawa *et al*,. 1984; Prokop and Bohn, 1985; van Langenhove *et al,* 1986; Bohn and Bohn, 1988: Williams, 1995; Luo and van Oostrom, 1995 and Brennan *et al*, 1996). Soil and compost appear to be the most common media used in early biofilters both in New Zealand and overseas. The performance of a soil biofilter depends on the internal pore structure, which, in turn, depends on the type of soil used. Soil biofilters tend to be cheaper to construct (Bohn, 1975). However, this is offset by the generally low porosity of soil, which results in high operating pressures and energy costs (MIRINZ unpublished data). Also, for a given gas retention time, a soil biofilter must be larger than a system containing a more porous medium. Many biofilters in New Zealand contain a mixture of soil and bark to overcome the limitations of using only soil.

The useful properties of compost are its high surface area, high water holding capacity and high microbial population. The compost should be well matured and have a uniform and open structure. A disadvantage of composts and other nutrient-rich organic media is that they tend to have a weak structure that is prone to consolidation over time, and thus to a loss of porosity. This loss of porosity is exacerbated by the high nutrient content, which promotes the decomposition of the medium. As a result, physical properties related to gas flow resistance are not stable, and compost media may need frequent replacement.

We are using pilot-scale biofilters to study the performance of different media (Luo and van Oostrom, 1996). The study aims to develop a medium that provides long-term odour removal and minimal build-up of back pressure. Preliminary results suggest that crushed bark from mature pine (*Pinus radiata*) trees is one of the best biofilter media, as it is available in large quantities of consistent quality and in specifiable particle size ranges. Bark also degrades slowly, has a relatively high moisture holding capacity and is reasonably resistant to consolidation by settling. Furthermore, finely crushed bark has a large total surface area and maintains a low resistance to gas flow. The odour removal capacity of bark is as good as or better than that of the other media we investigated (Luo and van Oostrom, 1997a). In a laboratory study, we found that the addition of activated sludge from wastewater treatment to a fresh bark biofilter improved odour removal performance (MIRINZ unpublished data). Further work is being undertaken to determine whether the sludge improves performance by increasing the biological activity (eg, through supplying nutrients and/or a microbial inoculum), or by a purely physical effect (eg, increased surface area for sorption), or both.

MIRINZ-designed biofilters generally consist of screened bark, with most of the bark mass consisting of particles in the size range 3-10 mm. This size range can maintain a low-pressure drop while giving a large surface area in the biofilter. A layer of coarse bark nuggets is usually placed below the fine bark. These nuggets have several functions: they separate the filter medium from the gas-distribution base; they are a sacrificial layer that protects the gas distribution system when the filter medium is turned or replaced; they assist the horizontal distribution of the gas in the base of the biofilter; they filter some particulates and condensibles; and they remove some odorous components before the gas enters the fine bark layer.

The biofilter medium or layers of media should each be installed to a consistent depth to ensure an even gas distribution, and each layer of medium should have consistent characteristics.

Multiple layers of media (in addition to the intermediate layer) in a biofilter make loosening of the media difficult if the integrity of each layer is to be maintained. If the layers are allowed to be mixed during the loosening process, the mixing must be thorough to avoid short-circuiting problems. It is doubtful whether the potential difficulties associated with a multi-layered biofilter are justified by any potential benefits.

Synthetic materials such as polystyrene spheres are sometimes added to a biofilter medium to increase the sorptive capacity of the filter. These spheres help to reduce system back pressure and extend the useful life of the biofilter medium (Leson and Winer, 1991). Also, the biofilter medium can be mixed with crushed limestone or other alkaline materials to neutralise acids that can build up over time due to microbial metabolism.

3.5 BIOFILTER SIZE AND LOADING

The physical dimensions of a biofilter bed are determined by the residence time required to achieve adequate deodorisation of the incoming gas stream and by the maximum volumetric flow of odorous gases the biofilter will be required to treat.

For individual known compounds, the medium volume required for the desired removal efficiency depends primarily on the loading rate of the odorous compound relative to the specific biofilters removal capacity (Leson and Winer, 1991). For example, Cho *et al*. (1991) reported that the removal capacities for hydrogen sulphide, methyl mercaptans, dimethyl disulphide and dimethylsulphide through a peat-type medium are 5, 0.9, 0.68, 0.38 g S kg^{-1} dry peat day^{-1}, respectively. Shoda (1991) found that the removal capacity for ammonia in peat biofilters is 0.16 g N kg^{-1} dry peat day^{-1}. A biofilter can therefore be accurately designed to treat a single odorous compound by using removal capacities and models of theoretical kinetics (Ottengraf and van den Oever, 1983; Ottengraf *et al*.. 1986; van Lith *et al*., 1990 and Yang and Allen, 1994).

The off-gases from wastewater treatment facilities typically contain a variety of odorous compounds rather than just one or two compounds (see Chapter 1 of this manual), and the composition may change substantially over time. Depending on the amount of knowledge of a particular gas stream, and previous experience with treating similar streams, pilot-scale testing may be recommended. The pilot-scale biofilter should have the same operating parameters as the proposed full-scale biofilter, including the gases to be treated and the medium characteristics.

Biofilter designers typically use either the loading rate of the gas to a biofilter or the gas residence time in a biofilter as a design criterion for determining biofilter size. The biofilter loading rate is often expressed as gas loading volume per biofilter volume per unit time (Frachetti and Kukenberger, 1994). Gas residence time should be calculated by dividing the biofilter influent gas flow rate (eg, m^3 gas h^{-1}) by the total medium pore volume. (Residence time is often expressed on the basis of the whole biofilter volume without considering the pore volume, but strictly speaking, this is incorrect. To avoid confusion, the basis on which residence time is calculated should be specified.)

The pore volume varies widely between different media, and it changes with moisture content and operation time. Gas residence time must not be confused with the odorous-compound retention time, which is the amount of time a particular compound remains in the biofilter after being sorbed onto the surface of the medium particles. Retention times for odorous molecules may vary from a few hours for highly biodegradable compounds to several years for compounds that are difficult to biodegrade (Ottengraf and van den Oever, 1983).

Biofilters treating odours from compost facilities and wastewater treatment plants often have a design loading rate of 0.5 to 6.7 m^3 gas m^{-3} medium min^{-1} (residence time of 9-120 seconds based on the whole biofilter volume) (Leson and Winer, 1991; Lang and Jager. 1992: Pinnette *et al*., 1993 and Frechen, 1994). Biofilters at New Zealand rendering plants have volumetric gas loading rates of approximately 0.06 to 0.68 m^3 gas m^{-3} medium min^{-1} (Luo and van Oostrom, 1995). Accordingly, the residence time of the gas in these biofilters ranges between about 1.5 and 16.7 minutes based on whole biofilter volume.

3.6 BIOFILTER CONFIGURATION

The choice of constructing an odour-control biofilter above or below ground level depends on such factors as the nature of the site, the local water table, civil design issues and economic considerations. Most biofilters are constructed above ground in tanks or enclosed on four sides using concrete or timber walls, although a few are constructed in pits with earthen walls. Most of these biofilters are open to the weather, although small biofilter systems are sometimes covered with plastic or steel roofs for shelter from rainfall. Two or more biofilter modules in parallel are sometimes used, so that odour can be controlled by one while the other is shut down for maintenance.

The depth of medium in biofilters ranges from about 300 to 2000 mm, with depths of 600-1000 mm being most common. Greater biofilter depths can be used, to minimise land requirements. However, increasing the depth of a biofilter increases the back pressure. This is due to an increased self-compression of the medium and the greater gas velocity through the filter. A biofilter depth of 2 m can be satisfactory if a porous medium that is resistant to compaction, such as pine bark, is used.

3.7 MANOMETERS

To monitor the pressure drops in a biofilter, manometers should be installed during biofilter construction. Manometers should be connected to the influent pipe as well as to one or more locations in the gas distribution system in the base of the biofilter. The static pressure head measured in the base of the biofilter indicates the pressure drop across the baiter medium. The difference in static pressure heads measured in the inlet pipe and in the base of the biofilter indicates the head loss in the gas distribution system.

Simple water-filled U-tube manometers give accurate and reliable measurement of static pressure head. These manometers can be constructed using flexible transparent hose formed into a U-shape, and filled with water to half the height of the "U". The manometer should be supported vertically at a location where the biofilter operators can easily read the manometer. The tubing connecting the manometer to the measurement point should be crush-resistant and have a constant fall to ensure that no liquid collects inside this tubing.

4. BIOFILTER OPERATION AND MAINTENANCE

The moisture content, drainage, pH, temperature, and nutrient availability of the medium, and the pressure drop across the medium, must be monitored and controlled within suitable limits to maximise biofilter performance.

4.1 MEDIUM MOISTURE

The medium should be moist, to encourage the sorption of odorous compounds and subsequent oxidation by microbial populations. Medium moisture content is important because it affects not only odour removal efficiency but also the pressure drop of a biofilter (eg, van Langenhove *et al*, 1988; van Lith *et al*., 1990: Bohn, 1992 and Pinnette *et al*., 1993). A low moisture content results in reduced biological activity and volatilisation of sorbed odorous compounds. Also, many organic-rich materials become hydrophobic and difficult to rewet if they are allowed to dry out. On the other hand, excessive moisture levels can reduce the availability of sorption sites for odorous compounds, increase the pressure drop across the biofilter and produce anaerobic zones that emit foul-smelling compounds (Ottengraf *et al*., 1986).

Because moisture affects the pressure drop and thus airflow through a biofilter, a biofilter watering system should be designed to distribute moisture evenly throughout the biofilter. Likewise, the leachate drainage system should allow for uniform drainage.

Depending upon the medium used, the recommended optimal moisture content normally ranges between 40% and 70% on a weight basis (Rands *et al*, 1981; Bohn and Bohn, 1986: van Lith *et al*, 1990; Leson and Winer; 1991 and Frachetti and Kukenberger, 1994). Several biofilter operators have found that for good odour removal, the biofilter medium should be kept at almost field capacity (Luo and van Oostrom, 1995). Our experiments with pilot-scale biofilters confirm this (Luo and van Oostrom, 1996).

Options for moisture control include humidification of the biofilter influent gas and irrigation of the biofilter surface. To avoid the base and possibly the whole biofilter drying out, the influent gas should ideally have a relative humidity of 100% at the entry point.

Warm and moisture-saturated gas emissions, such as those often discharged from rendering plants and thermophilic waste treatment processes, do not need to be humidified. In fact, if the temperature of the process gas is above ambient, water vapour will condense in the biofilter, which requires that the biofilter have good drainage characteristics. Where humidification is desirable (eg, for treating building ventilation air), this can be achieved by a fine water spray in the influent ducting, or by a packed-bed water scrubber.

Surface spraying systems can be also used to control moisture levels in the medium during extended dry periods. Simple garden sprinklers can be used and placed on the biofilter. If the influent is moisture-saturated, water application is required only to keep the surface of the biofilter moist. Much greater amounts of water are needed if the influent humidity is low, and the watering must carefully monitored and controlled to ensure that the biofilter medium is kept moist.

4.2 MEDIUM pH

Medium pH is often recommended to be in the range of 6 to 8 (eg, Frachetti and Kukenberger, 1994), although we have measured good performance from a biofilter with a medium of pH 4.5. The biological oxidation of sulphur- and nitrogen-containing compounds present in the gases may cause the pH to fall within the biofilter (Leson and Winer, 1991). Since this pH fall will affect the resident microbial population and may reduce odour-control performance, medium pH should be checked regularly.

The pH decline will generally begin at the base of the biofilter, and migrate upwards over time as the acidity in the base increases. To monitor this effect, it is necessary to measure pH deep into the biofilter, and perhaps at several depths.

If both pH and biofilter performance drop noticeably, alkaline materials should be mixed into the medium to raise the pH. Crushed limestone or shell ($CaCO_3$ sources) can be used to counter the observed pH drop. In contrast, the medium pH has increased in two full-scale and several pilot-scale biofilters treating animal rendering process gases after several years of continuous operation (MIRINZ unpublished data). The increase in pH is probably due to an observed accumulation of ammonium ion (measured to reach 5,600 mg N/kg d.w. near the base of the biofilters) and a lack of nitrification (a microbial process by which ammonium is converted to nitrate). These media did not have high nitrification activities (MIRINZ unpublished data). Accordingly, not enough ammonium was oxidised to nitrate, allowing the pH to increase in the media.

Controlled leaching may prove to be an important biofilter management tool to reduce the accumulation of undesirable substances and to maintain optimum pH in the medium. A "washing-out" procedure has been tested successfully in biofilters, both for reducing ammonium levels in media (MIRINZ unpublished data) and for reducing acidification and sulphate accumulation (Yang and Allen, 1994). The use of controlled leaching may be able to greatly increase the longevity of biofilter systems.

4.3 MEDIUM TEMPERATURE

Temperature affects not only microbial activity but also the solubility of odorous compounds in water and the sorption capacity of the biofilter medium. Although temperature is known to be an important factor in biological systems, few (if any) published studies have been undertaken to quantify the effect of temperature on biofilter odour removal performance. It is likely that the optimal temperature is a compromise between that giving maximum microbial activity and that maximising the adsorption of odorous compounds onto the biofilter medium and absorption into the liquid phase. van Lith *et al*. (1990) recommend that biofilters be operated within the temperature range of 10-40°C; Green (1994) suggests that maximum odour removal occurs at 35°C; and Leson and Winer (1991) recommend an operating temperature between 20 and 40°C for optimum results.

Biofilter temperature is largely controlled by the influent gas temperature but is also affected by ambient conditions. As temperature affects not only the activity but also the composition of microbial populations, sharp temperature fluctuations in the biofilter should be avoided. Biofilters can also generate heat, through their microbial activity. This phenomenon may enhance the performance of biofilters operating in cold weather (Prokop and Bohn, 1985).

4.4 MEDIUM NUTRIENTS

The microorganisms in biofilters require nutrients for growth. It is generally thought that most biofilter media and influent gases contain enough nutrients that they do not need to be added. In some cases, however, depending on the odorous compounds and the source of the biofilter media, the availability of specific nutrients might become limiting for microbial processes. For example, the addition of nitrogen and phosphorus to a pine-bark medium markedly improved the degradation of toluene in a laboratory-scale biofilter study (MIRINZ unpublished data). Gribbins and Loehr (1988) also studied how nitrogen concentrations in the medium affected biofilter odour-control. Their findings suggest that if biofilters are designed to operate at high loading rates and over long periods of time, operators must take care that adequate amounts of nitrogen are available in the biofilter.

4.5 PRESSURE DROP

One of the key factors in the design and maintenance of biofilters is the pressure drop across the biofilter medium. With a high pressure drop, more energy is required to force the gas through the biofilter. If the pressure drop increases in a biofilter over time, the speed or size of the fan will need to be increased to maintain a constant gas flow rate. A high biofilter pressure drop also increases the risk of "short circuiting" in the biofilter medium (ie, channelling of the influent gas through the filter untreated).

The pressure drop across a biofilter bed is a function of the gas loading rate (Leson and Winer, 1991; Yang and Allen 1994), and is influenced by the type, depth and moisture content of the biofilter medium (Williams and Miller, 1992: MIRINZ unpublished data). Cracks in or compaction of the biofilter medium can cause the pressure drop to change. Poor drainage and leachate collection can also contribute to a high pressure drop. Pressure drop across the gas distribution pipework can also increase when some of the pipe slots are blocked due to the accumulation of particles and condensibles. We recommend monitoring of biofilter pressure drop, as this will detect compaction and indicate when loosening or replacement of the medium is required.

Generally, the pressure drop across the medium (as determined by the static pressure head in the base of the biofilter) should be less than 100 mm water gauge and preferably much lower, especially when energy considerations are important.

Biofilter designers must take care to resolve pressure-drop-related issues when designing their systems. As already mentioned, selection of the medium can be very important, as the medium determines the particle size distribution, the available pore space, drainage characteristics and the bulk density. Use of a high porosity medium can initially minimise the pressure drop across the biofilter. However, over time, natural decay processes of the medium can cause the bed to settle and cause the pressure drop to increase. This effect can be overcome only by periodically turning and loosening the medium, or replacing the medium. We also suggest that surface compaction be avoided during construction and operation, by keeping equipment and vehicles off the biofilter surface.

5. TROUBLESHOOTING

Common problems with biofilters include gas short circuiting, uneven moisture levels in the medium, a short medium life, and insufficient odour removal. These are discussed in the following subsections.

5.1 GAS SHORT-CIRCUITING

Short-circuiting is one of the major problems causing poor and variable biofilter performance (Lang and Jager, 1992: Luo and van Oostrom, 1997b). Gas flow through a biofilter tends to follow the path of least resistance in the medium, and the shortened residence time of the gas in these regions of the biofilter gives reduced odour removal (van Oostrom and Luo, 1997). The short-circuiting is mainly due to non-uniform medium composition and packing density, and cracks or channelling in the medium. Uneven gas flow is also caused by poor design of the gas distribution system, damaged gas distribution pipes and blocked gas distribution pipework slots/holes. In our experience, the use of a geotextile fabric between the gas distribution layer and the biofilter medium can be a cause of short-circuiting. If the fabric has a very fine weave, the fabric can be a significant barrier to gas flow and water drainage. Any gaps in the fabric layer or small variations in the amount of moisture and sediment on this fabric will cause large variations in gas flow.

An uneven depth of medium across a biofilter can also cause uneven gas distribution. It is very important that all the material in the medium layer be turned when required, and re-placed to an even depth without compaction.

Short-circuiting can be detected in biofilters in several ways, depending on the nature of the influent gas. For an influent gas containing significant smoke (eg, emissions from some rendering processes), or warm water vapour, short-circuiting can be observed as localised smoke or water vapour (during cold weather) emissions from the surface of the biofilter. For warm influent gases, temperature variations in the biofilter can indicate uneven airflow. Short-circuiting is also indicated by uneven moisture loss. Another technique is to measure the discharge rate of gas at various locations on the biofilter surface using a sampling chamber technique (van Oostrom and Luo, 1997). Simply sniffing the discharge from such a sampling chamber can indicate short-circuiting of untreated gas through a biofilter.

5.2 UNEVEN MOISTURE LEVELS

Poor biofilter performance is sometimes due to poor moisture control (van Lith *et al*., 1990; Luo and van Oostrom, 1996). Many biofilter operators have called attention to the problems of an increased pressure drop and biofilter drainage on rainy days (Luo and van Oostrom, 1995). The biofilters that are covered by roofs generally have good moisture control. During dry weather, some organic media may dry out, and rewetting by irrigation has sometimes proved difficult. Much moisture loss can occur in the base of the biofilter if the influent gas is not moisture-saturated. To reduce this drying, we recommend humidifying the biofilter influent gas. In our experience, with a humidified influent, it would be better to heavily water the biofilter occasionally, on demand, than to apply a small amount of water regularly. The watering system should give a good and even coverage on the biofilter surface.

5.3 FREQUENT REPLACEMENT OF THE MEDIUM

Several biofilters have required medium replacement not long after beginning operation due to obvious deterioration in performance and high back-pressures (Luo and van Oostrom, 1995). In contrast, other biofilters have operated effectively for more than six years without medium change. The longevity of a biofilter depends on both the nature of the gas stream being treated, and the type of biofilter medium used. To allow biofiltration of the emissions from direct-fired meal dryers used in rendering plants, for example, the gases must be pre-treated to both cool the gases and remove dust and volatilised grease. Without such pre-treatment these constituents in the gas stream can rapidly clog the gas distribution system and biofilter medium. Even with good pre-treatment of the gas stream, the medium of a biofilter treating such a gas stream must have a very porous structure: otherwise it will need to be frequently loosened and/or replaced.

For the treatment of foul air from sewers containing high loadings of hydrogen sulphide, the accumulation of sulphate in a biofilter, and the resultant decline in pH, can be the main factor limiting the life of the biofilter medium. It is generally recommended that limestone chips or crushed shells are mixed into the biofilter media to extend the biofilter life.

5.4 FUGITIVE GASES

It appears that in some situations, poor biofilter performance has been blamed for an odour problem, whereas fugitive gases escaping from wastewater treatment facilities, gas delivery fan chambers and gas pipes are probably the main cause. An odour-control objective should be to ensure that all the significant sources of odour are captured and treated in the biofilter. In addition, the walls of some biofilters consist of timber boards or plywood sheets, with small gaps between. These gaps allow untreated gases to escape from the biofilters, and could be a significant source of fugitive odours. Biofilters should be constructed with airtight walls. The biofilter medium bed should also extend beyond the gas distribution layer to avoid untreated gases escaping around the edges of the biofilters.

6. CONCLUSIONS

Biological odour control technologies have been developed over the last few decades, and biofilters have now become a popular means of controlling odour from a variety of sources such as wastewater treatment plants. When properly designed, operated and maintained, biofilters have proved to be an effective odour control technology. However, some biofilters have operational difficulties, including poor moisture control, short-circuiting of gases and a high pressure-drop across the biofilter.

The gas distribution system in the biofilter must be designed to ensure a homogeneous gas flow through the biofilter medium. The design of the gas distribution base should also allow excess liquid in the biofilter medium to drain to waste. The biofilter medium chosen must be able to support and sustain a diverse microbial population. A biofilter medium must also have physical properties that sustain good drainage and low back-pressures in the long term. These properties must be balanced with the need for a medium to provide a large surface area for sorption processes. The biofilter medium selected not only affects the odour removal performance, but also how often the medium must be renovated or replaced. Along with selection of the medium, proper sizing of the biofilter is important. The required biofilter size is based on the gas loading rate and the residence time required to achieve adequate deodorisation of the incoming odorous gases.

For maximal performance from a biofilter, medium moisture content, medium pH, influent gas temperature and humidity, and pressure drop must be controlled. Medium moisture content affects both the odour removal efficiency and the pressure drop. Moisture content should be effectively controlled by humidification of the biofilter influent-gas, direct surface irrigation or both. pH changes in the medium can affect the resident microbial population and thereby affect the biofilter performance. If needed, the medium pH can be raised by lime addition. Significant fluctuations in the biofilter influent gas temperature should be avoided. Monitoring of biofilter back-pressure is strongly recommended, to indicate the need to loosen or replace the medium.

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APPENDIX C: CHEMISTRY OF ODOUR GENERATION

CONTENTS

1. CAUSES OF ODOUR

1.1 SOURCES OF SULPHIDE IN WASTEWATER

Sulphide in wastewater is normally sourced in four ways:

- sulphide discharged by industries;
- sulphide discharged in human wastes;
- sulphate reduced to sulphide under septic conditions;
- organic sulphur (eg, proteins) reduced to sulphide under septic conditions.

Domestic sewage normally contains 3-6 mg/l of organic sulphur, contained mostly in proteinaceous matter of excreta and food remains. Further organic sulphur (about 4 mg/l) comes from sulphonates derived from household detergents. Inorganic sulphate is present in variable concentration, depending on the hardness of the water supply, as the sulphate ion is one of the most universal anions occurring in natural waters. The resulting concentration of sulphate in domestic wastewater may be in a range of several hundreds of milligrams per litre.

1.2 GENERATION OF SULPHIDE IN SEWERAGE SYSTEMS

A critical offender in the chemistry of odours and one leading to H_2S generation, is the bacterial cycle involving the sulphur/sulphate compounds. Obligate aerobic and facultative anaerobic bacteria use up any dissolved oxygen in the wastewater and then revert to reducing chemically bound oxygen (eg, as sulphate). This results in conditions in which obligate anaerobic bacteria create H_2S (septicity), by the process of putrefaction.

Under these anaerobic conditions, gases including methane, carbon dioxide, H_2S, reduced sulphur compounds like methyl mercaptan and dimethyl sulphide, and a variety of other odorous products are generated. In addition, there can be vapours from volatile products within the sewage itself. The presence of oxygen in the air above the water does very little to reduce the anaerobic conditions in the sewage.

H_2S has an offensive odour (rotten eggs), is highly toxic, can lead to severe corrosion of local structures and has a deleterious effect on any subsequent treatment of the wastewater.

The formation of hydrogen sulphide takes place by the following method:

Atmosphere

↑

$$\underset{\text{sulphate}}{SO_4^{2-}} + \underset{\text{carbon}}{2C} + \underset{\text{water}}{2H_2O} \xrightarrow{\textit{bacteria}} \underset{\text{bicarbonate}}{2HCO_3} + \underset{\text{hydrogen sulphide}}{H_2S}$$

Figure C-1 highlights the important role of adequate oxygen in preventing the onset of septic wastewater and the c6f-i8equent generation of H_2S.

1.3 ROLE OF pH IN THE CHEMISTRY OF SULPHIDE

The chemistry of sulphide in wastewater is complex. In wastewaters, sulphide is a mixture of:

1. insoluble metallic sulphides (predominantly iron sulphides but also small amounts of sulphides of zinc, copper, lead, and cadmium, or any other heavy metal which is discharged to the sewer as trade waste). Being insoluble, this form of sulphide does not contribute to the creation of odour and corrosion problems; and

2. dissolved sulphide. This is a mixture of H_2S, HS^- (a non-volatile hydrosulphide ion) and S^{2-} (sulphide ion) existing in equilibrium with hydrogen ions, as shown by the following equation:

$$\underset{\text{Hydrogen sulphide}}{H_2S_{(g)}} \leftrightarrow \underset{\text{hydrosulphide ion}}{HS^-_{(aq)}} + H^+ \leftrightarrow \underset{\text{sulphide ion}}{S^{2-}_{(aq)}} + 2H^+$$

The proportion of dissolved sulphide present as H_2S, a volatile gas, is a function of pH. This is shown in Figure C-2. At neutral pH of 7, the distribution is approximately 50% volatile H_2S gas and 50% non-volatile hydrosulphide ion. At pH 6, 90% of sulphide is in the form of H_2S, while at pH 8 only 10% of dissolved sulphide is present as H_2S. Above a pH of about 9.2, none of the dissolved sulphide is in the H_2S form.

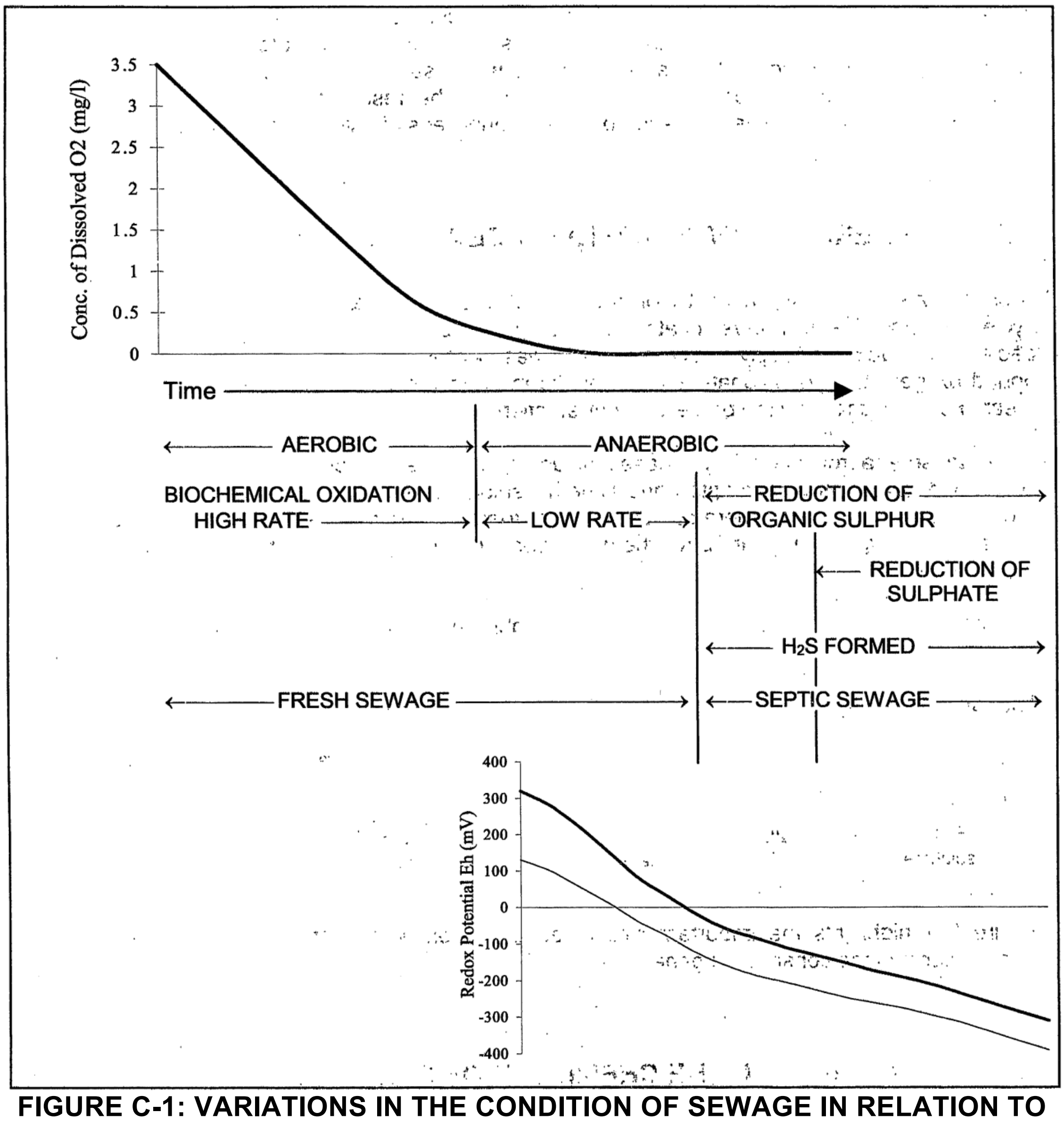

FIGURE C-1: VARIATIONS IN THE CONDITION OF SEWAGE IN RELATION TO CONCENTRATION OF DISSOLVED OXYGEN AND REDOX POTENTIAL

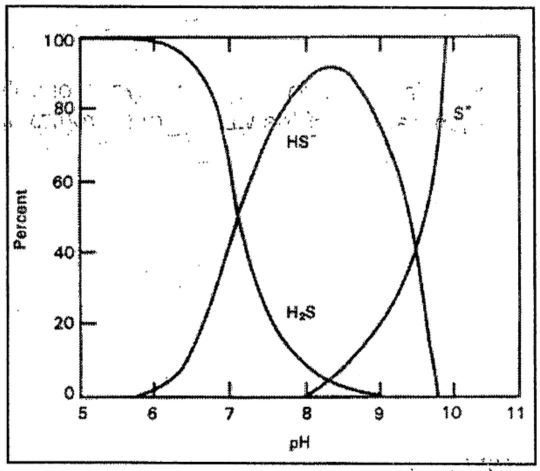

FIGURE C-2: EFFECT OF PH ON H2S EQUILIBRIUM

(From EPA/625/1-85/018; Design Manual – Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants; US Environmental Protection Agency (1985)

2. OXYGEN CHEMISTRY

2.1 DISSOLVED OXYGEN CONCENTRATION IN. EQUILIBRIUM WITH AIR

Henry's law is very useful when predicting saturation values for gases dissolved in liquids. It states that the amount of gas that dissolves in liquid at a given temperature is directly proportional to the partial pressure of the gas above the solution. It is only valid for dilute solutions and relatively low pressures that are normally the case in wastewater treatment.

Mathematically: $C^* \propto$ *Gas Partial Pressure*

or: $C^* =$ *Gas Partial Pressure x Henry's Law Constant*

For oxygen and water at 20°C and 1 atm pressure:

C^* *mg/l* = *Oxygen Partial Pressure x 40.6*

The greater the oxygen partial pressure, the greater the concentration of dissolved oxygen in equilibrium with the surrounding water. The constant is not the major influencing factor in the equation; rather, the concentration gradient is.

For air: oxygen partial pressure = 0.21 atm (Air is ~21% oxygen)
$\therefore C$ = 0.21 x 40.6
= 8.5 mg/l

For pure oxygen: oxygen partial pressure = 1 atm
$\therefore C^*$ = 1 x 40.6
= 4 mg/l

These values represent the saturation dissolved oxygen concentrations (D.O.'s) in water at 20°C and 1 atm absolute pressure.

Complete saturation is never quite achieved with pure oxygen under practicable conditions because dissolved gases (particularly carbon dioxide and nitrogen) diffuse into the pure oxygen slightly decreasing the partial pressure.

2.2 KINETICS OF OXYGEN TRANSFER

Since the solubility of oxygen in water is low, the oxygen transfer rate from, say, an oxygen bubble into the water is determined solely by the resistance to oxygen transfer of the water film surrounding the bubble.

Under these conditions:

Oxygen transfer rate $\propto$ (C - Dissolved oxygen concentration in the liquid)*

or:

Oxygen transfer rate = K_{La} x (C - D.O concentration)*

where; (C* - D.O. concentration) is the driving force for oxygen transfer and (K_{La}) is a constant that includes a large number of influencing factors, such as bubble surface area and the effect of liquid impurities.

Again, the constant is less important than the concentration gradient (C* - D.O. concentration). The greater the value of (C* - D.O. concentration), the greater the transfer rate.

If liquid of low D.O. concentration is continuously brought into contact with the surface of a bubble of oxygen, a high concentration gradient will be maintained. Oxygen will then transfer into the liquid at a continuously high rate. Oxygen transfer into:a.liquid that is slow moving will be slow because as oxygen diffuses from the bubble into the liquid, the concentration of dissolved oxygen in the immediate vicinity of the bubble's surface, rises towards the equilibrium level with the bubble's oxygen partial pressure. The concentration gradient with a bubble of air will, correspondingly, be much lower than for pure oxygen.

Thus for 1 mg/L D.O. (a common requirement in activated sludge):

For air:	Oxygen transfer rate	=	K_{La} x (C* - 1)
		=	K_{La} x (8.5 – 1)
		=	7.5 K_{La}
For pure oxygen:	Oxygen transfer rate	=	K_{La} x (C* - 1)
		=	K_{La} x (40.6 – 1)
		=	39.6 K_{La}

$\therefore$ Pure oxygen gives approximately 5 times the oxygen transfer rate.

Air or oxygen dissolution equipment that provides greater turbulence will enhance the oxygen transfer rate. Systems involving high.shear, where the bubble-liquid film is rapidly removed, achieve the highest rates of oxygen transfer.