

**An Introduction to Drinking Water
Contaminants, Treatment and Management**
**for Users of the National Environmental Standard
for Sources of Human Drinking Water**

Prepared for the Ministry for the Environment

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1 INTRODUCTION

The National Environmental Standard for Sources of Human Drinking Water (the NES) aims to reduce risks to the quality of water bodies from which the source water for drinking-water supplies is taken. It will do this by preventing discharge and water permits being granted, and preventing the inclusion of permitted activity rules in regional plans, if they will cause drinking water to become unsafe to drink after the existing treatment processes. To implement the NES, regional councils and consent applicants will need to understand the:

- likely contaminants that might be associated with a particular activity
- ability of the various treatment processes used in New Zealand to remove contaminants from the water.

This document provides guidance on these matters. It also identifies and briefly describes the groups, organisations and the Ministry of Health ‘tools’ that will help assess how planned new activities in a catchment could impact on the quality of drinking water sourced from that catchment.

This guide aims to provide regional councils and consent applicants with sufficient knowledge about treatment processes and sources of contaminants to enable them to implement and comply with the NES. It does not aim to make the reader an expert in assessing effects of activities on drinking water sources or drinking water treatment.

2 ROLES AND RESPONSIBILITIES IN THE PRODUCTION OF DRINKING WATER

2.1 Introduction

Several organisations and groups play a part in the production and management of drinking water. These are:

- water suppliers, who produce and supply drinking water for their consumers
- health protection officers and drinking water assessors working within public health units, who have responsibility for checking whether water suppliers are meeting the requirements of regulations and for providing advice
- the Ministry of Health, which develops regulations, ‘tools’ to encourage the good management of water supplies, support material to assist water suppliers in managing their supplies, and distributes support funding when it is available.

2.2 Drinking water suppliers

Most of New Zealand’s population is supplied with water by their local authority water suppliers (city or district councils). In Auckland and Wellington, residents receive their water from the local authority’s retailers who in turn receive their water from bulk water suppliers. The bulk water supplier in Auckland is the quasi-public-owned company, Watercare, and in Wellington it is the regional council. In addition to these suppliers, there are supplies owned and operated by:

- government departments, such as Defence (military bases), Justice (prisons), Conservation (national parks)
- schools
- large industries, which may provide water to a substantial number of workers
- camping grounds
- private individuals or groups of individuals, including marae supplies.

Water supplies run by local authorities will have an engineer or manager who has overall responsibility for the operation of the water supply. Treatment plant operators run treatment plants (see section 3.2 for more discussion on treatment plant operators).

The water supplier is responsible for providing safe drinking water to their consumers¹.

2.3 Public health units and drinking water assessors

The Ministry of Health and the district health boards have responsibilities for public health², which include them undertaking activities to protect health and prevent population-wide disease. Public health units, which operate within district health boards, carry out these activities. These include some activities related to drinking water supplies. If water supplies become contaminated, they can cause widespread illness, and for this

¹ Foreword of the *Drinking-water Standards for New Zealand* 2005.

² Defined in the New Zealand Health Strategy is “the science and art of promoting health, preventing disease and prolonging life through organised efforts of society”.

reason the Ministry of Health and public health units are responsible for overseeing the good management of water supplies.

Twelve public health units provide core public health services³ across the country; some cover more than one district health board. They deliver both health protection and health promotion activities⁴.

As noted in section 2.1, two types of staff in public health units may have responsibility for public health aspects of water supplies: health protection officers and drinking water assessors⁵. Health protection officers have post-graduate training in public health and may only have responsibility for water supplies, or they may have broader responsibilities that require them to work in other health protection areas or health promotion.

Drinking water assessors have received additional training to increase their expertise in water supplies, water treatment and the regulations associated with these areas. The key responsibilities of drinking water assessors are:

- assessing the compliance of water supplies with the Drinking-water Standards for New Zealand (DWSNZ)
- undertaking the public health grading of water supplies (see section 3.6)
- assessing the adequacy of public health risk management plans and their implementation (see section 3.5).

2.4 Ministry of Health

The Ministry of Health develops regulations and legislation designed to ensure that New Zealand's drinking waters are safe. To support regulatory and legislative initiatives, it has developed a suite of 'tools'. These gather information about the way in which water supplies are being managed and also aim to help water suppliers provide a safe product by better managing their supplies. Several of these tools are introduced in this document. The ministry is also responsible for distributing funding the government has allocated to assist water suppliers in improving their supplies. The DWAP (Drinking-water Assistance Programme) has been established for this purpose. There are two components to this programme: the TAP (Technical Assistance Programme) and CAP (Capital Assistance Programme). The TAP aims to help water suppliers provide safe water to their consumers using their existing resources. Financial assistance from the CAP may be sought by a water supplier if they are unable to adequately address the public health risks to their supply, even after the improvements made with the help of the TAP.

2.4.1 Health (Drinking Water) Amendment Act 2007

The Ministry of Health produces Drinking-water Standards for New Zealand. The purpose of these standards is to protect public health by explaining how to assess the quality and safety of drinking water. They do this by (i) defining maximum acceptable concentrations

³ Public health services are defined in the New Zealand Health Strategy as: "Goods, services or facilities provided for the purpose of improving or promoting public health". Core public health includes such things as environmental health, communicable disease control, tobacco control and health promotion.

⁴ Information about public health units can be found on the Ministry of Health's website: www.moh.govt.nz/water.

⁵ The division of responsibilities and staff arrangements with respect to drinking water assessors and health protection officers may vary between different public health units.

of contaminants that can be present in drinking water and (ii) specifying compliance criteria to be used to assess the quality of drinking water.⁶

Until recently, compliance with the DWSNZ was voluntary. New health legislation passed in October 2007 changes this situation. The Health (Drinking Water) Amendment Act 2007 requires drinking water suppliers to take all practicable steps to ensure they provide an adequate supply of drinking water that complies with the DWSNZ.

Other key elements of the Act include:

- requiring drinking water suppliers to introduce and implement public health risk management plans
- ensuring drinking water suppliers take reasonable steps to contribute to protecting sources from which they obtain drinking water from contamination
- requiring officers appointed by the Director-General of Health to act as assessors to determine compliance with the Act
- requiring record keeping and publication of information about compliance
- providing for the appropriate management of drinking water emergencies
- improving enforcement by providing an escalating series of penalties for non-compliance.

Further information about the Act can be found on the Ministry of Health's website: www.moh.govt.nz/moh.nsf/indexmh/drinking-water-proposed-legislation

⁶ More detailed information on the Drinking-water Standards for New Zealand is available in the companion technical publication *A Guide to the Ministry of Health's Drinking-water Standards for New Zealand*, also prepared by ESR for the Ministry for the Environment, see www.mfe.govt.nz.

3 WATER SUPPLY MANAGEMENT – INFORMATION SOURCES

3.1 Introduction

Section 2 has introduced those with major roles in the production and management of drinking water. Each of these players may produce or hold information regarding water supplies that could assist in evaluating whether a new catchment activity will meet the requirements of the NES. This section outlines the nature of the information available and from whom it can be obtained.

3.2 Treatment plant operators

Treatment plant operators undertake the day-to-day running of the water treatment plant, and are a source of detailed information about the operation of their water supply. To obtain information from the treatment plant operators, go through the water supply manager, who should be able to provide additional information about the operation of the water supply. If you do not know who the water supply manager is, call the local authority and ask to be put through to the water supply manager. When the water supply is not operated by a local authority, contact the public health unit and ask to be put through to a drinking water assessor, who might be able to help you contact the water supply of interest.

The operator may be able to provide the following information, depending on their level of training and experience with the treatment plant:

- the monitoring undertaken at the treatment plant, which may include samples taken for compliance purposes (eg, eg, *Escherichia coli*) and operational monitoring of parameters, such as turbidity and acidity/alkalinity (pH)
- advice on how well the treatment plant copes with increases in turbidity in the source water, and the level of turbidity increase that might be tolerated without compromising the treatment plant's ability to comply with the DWSNZ
- activities in the catchment that already contribute to the contaminants that must be removed by the treatment plant
- the degree of removal of common chemical contaminants, eg, eg, iron and manganese, provided they have already been identified as a problem and there are treatment processes in place to remove them
- how the flow rate or level of the source water at the abstraction point affects the water quality.

It will be more difficult for operators to estimate the ability of their treatment plant to remove a new contaminant that their plant is not specifically designed to remove, and for which they have not previously needed to carry out treatment. For example, if contamination of the water with cyanide is a possible consequence of a proposed catchment activity, the operator may be unable to estimate the extent to which the existing treatment processes will remove cyanide. In such a situation, an independent consulting engineer could be approached for advice on the likely extent of removal of the specific contaminant.

3.3 Water Information New Zealand

Water Information New Zealand (WINZ) is a national database of information on water supply management and water quality. It is maintained by ESR on behalf of the Ministry of Health. For further information, refer to section 12 of the companion report *A Guide to the Ministry of Health Drinking-water Standards for New Zealand*.

3.4 Annual Review of Drinking water

The Annual Review of Drinking-water Quality in New Zealand provides an overview of drinking water quality in New Zealand. For further information, refer to section 11 of the companion report - *A Guide to the Ministry of Health Drinking-water Standards for New Zealand*.

3.5 Public Health Risk Management Plans

3.5.1 Introduction

Plans to manage risk to water supplies are called Public Health Risk Management Plans (PHRMPs) by the Ministry of Health. The ministry strongly encourages water suppliers to use risk management planning as the basis for the management of their supplies. Some aspects of compliance with the DWSNZ refer to PHRMPs.

Previously, monitoring water quality has been used as the basis for water supply management. Reliance only on the periodic sampling and analysis of water is a poor approach to ensuring that safe water is *always* provided to a community. A water sample only provides information about the quality of the water at the particular time the sample was taken; the quality of the water between samples remains uncertain. The aim of the risk management approach to water supply operation is to give the water supplier (and consumers) confidence that the supply can provide consistently safe water. Risk management identifies potential problems and addresses them before poor water quality becomes apparent by water testing. The risk management approach to protecting water quality is proactive. When a water supplier relies solely on water testing to ensure safe water, the approach is reactive, and may result in consumers receiving unsafe water before test results are available. The risk-based approach to water supply management does not dispense with water tests; monitoring water quality is still necessary to check that the steps taken to protect water quality are working.

3.5.2 Useful information associated with PHRMP preparation

The Ministry of Health has prepared a suite of ‘guides’ to help water suppliers identify risks to their supply and determine how these might be managed. One of these guides may be helpful to those who have to work with the NES: s.1.1 *Surface and Groundwater sources* (Version 2)⁷ addresses the risks associated with catchment activities.

Section 1.1 *Surface and Groundwater sources* (Version 2) identifies:

- what are termed ‘events’ that may threaten the quality of the source water
- the possible causes of these events

⁷ This guide can be found at the MoH web address: www.moh.govt.nz/moh.nsf/.

- what can be done to reduce the likelihood of these events occurring (preventive measures)
- checks to ensure the preventive measures are working
- what to do if the events occur despite the preventive measures.

This information, of course, is provided to help a water supplier. It may be of limited value to someone working with the NES. This is partly because the guide was produced before the advent of the NES, and many of the preventive measures contained in the guide are actions now encapsulated in the approach being taken by the NES.

One other aspect of PHRMP preparation that may be helpful for NES implementation is the ‘Improvement Schedule’. The Ministry of Health requires PHRMPs to contain a list of improvements that have been identified through the risk assessment process as being necessary to ensure the safety of the water supplied to consumers. This list is the ‘Improvement Schedule’ and may help those implementing the NES because it will state when any upgrades that may assist in contaminant removal are planned.

3.6 Public Health Grading of Water Supplies

3.6.1 Introduction

Public health grading of water supplies has been undertaken since 1993. Its purpose is:

to provide a public statement of the extent to which a community drinking-water supply achieves and can ensure a consistently safe and wholesome product.

Two types of information are needed to do this:

- water quality monitoring data to show that the production of ‘safe and wholesome’ water is being *achieved*, which requires the grading to take some account of the compliance status of the water supply
- information that identifies risks to water quality and shows how well these are being managed, which helps to assess whether *consistently* good water quality is likely to be supplied.

The 1993 grading system was revised in 2003. From 1 January 2006, the only grades shown in the *Register of Community Drinking-water Supplies in New Zealand* (the *Register*)⁸ are those that have been undertaken based on the 2003 grading system. So far, only a relatively small number of supplies have been re-graded. Only those water supplies with populations of over 500 people are graded, although supplies serving populations down to 25 people are expected to be graded in the future.

The simple way in which the public health grade is expressed makes it readily understood by everyone. Consequently, poor grades in some supplies have given rise to public pressure for improvements to be made. Local authorities can be very concerned about the grade they receive.

⁸ An electronic version of the *Register* is available on the website www.drinkingwater.org.nz and is updated weekly.

3.6.2 How a supply grade is determined

The information used to base the grade for a water supply is collected using three questionnaires: one each for the source, treatment plant, and distribution zone. This information is gathered by drinking water assessors who visit each water supply for which they are responsible, and they reach agreement with the water supplier about responses to the grading questionnaires. A combination of the information from the source and treatment plant questionnaire is used to provide a joint source/plant grade, and a separate grade is determined for the distribution zone.

3.6.2.1 Source/plant grading

The source questionnaire seeks information about the nature of the source and in general terms, the types and level of contamination that may affect it. The information sought is:

- source type (eg, stream, lake, spring)
- security status of groundwater sources (yes/no)
- protection status of the catchment⁹ (yes/no)
- catchment condition (4-point scale)
- degree of human pollution (4-point scale)
- degree of animal pollution (5-point scale)
- degree of chemical pollution (3-point scale)
- median *E. coli* concentration (where available)
- occurrence of algal blooms (yes/no).

When the supply is graded, the details of catchment activities considered by the drinking water assessor and water supplier are distilled down to brief generic responses for the questionnaire, and are not captured by the grading process.

Environmental Science and Research Ltd (ESR)¹⁰ can provide the information that is captured by the grading process for supplies that have been graded.

Activities in a catchment that are granted consents may influence the responses to the questionnaire and therefore the grade of a supply. Although information about the likelihood of contamination of the source water is presently collected, it makes little contribution to the final grade for supplies that are adequately treated. The likelihood of contamination is only taken into account when the Plant Questionnaire shows an unsatisfactory level of treatment plant performance. Future revision of the grading system is likely to place greater emphasis on PHRMPs and how risks from catchment activities are being managed.

⁹ A protected catchment is defined as one that "... has major points of access fenced, and is controlled so that there is only strictly controlled human access and limited feral animals [access]".

¹⁰ Contact ESR, Water Programme, PO Box 29-181 Christchurch 8540.

The source/plant grade is determined through information gathered about the treatment plant and its compliance with the DWSNZ. The treatment processes used in the treatment plant are identified, but the grade depends mostly upon the extent of compliance with the DWSNZ at the treatment plant with respect to bacteria, protozoa and chemicals, and the level of control, supervision and record keeping at the plant.

The source/plant grade is designated in capital letters, and will lie in the range from ‘A1’ (top) to ‘E’ (bottom). The descriptions of each grade are given in Table 1.

3.6.2.2 Distribution zone grading

The distribution zone grade is determined by considering many different aspects of the distribution zone. These include DWSNZ compliance and factors that may increase or decrease the level of risk to consumer health. Like the source/plant grade, the grades run from ‘a1’ to ‘e’, and are designated in lower case to distinguish them from the source/plant grade. Their descriptions are given in Table 1. The grade obtained for the distribution zone depends on how well the water supplier has managed the water supply, and on microbiological and chemical compliance with the DWSNZ.

The distribution zone grade can be affected by activities in the catchment. One of the factors that determine the distribution zone grade is compliance with the DWSNZ. If a new activity in the catchment introduces contaminants that cannot be adequately removed by the treatment plant, their presence in the distribution zone may result in non-compliance with the DWSNZ and a reduction in grade.

Table 1 Descriptions of public health grades

Grade	Description
Source/plant Grade	
A1	Completely satisfactory, negligible level of risk, demonstrably high quality
A	Completely satisfactory, extremely low level of risk
B	Satisfactory, very low level of risk
C	Marginally satisfactory, low level of microbiological risk when water leaves the plant, but may not be satisfactory chemically
D	Unsatisfactory level of risk
E	Unacceptable level of risk
Distribution Network Grade	
a1	Completely satisfactory, negligible level of risk; demonstrably high quality; meets Aesthetic Guidelines in Appendix B and has ISO 9001:2000 accreditation
a	Completely satisfactory, extremely low level of risk
b	Satisfactory, very low level of risk
c	Marginally satisfactory, moderately low level of risk
d	Unsatisfactory level of risk
e	Unacceptable level of risk

3.6.3 Where to find information about public health grading of water supplies

The *Register* is produced each year by the Ministry of Health and is sent to all public libraries in the country. All registered water supplies are contained in this document and where a supply has been graded, the register lists its source/plant and distribution zone grades.

The source and treatment plant information collected by the grading assessment, which will be helpful in understanding the likely levels of source water contamination and the treatment capabilities of a particular treatment plant, is not recorded in the *Register*. This information is maintained within WINZ, and can be provided by ESR, or the public health unit with responsibility for grading particular supplies.

4 ORIGINS OF CONTAMINANTS IN DRINKING WATER SOURCES

4.1 Introduction

To determine the effect of a planned activity on the quality of water produced by a drinking water treatment plant, the likely contaminants reaching the plant's abstraction point need to be identified. To comply with the NES, the consent applicant will have to estimate the extent to which the levels of these contaminants will exceed the levels already challenging the treatment plant.

When assessing the ability of a treatment plant to produce acceptable water, the levels of contaminants in source water already challenging the treatment plant need to be taken into account. If existing levels are high, the expected additional input of a contaminant may be sufficient to exceed the treatment plant's capabilities and the contaminant's concentration may exceed its maximum acceptable value (MAV). The existing levels of microbial contaminants may be difficult to assess because of the limited information about their concentrations in source waters. For chemical contaminants, the priority status¹¹ will help in making this evaluation. For a contaminant to be given Priority 2 classification there must be evidence of it exceeding 50% of its MAV (which may include exceeding the MAV itself)¹². Therefore, a Priority 2 contaminant in a water supply is at least halfway to exceeding its MAV and in some cases may already exceed its MAV. If the MAV is not already exceeded, a relatively small increase in the amount of the contaminant in the source water may lead to the MAV being exceeded.

To make these estimates, the applicant will need to know which contaminants the activity may introduce into the environment, and the factors that will influence the contaminant concentration(s) finally reaching the abstraction point.

This section provides some guidance on the contaminants that might be associated with particular activities and advice on what needs to be considered in estimating the contaminant concentrations reaching the abstraction point. The information is generic and is not a substitute for a full assessment of the potential contaminants associated with a particular activity.

4.2 Factors to consider when assessing the likelihood of contamination

4.2.1 Introduction

The presence of a particular activity in a catchment, or recharge zone, does not necessarily mean that the activity will lead to an unacceptable level of pollution of the source water. By taking account of the factors discussed in the following subsections, an indication of which contaminants might reach a water supply's abstraction point at a concentration of concern can be gained. Figure 1 shows how the factors that influence the concentration of contaminants reaching a treatment plant are linked.

¹¹ Contaminants in the DWSNZ are assigned to one of four 'priority classes' depending on the level of their health significance. Those of highest significance are microbiological contaminants and are classed as Priority 1. Priority 2 contaminants are, in practice, exclusively chemical contaminants known to exceed more than 50% of their MAV in a water supply. Compliance with the DWSNZ requires Priority 1 and 2 contaminants to be monitored, but Priority 3 and 4 contaminants are of lower health significance and their monitoring is not required.

¹² Note that Priority 2 status is presently only assigned to contaminants in water supplies serving more than 500 people.

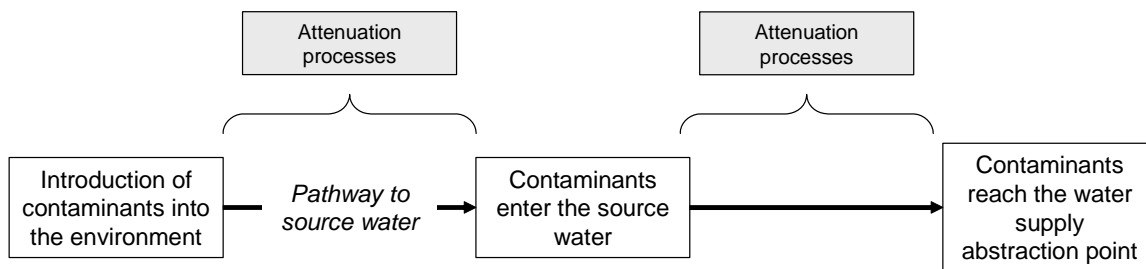


Figure 1 Factors influencing the arrival of contaminants at a treatment plant

4.2.2 Nature of contaminants the activity may introduce into the environment

As a first step, the contaminants that are likely to arise from a planned activity need to be identified. Table A1 (Appendix 1) provides a guide to possible contaminants from a range of activities. It is not exhaustive with regard to activities or with regard to contaminants from the listed activities, ie, for some activities there may be some additional contaminants not listed. Further, it is possible that some of the contaminants listed for an activity may not arise from it at a level of concern.

4.2.3 Contaminant loads released by the activity

The starting point for evaluating how a planned activity will affect a treatment plant's source water is to establish the load (weight/unit time) of the contaminant that will result from the activity. This alone will not determine the concentration (weight/volume) of the contaminant reaching the treatment plant's abstraction point, and other information discussed in the following sub-sections will be required.

For point source discharges, the parameters that influence the volume of discharge and the substances the discharge can be expected to contain will be known and should allow the load of contaminant to be estimated.

Estimation of a contaminant load from non-point source activities is not as straightforward, because the contaminants and the levels they are released into the environment may not be well characterised. Trying to identify the different factors that contribute to the contaminant load will help. For example, an estimation of the contaminant load from grazing animals should be possible on the basis of the number of animals, their daily manure and urine output, and the expected concentration of the contaminant in the manure or urine.

4.2.4 Pathways by which contaminants can be transmitted to the source water

Irrespective of the amount of contaminant released by an activity, it will not cause pollution of the source water unless there is some pathway by which the contaminants can reach the receiving water. The pathway for some landfills, for example, may not exist because of the landfill being lined to stop contaminants reaching the groundwater. There may be situations in which there is uncertainty about the existence of a pathway. In these circumstances, the existence of a pathway should be assumed until there is reasonable evidence that one does not exist. Planned preventive measures, such as lining a landfill, should be reasonable evidence of a pathway having been blocked or removed, unless shortcomings in the measures are evident from the proposal.

4.2.5 Processes that may attenuate contaminants before they reach the source water

Some degree of attenuation may occur as contaminants pass over land and/or through water. The extent of attenuation will be highly variable, depending on the nature of the discharge and environmental conditions.

After pathways have been identified, processes should be considered that may attenuate the concentrations of contaminants as they move along the pathway to the source water. Again, it is unlikely that the effects of these processes¹³ can be quantified, but there are factors that affect them that can help in deciding how important they might be.

The effectiveness of attenuating processes is increased if the time over which they act is increased, or they can act over a longer distance. Greater attenuation of the contaminant therefore occurs as the distance between the activity and the source water is increased. On the other hand, a steep landscape increases water flow into the source water. This reduces the time available for some processes, such as microbial die-off and chemical decomposition and reduces attenuation. Similarly, porous soils and substrata allow water to percolate rapidly into groundwater.

4.2.6 Processes that may attenuate contaminants in the source water

Even when the contaminants have reached the source water, there are still processes acting to reduce their concentration. These include:

- initial dilution by the receiving water (the source water),
- sedimentation as particles, including *Cryptosporidium* oocysts, settle to the river or stream bottom (Note that micro-organisms in the sediment have been found to survive longer than those in the overlying water. Hence a later increase in river flow because of rain can resuspend organisms deposited in the sediment and add to their concentration in the source water.)
- adsorption
- inactivation (this applies to micro-organisms and is the result of the exposure to sunlight)
- dilution by tributaries.

Resuspension of sediment can increase the concentrations of contaminants reaching the abstraction point.

¹³ These processes include, in the case of micro-organisms: die-off, adsorption, filtration, and inactivation by sunlight. For chemical contaminants, they include: adsorption, biodegradation, and chemical decomposition.

The following may help in estimating the degree of contaminant attenuation that occurs once the contaminants reach the source water:

- i. the greater the flow of water in a source (river or stream), the greater the dilution of the contaminant and therefore the lower the contaminant concentration at the abstraction point
- ii. the more tributaries that enter the source (or if a source is a tributary to a larger river), the greater the dilution and the lower the contaminant concentration reaching the abstraction point
- iii. more turbulent flows will minimise the opportunity for contaminants to settle to the bottom of the river or stream, which will tend to maintain their concentration in the water
- iv. the greater the distance between the activity and the abstraction point, the greater the opportunity for processes such as sedimentation, die-off, chemical decomposition and inactivation by sunlight to take place, so reducing contaminant concentrations.

4.2.7 The consequences of rainfall or irrigation

Water, either as rain or from irrigation, is usually the vehicle by which contaminants are moved along pathways to source waters. Some of the consequences of rainfall are noted in section 5.4.4.2.

Rainfall can reduce contaminant concentrations through dilution, but overall rainfall needs to be viewed as a factor that will increase contaminant concentrations in the source water. The increase in concentration will occur for a limited period, but the water treatment plant must be able to produce safe drinking water during this time. The assessment of a new catchment activity needs to consider the 'worst-case' level of contamination by trying to evaluate how a rain event will affect pollution of the source water. Where the planning for an activity includes measures to mitigate the effect of rainfall, the risk created by the activity will be reduced.

5 WATER TREATMENT

5.1 Introduction

The NES aims to ensure that the effects of new catchment activities on the ability of water supplies to produce safe water for their communities are adequately considered. The ability of a water supplier to provide safe water when an activity is introduced into a catchment depends on three factors: the changes in the quality of the water at the water supply's abstraction point¹⁴ as the result of the new activity; the types of processes being used to treat the water; and how well these processes are operated.

To assess the effect of an activity, an understanding of water treatment is necessary. This section provides an introduction to water treatment. In particular, it:

- describes the types of contaminants the treatment processes remove
- identifies the main treatment processes used in New Zealand
- provides semi-quantitative guidance on the ability of these processes to remove the contaminants listed in the DWSNZ.

5.2 Treatment processes

5.2.1 Introduction

Source waters, whether they are surface waters or groundwaters, can contain a range of contaminants that may make the water unsafe to drink or aesthetically unacceptable (eg, bad taste, odour or appearance). Such contaminants include: particles, microbiological contaminants, naturally occurring chemical substances and chemical substances derived from human activities. Of these, the two for which treatment is most important are particles and microbiological contaminants. Treatment for these contaminants is particularly important for surface waters and shallow groundwaters that are affected by events above ground. Deep groundwaters, or groundwaters from confined aquifers¹⁵ are expected to be of much better quality than surface or shallow groundwater, and in some instances are untreated, eg, Christchurch's groundwater sources.

The generic elements of a full treatment train (series of treatment processes) are depicted in Figure 2 in the order in which they will occur in the treatment plant. The 'pre-treatment', 'particle removal' and 'disinfection' processes will always occur in the order shown, although some may be omitted if the quality of the source water does not require them. The 'additional processes' cover processes that are specific to a particular supply, and their location will depend on the design of the particular treatment system.

One or more pre-treatment steps may be used. These are often unsophisticated processes designed to reduce the load of contaminants reaching the main particle removal processes, or to condition contaminants in the water to make their removal by later processes easier. They include settling (eg, in a reservoir or sedimentation basin to allow particles in the water to sink to the bottom), aeration and chemical pre-oxidation.

¹⁴ The place in the source where the treatment plant draws its water.

¹⁵ Aquifers protected from contaminants percolating down from the surface by an impermeable layer.

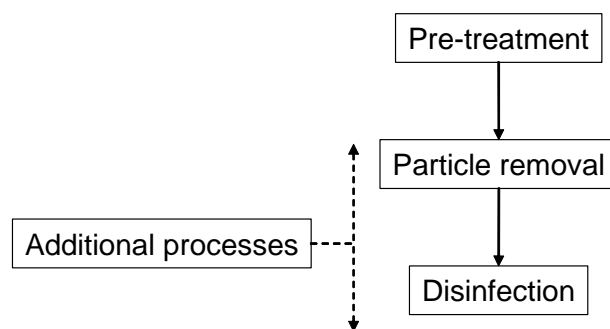


Figure 2 Generic elements of water treatment

Particle removal is the first of the main treatment steps, and usually consists of a series of processes. The last of these is filtration which is preceded by steps designed to improve filter performance. Particle removal is important because these processes remove the larger microbiological contaminants (protozoa, such as *Giardia* and *Cryptosporidium*), some of which are resistant to chlorine, as well as the non-living material that contributes to the cloudiness (turbidity) of the water. Particle removal is also important for the efficacy of the disinfection step.

The disinfection step must take place after the particles have been removed, when the water is as ‘clean’ as possible. Micro-organisms adsorb to particles in the water. Once adsorbed, they are shielded to a degree from the effects of the disinfectants. As much as possible of the particle load in the water must be removed before disinfection to ensure adequate inactivation¹⁶ of the organisms and to remove micro-organisms already adsorbed to particles.

The main treatment processes are not primarily intended to remove any of the large number of chemical contaminants listed in the DWSNZ¹⁷. As will be seen in a later section, some contaminants are coincidentally removed by particle removal and disinfection processes. Where contaminants in the source water cannot be removed satisfactorily by the main treatment processes, additional treatment processes may need to be incorporated into the treatment train. Additional treatment processes that do not have a direct role in removing contaminants may also be required to adjust the water chemistry to improve the performance of a process that is removing contaminants, eg, adjustment of the pH. The location of the additional treatment processes will depend on their function and the needs of the other processes.

This section briefly describes the treatment processes most likely to be encountered in New Zealand and explains their function. The principles of operation of a particular process are independent of the treatment plant, but the physical design and implementation

¹⁶ Disinfectants render micro-organisms incapable of reproducing, so that they are non-infectious. This does not necessarily mean that they are dead, hence disinfectants are said to ‘inactivate’ rather than ‘kill’ micro-organisms. Contrast this with particle removal processes that *remove* the micro-organisms from the water. The ability of a given disinfectant to inactivate a micro-organisms depends on the group to which the micro-organism belongs, e.g., *Cryptosporidium* is very resistant to inactivation by chlorine, but bacteria are not. There are also varying degrees of resistance to disinfection within a group, eg, *Campylobacter*, a bacterium, is more easily inactivated by chlorine than *E. coli*, also a bacterium.

¹⁷ Approximately 140 chemical contaminants are listed in the DWSNZ in Tables 2.2 and 2.3.

of the process can vary with the treatment plant. At the end of the section there is information about the number of treatment plants employing different treatment processes in New Zealand to indicate how common a particular process is.

5.2.2 Pre-treatments

Water treatment plants are likely to reliably produce safe drinking water, if the conditions under which they operate remain constant (see section 5.4.4.2). A source water of changing quality is difficult to treat. Treatment plants drawing water from underground or from a lake or reservoir will usually have a source water that changes little, or if it does, it changes gradually. Rivers and streams, however, are subject to rain events, and treatment plants abstracting water from these types of source can be exposed to rapidly changing source water quality. One of the functions of pre-treatment processes is to provide a 'buffer' against changes in source water quality, so that quality changes and the rate of change are reduced.

Pre-treatment processes may also be used to modify the water chemistry and possibly the contaminants themselves, to improve their removal by later treatment processes.

Where treatment plants experience biological growths in parts of their system, such as the clarifier tanks, pre-treatment may also be used to control these growths.

Sedimentation basins: Sedimentation basins reduce the load of sediment in the water reaching the main treatment processes, and they reduce the magnitude of water quality changes. This is done by providing a large impounded area in which the water flow is reduced, which gives time for particles to settle out under gravity. During rain events they provide a buffer against rapid changes in the quality of water entering the treatment plant. Insoluble chemical contaminants may also be partially removed by the settling process.

Infiltration galleries: Levels of turbidity and natural organic matter¹⁸ (NOM), and to some extent microbiological contamination, in river or stream water can be reduced by abstracting the water indirectly from the source through an infiltration gallery. By burying open-jointed or slotted pipes in the bed of a river, stream or lake, water percolates through the gravels and sands of the bed and into the pipes where it is diverted to a collection well on the bank and pumped out for the water supply. This crudely filters the water as it passes through the media of the riverbed so that a fraction of the particles, and contaminants that may adsorb to the riverbed media, are removed. This form of pre-treatment achieves little removal of *Cryptosporidium*.

Pre-oxidation: Pre-oxidation may be carried out using oxidising chemicals such as chlorine, ozone or potassium permanganate. It is typically used to modify NOM (the substances that give some waters a yellow-brown colour) to improve its removal during the coagulation/flocculation step. It may also be used to oxidise soluble iron or manganese (usually in groundwaters) and sometimes arsenic, to precipitate them for removal by particle removal processes. This process may also control unwanted biological growths in other parts of the treatment plant. A drawback of pre-oxidation is that it tends to increase disinfection by-product (DBP) formation. To minimise DBP formation, it is usually preferable to remove as much NOM as possible before chemical disinfectants are added to

¹⁸ Large organic molecules formed by decay of vegetation and animal remains.

the water. This may require avoiding the use of chlorine or ozone when the NOM concentration in the water is causing unacceptable levels of DBPs.

Pre-oxidation can destroy some cyanotoxins (toxins produced by cyanobacteria: blue-green algae). See Table A2.5 for guidance on the efficacy of oxidants in destroying toxins.

Aeration: Aeration of a source water can introduce oxygen into the water to oxidise contaminants, such as iron or manganese, to an insoluble form so that they can be removed as particles (as with pre-oxidation above). Passing air through the water will also assist in removing gases (eg, hydrogen sulphide, carbon dioxide) or volatile contaminants (eg, vinyl chloride, trichloroethene). The removal of contaminants by aeration is also known as *air-stripping*. Aerators can be designed to entrain air in the water by ‘breaking up’ the water and passing it through the air, eg, sprays or trickling towers, or by bubbling air through the water.

Copper sulphate treatment: Copper sulphate is an algaecide, and is sometimes used to control algal blooms in static source waters, such as reservoirs. This approach to controlling algae can result in enhanced taste and odour problems and elevated toxin levels in the water – on death, the algal cells break up and release toxins and taste and odour compounds into the water. Bloom development is better controlled by minimising factors, such as nutrient concentration, that encourage algal growth.

5.2.3 Particle removal

By weight, clay, silt and sand particles are the main contaminants removed by this group of processes, but particle removal processes also improve the microbiological quality of the water by physically removing the micro-organisms. The most important task of particle removal, from a public health view point, is the removal of protozoa – some of which are not easily inactivated by chlorine. Particle removal processes can also contribute to the removal of bacteria. Adsorption of bacteria onto larger particles in the water ensures the bacteria are removed with the material to which they are adsorbed. Free bacteria (those not adsorbed) are not as easily removed because of their small size.

The processes within this group may be used individually, but it is more common for two or more processes to be used in series to remove particles more effectively from the water.

5.2.3.1 Coagulation/flocculation

This is the first step in the main treatment train of a full conventional treatment system, and prepares the water for particle removal by subsequent processes. A coagulant, usually an aluminium (eg, alum) or iron salt, is added to the water. This encourages small particles in the water to stick together to form larger particles, which are more readily removed from the water by the processes that follow. The addition of the coagulant also results in the formation of ‘flocs’ (particles) of insoluble metal hydroxides. The flocs further assist in contaminant removal by providing surfaces for adsorbing contaminants, and trapping contaminants as floc formation occurs.

Particle removal is often the chief purpose of the coagulation/flocculation process, but by adjusting the coagulation conditions, NOM can also be removed. This helps to control the formation of DBPs (see section 5.2.4 and 5.4.4.1) following the disinfection process.

The coagulation/flocculation process, combined with the other processes discussed below, can remove metals, bacteria and protozoa, although to varying degrees that depend on the metal and the type of micro-organism. Its role in removing *Cryptosporidium* is important because chlorine cannot inactivate this protozoan under water treatment conditions. Some non-metals and pesticides are also partially removed by this process.

5.2.3.2 Clarification

Clarification follows the coagulation/flocculation step and provides more time for the particles to stick together and settle out of the water, thereby reducing the sediment load that has to be removed by the filters.

- A process called *direct filtration* is used in some supplies if the turbidity (particle content) of the source water is low. In this process, the clarification step is omitted and coagulant is dosed directly before the filters. This reduces the turbidity by increasing the efficiency with which particles stick to the sand grains within the filter.
- *DAF (dissolved air flotation)* is used in one New Zealand treatment plant, instead of clarification. DAF works by floating the larger particles out of the top of the clarifier rather than letting them settle to the bottom.

5.2.3.3 Filtration

Filters of one type or another are the final process by which particles are removed from the water. When the source water is highly turbid, coagulation/flocculation and clarification steps usually precede the filters, but for some low-turbidity source waters or in small water supplies with limited resources, the filter may be the only particle removal process.

No matter which type of filter is used, particles and other contaminants become trapped by the filtering medium. The amount of trapped 'dirt' will eventually reach a point at which the filter cannot satisfactorily operate and the filter must be cleaned. How this is done depends on the type of filtration, but in all cases treatment plant operators aim to maximise the period the filter is operating before cleaning is required. This is because the cleaning process reduces the efficiency of the operation. The cleaning process is discussed below for the commonly used rapid sand filtration.

The following filter types are found in New Zealand.

- *Rapid sand filters:* Sand filters are widely used for particle removal, but usually in combination with other processes. Although called 'sand' filters, they often contain two types of sand overlain by a layer of small coal particles. They strain out particles that are too big to pass through the spaces between the sand grains, and allow smaller particles to travel down into the sand where they are removed by adsorbing to the sand grains.

Rapid sand filters and other granular filtration systems (eg, granular activated carbon) are cleaned by a process termed 'backwashing'. This process forces water backwards through the filter (possibly in combination with the injection of compressed air to help in dislodging the 'dirt') and discharging this water to waste. Backwashing must be done with previously treated water, therefore the

more frequently backwashing is required, the greater the volume of treated water that has to be sent to waste during backwashing, and the less efficient the operation.

- *Diatomaceous earth filtration:* Diatomaceous earth (DE) is a porous sedimentary material made of the silica skeletons of diatoms (a type of microscopic algae). The DE is continuously fed into these filters with the water and builds up as a cake on the support membrane. DE can be used as a 'polishing' step following other filtration treatments, because it can remove fine particles more efficiently, or for filtering fairly clean source waters.
- *Bag filtration:* Bag filters are typically constructed from porous woven or felted fabrics. The fabric from which they are made is non-rigid. Water under pressure is forced through the fabric from the inside of the bag to the outside; as the water passes through the bag, particles are removed on the fabric surface or within the fabric. The shape of the bag is maintained during use by a rigid support or housing. A range of pore sizes can be removed by bag filters, but to provide protection against protozoa, they must be able to remove particles larger than 1 μm . As particles accumulate in and on the bag, the pressure drop across the bag fabric (ie, the pressure required to push water through it) increases and eventually reaches a point at which the bag must be replaced.

Bag filters tend to be used in small water supplies rather than large systems. A single filter unit may be used or several may be used in series.

- *Cartridge filtration:* These filters are similar to bag filters, but differ in the following respects. Cartridge filters are typically constructed of rigid or semi-rigid material, and they are housed in pressure vessels so that water is forced through them from the outside to the inside. Like bag filters they must be capable of removing particles greater than 1 μm in size to remove protozoa. As with bag filters, 'dirty' cartridges must be replaced.
- *Slow sand filtration:* Although these filters use sand as a medium, as the name suggests, the rate at which the water passes through them is about 10 times slower than rapid sand filters. Other than filtration rate, the most important difference in the two types of sand filter is that slow sand filters make use of biological activity to treat the water, ie, there is a microbial community living within the sand and on the surface of the sand bed. This biological activity plays an important part in removing micro-organisms and NOM. Unlike a rapid sand filter operating in conjunction with coagulation/flocculation and clarification, slow sand filters are not designed to remove large amounts of particulate matter from the water.
- *Membrane filtration:* Membrane filters are 'high-tech' systems. The types of membrane filtration normally used in drinking water treatment are microfiltration (MF) and ultrafiltration (UF). Their primary task is the removal of particles (including protozoa) and bacteria. They remove contaminants by size-exclusion, ie, the contaminant can be removed from the water because it will not fit through the pores in the membrane. All membranes have a distribution of pore sizes. The pore size of a particular membrane may be

specified as a ‘nominal pore size’ (the average pore size) or the ‘absolute pore size’ (maximum pore size). MF membranes generally have a nominal pore size of 0.1 µm and UF membranes a nominal pore size of 0.01 µm.

Nanofiltration (NF) and reverse osmosis (RO) membranes are generally employed to remove dissolved contaminants, eg, in water softening, as they are not designed to remove particles, although they can do this. They operate on a different principle from MF and UF, which allows the removal of particles as small as 0.001 µm approximately in the case of NF and 0.0001 µm in the case of RO. They operate at a higher pressure than MF and UF membranes, and are more expensive to purchase and operate.

Membranes are housed in modules. Banks of modules are set up within membrane filtration plants: the greater the number of membranes the greater the ability of the treatment plant to treat larger volumes of water.

In 2005, 13 New Zealand treatment plants reported the use of membrane filtration systems. The type of membrane was not recorded, but they are most likely to have been microfiltration or ultrafiltration technologies.

5.2.4 Disinfection

There are three methods of disinfecting presently in use in community water supplies in New Zealand.

- *Chlorination:* Chlorination is the most widely used disinfecting method world-wide. It inactivates bacteria, viruses and the protozoan, *Giardia*. It will not, however, inactivate *Cryptosporidium* rapidly enough for use in water treatment.

An important advantage that chlorine has over the other two main disinfectants used in New Zealand is that it remains present long enough in the water to provide a disinfectant residual after treatment¹⁹. This is important for the maintenance of a safe water supply. In the event of low levels of contamination entering the distribution zone, the chlorine provides a degree of protection against microbiological contaminants.

The efficacy of chlorine as a disinfectant is determined by the pH; higher acidity (that is, lower pH) enhances disinfection. As well as being a good disinfectant, chlorine is a moderately strong oxidising chemical and is therefore also used for oxidising contaminants²⁰ during treatment (see section 5.2.2).

- *Ozonation:* Ozone is a more powerful oxidising agent than chlorine and a stronger disinfectant, and it can be used in both roles during water treatment. It can rapidly inactivate *Cryptosporidium* and therefore provides a satisfactory barrier to this organism, as well as to viruses and bacteria. It is a very reactive gas and even

¹⁹ This is provided the initial chlorine dose is adequate. If the dose is not large enough to result in some chlorine being left over after it has reacted chemically with contaminants in the water, there will be no disinfectant residual.

²⁰ An example of this is treatment to remove soluble iron. Soluble iron when oxidised by chlorine forms an insoluble form of iron which can then be removed from the water by filtration.

in 'clean' water it decomposes rapidly which means it cannot provide a disinfectant residual after treatment.

- *Ultraviolet irradiation:* Ultraviolet (UV) light at a wavelength of 254 nm can inactivate micro-organisms by damaging their DNA. Like ozone, UV light can inactivate protozoa and bacteria. Some viruses are resistant to inactivation by UV light, although it is effective against the majority of viruses. The disinfection efficacy of UV light is compromised by particles in the water, as also happens with the chemical disinfectants. The intensity of the light determines the ability of UV light to inactivate micro-organisms, and particles decrease the intensity of light passing through the water.
- *Disinfectant combinations:* Some treatment plants may use more than one disinfectant. Common combinations are ozone and chlorine, or UV disinfection and chlorine. Chlorine is used in combination with these two disinfection systems because neither ozone nor UV irradiation provides a disinfecting residual. Ozonation or UV disinfection, therefore, is used to inactivate *Cryptosporidium*, and the chlorine is then added to maintain the good microbiological quality of the water during distribution to consumers.

All chemical disinfectants have the drawback of reacting with naturally occurring organic contaminants in the water to produce DBPs. These substances can have undesirable health effects (eg, cancer). However, it is generally agreed that adequate disinfection should not be compromised in trying to minimise the extent of DBP formation during treatment (WHO, 2004), because the consequences of a microbiologically unsafe water are felt within a matter of days, not decades as is the case if DBPs exceed their MAV.

Each of the oxidising disinfectants, ie, chlorine, ozone and chlorine dioxide (presently not used in New Zealand), can destroy some, but not all, cyanotoxins. Table A2.5 provides guidance about the toxin-destruction capabilities of each disinfectant.

5.2.5 Additional treatments

Activated carbon adsorption: Activated carbon contains a very high surface area per unit weight that can adsorb contaminants. Activated carbon adsorption can remove a wide range of contaminants from water, particularly trace organic contaminants including industry solvents and pesticides. In New Zealand, activated carbon is primarily used to remove taste and odour compounds formed in minute quantities by micro-organisms in the water. Some supplies may also introduce activated carbon treatment to deal with the cyanotoxins produced by blooms of blue-green algae.

Algae and some bacteria are the usual sources of tastes and odours in drinking water. The growth of these organisms, and therefore the concentrations of the taste and odour compounds or toxins they produce, depend on several factors – some of which are influenced by season. These factors include nutrient (nitrogen and phosphorus) concentrations which may be influenced by catchment activities, temperature, light intensity and oxygen concentration in the water. Algal blooms are more likely to develop in the summer when the water is warm and greater sunlight assists with photosynthesis.

Activated carbon can be used in two forms: powdered or granular. Whichever form is used, once the carbon's adsorption capacity is exhausted it is disposed of to waste²¹. Granular activated carbon is used like another filter medium, either as the medium in a standard rapid sand filter, or in a separate contactor that the water stream passes through. The contactor is located near the end of the treatment train so that high-quality water passes through it. Activated carbon used in this way can become biologically active (micro-organisms colonise it) which can improve its ability to remove contaminants. Powdered activated carbon is usually added to water before the final filtration step. This allows contact with the water and adsorption of the problem contaminants, before the carbon is removed by the filters and discharged to waste during the filter backwash. Use of carbon in this way avoids the major capital costs of installing special contactors, and is favoured when use of the carbon is intermittent.

Ion-exchange adsorption: Synthetic organic resins that can attract and adsorb positively or negatively charged ions (depending on the design of the resin) in the water are used in the ion-exchange adsorption treatment process. As with any adsorbing material, there is a limit to the amount of contaminant they can adsorb, but they can be regenerated, usually by pumping a brine solution through them. The most widely used ion-exchange systems are those used for removing positively charged ions. These are used to soften water, by removing calcium and magnesium, and for removing soluble iron and manganese (these metals in their insoluble form will foul the resins and inhibit their operation). Other contaminant metals in their soluble forms can also be removed by ion-exchange systems with varying degrees of efficacy.

Greensand filtration: Greensand is a naturally occurring material that is treated to form a layer of manganese oxide on the surface of the grains. This coating oxidises soluble iron and manganese to their insoluble form when they come in contact with the surface so that they can be removed by filtration. The coating is regenerated with potassium permanganate or chlorine, or a combination. Permanganate dosing needs to be carefully controlled to avoid excess manganese contaminating the treated water.

*Precipitation softening*²²: This form of hardness control is little used in New Zealand. It creates conditions in the water that make calcium and magnesium compounds precipitate so they can be removed as solids. Adjustment of the pH is required after the process to return it to a satisfactory level. Some heavy metals can also be removed from the water during this process.

pH adjustment: Optimum operation of some treatment processes requires adjustment of the water's pH, eg, oxidation of iron and manganese and the coagulation process. There may also be a need to adjust the pH of a water to reduce the tendency of the treated water to dissolve materials in the distribution zone or consumers' plumbing.

5.2.6 Combinations of treatment processes

As shown by Figure 2, there will usually be more than one treatment process in operation in a treatment plant. For some contaminants this will result in more than one process

²¹ Regeneration technology is employed in plants overseas when the use of the carbon is on such a scale that it is economically viable. The scale of use in New Zealand water treatment plants is not large enough to make regeneration viable.

²² Also known as 'lime softening' 'lime-soda softening' depending on how the process is operated.

contributing to the removal or inactivation of a contaminant. For example, bacteria are removed to some degree by particle removal processes and also by disinfection. For other contaminants only one process may reduce the contaminant's concentration, eg, *Cryptosporidium* is only removed by particle removal processes.

There are also some instances where a combination of two or more processes is required to achieve removal of a contaminant and removal of the contaminant fails if one of the processes is omitted. An example is the removal of soluble iron or soluble manganese by precipitation. The soluble metal is oxidised by aeration, chlorine or ozone to form an insoluble form of the metal. This is then removed by particle removal processes. Omission of either the oxidation step, or the particle removal process, results in the iron or manganese being present in the finished water.

The combination of coagulation/flocculation/clarification/filtration is commonly used in the treatment of surface waters. Treatment plants using direct filtration, in which the clarification step is dropped from this combination, will achieve a lower removal of particulates and protozoa than can be achieved using the full combination. The maximum turbidity level in the raw water that can be satisfactorily treated is also lower when direct filtration is used.

5.2.7 Treatment processes used in New Zealand

Table 2 lists treatment processes used by New Zealand water treatment plants, and the numbers of each in use²³.

The treatment processes have been grouped into the generic categories used in Figure 2. The order in which the generic processes would operate in the treatment plant are shown in descending order, except for the additional processes which are likely to be used before disinfection. As indicated in the earlier discussion, more than one process will usually be in use at a treatment plant.

5.3 Efficacy of contaminant removal by treatment processes

Estimates of the abilities of treatment processes to remove specific contaminants listed in the DWSNZ are provided in tables in the Appendix 2 (Tables A2.1–A2.6). The information contained in the tables is not exhaustive. The absence of an entry indicates that either the treatment process has no effect on the contaminant concentration, or no information has been found about its efficacy in removing that contaminant. Whichever is the case, it should be assumed that the process has a negligible effect on the contaminant concentration until information is available to show otherwise.

Tables A2.1–A2.6 should be used as a starting point to assess whether there are any obvious concerns about the ability of a treatment plant to remove the contaminants expected from a particular activity. Further information that might help in determining the ability of the treatment plant to deal with a particular contaminant should then be sought from the water supply engineer or treatment plant operator.

The tables, particularly Tables A2.2–A2.6 covering chemical contaminants, are *guides only* and should not be used to attempt quantitative calculations. The estimates of removal

²³ These data are taken from WINZ and are a guide only. The questionnaires used to capture this information for WINZ were not exhaustive.

in Tables A2.2–A2.6 are based predominantly on data from laboratory studies, although some pilot and full-scale studies also contribute to the estimates. The results from laboratory and pilot-scale studies do not always translate directly to what is found at full scale, and the tables should therefore be regarded as providing ‘best-case’ removals. Further, it is not possible in summary tables such as these to take account of the different variables that may affect the performance of a treatment process. These include different types of membrane, different activated carbon types, the nature of coagulants used, and the chemistry of the raw water.

Other factors that will influence the efficacy of a treatment process, but which cannot be included in the tables are discussed in section 5.4.

Table 2 Treatment processes used in New Zealand, the approximate numbers of treatment plants recorded as using the process, and primary contaminants the process is designed to remove.

Treatment process	Treatment plants	Primary contaminants
Pre-treatment		
Chlorine	40	Iron, manganese
Ozone	1	Iron, manganese
Potassium permanganate	6	Iron, manganese
Copper sulphate	3	Cyanotoxins (by control of cyanobacterial growth)
Aeration	30	Gases (eg, hydrogen sulphide, carbon dioxide) and volatile trace organic compounds
Particle Removal		
<i>Combined processes</i>		
Coagulation/flocculation/rapid sand filtration	82	Particles, protozoa
<i>Individual filtration processes</i>		
Bag filtration	8	Particles, protozoa
Cartridge filtration	26	Particles, protozoa
Diatomaceous earth filtration	5	Particles, protozoa
Membrane filtration	624	Particles, bacteria, protozoa
Slow sand filtration	6	Particles, bacteria, protozoa
Greensand filtration	4	Iron, manganese
Disinfection		
Chlorine	508	Bacteria, viruses, cyanotoxins
Ozone	22	Bacteria, viruses, protozoa, cyanotoxins
UV irradiation	621	Bacteria, viruses, protozoa
Chlorine/UV	13	Bacteria, viruses, protozoa, cyanotoxins
Chlorine/ozone	3	Bacteria, viruses, protozoa, cyanotoxins
Additional processes		
Ion exchange	5	Iron, manganese, hardness
Activated carbon	13	Pesticides, industrial solvents, taste and odour compounds, cyanotoxins

5.4 Factors affecting the efficacy of treatment processes

5.4.1 Introduction

The guidance to the efficacy of treatment processes provided in Appendix A2 assumes they are operating as well as they can. This section discusses factors that may influence the ability of a particular treatment plant to achieve the estimated levels of removal given in Appendix A2.

5.4.2 Process optimisation

One or more parameters determine treatment process performance. Some of these parameters can be controlled by the treatment plant operator, others cannot. For example, the pH and coagulant dose are important controllable parameters that determine coagulation performance, and chlorine dose and pH influence the effectiveness of disinfection by chlorination. The turbidity and NOM content of the raw water, which are outside the operator's control, also influence the quality of the water produced by the treatment plant.

To achieve the best contaminant removal, the treatment plant operator needs to optimise the controllable parameters for the quality of the water being abstracted. Continuously changing water quality makes this difficult, especially if the processes are under manual control.

With experience, the operator develops an idea of the approximate parameter settings required to treat the normal range of raw water quality. These will act as guides for establishing optimum plant performance, but monitoring of other parameters that show how well the treatment is working will be needed to fine-tune the process. For example, the turbidity of the water leaving the clarifiers indicates how well the coagulation/flocculation and clarification processes have been optimised, and the chlorine residual in the water and water's pH value can be used to assess the effectiveness of the chlorination.

The removals noted in the tables in Appendix A2 are unlikely to be achieved without treatment processes being optimised.

5.4.3 Process control

Once the optimum treatment conditions are established, the process must be controlled to maintain optimum treatment. In New Zealand, the levels of treatment plant control range from fully automated systems with alarms to alert operators to conditions that require their attendance, to small treatment plants with manual controls where checks on operation of the plant may only be undertaken every few days.

As well as hardware influencing treatment control, the training, skill and experience of the operator affects how well optimised treatment is maintained.

Without adequate control hardware and operator training, treatment plants may not function reliably. Failings in treatment control will create the greatest threat to the production of safe drinking water when source water quality is changing, such as during a rain event (see section 5.4.4.2).

5.4.4 Source water quality

5.4.4.1 Contaminants

The contaminants or constituents of water that are most likely to influence the performance of treatment processes are not the trace contaminants that have direct health consequences, but the major constituents of the water, which have no direct health consequences. These include: turbidity, NOM, hardness and some major ions, such as sodium ions.

Turbidity

Turbidity (particles) needs to be removed to avoid deterioration in the effectiveness of filtration, disinfection and adsorption processes. The ability of a treatment plant to adequately treat the water to remove particles must be evaluated if a new activity is likely to result in a major increase in the turbidity of the source water.

Filtration processes are part of the combination of treatment processes that remove particles from water, but filters will rapidly clog, or there will be breakthrough of particles through them (ie, there will be turbidity in the filtered water) if the turbidity of the water entering them is too high. Pre-treatment sedimentation or the combination of coagulation/flocculation and clarification must reduce the turbidity to a level that the filters can handle.

The efficacies of all disinfection processes, whether they are chemical or physical (UV), are adversely affected by particles in the water. Microbes that are adsorbed onto the surface of particles are given some protection from chemical disinfectants, and the intensity of UV radiation passing through water is reduced by scattering caused by particles.

Processes that remove contaminants by adsorption depend on the contaminants of concern reaching the adsorbing surface so that adsorption can take place. Water with unacceptably high levels of particles will rapidly reduce the surface area available for adsorption, and with it reduce the removal efficacy of the process.

Natural organic matter

Disinfection, oxidation and adsorption efficacies are reduced by NOM. New catchment activities that could contribute to the NOM concentration in the source water can adversely affect the capabilities of a treatment plant²⁴ unless the processes in use can adequately reduce the NOM concentration.

The concentration of a chemical disinfectant in water is one of the factors determining how quickly it can inactivate microbes. Chemical disinfectants react with NOM, which reduces their concentration, and so reduces their disinfection ability. The disinfectant dose added to the water can be increased to compensate for this, but this increases the concentrations of DBPs that will form, which is undesirable because of their possible health effects.

Disinfection by UV radiation is made less effective by NOM, because NOM absorbs light at the same wavelength generated by UV lamps.

The reduction in the concentration of chlorine or ozone that results from their reaction with NOM reduces their capacity to oxidise contaminants, affecting their disinfection ability.

²⁴ There are a few circumstances in which NOM has been reported to improve removal of some contaminants. This does not apply in the great majority of situations, and certainly not for the processes discussed in this section.

Fouling of ion-exchange resins and activated carbon surfaces affects the ability of both adsorption processes to remove contaminants from water.

Hardness and other major ions

Water hardness arises from calcium and magnesium ions in the water, and is often the result of the water having been in contact with limestone or marble (rock types consisting of calcium carbonate). High hardness creates problems of scale formation on water heating elements, and inhibits the lathering of soap.

The predominant treatment problems resulting from waters that are hard or contain high concentrations of other major ions concern are ion-exchange and UV irradiation.

Ion-exchange can be used to soften water, but if the primary use in a particular situation is to remove iron and manganese, an increase in source water hardness may result in the exchange resin removing calcium and magnesium and not iron and manganese. Waters high in sodium may also compromise the removal of iron and manganese.

The intensity of the output from UV lamps can become reduced because of the formation of calcium scale on the quartz sleeves in hard waters. This affects their disinfection capability.

5.4.4.2 Source water quality variability

The importance of process optimisation has been noted in section 5.4.2. Treatment processes function best when water quality conditions are constant. An optimised set of control parameters is only of value for a given source water quality. A change in source water quality therefore requires re-optimisation of the control parameters. The larger and more rapid this change, the more difficult it is for the treatment plant operator to continue to produce good quality water. A complete loss of control over water quality may lead to unsafe water being pumped into the distribution zone. Failure of the particle removal processes, for instance, may result in any *Cryptosporidium* in the raw water being present in the water supplied to consumers.

Rain events are the most common cause of changes in source water quality, and the more extreme the event the greater the likelihood of a breakdown in treatment barriers. Rain events present treatment plant operators with two problems simultaneously. First, changes in water quality require the process control parameters to be re-optimised. The speed with which this can be done will determine how well the barrier to contaminants is maintained. Second, at the time when maintaining optimum treatment is at its most difficult, the concentrations of contaminants in the source water are often at their greatest. The most apparent quality changes that occur with rain events are increases in turbidity and increases in colour (NOM content) of the water. The changes in water quality that are not so apparent are the increases in microbial contaminants.

Pathogen (disease-causing microbes) concentrations can increase substantially in source waters during rainfall. From non-point sources of contamination²⁵ this is partly due to rainfall washing more microbes from faecal material into the source water, and partly because of increased river flow re-suspending microbes contained in the sediment on the riverbed. Point contamination sources may also add to faecal contamination of the water

²⁵ Non-point sources of contamination are those that cannot be identified as originating at a particular location; contamination occurs over an area, such as run-off from pasture.

in rain events. For example, a waste water treatment plant that receives both stormwater and sewage may not be designed with sufficient buffering storage. A rain event will increase the amount of stormwater entering the treatment plant. This increase in flow may exceed the plant's ability to treat the water, and treatment stages may have to be by-passed resulting in untreated or partially treated water entering the water source.

With regard to implementation of the NES, new catchment activities that may lead to marked increases in turbidity during rain will increase the threat of the treatment plant producing unsafe drinking water during these periods. Examples of such activities might be major earthworks, or developments that increase the volume or flow of water through a catchment, so entraining more particulate matter.

For more information on water treatment refer to, for example, Williams and Culp (1986) or Letterman (1999).

5.5 References

Letterman RD, 1999, *Water Quality and Treatment*, 5th ed., American Water Works Assn, McGraw-Hill Inc., New York.

WHO, 2004, *Guidelines for drinking-water quality*, 3rd Ed, Vol. 1, WHO, Geneva.

Williams RB and Culp GL, 1986, *Handbook of Public Water Systems*, Van Nostrand Reinhold Co., New York.

APPENDIX 1 ACTIVITIES AND THE CONTAMINANTS THAT MAY CONTRIBUTE TO SOURCE WATERS

Table A1 contains information about the possible contaminants that may arise from a given activity. This is not an exhaustive tabulation of all possible activities, nor of all contaminants that could arise. Activities could produce contaminants that are not included in the table. The specific details of an activity will determine whether all, or only some, of the contaminants listed may be a concern.

This table is a starting point for determining which contaminants may arise from an activity, but is only a guide. The details of each specific activity should be determined in each case, in order to gather a complete understanding of the possible contaminants.

The table includes ‘indirect’ contaminants as well as those arising directly from the activity. For example, where the activity could introduce nutrients into a water source, cyanotoxins are potential indirect contaminants arising from the growth of algae encouraged by the nutrients. (Cyanotoxins have not been listed where the quantities of nutrients being released seem likely to be relatively small.)

The information contained in Table A1 can be augmented by information from the Ministry for the Environment’s Hazardous Activities and Industries List²⁶.

Abbreviations:

DBP	Disinfection by-products
NOM	Natural organic matter
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
TPH	Total petroleum hydrocarbons

²⁶ www.mfe.govt.nz/issues/hazardous/contaminated/hazardous-activities-industries-list-scheduleb.pdf

Table A 1 Possible contaminants from activities grouped by land use.

Note: This should not be considered an exhaustive list of all possible activities, nor of all contaminants that could arise.

Superscript 'I' indicates indirect contaminants not introduced by the activity but which develop in the water as the result of other contaminants from the activity.

The term 'pesticides' refers to pesticides and herbicides. The term 'herbicides' is expressly used when herbicides only is meant.

Contaminants in italics are those for which a maximum acceptable value (MAV) or guideline value (GV) has been assigned in the Drinking-water Standards for New Zealand 2005. Non-italicised contaminants do not have a MAV or GV in the DWSNZ, but are listed here because (i) they may be precursors for contaminants listed in the DWSNZ (eg, phosphate may contribute to the production of cyanotoxins), or (ii) may be undesirable from a health perspective even if they do not have a MAV (eg, brodifacoum, TPH).

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Land use category 1. Agriculture				
Use of pesticides	Range of pesticides, metals	<i>Pesticides, zinc, copper, cadmium, manganese</i>		
Use of artificial fertilisers	Range of artificial fertilisers	<i>Ammonia, nitrite, nitrate, urea, phosphate, potassium, sulphate, calcium, magnesium, cadmium, manganese, cyanotoxins¹</i>		Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds.
Use of manure as fertiliser	Manure	<i>Ammonia, nitrite, nitrate, copper, zinc, cyanotoxins¹</i>	<i>Bacteria, viruses, protozoa</i>	The period of manure storage before use will affect the microbial risk. Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds.

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Fuel storage and use	Petrol, diesel	<i>Benzene, toluene, xylene, ethylbenzene, TPH</i>		
Silage production	Silage leachate	<i>Ammonia, nitrite, nitrate, cyanotoxins¹, NOM,</i>	<i>Bacteria, viruses, protozoa</i>	Acids formed in the silage may influence the pH of the water Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds
Dairy shed operation	Washwater	<i>Ammonia, nitrite, nitrate, phosphate, cyanotoxins¹, chlorine, chloramines, DBPs</i>	<i>Bacteria, viruses, protozoa</i>	Chlorine could react with organic waste to form chloramines and other DBPs Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds
Spray irrigation of effluent	Effluent	<i>Ammonia, nitrite, nitrate, cyanotoxins¹, turbidity, zinc, copper</i>	<i>Bacteria, viruses, protozoa</i>	Level of microbial risk will depend on the time the manure has been stored for before use.
Effluent pond operation	Effluent			

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Grazing animals	Manure deposited in pasture			Levels of contaminants from well-operated effluent ponds should be low Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds Grazing close to the water's edge will weaken and erode the bank
Cultivation (tilling the soil only)	Soil, silt	<i>Turbidity</i>		Cultivation close to the water's edge will weaken and erode the bank
Land use category 2. Forestry				
Sewage sludge application	Sewage	<i>Ammonia, nitrite, nitrate, phosphate, metals, cyanotoxins¹,</i>	<i>Bacteria, viruses, protozoa</i>	
Use of pesticides	Range of pesticides	<i>Pesticides</i>		
Use of poisons (feral animal control)	Poisoned baits	<i>Cyanide, 1080, brodifacoum</i>		
Use and maintenance of vehicles	Petrol, diesel, oil	<i>Benzene, toluene, xylene, ethylbenzene, TPH</i>		
Fuel storage	Petrol, diesel			
Land use category 3. Mining and Quarrying				
Use and maintenance of vehicles	Petrol, diesel, oil	<i>Benzene, toluene, xylene, ethylbenzene, TPH</i>		

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Fuel storage	Petrol, diesel			
Ore extraction	Extraction chemicals	<i>Cyanide, metals</i>		The metals of concern will depend on the composition of the ore
Collection and treatment of acid mine drainage	Mine drainage	<i>Metals, sulphate</i>		The low pH of mine drainage may affect the pH of receiving water and affect treatment operation
Open cast mining and quarrying	Dust	<i>Turbidity</i>		Activities requiring use of explosives will eject particulates into the air
Land use category 4. Industry and Commerce (Heavy and Light Industry)				
Brewing	Materials used in the process, and process effluent	Detergents, organic matter		
Ceramics	Glazes	<i>Metals</i>		
Cold storage	Refrigerants	<i>Ammonia, nitrite nitrate</i>		
Drum reconditioning	Range of organic and inorganic chemicals, degreasers, detergents	<i>Industrial solvents, metals</i>		
Electronics	Alkalis, acids, cyanides, solvents, metals	<i>Cyanide, TPH, metals, PCBs, methylene chloride, tetrachloroethene, trichloroethane, acetone, toluene</i>		Alkalis and acids in large-enough quantities may influence source water pH, and possibly treatment plant operation
Fertiliser/agrichemical production	Fertilisers and pesticides	<i>Ammonia, nitrite, nitrate, urea, phosphate, potassium, sulphate, calcium, magnesium, cyanotoxins¹</i>		Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds
Fish processing	Process effluent (high in organic waste)	Organic matter		

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Foundries	Acids, metals, fluxes	<i>Metals, nitrate, chloride, sulphate, phosphate</i>		Acids may give rise to nitrate, chloride, sulphate, and phosphate and affect the pH of the source water.
Furniture production	Glues, polishes, paints	<i>Toluene, dichloromethane</i>		
Meat and milk processing	Processing effluent including cleaning chemicals	<i>Ammonia, nitrite, nitrate, phosphate, chloride, sodium, calcium, magnesium, organic substances, cyanotoxins¹, turbidity, chlorine</i>	<i>Bacteria, viruses and protozoa</i>	Caustic cleaning chemicals can result in high pH effluent Under suitable conditions the introduction of nutrients into a source water may lead to algal growth and the presence of cyanotoxins, and taste and odour compounds
Metal cleaning/electroplating	Cleaning and plating chemicals, metals, acids	<i>Cyanide, metals, industrial solvents, nitrate, chloride, sulphate, phosphate, detergents, EDTA</i>		Acids may give rise to nitrate, chloride, sulphate, and phosphate and affect the pH of the source water.
Paper making	Bleaching chemicals, caustic soda	<i>Chlorate, chlorine, sulphate, DBPs, sodium, NOM</i>		The quantities of chlorinated organic compounds (DBPs) should be small in a well-run plant
Printing	Solvents, inks, dyes	<i>Industrial solvents (eg, dichloromethane, toluene, xylene)</i>		
Product storage	Fumigants	<i>1,3-dichloropropene, chloropicrin, cyanide, methyl bromide</i>		The nature of the fumigation will determine which fumigants are a concern
Resins	Range of organic chemicals	<i>Formaldehyde, urea, organic acids, esters amines and peroxides</i>		
Rubbers and plastics	Solvents, plasticisers, paints and other organic substances	<i>Industrial solvents, cyanide, zinc, formaldehyde, plasticisers</i>		
Tanning	Tanning chemicals	<i>Chromium, calcium, sulphate</i>		

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Wood processing	Preservatives and other treatment chemicals	<i>Pentachlorophenol, copper, chromium, arsenic, boron, industrial solvents, chlorpyrifos, creosote, PAHs</i>		
Wool scouring	Degreasing agents, pesticides	Detergents, grease, pesticides (including <i>chlorpyrifos, diazinon</i>)		The classes of pesticides likely to be derived from wool are: organophosphates, synthetic pyrethroids, insect growth regulators
Land use category 4. Industry and Commerce (Commerce and Community)				
Car washes	Soaps, detergents, waxes, oil ,	Detergents, TPH, <i>PAHs</i>		
Cemeteries	Embalming fluids, bodies, coffin construction materials, fertilisers	<i>Formaldehyde, arsenic, mercury, lead, copper, zinc, ammonia, nitrite, nitrate, chloride, sulphate, phosphate, sodium, potassium, magnesium, cyanotoxins¹</i>	<i>Bacteria, viruses</i>	The properties of the soil and age of the cemetery, <i>inter alia</i> , will influence the nature of contaminants in the groundwater
Defence Establishments	Disinfectants, human waste, chemical dumps, fuel and oil	<i>Chlorine, industrial chemicals, benzene, toluene, xylene, ethylbenzene, TPH</i>	Bacteria, viruses, protozoa	
Dry-cleaning	Dry-cleaning chemicals	<i>Tetrachloroethene, trichloroethane, ammonia, phosphate, chloride</i>		The phosphate and chloride originate from phosphoric and hydrochloric acids
Hospital	Disinfectants, biological waste, radiological waste, other miscellaneous chemicals	<i>Formaldehyde, chlorine,</i>	<i>Bacteria, viruses, protozoa</i>	Reticulation of waste disposal should eliminate the hazards associated with this activity
Laboratories (school, medical and research)	Disinfectants, biological waste, other miscellaneous chemicals	<i>Formaldehyde, chlorine,</i>	<i>Bacteria, viruses, protozoa</i>	Viruses and protozoa would not be expected from school laboratories
Laundromats	Detergents, bleaches, dyes	<i>Chlorine</i>		

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Offices	Detergents, solvents	<i>Industrial solvents</i>		
Photographic processing	Photographic processing chemicals	<i>Cyanide, silver, amines</i>		
Prisons	Disinfectants, human waste	<i>Chlorine</i>	<i>Bacteria, viruses, protozoa</i>	
Scrap yards	Petroleum products, solvents, metals, acids, alkalis	<i>TPH, metals, industrial solvents, PAHs</i>		
Swimming pools	Disinfectants, other pool treatment chemicals, human waste	<i>Chlorine, chloramines, DBPs, lithium</i>	<i>Bacteria, viruses, protozoa</i>	Lithium could arise from lithium hypochlorite - a form of pool chlorine
Land use category 4. Industry and Commerce (Transport , Storage and Utilities)				
Airport operation	Fuels, fire-fighting foams, solvents, de-icing substances, fumigants	<i>TPH, industrial solvents</i>		
Electricity	Transformer coolants	<i>PCBs, fluorinated hydrocarbons, silicone oils</i>		
Fuel storage and sale	Fuel storage and sale	<i>Benzene, toluene, xylene, ethylbenzene, TPH</i>		
Railway operation	Spraying of tracks, diesel and oil leaks, human waste (if toilet effluent is vented onto tracks)	<i>TPH, Pesticides, PAHs, ammonia, nitrite, nitrate</i>	<i>Bacteria, viruses, protozoa</i>	Spills of cargo carried by rail may result in a wide range of contaminants being introduced into water <i>if there is a pathway to the source water.</i>
Road transport	Asphalt, fuel and oil leaks, chemicals for roadside weed control, metals	<i>TPH, PAHs, Benzene, toluene, xylene, ethylbenzene, herbicides, metals</i>		Spills of cargo carried by road may result in a wide range of contaminants being introduced into water <i>if there is a pathway to the source water.</i>

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Sewerage reticulation	Sewage (human waste, trade waste)	<i>Ammonia, nitrite, nitrate, metals, industrial solvents, cyanotoxins¹</i>	<i>Bacteria, viruses and protozoa</i>	A wide range of industrial and domestic contaminants may be present in sewage
Sewage treatment				
Stock effluent and camper van effluent disposal facilities	Animal and human waste	<i>Ammonia, nitrite, nitrate, metals, cyanotoxins¹</i>	<i>Bacteria, viruses and protozoa</i>	
Tyre storage	Tyres	TPH, PAHs		
Land use category 5. Open space				
Car parks	Fuel and oil leaks, asphalt surface	<i>Benzene, toluene, xylene, ethylbenzene, TPH, PAHs</i>		
Clay target clubs	Lead shot	<i>Lead, PAHs</i>		
Disposal of stormwater run-off	Fuel and oil spills and other contaminants on asphalt road surfaces, faecal material from animals, weed and pest control chemicals, fertilisers, metals	<i>Ammonia, nitrite, nitrate, urea, phosphate, potassium, sulphate, calcium, magnesium, pesticides, benzene, toluene, xylene, ethylbenzene, TPH, metals, cyanotoxins¹</i>	<i>Bacteria, viruses, protozoa</i>	
Golf courses	Chemicals used for up-keep of the course (fertiliser, pesticides); fuel storage	<i>Ammonia, nitrite, nitrate, urea, phosphate, potassium, sulphate, calcium, magnesium, pesticides, benzene, toluene, xylene, ethylbenzene, TPH, cyanotoxins¹</i>	<i>Bacteria, viruses and protozoa</i>	The inclusion of microbial contaminants assumes an on-site disposal system
Recreational parks	Fertilisers, weed control chemicals, fuel and oil from vehicles			Parks without reticulated sewerage will require on-site sewage disposal systems
Sports fields	Fertilisers, weed control chemicals, fuel and oil from vehicles			Sports fields without reticulated sewerage will require on-site sewage disposal systems

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Land use category 6. Residential (urban, lifestyle block, rural)				
Disposal of household waste	Household chemicals, garden chemicals, petrol, diesel and oil	<i>Metals, TPH, Benzene, toluene, xylene, ethylbenzene, industrial solvents, nitrate, phosphate, pesticides, industrial solvents, metals, chlorine</i>		The contamination risk associated with this activity is likely to be small because of their small scale
Use of fertilizers	Fertilizers	<i>Ammonia, nitrite, nitrate, urea, phosphate, potassium, sulphate, calcium, magnesium</i>		
Keeping pets or livestock (lifestyle blocks)	Animal waste, pest control chemicals	<i>Ammonia, nitrite, nitrate, pesticides</i>	<i>Bacteria, viruses, protozoa</i>	
Fuel Storage	Petrol, diesel, oils	<i>Benzene, toluene, xylene, ethylbenzene, TPH</i>		
On-site disposal of sewage	Human waste, detergents	<i>Ammonia, nitrite, nitrate, detergents, cyanotoxins¹</i>	<i>Bacteria, viruses, protozoa</i>	
Weed and pest control	Pesticides	<i>Pesticides</i>		
Land use category 7. Vacant Land				
Illegal dumping	Wide range of possible chemicals	<i>Metals, TPH, Benzene, toluene, xylene, ethylbenzene, industrial solvents, nitrate, phosphate, pesticides</i>	<i>Bacteria, viruses and protozoa</i>	Acids or alkalis in the dumped material may result in extreme pH values in receiving water.
Land use category 8. Landfill				
Disposal of industrial waste	Wide range of possible chemicals	<i>Metals, TPH, Benzene, toluene, xylene, ethylbenzene, industrial solvents, nitrate, phosphate, pesticides, cyanide</i>		

Activity	Contaminating material	Contaminants		Comment
		Chemical	Microbiological	
Disposal of waste from water and wastewater treatment systems	Waste sludge (which includes treatment chemicals)	<i>Metals, cyanotoxins¹, NOM, acrylamide</i>	<i>Bacteria, viruses and protozoa</i>	
Disposal of household waste	Household chemicals, garden chemicals, petrol, diesel and oil	<i>Metals, TPH, Benzene, toluene, xylene, ethylbenzene, industrial solvents, nitrate, phosphate, pesticides, industrial solvents, metals, chlorine</i>		Which contaminants are present will depend on how well the landfill system is controlled
Land use category 9. Fishing				
Onshore aquaculture	Faecal matter, pesticides	<i>Pesticides, ammonia, nitrite, nitrate, phosphorus, pesticides, cyanotoxins¹</i>	<i>Bacteria, viruses and protozoa</i>	
Land use category 10. Conservation land				
On-site sewage disposal	Human waste	<i>Ammonia, nitrite, nitrate, cyanotoxins¹</i>	<i>Bacteria, viruses and protozoa</i>	
Disposal of domestic waste	Tin cans	<i>Metals</i>		Burial of cans if they are not taken off site
Feral animal control	Poisons	<i>Cyanide, 1080, brodifacoum</i>		

APPENDIX 2 TREATMENT PROCESSES AND THEIR EFFICACIES

A2.1 Microbiological Contaminants

Table A2.1 lists the extent to which microbiological contaminants are removed by a range of treatment processes. The data in the table are ‘log removal values’: a value of 3, for instance, indicates that the concentration of the contaminant is reduced by 3 log₁₀ units, ie, 10³ or 1000-fold or 99.9% reduction. The absence of an entry in the table indicates that no information about the efficacy in removing that contaminant has been found.

The table is based on:

- i) the maximum values, or combinations of these, tabulated in the *Guidelines for Drinking-water Quality* (WHO, 2004).

The WHO guidelines list the conditions under which each disinfection process can achieve a 100-fold (2 log) inactivation of each organism type. A default value of 2 is therefore entered in the table, although this is probably an under-estimate of the inactivation achievable by the disinfection processes. Chlorine is given an inactivation value of 3.5 log (c. 3,200-fold reduction) which is a conservative estimate based on a study by Hijnen *et al.*²⁷.

- ii) for protozoa removal: the log removals assigned to treatment processes by the DWSNZ²⁸.

Removal values for *Giardia* are assumed to be the same as *Cryptosporidium* except for chlorination. Although chlorine is ineffective against *Cryptosporidium* for water treatment, it can inactivate *Giardia* provided sufficient chlorine is used.

The efficacies of all the processes depend on the conditions of operation, such as pH, chemical dose, and temperature.

Most treatment plants will contain more than one treatment process. The order of treatment processes has been discussed in section 5.2.1 and Table A2.1 has been set out so that the expected order in which the processes will be encountered is from top to bottom. (Note that not all the processes listed will be used in one treatment plant).

The order in which the processes occur does not affect the calculation of their combined effect on the microbial concentration. In the simplest situation, the overall log removal is calculated by adding the values of the individual processes from the table together.

Example 1: The removal of bacteria by a treatment plant using coagulation / clarification / filtration followed by chlorination can be estimated to be 3 log + 3 log = 6 log, or 10⁶ (1,000,000-fold reduction). Note that the value 2 for the ‘Rapid sand filtration’ in the table is not in the calculation because this is included in the ‘filtration’ part of the coagulation/clarification/filtration combination.

²⁷ Hijnen *et al.*, 2000, *Wat. Res.*, **34**, 1659-1665

²⁸ DWSNZ Table 5.2

Table A2.1 Treatment efficacies for micro-organisms (log₁₀ units)

Contaminant	Group	Bacteria	Viruses	Protozoa	
				<i>Giardia</i>	<i>Cryptosporidium</i>
Coagulation/ clarification/rapid sand filtration		3	3.5	3	
Coagulation/dissolved air flotation/filtration				3	
Coagulation/ rapid sand filtration				2.5	
Precipitation softening/clarification/filtration		2	4	3	
Rapid sand filtration		2	3		
Slow sand filtration		2.3	4	2.5	
Diatomaceous earth		3 ^a	1.7 ^a	2.5	
Membrane filtration (microfiltration)		4	<1	4 ^b	
Cartridge filtration				2	
Bag filtration				1	
Activated carbon				0.5	
Chlorination		3.5	2	2 ^c	Ineffective
Ozonation		2	2	3	
Chlorine dioxide treatment		2	2	3	
UV Irradiation		2	2	3	

a Requires chemical pre-treatment with coagulants

b Higher log removals may be achieved depending on the nature of the membrane

c For a water temperature of 10°C and a contact time of 30 min, a chlorine concentration of c. 3 mg/L free available chlorine at pH 7-7.5 is required to achieve this level of removal (WHO, 2004).

Example 2: The removal of *Cryptosporidium* by coagulation/dissolved air flotation/filtration followed by chlorination can be estimated to be 3 log or 10³ (1,000-fold reduction). Chlorine makes no contribution to reducing the *Cryptosporidium* concentration, therefore only the value from the particle removal processes is used in the calculation.

It is important to note that simply adding the log values in the table may not give a reliable indication of the reduction in the concentration of micro-organisms if treatment processes acting by similar mechanisms are used. For example, if the disinfection processes ozonation and UV disinfection were both being used together in a treatment plant, only one of these processes would be included in the calculation, ie, a maximum of 3 log units (1,000-fold reduction). A similar situation would apply if two particle removal processes using the same mechanism were in use, eg, coagulation/flocculation/clarification and precipitation softening/clarification (which both operate by chemical precipitation) were used. These restrictions occur because once a particular process has achieved its maximum reduction of a contaminant, a second process that works in the same way is unlikely to be able to further reduce the contaminant.

Advice should be sought from a consulting engineer, or a drinking water assessor, if there is uncertainty about estimating the reduction achievable by a combination of processes.

A2.2 Chemical Contaminants (listed in the DWSNZ)

Tables A2.2–A2.6 show the extent to which chemical contaminants are removed by various treatment processes. Where it is known, the minimum concentration (in mg/L) of a contaminant that can be achieved by a treatment process is also provided²⁹. For some contaminant-process combinations, more than the treatment explicitly noted in the table may be required for removal. For example, the removal of manganese by chlorination or ozonation also requires a particle removal process to reduce the precipitated metal. Section 4.2 of the users' guide provides the information that will assist in knowing what combination of processes is required.

The absence of an entry in the table indicates that either the treatment process has been found to have no effect on the contaminant concentration, or no information about the efficacy in removing that contaminant has been found. In the absence of any information it should be assumed that the treatment process achieves no significant removal of the contaminant.

The tables provide only a guide to the removal capabilities of the various treatment processes, and should not be used to attempt quantitative calculations. It is not possible in summary tables such as these, to take account of the different variables that may affect the performance of a treatment process. These include different types of membrane, different activated carbon types, the nature of coagulants used, and the chemistry of the raw water. Further discussion of the limitations of the tables is provided in s.5.3.

Some advanced treatment technologies that are not used in New Zealand are reported to be able to remove some of the contaminants in Tables A2.2–A2.6 (eg, ozone/hydrogen peroxide oxidation; reverse osmosis filtration). Removal capabilities for these processes have not been recorded³⁰.

Information in the tables is from WHO (2004) unless otherwise indicated.

For a discussion on estimating the removal of chemical contaminants by combinations of treatment processes, see the note after Table A2.6.

²⁹ The estimate of the percentage removal is valid, until the calculated contaminant concentration it will achieve is less than the stated minimum concentration. In this situation the percentage removal is limited by the minimum concentration.

³⁰ Membrane filtration is noted as being effective for several pesticides. This information is from the WHO and probably refers to the use of nanofiltration or reverse osmosis filters, neither of which is used in New Zealand. Where information about membrane processes has been gathered from sources other than the WHO guidelines, any information recorded in Tables A2.2–2.6 under membrane treatment is for microfiltration and ultrafiltration only.

Table A2.2 Treatment efficacies for inorganic chemical contaminants of health significance

Table symbols: * limited removal; ** more than 50% removal; *** more than 80% removal

Where a < value is noted in the table, this is the minimum concentration (mg/L) that can be achieved by the process, even if the combination of initial concentration and percentage removal indicate that a lower concentration can be achieved.

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Slow sand filtration	Activated carbon	Activated alumina	Ion exchange	Greensand filter	Chlorination	Ozonation	Chlorine dioxide treatment
Metals (The form of the metal affects its removal. These are best-case values)											
Antimony	* ^a		** ^b				* ^c				
Arsenic	*** <0.005	*** <0.005	*** <0.005			*** <0.005	*** <0.005				
Barium		***									
Cadmium	*** <0.002	*** <0.002	*** <0.002	** ^d			*** <0.002				
Chromium	*** ^e	*** ^f					*** ^g <0.01				
Copper	*** ^h	*** ⁱ			*** ^j		*** ^k <0.05				
Lead	*** ^{e, l}	*** ⁱ		** ^c	*** ^m		*** <0.01				
Lithium											
Manganese			*** <0.05				*** <0.02	*** ⁿ	*** <0.05	*** <0.05	
Mercury	*** <0.0001	*** <0.0001	*** <0.0001		*** <0.0001						
Molybdenum											
Nickel		*** ^l			** ^m		*** ^k <0.01				

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Slow sand filtration	Activated carbon	Activated alumina	Ion exchange	Greensand filter	Chlorination	Ozonation	Chlorine dioxide treatment
Selenium	**		*** <0.01			*** <0.01	*** <0.01	*** ^o <0.01			
Silver	** ^p	** ^p									
Tin											
Uranium	**	**				*** <0.001	*** <0.001				
Non-metals											
Beryllium	*** ^q	*** ^q									
Boron							*** ^r <0.1				
Fluoride	**		*** <1			*** <1					
Disinfectants and disinfection by-products											
Bromate											
Chlorate											
Chlorine					*** ^s						
Chlorite					* ^t						
Cyanogen chloride									** ^u		
Monochloramine											
Miscellaneous											
Cyanide									** ^s	*** ^v	*** ^v
Nitrate			*** <5	** <5			*** <5				
Nitrite				*** ⁴					*** <0.1	*** <0.1	

References Table A2.2:

- a Kang et al., 2003, *Wat. Res.*, 37, 4171–4179
- b Kang et al., 2000, *Desalination*, 131, 293–298
- c USEPA, 1998, *Small system compliance technologies list for the non-microbial contaminants regulated before 1996*, EPA 815-R-98-002,
- d Erb et al., 1982, *Wat. Sci. Tech.*, 14, 641–653
- e Choudhury et al., 2004, *Chem. Biochem. Eng. Q.*, 18, 295–302
- f Parks and Edwards, 2006, *J. Environ. Eng.*, 132, 489–496
- g Korngold et al., 2003, *Separation and Purification Technology*, 33, 179–187
- h Truitt and Weber, 1979, *Wat. Res.*, 13, 1171–1177
- i Swiderska-Broz, 1991, *Wat. Sci. Technol.*, 24, 247–254
- j Ahmedna et al., 2004, *Wat. Res.*, 38, 1062–1068
- k Korngold et al., 1996, *Desalination*, 104, 197–201
- l Hankins et al., 2006, *Separation and Purification Technology*, 51, 48–56
- m Corapciolu and Huang, 1987, *Wat. Res.*, 21, 1031–1044
- n Spoljaric and Crawford, 1978, *Environ. Geol.*, 2, 215–222
- o Viraraghavan, 1999, *Water Supply*, 17(3–4) 163–167
- p Benefield and Morgan, 1990, Chemical Precipitation, in *Water Quality and Treatment*, 4th ed., American Water Works Assn., McGraw–Hill Inc., New York
- q Lytle et al., 1992, *Aqua* (Oxford), 42, 330–339
- r Simmonot et al., 2000, *Wat. Res.*, 34, 109–116
- s White, 1986, *Handbook of Chlorination*, Van Nostrand Reinhold Co. New York
- t Gonce and Voudrais, 1994, *Wat. Res.*, 28, 1059–1069
- u Na and Olson, 2004, *Environ. Sci. Technol.*, 38, 6037–6043
- v Parga et al., 2003, *Waste Management*, 23, 183–191

Table A2.3 Treatment efficacies for agricultural contaminants of health significance

Table symbols: * limited removal; ** more than 50% removal; *** more than 80% removal.

Where a < value is noted in the table, this is the minimum concentration (mg/L) that can be achieved by the process, even if the combination of initial concentration and percentage removal indicate that a lower concentration can be achieved.

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Activated carbon	Air stripping	Ion exchange	Diatomaceous earth	Chlorination	Ozonation	Chlorine dioxide treatment
Alachlor			*** <0.001	*** <0.001					**	
Aldicarb			*** <0.001	*** <0.001				*** <0.001	*** <0.001	
Aldrin + Dieldrin	**		*** <0.00002	*** <0.00002					*** <0.00002	
Atrazine	*	** ^a	*** <0.0001	*** <0.0001			* ^b	* ^c	*** ^a	
Azinphos methyl									** ^d	
Bentazone										
Bromacil										
Carbofuran		*** ^c	*** <0.001	*** <0.001		*		* ^c		
Chlordane		* ^c	*** <0.0001						*** <0.0001	
Chlorotoluron			*** <0.0001						*** <0.0001	
Chlorpyrifos							*** ^b			
Cyanazine			*** <0.0001	*** <0.0001						
2,4-D	*			*** <0.001					*** <0.001	

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Activated carbon	Air stripping	Ion exchange	Diatomaceous earth	Chlorination	Ozonation	Chlorine dioxide treatment
2,4-DB										
DDT + isomers	*** <0.0001		*** <0.0001	*** <0.0001				*	*	
Diazinon									*** ^f	
1,2-dibromo-3-chloropropane				*** <0.0001	** <0.001					
1,2-dibromoethane				*** <0.0001	*** <0.0001					
1,2-dichloropropane			*** <0.001	*** <0.001						
1,3-dichloropropene										
Dichloroprop										
Dimethoate				**				*** <0.001	**	
Diquat										
Diuron								**g	* ^h	
Endrin	*			*** <0.0002						
Fenoprop										
Heptachlor and its epoxide										
Hexachlorobenzene										
Hexazinone										
Isoproturon			*** <0.0001	*** <0.0001				**	*** <0.0001	
Lindane				*** <0.0001					**	
Malathion										

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Activated carbon	Air stripping	Ion exchange	Diatomaceous earth	Chlorination	Ozonation	Chlorine dioxide treatment
MCPA				*** <0.0001					*** <0.0001	
MCPB										
Mecoprop				*** <0.0001					*** <0.0001	
Metalaxyl										
Methoxychlor	**			*** <0.0001					*** <0.0001	
Methyl parathion							**b		*f	
Metolachlor				*** <0.0001					**	
Metribuzin								***c		**c
Molinate										
Oryzalin										
Oxadiazon										
Pendimethalin										
Pentachlorophenol				*** <0.0004						
Permethrin										
Picloram										
Pirimiphos methyl										
Primisulfuron methyl										
Procymidone										
Propanil										
Propazine		**a								
Pyridate										
Pyriproxifen				*** <0.001						

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Activated carbon	Air stripping	Ion exchange	Diatomaceous earth	Chlorination	Ozonation	Chlorine dioxide treatment
Simazine		** ^a	*** <0.0001	*** <0.0001				*	**	
2,4,5-T	**			*** <0.001					*	
Terbutylazine	*			*** <0.0001					**	
Thiabendazole										
Triclopyr										
Trifluralin			*** <0.0001	*** <0.0001						
1080										

References Table A2.3:

- a Jiang and Adams, 2006, *Wat. Res.*, 40, 1657–1667
- b Agdi et al., 2000, *J. Environ Monit.*, 2, 420–423
- c Miltner et al., 1989, *J. Am. Wat. Wks. Assn.*, 81(1), 43–52
- d Ong et al., 1996, *Food Chem.*, 55, 153–160
- e Westerhoff et al., *Environ. Sci. Technol.*, 39, 6649–6653
- f Wu et al., 2007, *Food Control*, 18, 466–472
- g El-Dib and Aly, 1977, *Wat. Res.*, 11, 611–616
- h Amir Tahmasseb et al., 2002, *Sci. Total Environ.*, 291, 33–44

Table A2.4 Treatment efficacies for industrial contaminants and miscellaneous organic compounds of health significance

Table symbols: * limited removal; ** more than 50% removal; *** more than 80% removal.

Where a < value is noted in the table, this is the minimum concentration (mg/L) that can be achieved by the process, even if the combination of initial concentration and percentage removal indicate that a lower concentration can be achieved.

Contaminant	Coagulation	Membrane filtration	Activated carbon	Air stripping	Chlorination	Ozonation	Chlorine dioxide treatment
Industrial solvents and other industrial chemicals							
Acrylamide							
Benzene			*** <0.01	*** <0.01		*** <0.01	
Carbon tetrachloride	*	*** <0.001	*** <0.001	*** <0.001			
1,2-dichlorobenzene			*** <0.01	*** <0.01		*** <0.01	
1,4-dichlorobenzene			*** <0.01	*** <0.01		*** <0.01	
1,2-dichloroethane			*** <0.01	*		*	
1,1-dichloroethene			*** <0.01	*** <0.01		*** <0.01	
1,2-dichloroethene (cis)							
1,2-dichloroethene (trans)							
Dichloromethane							
EDTA (edetic acid)			*** <0.01				
Epichlorohydrin							
Ethylbenzene	*		*** <0.001	*** <0.001		*** <0.001	

Contaminant	Coagulation	Membrane filtration	Activated carbon	Air stripping	Chlorination	Ozonation	Chlorine dioxide treatment
Hexachlorobutadiene			*** <0.001				
Monochlorobenzene							
Nitrilotriacetic acid (NTA)			***				
Styrene			*** <0.002	*** <0.02			
Tetrachloroethene			*** <0.001	*** <0.001			
Toluene			*** <0.001	*** <0.001		*** <0.001	
Tributyltin oxide							
Trichlorobenzenes (total)							
1,1,1-trichloroethane							
Trichloroethene			*** <0.02	*** <0.02		*** <0.02	
2,4,6-trichlorophenol						*** ^a	
Vinyl chloride							
Xylenes (total)			*** <0.005	*** <0.005			
Polycyclic aromatic hydrocarbons (PAHs) and plasticisers							
Benzo[a]pyrene							
Di(2-ethylhexyl)phthalate							
Di(2-ethylhexyl)adipate							
Fluoranthene	** ^b						

References Table A2.4:

a Chu and Wong, 2003, *Chemosphere*, 51, 289–294

b Kim et al., 2002, *Waste Management and Research*, 20, 341–349

Table A2.5 Treatment efficacies for cyanotoxins

Table symbols: * limited removal; ** more than 50% removal; *** more than 80% removal.

Where a < value is noted in the table, this is the minimum concentration that can be achieved by the process, even if the combination of initial concentration and percentage removal indicate that a lower concentration can be achieved.

Contaminant	Coagulation	Membrane filtration	Slow Sand filtration	Activated carbon	Permanganate	Chlorination	Ozonation	Chlorine dioxide treatment
Anatoxin								
Anatoxin-a(s)							*** ^a	
Cylindrospermopsin						*** ^b		
Homoanatoxin-a								
Microcystins	* ^c		** ^f	* ^d	*** ^c <0.001		*** ^a	
Nodularin								
Saxitoxins				** ^g		*** ^h		

References Table A2.5:

- a Rositano et al., 2001, *Wat. Res.*, 35, 23–32
- b Rodriguez et al., 2007, *Wat. Res.*, 41, 2048–2056
- c Lambert et al., 1996, *Wat. Res.*, 30, 1411–1422
- d Drikas et al., 2001, AWWA Water Quality Technology Conference, Nashville, Tennessee
- e Rodriguez et al., 2007, *Wat. Res.*, 41, 102–110
- f Bourne et al., 2006, *Wat. Res.*, 40, 1294–1302
- g Orr et al., 2005, *Wat. Res.*, 40, 1294
- h Nicholson et al., 2003, *Environ. Tech.*, 24, 1341–1348

Table A2.6 Treatment efficacies for water constituents/contaminants of aesthetic significance.

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Activated carbon	Chlorination	Ozonation	Ion-exchange	Slow sand filtration	Air-stripping
Physical constituents									
pH	pH cannot be 'removed' but adjusted by the use of acidic or alkaline materials. pH adjustment is used in many stages of treatment, but the adjustment needed to ensure a satisfactory pH for the consumer will be undertaken after the last process that may cause a shift in pH outside the desirable range.								
Turbidity	*** ^a <0.1NTU		*** ^b	Other particle removal processes in Table A1.1 are also capable of achieving a better than 80% reduction in turbidity					
Total dissolved solids									
Colour	* to ** ^c						** ^d		
Metals									
Aluminium									
Calcium							*** ^e		
Copper	See Table A1.2								
Iron	See treatments for manganese Table A1.2. The chemistries of iron and manganese allow them to be removed by the same processes. The extent of iron removal will be the same or better than that of manganese.								
Magnesium							*** ^e		
Manganese	See Table A1.2								
Sodium									
Zinc	** ^f	*** ^g		*** ^h			*** ⁱ	** ^j	
Anions									
Chloride									
Sulphate							*** ^d		
Gases									
Ammonia					*** ^k			*** ^j	*** ^l
Hydrogen sulphide					** ^m				
Trace organic compounds									
2-Chlorophenol									
1,2-Dichlorobenzene	See Table A1.4								

Contaminant	Coagulation	Precipitation softening	Membrane filtration	Activated carbon	Chlorination	Ozonation	Ion-exchange	Slow sand filtration	Air-stripping
1,4-Dichlorobenzene	See Table A1.4								
2,4-Dichlorophenol									
Ethylbenzene	See Table A1.4								
Monochlorobenzene	See Table A1.4								
Styrene	See Table A1.4								
Toluene	See Table A1.4								
1,2,3-Trichlorobenzene	See Table A1.4 as for Total trichlorobenzenes								
1,2,4-Trichlorobenzene									
1,3,5-Trichlorobenzene									
2,4,6-Trichlorophenol	See Table A1.4								
Xylene	See Table A1.4								
Disinfectant									
Chlorine	See Table A1.2								

References Table A2.6:

- a Gao et al., 2007, *Separation and Purification Technol.*, 56, 225–230
- b Chiemchaisri et al., 2005, *Wat. Sci. Technol.*, 51, 93–100
- c Amirtharajah and O’Melia, 1990, Coagulation Processes, in *Water Quality and Treatment*, 4th ed., Am. Water Works Assn., McGraw-Hill Inc. NY
- d Hongue et al., 1999, *Wat. Sci. Tech.*, 40(9), 251–221
- e Sorg et al., 1999, *J. Am. Wat. Wks Assn.*, 91(8), 85–97
- f Truitt and Weber, 1979, *Wat. Res.*, 13, 1171–1177
- g Swiderska–Broz, 1991, *Wat. Sci. Tech.*, 24, 247–254
- h Corapciolu and Huang, 1987, *Wat. Res.*, 21, 1031–1044
- i Vaaramaa and Lehto, 2003, *Desalination*, 155, 157–170
- j Erb et al., 1982, *Wat. Sci. Tech.* 14, 641–653
- k Williams and Culp., 1986, *Handbook of Public Water Systems*, Van Nostrand Reinhold Co. New York
- l Ip and Raper, 1978, *Progress in Water Technology*, 10, 587–605
- m White, 1986, *Handbook of Chlorination*, Van Nostrand Reinhold Co. New York

Estimating removals by combinations of processes

Most treatment plants will contain more than one treatment process. The order of treatment processes has been discussed in section 5.2.1 and Tables A2.2–A2.6 have been set out so that the approximate order in which the processes will be encountered is from left to right (remember that not all the processes listed will be used in one treatment plant).

The order in which the processes occur does not affect the calculation of their combined effect on the microbial concentration. In the simplest situation, the overall percentage removal can be estimated by considering the percentage of a contaminant remaining after each treatment process.

Example: Consider a hypothetical situation in which there are three treatment processes in use that are able to remove the contaminant to some degree (in practice, it is unlikely that there will be more than two). The efficacy of each process is as follows: Process A – **; Process B – ***, and Process C – **. Using the precautionary approach, the lowest percentage removal in each bracket should be used. This gives Process A – 50% removal; Process B – 80% removal and Process C – 50% removal.

Consider starting with an initial contaminant concentration of 100 units, after each process step the remaining concentration will be as follows:

	Process A		Process B		Process C		
Remaining concentration	100	→	50	→	10	→	5

The overall percentage removal is therefore 95% (initial concentration minus final concentration, assuming the initial concentration is taken as 100 units).

As with the calculation of the combined effects of treatment processes that operate by the same mechanism for removing microbial contaminants (see notes with Table A2.1), it may not be valid to calculate the effect of combinations of treatment processes for chemical contaminants assuming that all processes will contribute to the removal. For example, the removal of manganese by ion-exchange or greensand filtration relies on adsorption. As a result, if the two processes were used sequentially, the overall percentage removal should not be estimated based on a contribution to removal from each process. The efficacy of the process with the greatest individual removal efficacy should be used in the estimation. In this case both have a *** (minimum 80%) efficacy, so that the overall efficacy would be conservatively estimated at 80%.