Urban Water Research Association of Australia

Disinfection of Wastewater Effluent
A Review of Current Techniques

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FOREWORD

This report is based on a project originally entitled "Australian guidelines for the disinfection of wastewater treatment plant effluent" (UWRAA research project no SS-60). To prevent confusion with the National Water Quality Management Strategy documents, the title has been modified to "Disinfection of Wastewater Effluent - A Review of Current Techniques".

Organisational responsibility for the project was as follows:

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SYNOPSIS

Disinfection is the process of reduction of pathogens of concern to humans, animals, or plants to acceptable levels of risk of transmission of disease. This report critically examines the processes available for disinfection of pathogen-containing wastewater and comparing their effectiveness, practicality, reliability, effects on the environment and human health and the costs involved. It also details the circumstances under which disinfection should be practised. The disinfection methods generally considered for use in Australia consist of chemical methods (chlorine, chlorine dioxide and ozone), physical methods (UV irradiation and membrane microfiltration), and biological methods (ponds).

When determining disinfection needs for wastewater treatment plant effluent, it is the pathogens present in the effluent that need to be inactivated. Care should be taken in using bacterial indicators such as *E. coli* or thermotolerant coliforms to design and control disinfection processes as these indicator organisms are known to be more susceptible to some disinfection processes than are pathogens. The effectiveness of disinfection methods should not relate to removal of indicator organisms alone. Research has shown that there are large variations in pathogen removal through processes in wastewater treatment plants. Literature values should not be used to assess pathogen removal. Site specific data should always be obtained.

To optimise disinfection, it is advisable to reduce suspended solids levels to the most practicably achievable levels for the system, to reduce organic compounds entering the wastewater treatment plant as these are difficult to remove in secondary treatment plants without advanced treatment and to reduce inorganic compounds that interfere with the disinfection method.

In relation to specific disinfection methods a number of conclusions have been reached. Briefly the effectiveness of chlorine for inactivation of viruses, helminths and protozoa is lower than for bacteria and depends to a large extent on having the appropriate conditions, viz. optimum pH, adequate chlorine contact time and low levels of ammonia and suspended solids. Ultraviolet irradiation which is gaining popularity in Australia is effective for disinfection of bacteria and viruses, but has yet to be fully assessed for inactivation of protozoa and helminths.

Also problems exist when treating effluent with suspended solids greater than 20 mg/L. Reliability of UV equipment was raised as a major concern by authorities considering UV irradiation as a disinfection method. Although very effective, chlorine dioxide has only been sparingly used in Australia because of its complexity which requires constant supervision and high operating costs. The use of ozone for disinfection of wastewater has not been practised in Australia to date. Membrane microfiltration is gaining popularity in Australia although it is relatively complex, requiring a high degree of maintenance and system control to provide continuous disinfection. Ponds have been traditionally used in Australia and remain the disinfection method of choice by some authorities, however they have not been purposely designed for disinfection.

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1. INTRODUCTION

In January 1992 the Australian Water Quality Centre (AWQC), in South Australia, commenced a review of methods for the disinfection of wastewater effluent. The review also considered environmental effects of alternative methods and collated the various standards, guidelines etc. used around Australia. Following this review and the presence of a number of other reviews there was widespread support in Australia for the preparation of guidelines for disinfection of WWTP effluent and this project subsequently commenced in October 1993.

In order to produce an appropriate guidelines document, input from organisations around Australia was vital. Five workshops were staged in Brisbane, Sydney, Melbourne, Adelaide and Perth, with representatives from the Health, Environment, Wastewater Treatment Authorities and Local Government being represented.

The issues discussed at the workshops have assisted in developing the focus for the guidelines, and have provided the authors with information regarding relevant research and other studies which have been an invaluable resource.

Raw wastewater contains many disease causing organisms (pathogens). These are excreted in the faeces of infected persons in the general community. Following the treatment of wastewater by primary and secondary treatment processes pathogen numbers are reduced. However the effluent will still contain some pathogens. Processes in the Wastewater Treatment Plant (WWTP) are designed to reduce the levels of organic matter through biological assimilation and some pathogens do survive the treatment processes, although most are less able to adapt and multiply in the chemical and physical conditions experienced in the processes.

Disinfection can be defined as the process of reduction of pathogens of concern to humans, animals or plants to acceptable levels of risk of transmission of disease. WWTP effluent needs to be disinfected when the levels of pathogens exceed that allowed for discharge to the environment, or reuse.

In recent years there has been considerable discussion about chlorination of WWTP effluent. It has long been recognised that chlorination of primary treated wastewater and poor quality secondary treated wastewater is expensive and not best practice. For various reasons, alternative methods of disinfection have been proposed. The alternatives include ultraviolet (UV) irradiation, ozone, chlorine dioxide or microfiltration. As well as these, the traditional use of ponds for stabilisation (biochemical oxygen demand removal) have also been investigated for effective disinfection.

The information presented in this report includes:

- a discussion of the major factors which affect the performance of each disinfection option
- the types of wastewater for which each method is best suited
- the monitoring, controllability and reliability associated with each method
- an estimate of costs

2. WHEN IS DISINFECTION REQUIRED?

Information relating to the levels of disinfection required for different circumstances may be available from Local Health Authorities or in relevant State EPA guidelines. At the national level the following documents may be of some assistance in determining whether disinfection is required.

- National Water Quality Management Strategy (NWQMS) Effluent Management Guidelines
- NWQMS Guidelines for Reclaimed Water
- ANZECC Guidelines for Fresh and Marine Waters

In a survey of all States conducted in 1992, it was found that the microbiological and chemical criteria for discharge were not standardised. However the microbiological and chemical criteria for effluent reuse reflected the then NH&MRC / AWRC Guidelines for use of reclaimed water in Australia (1987).

As a note of caution, care should be taken when using ANZECC Guidelines for Fresh and Marine Waters as "emission standards" as they were not developed for that purpose."

The decision to disinfect should be based on the protection of public health, or where the health of other animals or plants is threatened by risk of disease from organisms present in the wastewater.

This document deals with aspects of public health only, referring to human pathogens when the term pathogens is used, unless otherwise specified.

Appropriate risk assessment should be undertaken on a site specific basis. If there is an unacceptable risk to public health from the discharge or reuse of wastewater that has not been disinfected, then disinfection will be required. The pathogens present in the wastewater need to be inactivated. Section 3.3 discusses this aspect in more detail.

3. PATHOGENIC ORGANISMS

The pathogens potentially present in untreated domestic wastewater are listed in Table 1.

The numbers and types of pathogens need to be known so that relevant exposures can be determined. This is a costly exercise and in the past has rarely been performed.

3.1 Indicator Organisms

There have been representative organisms selected from the four groups of pathogens to represent each group. Traditionally, the following have been used:

Salmonella spp for enteric bacteria
Enteroviruses for human enteric viruses
Entamoeba histolytica or *Giardia lamblia* for protozoa
Ascaris lumbricoides for helminths

Another protozoa, *Cryptosporidium,* is more resistant to disinfection than *Giardia*. This pathogen may be more suitable as a representative for the protozoa.

Bacterial indicator organisms such as *Escherichia coli* and thermotolerant (faecal) coliforms have traditionally been used to assess the levels of pathogenic organisms in streams, estuarine and marine environments, and have been adopted as a quality indicator for effluent leaving a waste water treatment plant. However care should be taken in using bacterial indicators to design and control disinfection processes as these indicator organisms are known to be more susceptible to some disinfection processes compared to pathogens.

The effectiveness of disinfection methods should not relate to removal of indicator organisms only.

TABLE 1

PATHOGENS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

Bacteria	*Shigella* spp *Salmonella* spp *Vibrio* spp *Escherichia coli* (enteropathogenic) *Yersinia enterocolitica* *Leptospira* spp *Legionella* *Campylobacter jejuni*
Viruses	Enteroviruses (71 serotypes - Poliovirus, Coxsackievirus A & B, Echovirus, 4 other numbered enteroviruses) Enterovirus 72 (formerly Hepatitis A virus) Norwalk virus Adenovirus (47 serotypes) Astrovirus (5 serotypes) Calicivirus (2 serotypes) Coronavirus 1 Enterically transmitted non-A, non-B Hepatitis virus Parvovirus (2 serotypes) Reovirus (3 serotypes) Rotavirus (4 serotypes) "small round viruses" (2 serotypes) (possibly enteroviruses)
Protozoa	*Entamoeba histolytica* *Giardia lamblia* *Balantidium coli* *Cryptosporidium*
Helminths	*Ascaris lumbricoides* (stomach roundworm) *Ancylostoma duodenale* (hookworm) *Ancylostoma* spp (hookworm) *Necator americanus* (hookworm) *Strongyloides stercoralis* (threadworm) *Trichuris trichiura* (whipworm) *Taenia* spp (tapeworm) *Enterobius vermicularis* (pinworm) *Echinococcus granulosus* spp (tapeworm) (It is advisable that helminths be monitored regularly to ascertain the most prevalent or resistant helminths in the community being served. This has been observed to vary according to the season.)

3.2 Levels of Pathogens Following Treatment Processes

Feachem et al. (1983) summarised the removal of pathogens through WWTP processes. This is shown in Table 2.

There is such a large variation in the performance of WWTP processes and pathogen removal that it is advisable to use data from site specific evaluation rather than rely on literature values.

TABLE 2

ESTIMATED LOG_{10} (PATHOGEN REMOVALS) DURING TREATMENT IN WWTP

(Feachem et al., 1983)

WWTP Process	Bacteria	Helminths	Viruses	Protozoan Cysts
Primary Sedimentation				
-Plain	0 - 1	0 - 2	0 - 1	0 - 1
-Chemically assisted	1 - 2	1 - 3	0 - 1	0 - 1
Activated sludge	0 - 2	0 - 2	0 - 1	0 - 1
Biofiltration	0 - 2	0 - 2	0 - 1	0 - 1
Aerated lagoon	1 - 2	1 - 3	1 - 2	0 - 1
Oxidation ditch	1 - 2	0 - 2	1 - 2	0 - 1
Waste stabilisation ponds	1 - 6	1 - 3	1 - 4	1 - 4
Effluent storage reservoirs	1 - 6	1 - 3	1 - 4	1 - 4

3.3 What is the Risk of Infection Or Illness Associated with the Discharge Or Reuse of Wastewater Effluent?

The determination of the risk to public health is complex.
Quantitative evaluation of risks associated with exposure to microbial contaminants has been described by Haas (1983), Rose and Gerba (1990), Rose et al. (1991) and Regli et al. (1991).

The four fundamental steps used in a formal risk assessment are:

- Hazard identification
- Dose - response determination
- Exposure assessment
- Risk characterisation

3.3.1 Hazard identification

Any pathogenic organism present in the effluent can be potentially hazardous.

However, viruses and protozoa are resistant to conventional treatment, have high infectivity potential and the uncertainties associated with determining their viability make them the most frequently identified hazards.

3.3.2 Dose-response determination

Dose-response determination provides the dose required to elicit a measurable response in a host or test subject. This determination may not rely on symptoms of illness or disease being apparent, but can be based on infection. Infection is the immunological response to pathogenic agents by a host and may occur without the host necessarily showing signs of the disease. *This is determined by assessment of the levels of antibodies for viruses in a person's blood, or the excretion of bacteria, helminths or protozoa.*

Infection is therefore likely to occur at lower doses than illness and may not result in clinical symptoms being observed. Hence dose-response determination can give relatively low levels of microorganisms being found to cause an infection. This has been illustrated by the studies in California related to reuse of effluent, and the quantification of risk by Regli et al (1991).

Risk of infection is affected by the ability of the organism to take hold and reproduce in the intestinal region.

The ability of infectious agents to survive outside their host is determined by environmental conditions. All pathogens are adversely affected by conditions outside their host. The half life is likely to be longer in freshwater than in the marine environment due to higher osmotic pressure in the latter. Following land application, the drying process results in desiccation of bacterial cells and viruses on the soil surface resulting in quite short half lives for these organisms. Although the soil contains naturally occurring microorganisms, the survival of pathogens is adversely affected by the drying process. Organisms that rely on an egg, cyst or spore stage may persist longer in any environment. This stage is designed to be resistant to adverse conditions.

There is limited information available about population dynamics of important pathogen species, particularly the environmental conditions likely to affect the rate of decay of these organisms in the presence of other competing organisms.

3.3.3 Exposure

Incidences that will result in exposure to waste water include:

- cross connections of reclaimed water into the potable water supply
- ingestion of reclaimed water from impoundments
- swimming (primary contact recreation) in water bodies receiving effluent as a sole or partial source of water
- inhalation of sprayed effluent

- boating, angling, wading (secondary contact recreation) in water bodies receiving effluent as a sole or partial source of water
- contamination of hands with effluent and subsequent ingestion
- ingestion of food grown using effluent as an irrigation water
- ingestion of food grown in the aquatic environment to which effluent is discharged

There have been attempts to estimate the amount of wastewater effluent ingested or likely to be ingested for all of these exposure scenarios. The maximum amount likely to be ingested is based on the estimated daily ingestion of water for an adult which is taken to be 2 L/person/day. This may occur where there is a cross connection into the potable water system. The next highest amount is the 100 mL/person/swimming event ingested during swimming in a freshwater recreational impoundment or stream comprised solely of WWTP effluent. The exposures and estimates of effluent ingested are summarised in Table 3.

Ingestion of reclaimed water is most likely to occur where it is used for irrigation of urban areas which have public access, or where reclaimed water is discharged into primary contact recreation impoundments. This is also the case where bathing beaches are located at the site of effluent discharge. In this case there is dilution of the effluent in the marine environment, however, and natural dieoff and these factors must be taken into account. Reliability of treatment processes would be paramount in these situations.

TABLE 3

ESTIMATES OF EXPOSURE TO EFFLUENT - INGESTION

EXPOSURE	ESTIMATE OF AMOUNT INGESTED /person
Drinking water source	2 L/day
Primary contact recreation Swimming	100 mL/event
Secondary contact recreation Boating, Wading, Fishing	10 mL/event
Golfing, Playing field sports	1 mL/event

3.3.4 Risk characterisation

Risk can be defined as the product of frequency and a term that incorporates both severity and sensitivity. Sensitivity relates to the likelihood of infection occurring and is related to the number of persons likely to come in contact and be infected by pathogens in the waste water. Severity relates to the impact of infection on the person infected. The extremes are no symptoms and death. Hence the more often a waste water is discharged (frequency), and the greater the number of people exposed to the waste water, or the greater the impact of infection on the persons infected, the greater the risk.

There are few epidemiological studies available which relate doses, exposures and infection (or illness) for the pathogens in waste water. Most studies relate to the concentration of indicator organisms in marine or freshwater environments, and the incidence of illness in recreational users in contact with these environments.

This is an area that requires considerably more research. Treatment processes are being designed on removal of indicator organisms to levels based on results of epidemiological studies. However the methodology of these studies are constantly being questioned in the literature.

3.3.5 Risk Management

To manage risk, the frequency of persons exposed to waste water can be reduced. If this is difficult to control, the sensitivity should be reduced by reducing the numbers of persons being infected by pathogens in the waste water or the severity should be reduced by targeting the pathogens that have the highest impact on humans following infection.

For reuse of effluent, procedures and regulations need to address the issues of cross connections, identification of componentry, improper or unintended use of the effluent, development of construction and design standards and assurance of effluent quality. Barriers should be in place to assure the general public that the risk to them is minimal.

For discharge to the aquatic environment, procedures and regulations need to address the issues of dilution and dispersion, assurance of effluent quality, exposure for frequent users of the recreational areas affected and exposure assessment for the general public.

Standards should reflect the source of the discharges, the levels of pathogens likely to be present, and levels acceptable in the discharge.

It is necessary to keep operational records in order to evaluate the effectiveness of processes and show that due diligence has been complied with. An operational record would provide information on the failure of key processes such as filtration or disinfection and would identify what remedial action had taken place to protect public and environmental health. Following any incident an operations record would allow an assessment of whether treatment processes were at fault or whether other factors outside the control of the treatment plant contributed to the incident.

Contingency plans should be in place for emergencies such as pump failures, process failures and overflows. These contingency plans should be approved by the relevant health and environment authorities.

3.4 Flow Chart for Decision Making Based on End Use

In 1986 the US EPA published a Municipal Wastewater Disinfection Manual (US EPA, 1986). This manual included a decision making flow chart for evaluating site specific wastewater disinfection requirements. This flow chart appears in Appendix II. It was based on the traditional use of chlorine and the discharge of the wastewater to a water body, making decisions that either accept or reject chlorine. With the advent of Environmental Protection Authorities in Australia that are discouraging the use of chlorine, such a decision making flow chart needs to be modified to reflect the nature of decision making in Australia. There is also a requirement to consider wastewater reuse more fully as disinfection is of major significance for reuse. The modified flow chart is shown in Figure 1.

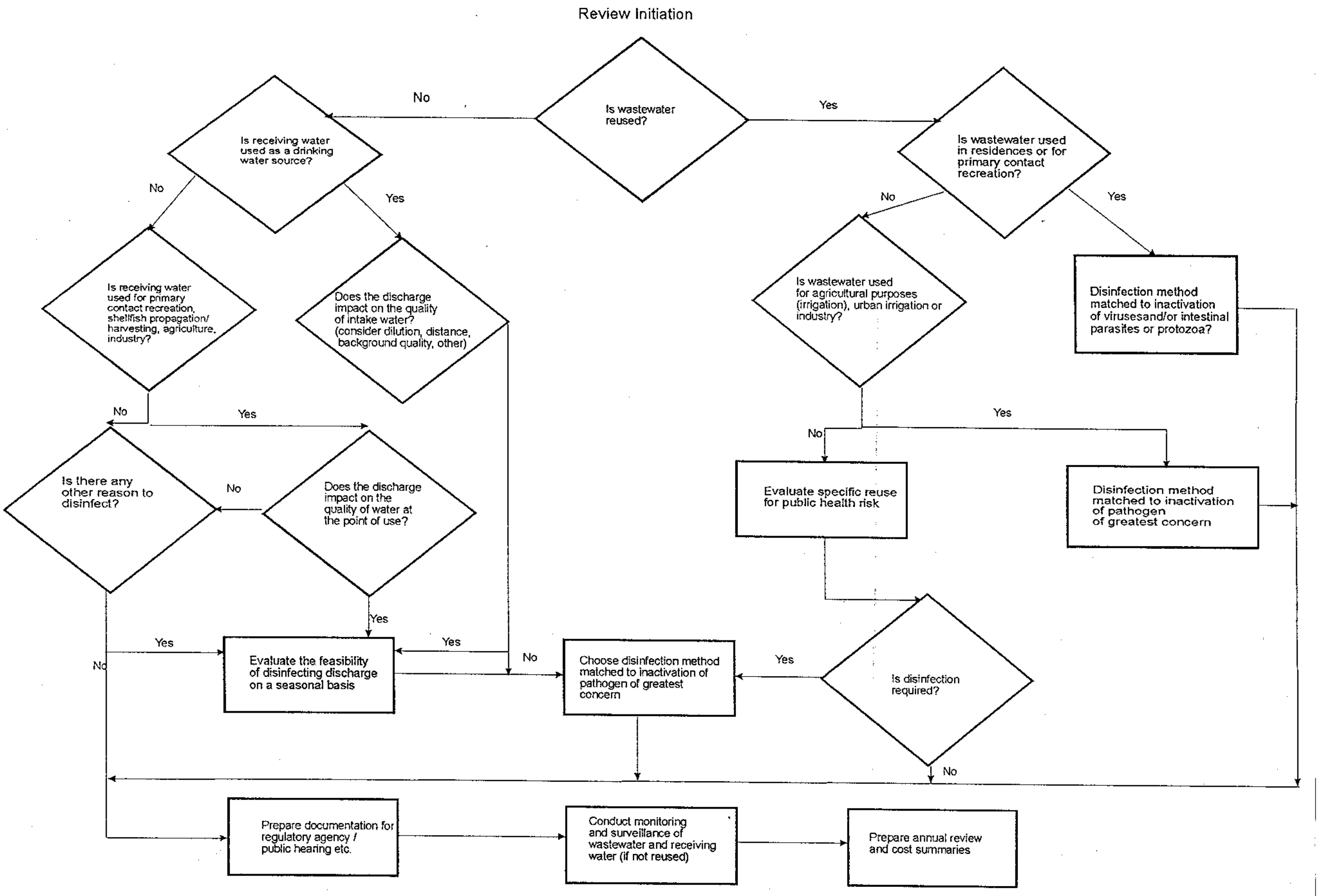

FIGURE 1 FLOW CHART FOR CHOOSING DISINFECTION OF WASTEWATER

4. EVALUATION OF METHODS OF DISINFECTION

The disinfection methods generally considered for use in Australia consist of chemical methods (Chlorine, Chlorine dioxide, and Ozone), physical methods (UV irradiation and Membrane microfiltration), and biological methods (Ponds). It would be unlikely that any alternative to these would be considered at the present time.

To evaluate the disinfectant alternatives, it is necessary to have some criteria that the disinfection process should satisfy. These should be defined and may include the following:

- The method must be effective;
- The method must be practical;
- The method must be reliable;
- The method must not cause adverse effects on the environment or to human health; and
- The method must match the community's willingness to pay.

Based on best practice and consideration of all factors affecting the disinfection process, ideally the following step wise decision making path should be followed:

Step 1. Examine wastewater for pathogenic organisms - sufficient data should be collected to gain statistically robust information.

Step 2. Based on data from Step 1. and following discussions with relevant Health Officers, select the organism(s) having the greatest potential for causing disease - greatest risk.

Step 3. Obtain agreement on the acceptable levels of microorganisms in the effluent.

Step 4. Search literature for suitable disinfection methods and doses to achieve the disinfection required.

Step 5. If there is insufficient literature, conduct pilot studies.

Step 6. Assess the chemical and physical quality of the effluent for parameters that may affect each of the disinfection methods being considered.

Step 7. Determine the adverse human health and environmental effects and relevant occupational health and safety issues for each method being considered.

Step 8.	Compare capital and operating costs for each disinfection method being considered, including the cost of monitoring and controlling the methods.
Step 9.	Evaluate the feasibility of automation if required.
Step 10.	Select method.
Step 11.	Conduct pilot study to optimise conditions for disinfection, if not previously done.
Step 12.	Modify design if necessary.
Step 13.	Install system.
Step 14.	Commission system.
Step 15.	Perform regular assessment and reporting of disinfection performance.
Step 16.	Modify operating conditions as required.
Step 17.	Put in place a Total Quality Management Plan.

As more stringent standards are introduced for use of reclaimed water it is likely that the disinfection process will receive closer scrutiny. The decisions made in selecting the method of disinfection and in determining how the system will be monitored and evaluated will likely be receiving closer scrutiny as well.

4.1 Effectiveness

To evaluate the effectiveness of the method it is necessary to have a standard to compare the method to. This is likely to be inactivation of a specific organism to a satisfactory degree.

Since the almost universal adoption of the thermotolerant coliform group (also known as faecal coliforms) as an indicator organism, it has been accepted practice that these are monitored for meeting discharge criteria as specified in licences. However these organisms are known to be more susceptible to disinfection methods than some pathogens including enteroviruses and intestinal parasites. The disinfection process should ensure that pathogens of concern are adequately inactivated.

Recommendation:

Disinfection doses should be related to inactivation of pathogens and not be related only to inactivation of bacterial indicator organisms such as thermotolerant coliforms.

Strategy:

A representative organism from the groups of pathogens may be chosen as outlined earlier. Thus if viruses are of concern the method may be evaluated for inactivation of enteroviruses; if pathogenic bacteria are of concern, the method may be assessed using *Salmonella* spp; if helminths are of concern, the method may be assessed using *Ascaris* or another helminth prevalent in the community (eg. hookworm); if protozoa are of concern, the method may be assessed using *Giardia* or *Cryptosporidium*.

The protocol for assessing the effectiveness of the disinfection method should be a standard one and scientifically sound. It is likely that seeding (introducing a known concentration) of organisms will be undertaken as performance at varying organism densities will be required to determine the concentration (or intensity) and contact times necessary for effective disinfection. However the protocol for these assessments is as yet far from standardised, and the literature contains many variations of methods for these experiments. This is an area worthy of further research.

Characteristics affecting effectiveness

Effective disinfection may be difficult to achieve:

- in an effluent with relatively high suspended solids
- where suspended solids fluctuate widely, or
- where organic compounds are present at levels that create an unacceptably high demand for the disinfectant.

Organic compounds (including proteins, humic acids and fulvic acids) react with chemical oxidising agents such as chlorine, ozone and chlorine dioxide, and increase the amount of chemical required to achieve disinfection. This is known as "demand" and can be determined experimentally by measuring the difference between the initial dose and the level of disinfectant remaining after the designated contact time.

Some organic compounds contribute to increases in the UV absorbance of an effluent. Hence if UV irradiation is being considered, the UV absorbance of the effluent will be a prime factor in assessing the viability of the process.

Other inorganic chemical compounds present in the wastewater may affect some disinfection processes. The levels of sulfites, sulfides, nitrites, ammonia, or compounds containing iron, calcium, and manganese have been noted as interfering in disinfection processes. Particular compounds and the interference caused is discussed in more detail where appropriate for each disinfection method (see separate sections).

Recommendation:

To optimise disinfection it is advisable to:

- reduce suspended solids to most practicably achievable levels for system
- reduce organic compounds entering the wastewater treatment plant as these are difficult to remove in normal wastewater treatment plants without advanced treatment
- reduce inorganic compounds that interfere with the disinfection method

4.2 Practicality

The practical aspects of the disinfection method include

- the ease of operation,
- reliability and
- efficiency

If a disinfection method is simple to operate and maintain, the method is likely to be optimised for maximum inactivation of microorganisms. The more complicated the method, the less likely it is that optimum performance will be attained.

The reliability may then be compromised. This is an area that needs further clarification through process performance evaluation over a long term. The assurance of reliability is discussed in Section 4.3.

Design of systems should incorporate:

- practicality,
- ease of cleaning, and
- ease of maintenance.

4.3 Reliability

Reliability needs to be factored into any process.

Water and Wastewater Quality Criteria often incorporate a reliability (compliance) factor by ensuring that 4 out of 5 samples must be below a certain level and that a geometric or arithmetic mean is defined where all 5 samples must produce a mean not exceeding that specified. This relates to the availability of effective disinfection for the maximum amount of time possible. To enable this to occur the system must have sufficient means of control including detection of failure, means of alerting staff to failure and emergency procedures to follow in the event of failure.

Implementing normal operating procedures, maintenance programs and contingency plans for emergencies all assist in assurance of reliability.

Some chemical residuals are difficult to measure (eg. chlorine dioxide), and it has been discussed at workshops around Australia that some operators may not understand the chemistry of disinfection processes and hence may not know what they are measuring (eg. chlorine - free, combined or total) and what the results mean. The control of disinfection and effectiveness is often directly related to the residual maintained through the contact tank or vessel. Hence the interpretation of residual measurement results has a strong bearing on the effectiveness and reliability of the process.

Training in operational procedures should be undertaken so that operators are competent. Minimising the organic content of the effluent generally requires an advanced treatment process including coagulation, flocculation and filtration with possible activated carbon treatment. For some uses of reclaimed water, levels of bacteria, viruses and other microorganisms to be achieved following disinfection are low (stringent standards). These are the types of effluent that are likely to need advanced treatment so that reliability is assured through minimising interfering substances.

Staff training, procedure manuals (operation, maintenance and emergency) and occupational health and safety programs can be used to address the issues of system reliability and emergency procedures during system failures.

4.4 Adverse Effects

Where chemicals are housed and used there is always potential for chemical spills/leaks. These may be directly hazardous to human health or may adversely affect the aquatic environment if not adequately confined. Reduced incidence of spills or accidents will occur if appropriate programs are in place and procedures are followed. The occupational health and safety risks need to be adequately considered for all disinfection methods.

Adverse effects for the environment may occur where chemical residuals persist in the effluent. For example, chlorine residuals have caused fish kills and many authorities overseas and some in Australia have specified upper limits for total residual chlorine in effluent.

There may also be adverse effects for the environment due to the formation of disinfection byproducts. These are generally organic compounds. Some are known to bioaccumulate while others are known to be mutagenic or carcinogenic to biota.

The reaction of a chemical disinfectant with an appropriate precursor organic compound to produce mutagenic or carcinogenic compounds depends on conditions being suitable for this to occur. This is a complex area of study.

It is difficult and costly to monitor the wastewater for these potentially toxigenic chemicals. Where wastewater is being discharged to sensitive areas, such as fish breeding grounds, the environmental authority may require a monitoring program. This may include monitoring the biota in the aquatic environment (known as biological monitoring) to detect any chronic as well as acute toxic effects that the discharge may have. The analysis of potential toxigenic agents may then be required if adverse environmental effects are detected.

The biological monitoring program should follow standard acceptable methods, as recommended for example by the US EPA.

4.5 Costs

Disinfection costs include both capital costs for purchase of equipment, installation, and associated pipework and earthworks, and operating costs which include all consumables such as chemicals and power. There are also costs associated with monitoring and controlling the process and these are often not included in the costing prior to installation of a disinfection system but may have a large impact on the ongoing costs. These include, for example, changeover of chlorine cylinders or drums and maintenance of residual testing equipment as well as costs associated with chemical and microbiological analyses.

Part 5 in each of Sections 5 to 10 summarises the factors that need to be costed for each of the methods. Section 11 discusses cost comparisons further.

5. CHLORINATION

5.1 Characteristics and Mode of Inactivation

Chlorination is disinfection using chlorine gas or a hypochlorite solution as a source of chlorine. There are a number of forms that chlorine can take, depending on the pH or on the presence of ammonia. These are:

- hypochlorous acid ($HOCl$)
- hypochlorite ion (ClO^-)
- monochloramine (NH_2Cl)
- dichloramine ($NHCl_2$)

Each of these species is an oxidising agent. In general, dichloramine is not present in effluent unless the pH drops below 7.0 (White 1992), due to the competition of reaction of chlorine with organic compounds. The proportions of hypochlorous acid and hypochlorite ion are dependent on the pH, with greater proportions of hypochlorite ion as the pH increases.

The oxidation potential indicates the strength of the oxidising capability of a species. The oxidation potential of hypochlorous acid is 1.50 Volt; the oxidation potential of monochloramine is 0.75 Volt. Hence the hypochlorous acid species is the more potent oxidising agent. Oxidation occurs more rapidly when hypochlorous acid is present than when monochloramine is present.

During disinfection, the cell wall constituents or proteinaceous components are oxidised leading to lysis of cells (for bacteria) or inactivation of specific functional sites such as viral attachment to host cells. Chlorine oxidises the lipoproteins in the walls of protozoan cysts/amoebic cysts. These reactions are more rapid when hypochlorous acid is present than when monochloramine is present. This is illustrated in the smaller product of concentration of disinfectant and the time of contact with the disinfectant (c.t value or product). This is described further in the following part.

5.2 Effectiveness

Hypochlorous acid is an effective disinfectant for bacteria and at longer detention times is effective against some viruses. However for wastewaters containing ammonia the active disinfectant species is monochloramine unless breakpoint chlorination is achieved. Monochloramine is a much less effective disinfectant particularly for viruses. Where wastewaters contain organic nitrogen (protein, amino acids) this can also react with the hypochlorous acid to form organic chloramines which may not be biocidal, but which incidentally can be measured in total chlorine residual measurements. Hence the disinfectant species present are not equally effective for disinfection. This can be seen from Table 4. The lower the c.t value the more efficient the disinfection, requiring either less time or less disinfectant (lower concentration).

TABLE 4

C.T_{99} VALUES FOR INACTIVATION OF SPECIFIC MICROORGANISMS BY THE CHLORINE DISINFECTANT SPECIES (from Morris, 1986)

Microorganism	**Ct value for HOCl**	**Ct value for ClO^-**	**Ct value for NH_2Cl**
Bacteria *Escherichia coli*	0.02	1.0	50
Virus Poliovirus 1	1.0	10	500
Protozoa *Entamoeba histolytica*	20	8000	150

pH = 7.0; T = 20C

Disinfection of an effluent with a higher level of suspended solids than would normally be recommended for the method results in an increase in the time required to achieve effective disinfection with a chemical disinfectant such as chlorine (when the temperature, pH and concentration at end of contact time are kept constant).

Sproul (1976) reported that chlorination of primary or secondary treated wastewater gave at best a 50 % reduction of viruses, whereas chlorination of tertiary treated wastewater (precipitation of phosphorus and sedimentation, followed by activated carbon adsorption) achieved a 99 % reduction of viruses. Thus the chlorine demand of a primary or secondary treated wastewater is substantially higher than for the tertiary treated wastewater. This is because chlorine as hypochlorous acid does not discriminate between microbiological protein and other proteinaceous material in its oxidising reactions, and there is more of this material in a secondary treated wastewater than there is in a tertiary treated wastewater.

The effectiveness of chlorine for the inactivation of viruses, helminths and protozoa depends largely on having the right conditions, viz; optimum pH, sufficiently long chlorine contact time and low levels of ammonia and suspended solids.

5.3 Practicality

As chlorine has been used extensively in the past, operators are familiar with the process and it is seen as the most practical disinfection method. Design factors including initial mixing requirements and chlorine contact tank design etc. have been widely reported through the literature for many years. In recent times, however, there has been an increased need for residual chlorine analysers and dechlorination. The systems have become more complex and less practical.

White (1992) lists the elements of an optimum chlorination system. These are:

- A proper and workable automatic chlorine residual control system.
- Adequate initial mixing.
- Sufficient contact time (not less than 30 minutes at peak dry weather flow) in a contact basin that has a minimum of short circuiting, ie. 80 - 90 % plug flow.
- Competent and dedicated personnel.
- Laboratory facilities sufficient to provide proper support to operating personnel.
- Reliability.

Rapid initial mixing is required for all chemical disinfectants, not just for chlorination. There have been different mixing requirements reported for inactivation of coliforms compared to inactivation of viruses with a more rapid initial mixing being required for viruses (Calmer, 1993).

Contact times for a particular concentration of disinfectant depend on the initial level of organisms, and the final level of organisms allowed. The concentration of disinfectant is affected by temperature and pH as the proportions of hypochlorous acid and monochloramine are affected by these. Longer contact times may require a larger area of land to accommodate contact basins.

Staff availability is a problem at smaller plants due to cost of labour. In such situations it is likely that systems will need to operate without constant supervision. This requires automatic dosing of chlorine, according to flow if dosed at a fixed rate or according to demand if chlorine residuals are monitored. There must also be provision for automatic changeover of chlorine cylinders so that the disinfection process is not affected by exhaustion of chlorine.

5.4 Reliability

For all systems and particularly where the system is automated, alarms and systems for detecting failure are the main means of ensuring process reliability. Where disinfectant residuals are used as a means of ensuring adequate disinfection these need to be monitored.

The control system may include:
- a sample withdrawal pipe,
- sample pump,
- sample transport line,
- residual analyser,
- effluent flowmeter,
- controller and
- chlorinator.

There may also be:

- an injector,
- chlorine solution transport line,
- a mixing area and
- a contact area.

There have been variations between operators noted when measuring chlorine residuals, which raises concern about accuracy and quality assurance. White (1992) states that chlorination may not be adequately controlled unless chlorine residual analysers are used. There have been operational problems noted with chlorine residual analysers, including blockages caused by suspended and gross solids.

For a reliable chlorine control system, daily operator attendance is essential as daily cleaning and calibration of residual analysers is needed. Poorly designed and/or operated chlorine control systems have been responsible for excessive chlorine dosage at most of the full-scale plants studied by White (1992).

If the effluent varies in flowrate but is relatively constant in chlorine demand, a feed forward control of chlorine adjusts the feed without measuring the residual. Manual adjustment may be required for setpoint. An effluent with fluctuating demand favours feedback control basing the applied dosage on an actual analysis of the residual concentration. A compound control system incorporates both to rapidly compensate for flow changes while trimming to setpoint based on actual measurements.

Oxidation reduction potential (redox potential) has been assessed for control of chlorination. However White (1992) states that it is not possible to evaluate the potential measurements of individual forms of residual chlorine due to interfering substances and hence there is no way of knowing which forms of chlorine are present and how effective they are. Strand and White (1993), on the other hand, report that biocidal effectiveness can be managed effectively through redox control of chlorination with up to 50 % saving in chlorine used, and for dechlorination less chemical is required. Such contradictions need further investigation but if the redox potential control is found to be suitable for optimising disinfection there are significant benefits to chlorination in terms of chemical consumption. This is an area worthy of further research.

5.5 Adverse Effects

Free and combined chlorine residuals at low levels are toxic to aquatic organisms including fish and macro invertebrates. In addition to well documented fish kills, there have also been reports of fish avoiding areas where chlorinated effluent is discharged. This has the potential of causing losses to industry when chlorinated effluent is discharged to fish breeding areas, due to disruption to natural cycles of reproduction. The environmental and ecological impact of such practices is still being researched.

Occupational health and safety issues regarding the storage of chlorine gas have been raised in recent years. Each State has individual Workcover (or equivalent) requirements which address occupational health and safety issues regarding the storage and use of hazardous substances including chlorine. The potential for gas leaks needs to be addressed and may require the installation of gas leak detectors. Some authorities have been concerned with the storage of chlorine at WWTP in metropolitan or populated areas. The community's awareness of the hazards associated with chlorine and chlorine gas in particular has been raised in recent times and some communities have requested that chlorine not be used for wastewater disinfection (Personal communication, Maroochy Shire Council, Qld, 1994).

There is a federal code of practice (Australian Dangerous Goods Code) which addresses the transport and storage of hazardous substances including chlorine gas. Hypochlorite liquid is not covered by this legislation. In the USA, chlorine gas and sulfur dioxide gas (used for dechlorination) are listed as hazardous substances and require stringent measures to be in place to control spills or leaks, or in the case of fire. There is a Uniform Fire Code in the USA which dictates the minimum requirements for storage and use of hazardous substances. If similar requirements were to be enforced in Australia, there would likely be major expenses involved in the storage and use of chlorine gas in particular (Gilardi, 1993).

5.6 Cost

Capital costs include:

- Purchase and installation of Chlorine contact tanks including earthworks
- Housing for chlorine storage
- Pipes, dosing meters
- Chlorine residual analyser
- Other monitoring equipment such as gas leak detectors

Operating costs include:

- Maintenance and calibration of dosing equipment and analyser including labour
- Cleaning of contact tank (solids sediment - this is particularly important for primary and secondary effluent) including labour
- Chemical costs, including transport and changeover of tanks, cylinders etc. including labour

Section 11 summarises capital and operating cost estimates for each of the disinfection methods.

6. UV IRRADIATION

6.1 Characteristics and Mode of Inactivation

UV disinfection relies on the transfer of electromagnetic energy from a source (lamp) to an organism's cellular material (specifically the nucleic acids). The nucleic acids, DNA and RNA, absorb light of different wavelengths but have a maximum absorption of UV light at a wavelength of 255 to 260 nm. The UV absorbed damages or modifies the genetic information stored in the DNA, rendering the cell unable to replicate. Low pressure mercury lamps have been used to provide this UV light, having a wavelength of 253.7 nm, which is close to the optimum. In the past low intensity lamps have been predominant. In recent years technology has developed the medium and high intensity UV lamps which may find greater application in treating larger flows as fewer lamps are needed. The two design types for UV disinfection are the quartz tube systems where the quartz jacketed UV lamps are immersed in the effluent stream and the teflon tube system where the effluent flows through the teflon tube and the UV lamps are external to the teflon tube not in contact with the effluent. It has been reported that each system has its advantages and disadvantages (US EPA, 1986) and that the requirements of each site need to be matched to the performance potential of each system before a choice is made. There has been a trend towards modular in-channel systems in the U.S.A.

6.2 Effectiveness

UV irradiation is effective for bacteria and viruses but has yet to be fully assessed for inactivation of protozoa and helminths. Rice and Hoff (1981) report that cysts of the protozoa *Giardia lamblia* were resistant to high doses of UV radiation. Doses of 42 - 63mW.s/cm2 failed to produce 90 % (1 log10 unit) reduction in cyst numbers whereas a dose of 3mW.s/cm2 produced a 99.9 % (3 log10 units) reduction of *E.coli* numbers. Hence even 20 times the dose for indicator organisms will not inactivate these protozoa. *Cryptosporidium* oocysts have been found to be more resistant to oxidising disinfectants than *Giardia* cysts, hence it may be assumed that *Cryptosporidium* oocysts may be more resistant to UV radiation as well.

It is therefore essential that processes prior to disinfection with UV be designed for helminth, cyst or oocyst removal where these are an identified health risk.

The critical factors for effective UV disinfection are:

- Intensity
- Exposure time
- Effluent quality
- TSS in influent
- UV absorbance of wastewater (or per cent transmission)
- Flow rate at time of sampling which will determine detention time

The characteristics of an effluent that affect the UV absorbance include particulate matter, suspended solids, and chemical constituents in the effluent that absorb UV light at the same radiation as used for disinfection. However studies have shown that particle size does not correlate with UV disinfection performance data (Emerick and Darby, 1993). Salts of calcium and magnesium have been identified as causing inorganic scale on the surface of quartz tubes in UV reactors. In addition to the hardness components, there are ion exchange type reactions which have been detected. Hence Iron (Fe) ions and Aluminium (Al) ions have been deposited on negatively charged quartz surfaces as well as calcium and magnesium (Blatchley et al. 1993).

Wastewaters with suspended solids greater than 20 mg/L should not be treated with UV irradiation as organisms occluded by suspended solids will not be affected by UV light. This relates to a turbidity of approximately 10 NTU. UV irradiation is significantly more effective in a sand filtered effluent than in the corresponding unfiltered secondary effluent (Qualls et al., 1983) due to lower turbidity and suspended solids levels. An advanced treatment process or a tertiary treated effluent have been essential for effective disinfection to satisfy the strict requirements for effluent reuse in California, USA (Snider et al. 1991).

6.3 Practicality

The UV system should be easy to maintain and operate, and faults should be easily detected. The design of the system should allow cleaning and maintenance to be performed without disruption of effective disinfection.

Various models have been proposed for design and operation of UV disinfection equipment (Qualls and Johnson, 1985). No one model was suitable for a wide variety of effluent. Each effluent must be considered as specific in its absorbance of UV light and thus the effectiveness of a UV system needs to be matched to the characteristics of the effluent to be disinfected.

Scheible (1993) lists the following observations on practical aspects of UV disinfection:

- removal of the modules is appropriate and probably best for most plants. Cages are suggested for larger plants for removing bundles of lamp modules.
- moving hoists/cranes will aid removal of the module bundles or vertical lamp modules.
- dip tanks are convenient to use and assist in cleaning modules removed from the channel.
- in-place recirculation is effective, particularly for vertical lamp modules. Agitation should be provided during the recirculation cycle. Plant should still plan to remove the modules once per year for a rigorous cleaning.
- the cleaning agent(s) that suits the facility depends on the nature of fouling. A trial and error series of tests should be conducted, using readily available, off-the-shelf commercial products.
- small-scale pilot studies would aid in determining the cleaning agents and frequency most suitable to a specific plant.
- monitoring faecal coliforms is an effective tool for determining the need for cleaning lamps.

6.4 Reliability

Reliability is extremely important for effective UV irradiation as there is no residual chemical to assure post contact chamber disinfection. This has been raised as a major concern by authorities considering disinfection methods. The only reliable measurement of effectiveness is to monitor the organism levels following the disinfection process (at least 24 hours is required to perform these analyses and obtain results) unless the dose reaching the microorganisms can be assured.

On-line measurement of turbidity using a turbidimeter and on-line measurement of UV irradiation using a photometer are methods used to control the process from an operations point of view and thus ensure reliability.

There needs to be more information supplied from manufacturers and system designers regarding :

- the reliability of UV lamps and the lamp output as the lamp ages;
- the design features which are of most significance such as the hydraulics of the system

Maintenance is an extremely important part of effective and reliable operation of a UV disinfection system. Lamp replacement, and regular cleaning of channels (or tubes) and lamps is essential to maintain the dose at correct levels.

Ideally lamps should be replaced every 7500 hours of use. With the development of electronic ballasts, it has been reported that lamp life has increased to approximately 13000 hours. In small systems where it is likely that the system would operate with all lamps on at all times, the lamps would need replacing at approximately 10 to 12 month intervals or 18 month intervals for electronic ballasts. However in medium to larger systems, where the lamps are in banks or modules that can be turned on or off according to the flow, the time for lamp replacement can be extended to once per two years or even less frequently where electronic ballasts are used.

Lamp replacement may be linked to the results of microbiological analysis. If the performance drops off, there should be a subsequent increase in indicator organism numbers. However, if microbiological analyses are not performed frequently then this should not be used as an operational control.

Over time the quartz systems need replacement of the quartz sheaths. This has been estimated at approximately once every ten years.

The larger the system, the more benefit there is from having flow controlled lamp usage, with automatic control being the most practical for the larger systems.

The provisions for cleaning and maintenance need to be incorporated into the system. Cleaning and maintenance should not affect the performance of the system. The system should always be available for effective disinfection and should operate continuously.

A survey of 30 WWTPs that use UV disinfection was conducted in the USA (Scheible, 1993) and revealed that cleaning practices are highly variable with respect to how the cleaning was performed, the type of cleaner used and the frequency of cleaning.

A suitable control system may include the following measures:

- A photometer to measure UV light intensity
- For filtration, it is necessary to measure turbidity
- Flow needs to be accurately measured and doses regulated according to flow, by switching on/off lamps
- System failure must be detected through alarms, warning lights etc.
- Flow diversion and/or duplicate treatment units in the event of system failure

6.5 Adverse effects

Safety considerations for workers when operating and maintaining the system are paramount. There have been reported incidents of workers exposed to dangerous levels of UV radiation causing severe short term eye damage, and skin damage.

The main environmental effects from using UV irradiation as a means of disinfecting wastewater are the energy requirements and the disposal of cleaning solutions.

6.6 Cost

Capital costs include:

- UV system including electrical/electronic componentry
- Channels for quartz unit if required
- Monitoring system/ Control system

Operating costs include:

- Maintenance - labour
- Lamp replacements including lamps and labour
- Power costs

Section 11 summarises capital and operating cost estimates for each of the disinfection methods.

7. CHLORINE DIOXIDE

7.1 Characteristics and Mode of Inactivation

Chlorine dioxide (ClO_2) is an unstable gas formed by the reaction of chlorine with sodium chlorite. Hydrochloric acid is usually added to maximise ClO_2 production. However a chlorine dioxide solution will always contain chlorite ions (ClO_2^-), chlorate ions (ClO_3^-) and hypochlorous acid (free chlorine, HOCl) as well as chlorine dioxide. Due to its instability (explosive at temperatures greater than -40C and at concentrations in vapour of about 14 % in air) it must be generated on site and cannot be stored.

Chlorine dioxide is a strong oxidising agent with an oxidation potential of 0.95 Volt for ClO_2. As an oxidising agent it reacts with all proteinaceous material in addition to protein components of microorganisms. The kinetics of the reaction between chlorine dioxide and organic matter indicate that the reaction is rapid and chlorine dioxide is rapidly depleted. Thus the demand for chlorine dioxide in effluent is likely to be high.

7.2 Effectiveness

Chlorine dioxide has lower Ct_{99} values for a 2 log inactivation of *E.coli*, Poliovirus 1 and *Entamoeba histolytica* than ClO^- and monochloramine (see Table 5) and is more effective for inactivation of *Entamoeba histolytica* than hypochlorous acid.

TABLE 5

CT_{99} VALUES FOR CHLORINE DIOXIDE (CLO_2) COMPARED TO CHLORINATION

(from Morris, 1986)

pH = 7, T = 20C

Microorganism	Ct value for HOCl	Ct value for ClO^-	Ct value for NH_2Cl	Ct value for ClO_2
Escherichia coli	0.02	1.0	50	0.2
Poliovirus 1	1.0	10	500	1.5
Entamoeba histolytica	20	8000	150	5

Chlorine dioxide reacts rapidly with organic matter (high demand) and at a faster rate than chlorine, however the process is oxidation not halogenation, hence chlorinated organic compounds should not be formed. Some products of oxidation of organic compounds with chlorine dioxide include aldehydes which have been identified as carcinogenic or mutagenic. In view of the increased demand and the potential for carcinogenic or mutagenic compounds being formed it would be advisable to reduce organic carbon concentrations to minimal levels in the effluent prior to disinfection with chlorine dioxide.

Chlorine dioxide reacts with nitrites oxidising them to nitrates. A partially nitrified effluent is likely to have a strong demand for chlorine dioxide.

7.3 Practicality

Chlorine dioxide must be generated on site as it is unstable, and explosive. The generation of chlorine dioxide requires chlorine, sodium chlorite and hydrochloric acid. These three chemicals cannot be stored together therefore housing for each chemical is required. The system is complex and requires constant supervision.

The mixing of the chemicals needs to be carefully controlled to produce the optimum yield of chlorine dioxide. This would minimise costs.

7.4 Reliability

The complex control and dosage system may increase the risk of system failure. Chlorine dioxide residuals are difficult to monitor. At the only plant using this method for disinfection of wastewater in Australia, redox potential is used to determine correct dosing rates.

The complexity of the system requires that alarms and warning devices be standard requirements to detect failure. Automatic diversion of flow, back up power supply and/or duplicate treatment units may be required.

7.5 Adverse effects

Chlorine dioxide residuals are toxic to aquatic organisms in the environment.

The occupational health and safety issues must be adequately addressed as chlorine dioxide is explosive. The generation of chlorine dioxide requires the storage of three hazardous chemicals which have the potential to cause damage to human health if leaks occur.

The high energy requirements for generation of chlorine dioxide is also an adverse effect on the environment.

7.6 Costs

Chlorine dioxide generation is high in operating costs. Chemical costs for a 25,000ep WWTP may be of the order of $360/day compared with $21 for chlorine alone (Chee Liew, Personal communication, Hobart City Council). The operating cost difference is $110,000 per year. Capital costs have been reported as being similar to chlorine, however separate chemical storage are required for chlorine, sodium chlorite and hydrochloric acid, so capital costs may reflect this. Section 11 summarises capital and operating cost estimates for each of the disinfection methods.

8. OZONE

8.1 Characteristics and Mode of Inactivation

Ozone (O_3) is an unstable gas, blue in colour with a characteristic pungent odour. It is produced from dry air or oxygen, formed by the corona discharge of high voltage (4000-30000V) electricity.

Ozone has an oxidation potential of 2.07 Volt, making it the strongest oxidising agent. It reacts with all proteinaceous material as well as the microorganisms to be disinfected.

Ozone has not been used for wastewater disinfection in Australia to date.

8.2 Effectiveness

Ozone is the most effective chemical disinfectant available, particularly for the pathogenic intestinal parasites. Table 6 illustrates this through the comparison of the Ct values of each of the oxidising agents. The Ct_{99} value refers to the product of disinfection concentration and contact time for 99 % inactivation of the organism.

TABLE 6

CT_{99} VALUE OZONE (O_3) COMPARED TO THE OTHER OXIDISING AGENTS USED FOR DISINFECTION (from Morris, 1986)

Microorganism	**Ct value for HOCl**	**Ct value for ClO^-**	**Ct value for NH_2Cl**	**Ct value for ClO_2**	**Ct value for O_3**
Escherichia coli	0.02	1.0	50	0.2	0.005
Poliovirus 1	1.0	10	500	1.5	0.005
Entamoeba histolytica	20	8000	150	5	2

pH = 7.0, T = 20C

However a high quality of effluent with a low chemical oxygen demand (COD) of approximately 30 mg/L is required for ozonation, This may preclude its choice for most wastewater treatment plants currently operating in Australia as the COD is usually in excess of 50 mg/L.

With the advent of advanced wastewater treatment processes and nutrient reduction, and the necessity for clarification for effluent reuse, the improved quality of the effluent will encourage the use of ozonation.

8.3 Practicality

There has been a large amount of literature produced regarding the design factors required for effective disinfection of wastewater with ozone.

The materials in contact with ozone need to be high quality stainless steel to avoid corrosion. Ozone needs to be generated on site and there is a high degree of complexity involved with the generation equipment and the assessment of ozone concentrations which may involve the measurement of ozone in the gases being released from the contact chamber (commonly known as the off gases).

There is a need to monitor ozone being released to the atmosphere. Each state has a limit allowed in the air, for safety to human health and the environment. Environmental health authorities should be consulted to determine what levels are considered safe.

Its complexity does not encourage its use. However for large WWTPs with an appropriate level of technical support, it may be considered.

8.4 Reliability

The reliability of ozone is dependent on the continuous production of the gas and the effective transfer of the gas to the wastewater. There has been much research to optimise transfer efficiencies and the bibliography should be consulted to obtain references evaluating the various designs.

Alarms and system control are essential due to the complexity of the system. The staff involved should be highly competent with a detailed understanding of the processes occurring. An ozone system cannot be installed and left to operate automatically without supervision, unless sophisticated surveillance and automatic shutdown or diversion is available.

8.5 Adverse effects

Ozone concentration in the atmosphere in excess of 0.25 ppm is generally considered damaging to human health. It is advisable to contact environmental health authorities to determine what standards are to be met. The literature have reported that the measurement of ozone in the off gases is required both for operational requirements and also for protection of human health as ozone levels in the air are regulated.

Ozone residuals do not persist in the aquatic environment due to the high reactivity of ozone and its low solubility. Therefore there is no requirement generally for ozone to be measured in the effluent.

Ozone reacts with all proteinaceous organic matter present and may result in the formation of undesirable compounds. This is an area still being researched. It has been reported that ozone can increase the mutagenicity of a wastewater (Jolley et al. 1982). The higher the quality of the wastewater being disinfected the less likelihood that undesirable organic compounds will be formed.

There is a high energy consumption required for generation of ozone. This is an adverse environmental impact.

8.6 Costs

Ozone is the most expensive of all chemical disinfection methods, due mainly to the high cost of materials in contact with the ozone. At Indianapolis, Indiana, USA the capital cost for ozone was 8.0% of total capital cost for plant, and operating cost was 3.66 % of total operating cost for the plant.

Due to the limited use of ozone for disinfection of effluent there is little information regarding capital or operating costs.

Section 11 summarises capital and operating cost estimates for each of the disinfection methods.

9. MEMBRANE MICROFILTRATION

9.1 Characteristics and Mode of Inactivation

Membrane microfiltration relies on filtering of the wastewater through microporous polymer membranes. Bacteria, protozoa and helminths are filtered by these membranes, and any viruses attached to suspended solids are also filtered out. The filtrate is theoretically free of microorganisms.

For disinfection, the system must operate to achieve as pure a filtrate as possible to meet discharge requirements for microorganisms.

9.2 Effectiveness

Kolega et al. (1989) studied the disinfection of secondary wastewater effluent by membrane microfiltration. They concluded that membrane microfiltration is effective in removing all indicator bacteria (total coliforms, faecal streptococci) and naturally occurring wastewater viruses (enteroviruses) from an activated sludge secondary effluent. The process does not require a good quality effluent as a feed liquid, although prescreening is necessary.

Jacangelo et al. (1991) reported results of analysing influent and effluent for a low pressure microfiltration system. These are shown in Table 7. As can be seen there are large reductions in numbers of all organisms. The filtration system works effectively.

The performance of the microfiltration system in terms of faecal coliform, coliphage and human virus reductions was adequate for disinfection although the mechanism of virus removal could not be explained.

TABLE 7

EFFECTIVENESS OF MEMBRANE FILTRATION
(adapted from Jacangelo et al., 1991)

Microorganism	Size Exclusion	Density	Number of Samples	% Positive	Median Density
Faecal Streptococci	0.2 m	4.0 x 10^2 to 6.2 x 10^5 /mL	70	0	< 1 /mL
Faecal Coliforms	0.2 m	1.5 x 10^5 to 2.6 x 10^5 /100mL	9	0	< 1 /100mL
Enterococci	0.2 m	2.7 x 10^2 to 6.2 x 10^3 /100mL	9	0	< 1 /100mL
		10^4 to 10^5 / gallon			
Giardia muris	0.01 m	10^4 to 10^5 pfu/mL	15	6.7	< 1 /5 gallon
Phage - MS2 virus	0.01 m		49	0	< 1 pfu/mL

9.3 Practicality

Theoretically the process is quite simple. In practice however there is a high degree of maintenance and system control required to provide continuous disinfection. As wastewater can contain quite high levels of suspended solids (compared to drinking water sources) it is necessary to prefilter or screen the effluent to remove grit that would otherwise block the membranes. These screens also require backwashing as does the microfiltration system itself. Thus the complexity of the system is reasonably high and breakdowns or backwashing cycles may result in a disruption to continuous disinfection unless duplicate units are available.

A full scale membrane microfiltration system for disinfection has been in operation in New South Wales for four years. A report by Water Board et al (1992) summarises the trials carried out with this unit.

9.4 Reliability

The reliability of the system is directly related to the provision of continuous microfiltration. This involves the detection of membrane failure, and the provision of backup units including backup power supply.

The regular microbiological analysis of the filtrate is essential to assessment of the reliability of the system.

In order to treat an effluent stream, it is reported that the following analyses be performed:

- Total solids content including suspended solids, and total dissolved solids
- Specific chemicals such as oxidising chemicals and organic solvents which can be deleterious to membranes
- pH
- Operating temperature

9.5 Adverse effects

The system requires cleaning, generally with a caustic solution which necessitates the storage, use and disposal of caustic solution. The OHS program would need to address these hazards. In addition to the caustic solutions being a hazard to workers, the noise generated by the system may necessitate housing of the unit if in a populated area. Protection of workers from ear damage may be required.

The environment would be adversely affected by the direct disposal of caustic solution which can entail noise and energy requirements both of which can be significant.

9.6 Costs

Due to the improvements in design in recent years, microfiltration systems have reduced in capital cost, however this is still higher than other methods of disinfection. As prescreening of the effluent prior to microfiltration is necessary, there is also a capital cost of this equipment. Memtec estimate the installed cost of a rotating disc screen of between $25000 (for 1 screen) and $40000 (for 3 screens). This would depend however on the type of screen used. All of the components should be included in the costs obtained from suppliers.

Operating costs include:

- feed pump electrical costs,
- air compressor electrical costs,
- chemical cleaning agents,
- membrane replacement costs,
- maintenance and service agreements, and
- labour.

Maintenance includes pump and compressor maintenance and periodic calibration of flowmeters, pressure gauges and transducers.

Membrane life is generally quoted as 3 to 5 years.

Cleaning cycle is 2 to 3 hours long.

Section 11 summarises capital and operating cost estimates for each of the disinfection methods.

10. PONDS

Ponds have been traditionally used as stabilisation lagoons (BOD removal) or for disposal by evaporation.

10.1 Effectiveness

In Australia, ponds have been seen as the disinfection method of choice by some authorities. Traditionally, however, most ponds have not been designed for the purpose of disinfection, with pond size determined by the BOD loading per unit area. In recent times however there has been increasing use of existing ponds for optimising disinfection. The assessment of existing ponds for effective disinfection is being considered by more authorities. The effect of raising embankments, for example, to the performance of the ponds for disinfection has been positive, thus increasing detention time.

Detention time and sunlight photooxidation are the two major influences in effective disinfection. Provided that sunlight intensity is adequate, detention time becomes the major factor. Where sunlight intensity is reduced below optimum levels, detention time may need to be increased to achieve the desired level of disinfection.

Virus destruction can only be accomplished on high quality effluent or by long detention times in ponds, eg. in excess of 14 days.

The World Health Organisation (Mara & Cairncross, 1989) report that a number of lagoons in series are more effective than single large lagoons due to the minimising of short circuiting.

10.2 Practicality

Ponds are the simplest of all disinfection methods, provided that the land is available and the detention times are incorporated in the design. The processes are all biological, and as such are more difficult to control, although it is considered that there is no need to control such a system. It controls itself through transition from growth of one species or type of organism to growth of the predator of these organisms, with changing dominant species. Such an ecological system may cause some problems with excessive growths of undesirable organisms such as blue green algae if conditions are conducive to such organisms becoming dominant.

Deposition of solids in lagoons is a problem, when not allowed for. These deposits can cause the lagoons to malfunction due to short circuiting. Adequate volumes should be allowed in design to cater for these deposits, or the lagoons should be designed for ease of cleaning or desludging with minimum down time.

10.3 Reliability

Provided lagoons are designed correctly, short circuiting should be avoided and detention time should be assured. This is the major reliability factor for effective disinfection. Baffles have been used in the past for ensuring that short circuiting is minimised, and recent research has evaluated the performance of over and under baffles. These have been observed to be very effective.

10.4 Adverse effects

The change in dominant species from bacteria through protozoa to algae means that algae are likely to be present in wastewater being discharged or reused from lagoons. This creates a problem of discharge of algae to marine environments where they subsequently die and cause a significant depletion of oxygen in the receiving water due to high BOD levels as the algae decompose. For reuse, the wastewater may need to be screened to allow pumping as algae have been observed as a major cause of blockages in irrigation lines.

10.5 Costs

Land purchase	site specific
Lagoon construction	\$5 - 10 / m^3 depending on the soil suitability
Pumps (if required)	as per suppliers quote

Section 11 summarises capital and operating cost estimates for each of the disinfection methods.

11. COST COMPARISONS

Each site will need to be assessed individually for equipment required and the technical skills of local labour, and thus for actual capital and operating costs.

The following cost comparisons have been developed as a guide. Some costs have been determined in studies performed for the Public Works Department in New South Wales (Scott Harris, Personal Communication) and for Barwon Water (formerly Geelong & Districts Water Board, Gwyn Williams, Personal Communication). Due to the difficulty in obtaining cost comparisons, these sources plus costs for membrane microfiltration (Rhett Butler, Memtec Limited, Personal Communication) have been used to prepare the following tables and figures.

The comparisons presented relate to equivalent population and assume 240 L/p/day as an equivalent population (e.p.) volume of effluent to be disinfected. Operating costs have been expressed as cents/kL effluent disinfected to compare options and also to show economies of scale where they exist. The source of some costs may have been based on flat rate cents/kL limiting this analysis (see operating costs for ozone). These are summarised in Figure 2.

The capital costs prepared for the Public Works Department in NSW allow for all equipment required for adequate disinfection to be achieved under three (3) times Average Dry Weather Flow (ADWF) conditions. The costs also include associated buildings and civil works and automatic dose control of chemicals. Capital costs of membrane microfiltration have been supplied by Memtec Ltd (Rhett Butler, Personal communication) and do not include costs for prescreening. These are summarised in Figure 3.

Operating costs should also incorporate costs of monitoring the disinfection process. This may involve the types of analyses listed in Table 8.

FIGURE 2 OPERATING COSTS FOR DISINFECTION OPTIONS

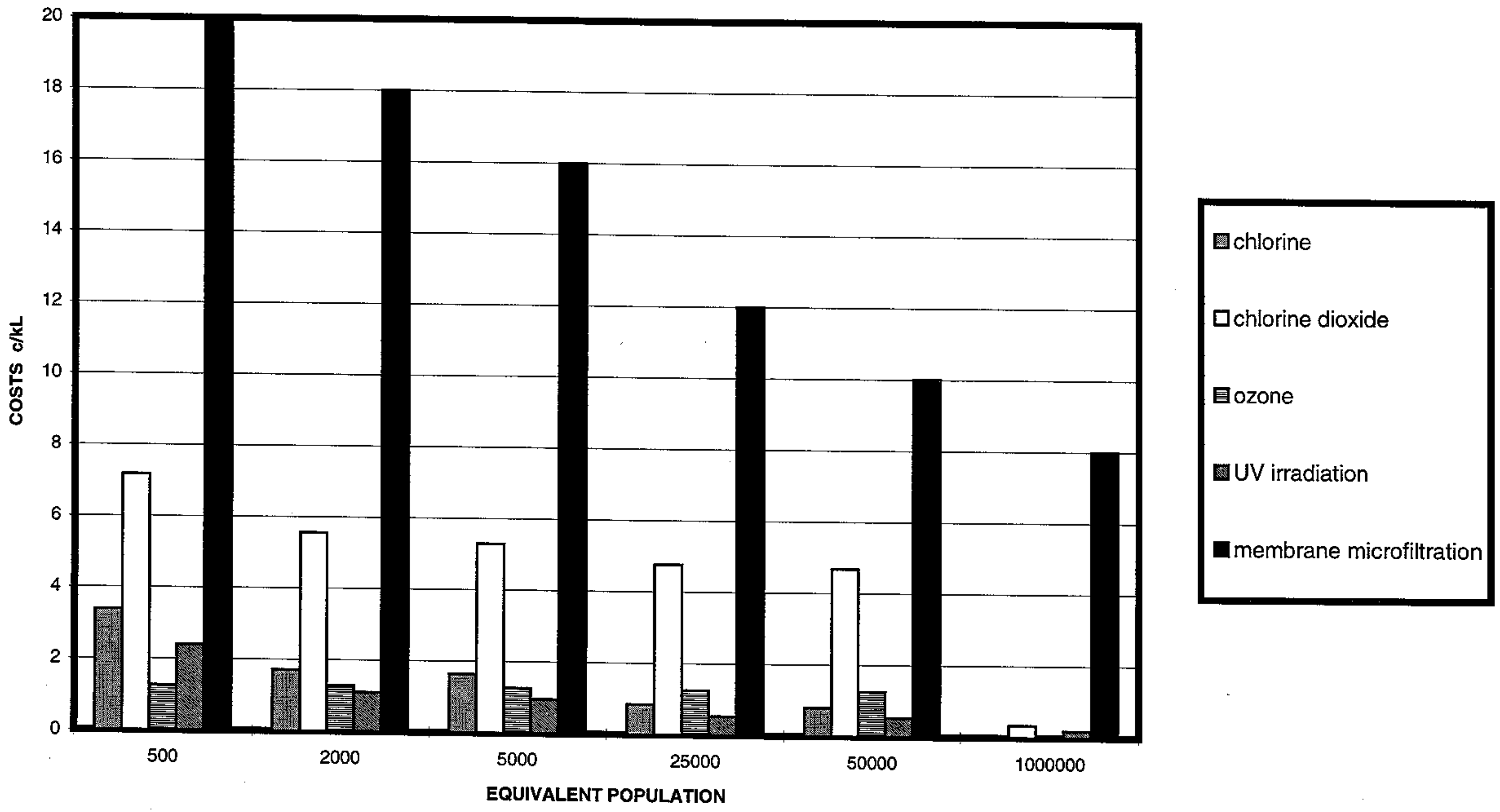

FIGURE 3 CAPITAL COSTS FOR DISINFECTION OPTIONS

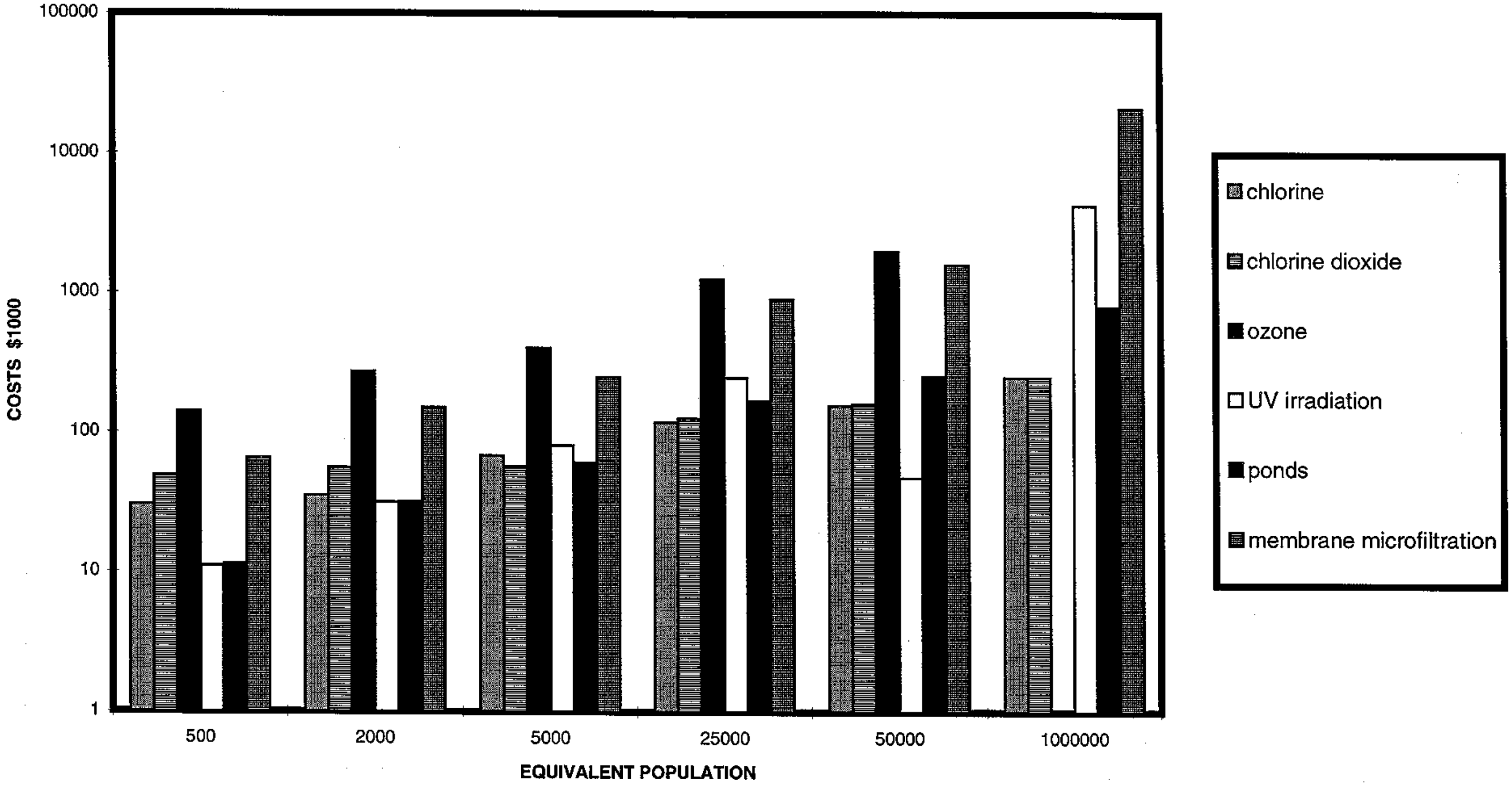

TABLE 8

APPROXIMATE COSTS FOR ANALYSIS

ANALYSIS	ANALYTE	COST $
Nutrients	Ammonia Ox-N TKN Total P Soluble P	Range between 10 and 40 each
Physical characteristics	Suspended solids Turbidity UV Transmission Colour	Range between 10 and 20 each
Chemical	pH COD BOD TDS (from EC) Alkalinity Sulfate Hardness Sodium absorption ratio Aluminium Chlorine demand	Range between 5 and 60 each
Microbiological (5 samples per sampling episode as per ARMCANZ/ ANZECC/NHMRC guidelines, still in draft form. Numbers of other samples to be determined by method requirements.)	Heterotrophic Plate Count Total coliforms Thermotolerant coliforms Faecal streptococci enumeration plus Sample Preparation	Range between 40 and 250 for each set of 5 samples per sampling episode
	Enterovirus enumeration	500 approx each
	Bacteriophage test single plate analysis	30 approx each
	Protozoa - (Giardia or Cryptosporidium)	500 first sample then 200 each
	Helminths	200
Other	Particle size analysis	50

12. DESIRABLE EFFLUENT QUALITY FOR DISINFECTION

Table 9 summarises the desirable effluent quality for each disinfection option where such information is available.

Where any criteria are outside those recommended, the disinfection option is unlikely to be effective due to interferences in the disinfection process. It is recommended in these cases that additional treatment prior to disinfection is performed or an alternative disinfection method be used.

Pilot studies should be conducted prior to choosing a disinfection method as each effluent has its specific combination of characteristics which need to be considered.

TABLE 9

DESIRABLE EFFLUENT QUALITY FOR DISINFECTION

	Chlorine	**UV**	**Ozone**	**Chlorine dioxide**	**Membrane microfiltration**	**Ponds**
Degree of treatment	Secondary (bacteria only) filtered for parasites and/or viruses	Filtered nitrified	Filtered nitrified	Secondary	Secondary plus pre-screening	Secondary
BOD mg/L	< 20	< 20	< 20	< 20	NA	NA
SS mg/L	< 20	< 20 ideally < 10	10 - 15	< 20	NA	NA
COD mg/L	No figures available	< 50 ideally < 30	< 50 ideally < 30	No figures available	NA	NA
TOC mg/L	No figures available	No figures available, however humic substances absorb UV radiation, so these should be minimised	No figures available	No figures available, however organic compounds react rapidly with chlorine dioxide, so these should be minimised	NA	NA
Turbidity NTU	< 10	< 5	< 5	< 10	NA	NA
UV transmission %	NA	> 60	NA	NA	NA	NA
Dose	Derived from bench scale studies with effluent, C.t values, specific organism to be inactivated	Minimum actual dose 30 to 40 mW.s/cm^2 to achieve viral inactivation	Derived from pilot scale studies and measurement of ozone in off gases	Derived from bench scale studies with effluent, C.t values, specific organism to be inactivated	NA	NA

TABLE 9 (CONT)

	Chlorine	**UV**	**Ozone**	**Chlorine dioxide**	**Membrane microfiltration**	**Ponds**
Ammonia mg/L	Essential if monochloramine formation is required	< 1	< 1	NA	NA	NA
Nitrite mg/L	Minimal	NA	< 0.15	< 0.1	NA	NA
Nitrate mg/L	NA	Maximised	Maximised	NA	NA	NA
pH	6.5 - 8.0	NA	6.0 - 8.0	6.0 - 9.0	Neutral	Neutral to maintain biological growth conditions
Temperature	Rate of reactions dependent on T	Lamp output affected by increases in T	Ozone solubility decreases with increase in T (dependent on vapour pressure)	Rate of reactions dependent on T	NA	Longer detention times required in cooler climate due to lower sunlight intensity
Time for reaction or detention time (minutes)	30 - 60, for bacteria, up to 120 for viruses	Dependent on flow rates, usually about 10 - 20 seconds. Flows should be greater than 100L/min for teflon tube (89 mm diam), optimum 200 L/min	10 - 30	5 - 30	Dependent on flow rates	10 - 20 days for pathogens > 21 days for Taenia saginata (parasite causing beef measles)

NA = Not Applicable

CONCLUSIONS

1. When determining disinfection needs for wastewater treatment plant effluent, it is the pathogens present in the effluent that need to be inactivated. Care should be taken in using bacterial indicators such as *E. coli* or thermotolerant coliforms to design and control disinfection processes as these indicator organisms are known to be more susceptible to some disinfection processes than are pathogens. The effectiveness of disinfection methods should not relate to removal of indicator organisms alone.

2. Research has shown that there are large variations in pathogen removal through processes in wastewater treatment plants. Literature values should not be used to assess pathogen removal. Site specific data should always be obtained.

3. Disinfection is recommended where the following is likely to occur

    - Cross connections of reclaimed water to the potable water supply
    - Ingestion of reclaimed water from an impoundment
    - Swimming in water bodies receiving effluent as a sole or partial source of water
    - Boating, angling, wading, secondary contact recreation in water bodies receiving effluent as a sole or partial source of water
    - Inhalation of sprayed effluent
    - Contamination of hands with effluent and subsequent ingestion
    - Ingestion of food grown using effluent as an irrigation water
    - Ingestion of food grown in the aquatic environment to which effluent has been discharged

4. To optimise disinfection, it is advisable to reduce suspended solids levels to the most practicably achievable levels for the system, to reduce organic compounds entering the wastewater treatment plant as these are difficult to remove in secondary treatment plants without advanced treatment and to reduce inorganic compounds that interfere with the disinfection method.

5. Chlorine has been the disinfection method most widely used in Australia to date and is familiar to most employees in the wastewater industry. However its effectiveness for inactivation of viruses, helminths and protozoa in wastewater will vary depending on the conditions under which disinfection is being practised. Therefore where viruses, helminths or protozoa are to be inactivated, chlorine must only be used under the right conditions, viz; optimum pH, good process control on chlorine residuals, sufficiently long chlorine contact time, and low levels of ammonia and suspended solids. Also chlorine can have an adverse effect on the aquatic environment. Free and combined chlorine residuals at low levels are toxic to aquatic organisms including fish and macroinvertebrates.

6. Ultraviolet irradiation which is gaining popularity in Australia is effective for disinfection of bacteria and viruses, but has yet to be fully assessed for inactivation of protozoa and helminths. Effluent with suspended solids greater than 20 mg/L, which relates to a turbidity of approximately 10 NTU, should not be treated with UV irradiation as organisms occluded by suspended solids will not be inactivated by UV irradiation. Reliability is extremely important for effective UV irradiation as there is no residual chemical to assure post contact chamber disinfection. This has been raised as a major concern by authorities considering UV irradiation as a disinfection method. The main environmental effects from using UV irradiation are the energy requirements and the disposal of cleaning solutions.

7. Chlorine dioxide has been sparingly used in Australia as a substitute for chlorine for disinfection of wastewater even though it is more effective. The system is complex, requires constant supervision, and is expensive to operate due to high chemical costs.

8. The use of ozone for disinfection of wastewater has not been practised in Australia to date mainly because of its complexity and the cost of ozone resistant materials. There is little information regarding capital or operating costs, however ozone is known to be the most effective of the chemical disinfectants.

9. Membrane microfiltration is gaining popularity in Australia. It is relatively complex, requiring a high degree of maintenance and system control to provide continuous disinfection. There are a number of waste streams including caustic solutions associated with microfiltration that need to be disposed of or recycled.

10. Ponds or lagoons have been traditionally used in Australia and remain the disinfection method of choice by some authorities. However they have generally not been purposely designed for disinfection. As detention time is the main factor affecting effective disinfection, short circuiting should be minimised. It is recommended that a series of ponds be used rather than a single large pond. Adverse effects associated with ponds relate to the growth of algae in the ponds and the subsequent depletion of oxygen when the pond effluent is disposed into the freshwater or marine environment due to the high biochemical oxygen demand (BOD) as the algae decompose in the receiving environment.

11. There are a number of general characteristics that are desirable for effluent that is to be disinfected. Of note is that for all chemical methods, and for UV irradiation, the BOD levels should be less than 20 mg/L. Suspended solids should be below 20 mg/L for these with ideal levels for UV irradiation below 10 mg/L. When using UV irradiation or ozone for disinfection, turbidity of the effluent should be less than 5 NTU. The UV transmission of the effluent should be greater than 60 %. In general variation in pH between 6.0 and 8.0 does not adversely impact on the disinfection processes discussed here.

RECOMMENDATIONS

1. The effectiveness of disinfection methods in inactivating helminths and protozoa, particularly *Giardia and Cryptosporidium,* needs further investigation.

2. Control systems are essential in all disinfection processes. New technology is continually being developed that allows processes to be monitored more accurately. The wastewater industry should be encouraging the research and development of new technologies in the disinfection monitoring process.

3. The pressure of reusing effluent as a means of conserving water resources will lead to increased emphasis on disinfection effectiveness and reliability. Viruses and protozoa should be used as indicators for assessing effectiveness of disinfection in these situations where practical. Quality assurance should be incorporated in the disinfection process to ensure reliability.

4. Potential adverse environmental and human health effects should receive greater attention both when selecting the method of disinfection and operationally.

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The first draft was ably reviewed by the following persons:

Mr Alan Maus	Scientific Officer Headworks and Treatment, WAWA and other colleagues at WAWA
Mr Keith Barr	A/Supervising Engineer Processing, Brisbane City Council and other colleagues at BCC
Mr Scott Harris	Process R & D Manager, NSW Public Works Dept.
Mr Adrian Farrant	On secondment to NSW EPA

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APPENDIX I

DETAILS OF WORKSHOPS AND PARTICIPANTS

BRISBANE WORKSHOP

DATE: Monday 14 February 1994
LOCATION: Brisbane City Council
PARTICIPANTS:

Mr Bob Craswell	Manager Pollution Control, Dept of Environment and Heritage
Dr Ross Sadler	Senior Technical Advisory Officer, Queensland Health Dept
Mr Keith Barr	A/Supervising Engineer Processing, Brisbane City Council
Mr Harry Ferguson	Supervising Microbiologist, Brisbane City Council
Mr Mark Pascoe	Officer-in-Charge, Luggage Point WWTP, Brisbane City Council
Dr Mube Nalbantoglu	Contract Engineer, Brisbane City Council
Mr Michael Lever	Chemist-in-Charge, Water Treatment, Brisbane City Council
Ms Anne Woolley	Senior Scientist, DPI Water Resources
Mr Richard Steidl	Engineer, DPI Water Resources
Mr John Bowden	Senior Microbiologist, Gold Coast City Council
Mr Graham Logan	Senior Engineer, Gold Coast City Council

SYDNEY WORKSHOP

WHEN: Wednesday 16 February 1994
WHERE: Water Board, Sydney
PARTICIPANTS:

Ms Cathy Cole	Manager Wastewater Treatment, Hunter Water Corporation
Mr Geoff Noonan	Manager - Waters and Catchments Policy, NSW EPA
Mr Adrian Ridgley	A/Manager, Technical Consultancy Group, Inland Wastewater, Water Board
Mr Ramesh Bhana	Project Manager, Water Board
Mr Ivan Lim	Facilities Planning, Water Board
Mr Geoffrey Richards	Scientific Officer, NSW Health Department
Mr Ken Barnett	Manager, Research & Development, ACTEW
Mr Scott Harris	Process -R&D Manager, Public Works Dept NSW

MELBOURNE WORKSHOP

WHEN: Friday 18 February 1994
WHERE: Melbourne Water
PARTICIPANTS:

Mr David Gregory	Process Chemist, Melbourne Water
Mr Con Vrazanis	Senior Process Engineer, Melbourne Water
Mr Grant Haylock	Process Engineer, Melbourne Water
Mr Paul Hansen	Engineer, Treatment Technology Section, Melbourne Water
Mr Bob Eden	Senior Engineer, Water Technology Unit, Vic Dept of Health & Community Services
Mr Carsten Osmers	Manager - Yarra Region, Vic EPA
Mr Gwyn Williams	Manager, Special Projects Group, Barwon Region Water Authority

Mr Peter Ashton	A/Manager, Laboratory, Barwon Region Water Authority
Mr Jamie Wood	Senior Waste Management Officer, Tas Dept of Environment & Land Management
Mr Joe Conti	Environmental Health Officer, Tas Dept of Community & Health Services
Mr Chee Liew	Deputy City Engineer, Hobart City Council
Mr Bill Piesse	Launceston City Council

ADELAIDE WORKSHOP

WHEN:	Tuesday 22 February and Thursday 3 March 1994
WHERE:	SA Water, Australis Building, Adelaide
PARTICIPANTS:	
Dr Ted Maynard	Senior Medical Consultant, SA Health Commission
Mr Bob McLennan	Manager, Professsional Services, Environment Protection Authority
Mr Phil Thomas	Senior Chemist, Wastewater Treatment, Australian Water Quality Centre
Ms Suzanne Hayes	Microbiologist, Australian Water Quality Centre
Mr Wayne Phillips	Manager, Environmental Engineering, SA Water Engineering Services
Mr Jerry Brown	Supervising Engineer, Wastewater Treatment, SA Water Engineering Services
Mr Harry Hicks	Group Manager, SA Water Operations
Mr Brian Maguire	Operations Manager, SA Water Operations

PERTH WORKSHOP

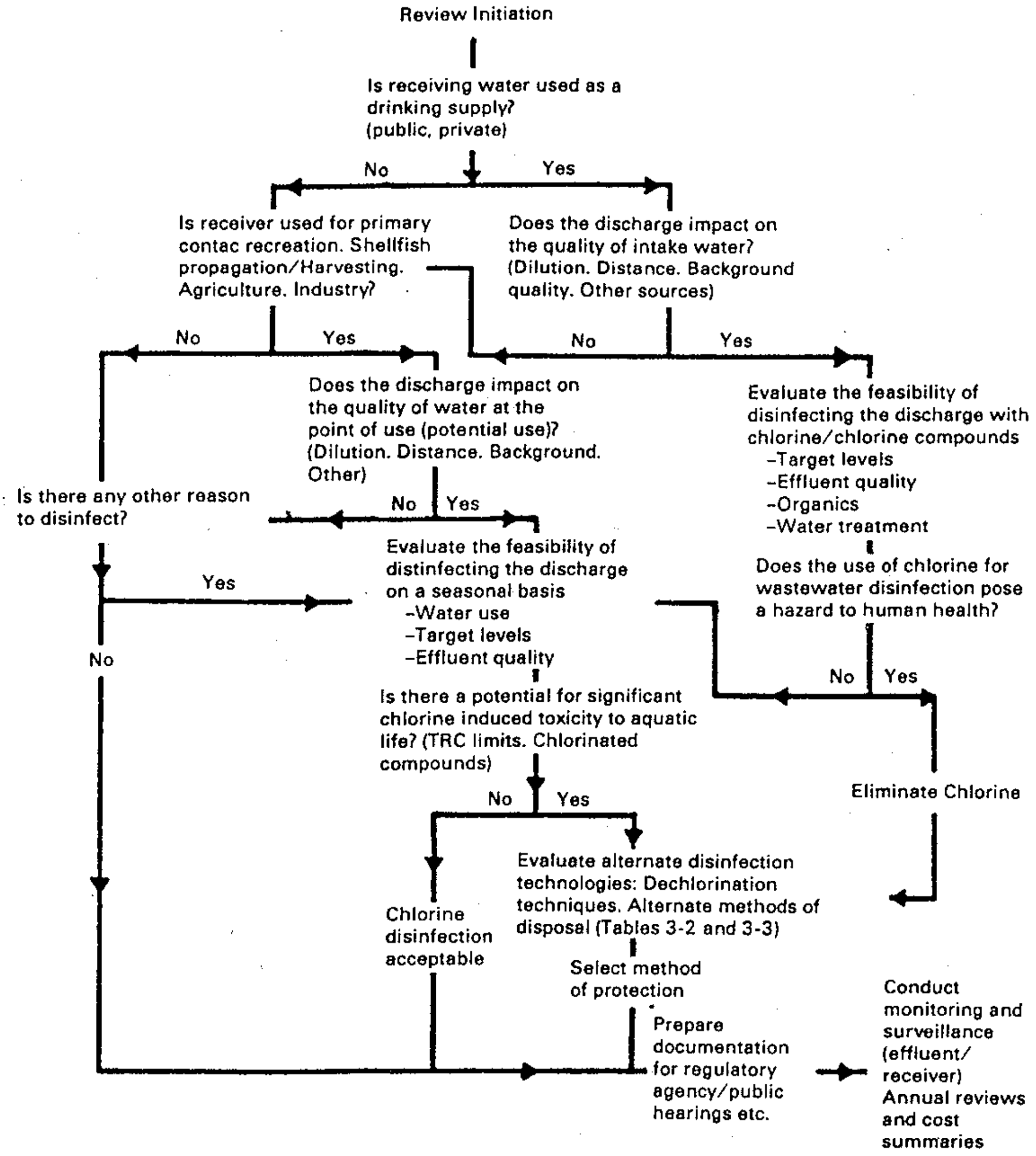
WHEN:	Friday 25 February 1994
WHERE:	Water Authority of Western Australia,Leederville
PARTICIPANTS:	
Dr Richard Lugg	Medical Consultant, Environmental Health, Health Dept of WA
Mr Barry Sanders	Regional Manager, Headworks & Treatment, WAWA
Dr Bert Mueller	Principal Engineer, Wastewater Design, WAWA
Mr Hugh Rule	Principal Engineer, Wastewater Treatment, WAWA
Mr Alan Maus	Scientific Officer, Headworks & Treatment, WAWA
Mr Bill Chapman	Operations Manager, WAWA
Mr Guy Watson	Pollution Control Division, WA EPA
Mr John Bridgham	Northam Town Council

APPENDIX II

FLOW CHART PROPOSED BY US EPA FOR DECISION MAKING FOR DISINFECTION OF SEWAGE EFFLUENT

(US EPA, 1986)

Framework for evaluating site-specific wastewater disinfection requirements.



APPENDIX III

BIBLIOGRAPHIES

CHLORINE BIBLIOGRAPHY

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