GUIDANCE FOR THE USE OF RECYCLED WATER BY INDUSTRY

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Executive Summary

With water shortage become a critical issue global the need to utilise non-potable water for non-potable use is increasing. One important route to achieve this is the use of recycled water in an industrial setting, that is to say using recycled water for applications such as cooling, boiler feed, washing and process uses. Such use can often provide benefits across the triple bottom line representing economic savings for a company while decreasing the pollution load on the environment and “freeing” water for use in domestic purposes.

This document aims to provide information on the key issues confronting the industrial water user in respect to the use of recycled water on a site. The information is both technical (corrosion processes, health issues etc.) and non-technical (public perceptions, product acceptance etc.).

Health is one of the primary concerns with people’s use of recycled water. For industrial uses (non-potable) the concern will be with biological threats rather than chemical as the latter would require large doses over an extended time period to be a significant concern. In terms of biological risk, where the water meets Victorian and Australian recycled water guidelines only the regrowth of bacteria and to a the entry of opportunistic pathogens would be a concern. This can easily be negated with the proper controls.

General controls for human health with regards to recycled water use focus on biocides and protocols. Biocides can be oxidising (halogens and their derivatives, ozone, peroxide, UV irradiation) or non-oxidising (biguanides, aldehydes, phenols and thiol oxidisers). While recycled water typically contains a high chlorine residual, where long residence times are encountered a program encompassing both classes of biocide is recommended. Protocols for protecting employees focus on preventing unintended uses by establishing procedure for use and reporting of problems. In general recommendations follow what is already outlined in the Victorian and Australian Guidelines.

Animal and livestock health should also be considered where a product will potentially be ingested by animals. The Australian Guideline approach to human health could be potentially adapted to animal use. Depending on the use this can be based around the Phase 1 Guidelines or the Phase 2 (which covers direct and indirect potable reuse). While a number of pathogens effect both animals and humans, of particular concern are *Taenia saginata* and *Taenia solium* (tape worm) which passes from humans to cattle or pigs and back and *Mycobacterium paratuberculosis*, the infection of which may take four or more years to detect. Ultimately, responsible risk assessment should be performed following to the Australian Guidelines for the protection of animals where required.

Corrosion is also a significant concern in industrial processes. In general the characteristics of water to be aware of are:

- pH (will influence the species of corrosion products and solubilities)
- Temperature (influences the rate of corrosion)
- Alkalinity (indicative of the buffering capacity of water and should be greater than 20 $mg.L^{-1}$)
- Total dissolved solids (TDS - includes ionic species; high levels can cause corrosion, also specific species can accelerate corrosion on particular metals, eg Cl^- on stainless steel and Cu^{2+} on steel)
- Conductivity (an indicator of ionic species in solution with higher conductivity increasing the potential for corrosion)

While traditionally recycled water has a higher TDS and conductivity than potable, it does not necessarily follow that it will cause greater corrosion. It is possible that the greater alkalinity and greater concentration of phosphates and natural organic matter (NOM) will help protect some metals. While corrosion management measures such as the addition of corrosion inhibitors, pH adjustment and the use of cathodic protection can help minimise corrosion affects, the requirements of individual processes are variable and need to be determined on a case-by-case basis.

Microbially influenced corrosion (MIC) occurs from the presence of microbes enhancing the corrosion processes. The process is universal with biological films forming in any quality water, however the higher level of nutrients in recycled water tends to cause concern with this water for industrial users. The mechanisms of MIC are diverse and often rely on both organic and inorganic materials to metabolise. While the presence of a biological films is enough to stimulate corrosion, specific mechanisms may be accelerated by the presence of sulphates (and related species), Fe^{2+} and Mn^{2+}. The level of these species and other nutrients (nitrates, phosphates and assimilable organic carbon) in recycled water is higher than potable, however control is achievable using disinfection. The chlorine residual of recycled water is typically higher than the potable supply, but where long residence times will cause it to deplete, the use of an oxidising biocide (such as chlorination) in conjunction with a non-oxidising biocide and a surfactant (to remove any film that forms) should provide the necessary control.

One significant non-technical concern for industrial users taking recycled water is the public's perception of the product and the company. In general this is linkied with negative perceptions of recycled water, perceived human health risks and the psychological "yuck" factor. It must be emphasised that these are perceived risks and do not necessarily have a scientific basis.

Studies in recycled water use in the past have shown that:

- Public acceptance is tied with the intimacy of use (that is the closer the use to consumption, the less acceptable it is)
- Public acceptance will decrease when a use is salient
- Public acceptance is directly related to trust in the people and organisations involved in the project
- Public acceptance may be decreasing over time (or is at least variable over time)
- Public acceptance is related to knowledge, but not wholly dependent on it

Some of these ideas also appear in previous surveys into industrial use of recycled water with the objection in making canned foods higher than facial tissues higher than electronic goods. In general products for consumption (food, beverages, pharmaceuticals, toiletries and cosmetics) would be considered high risk for backlash when recycled water is used anywhere in the manufacturing process. Other industries may be at lesser risk, but should attempt to identify consumer concerns for their product prior to use. As was noted above trust is also key and well-known brand names may have some protection.

Employee perceptions are also worthy of consideration due to the potential problems with industrial action and loss of productivity entailed in not addressing concerns. In general, active and open dialogue and education will help reach this goal.

In terms of company image, current media attention on drought and water shortage has also focused attention of large industrial water users, attaching a negative stigma to the large use. Recycled water represents one option to decrease potable water use onsite. Recycled water use may also help a green marketing strategy. Although green marketing has been questioned since the overabundance and questionability of claims in the 1990's, current belief seems to be that companies can benefit. Studies suggest an increase in profitability and greater competitive advantage from green marketing and practises.

A review of the biological, chemical and physical water quality parameters of concern for a variety of industries identified some critical parameters which may cause health, corrosion, scaling, fouling and process issues. These are summarised in Table 1.

In application, minimum water qualities have been determined based around current international practice and known existing requirements. Table 2 summarises this data. It is important to note that recycled water quality will vary from site to site and therefore Table 2 should serve only as a guide. It is also important to remember that water can be further treated once it reaches a site to achieve the required qualities and that a lower quality water should not be immediately dismissed.

Table 1. Summary of recycled water quality parameter and potential industry impacts

Parameter	Impact				
	Health	Corrosion	Scaling	Fouling	Process
Microbiological	Y	Y	Y	Y	PD
Colour					Y
Temperature	Y	Y	Y	Y	Y
Odour (BOD/DO)	Y				Y
Turbidity		Y	Y	Y	Y
pH		Y	Y		Y
Hardness			Y		Y
Alkalinity		Y	Y		
Salinity		Y			Y
Dissolved solids		Y	Y		Y
Calcium, Mg			Y		
Metals	Y				Y
Ammonia		Y		Y	
Nitrate		Y			
Residual organics	Y			Y	
Silica			Y		
Sulphate		Y	Y		
Phosphate		Y	Y	Y	
Suspended solids				Y	Y
Fluoride			Y		
Chloride		Y			

PD – process dependent

Table 2. Fit for purpose water qualities for various end uses

Use	Treatment Level	Further Treatment Potentially Required
Cooling	Tertiary	Nitrification
Boiler	MF/RO	Demineralization
Wash - Housekeeping and Dust Suppression	Secondary	Subject to controls
	Tertiary	None
Pollution Control	Secondary	Ammonia and Phosphate reduction
Quality Control	Tertiary	Final rinse may need higher quality
Transport	Secondary	Filtration
Separation - Unimetallic	Secondary	Filtration, Flotation tests
Separation – Ore Selective	Tertiary	Flotation tests
Lubrication	Tertiary	
Fire Control	Secondary	Subject to controls
	Tertiary	
Irrigation - Restricted	Secondary	Subject to controls
Irrigation - Unrestricted	Tertiary	
Toilet Flushing	Tertiary	Aesthetic improvements
Textiles	Tertiary	Colour removal
Paper/Pulp	Tertiary	Colour removal
Electronics	MF/RO	Demineralization

Finally, any consideration of recycled water must keep in mind the current local guidelines and requirements. This report is aimed at a Melbourne audience and therefore throughout this report the Victorian and Australian Guidelines are referenced. It is important that any potential users of recycled water refer to the most current version of these guidelines that can typically be found online.

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CHAPTER 1 Introduction

Water is a current major global, national and local issue. Historic drought and unprecedented restriction levels are now substantially influencing almost all Australia's major cities. Increased population, changes in climatic conditions and the increasing price of water will also influence the use of water and there is a growing need for the identification of alternative resources in many regions of Australia. The current situation in south east Queensland where industrial water users are under 25% restrictions, acts as a potential warning to other Australian industries.

In light of current reduced water availability in Australia, it is prudent to look at ways of saving high quality water for drinking and domestic purposes. The potential for substitution of non-potable water for potable water currently used in industry is therefore of great importance. One significant option is the use of treated municipal effluent. It is possible for wastewater to be treated to a high quality, in the case of microfiltration/reverse osmosis (MF/RO) treatment this is water will contain lower concentrations of contaminants than regular mains water. However, this water is better suited to non-potable purposes due to concerns regarding the impacts on human health and the need to remineralise RO treated water to make it palatable. Using this highly treated water for non potable applications overcomes the potential public acceptance issues with direct and indirect reuse.

The focus of this document is on replacement of potable water by recycled water, however decisions should not be limited to this substitution. Potable water supplies can also be protected by replacing river water used industrial applications and significant environmental protection can be achieved by reducing ground water use in areas where over-abstraction occurs. Even substituting recycled water for once-through sea water cooling could prove beneficial by reducing pollution loads from the return stream. The majority of discussion uses potable water as the baseline. This is the highest quality water in just about all situations and river and ground water substitution could be significantly easier due to potentially higher levels of dissolved salts and organic matter. Such substitutions should always be kept in mind.

This work is part of a Smart Water funded project with the aim to provide guidance and a decision support framework for potential users of recycled water. The use of recycled water in industry in Australia, though practised, is not particularly well established and is not common in Melbourne despite the city containing large industrial areas. Part of the problem is unaddressed industry concerns with the use of water on their site. Though guidelines for the use of recycled water have been developed in Victoria [1] and Australia [2], these tend to focus on potential health effects and do not necessarily reflect the requirements of industrial uses. Consequently, in industrial applications situations may arise where the wrong quality water is recommended for a specific task. One such example is the current Victorian guidelines that state that Class C water is suitable for boilers. However, this review has shown that a much higher quality is required from a technical point of view. One of the aims of this study is to determine what quality of water is required for specific end uses in industry and what additional treatment is required. Ultimately the project aims to define fit for purpose water qualities rather than recommend the highest possible quality as is typically seen.

To help provide support to industrial decision makers it is also important to have answers for any potential concerns with the use of recycled water on a site. This will be partly technical in nature, but will also need to consider social and environmental concerns such as product acceptance and perceived and real health risks. Figure 1.1 shows a decision matrix developed at the beginning of this study that was aimed to determine the main issues for industrial recycled water users. The matrix aims to the components of an industrial process that will be affected if changes to water quality are made. This separates all industrial operations into three components: inputs (blue), processes (green) and outputs (yellow) and refers only to the industrial process operations. For example, the term "reactants" only applies to the reactants or starting products for the process and does not refer to water treatment compounds or residuals from the water treatment process. The issues raised in this matrix will be addressed in the guidance and decision support framework wherever practical.

The issues and concerns can be addressed through the use of case studies which will provide examples to industries so that they do not feel they are trying to pioneer a new trend, but will be entering into a field that has been researched and applied. The use of case studies also highlights the benefits and pitfalls that have previously been encountered.

It is hoped the final product of this report will provide the backbone of an information package that can be tailored to individual needs based around independent subchapters. This information package would be available to decision makers to assist with the computerised decision support framework.

Important Notes.

The references to Victorian and Australian Recycled Water Guidelines were current at the time of writing, but they are always subject to review. Any decision maker should ensure the most current guidelines and legislation will be followed for any proposed project. In particular at the time of writing, the Victorian Guidelines are under review with the aim of producing a risk assessment based approach similar to the Australian guidelines developed in 2006. As such, this document refers to the Victorian classification system only occasionally and instead adopts the generic, secondary/tertiary/MF/RO labelling of water qualities. These qualities refer to the level of treatment of the recycled water and serves as a rough guide to its quality. They are not necessarily a guide to the health implications which would need to be assessed within the framework of the Australian Guidelines in order for the necessary barriers to be put in place. It should also be noted that the quality of water will vary for different sewage treatment plants. While the water qualities have been assessed generally, it should serve only as a guide.

Format of the Report

Chapter 2 of this report discusses the general technical and non-technical issues with the use of recycled water on industrial sites. This addresses concerns such as employee and public health, acceptance of water and products, corrosion related problems and company image. This provides the necessary background to assist the decision-making process.

	$$	Quality	Wellbeing/ Health
Reactants	Will less/more be required?	Will higher quality be required?	
Water	Will cost increase or decrease?	Will the quality be acceptable to the process? Will further treatment be required?	Will supply be consistent? What is the risk of cross-connection?
Energy	Will demand increase or decrease?	Will on site production be required?	
Staff/ Employees	Will there be pressure for increased wages and benefits?	Will training be required for users? Will specialists need to be hired?	What are the potential health effects and risks? What level of exposure will workers have?
Plant/ Equipment	Will maintenance costs increase? Will new plant be required? What will the retrofitting costs be?	Will higher quality materials be required in plant/equipment construction?	What is the risk of corrosion, biocorrosion, scaling, fouling etc?
Product	Will the price of the product be effected?	Will product quality be effected?	Are the runs guaranteed to produce usable product? Will there be consumer backlash against the product?
Trade Waste	Will there be an increase in contaminant levels and what are the risk of fines?	Will there be more or less contaminants?	Will pipework need upgrading or greater maintenance?
Scheduled Waste	Risk of fines? Increased costs of removal?	Will the nature of the waste change?	How will the waste impact the surroundings (smells etc)?
Company Image	Will the green label increase sales? Will it be marketable? Possible incentives?	Will there be a greater brand respect?	Will this help meet company goals or mission statement? Eg “Grow me the Money” recognition scheme.

Figure 1.1. Decision matrix outlining what should issues should be considered when taking recycled water.

Chapter 3 assesses individual water uses. As part of the preliminary development of this project, eight main water uses were identified: Cooling, boiler feed, washing, transport and separations, fire control, external uses (irrigation), toilet flushing and process uses. The last of these is too large a category to consider in this document and should be assessed on a case-by-case basis, although a discussion of some industries has been performed in Section 3.5 were the use of recycled water is established. A detailed discussion of each water use is included in the report. These Sections have been designed as stand alone documents allowing the user to pick the relevant water uses under consideration to gain the knowledge required to make a decision.

The final section of the report, Chapter 4, contains a number of case studies. These case studies are focused on recycled water use, but also include some examples of demand management and cleaner production works carried out in Australian industries. These highlight the benefits the users have seen in taking recycled water as well as stating potential pitfalls, and can be used as a guide of water qualities that are typically used.

CHAPTER 2 General Considerations

The following chapter is a discussion of the general considerations with recycled water use. These are the issues, concerns and benefits from using recycled water regardless of the end use. It contains information from a quality point of view as well as a social and environmental point of view. The aim is to address the typical concerns held by decision makers and to highlight any real problems that may exist.

2.1 General Benefits of Recycled Water

2.1.1 Reliability of Supply

Australia is a dry continent. Since 1860 there have been 10 major droughts in Australia [3]. The latest drought has yet to break, despite recent flooding in parts of Victoria and New South Wales, and is considered by some to be the result of climate change. Water reserves have been reaching low levels in just about all of Australia's major cities. The drought has also been underpinned by the apparent changes in climatic conditions in Australia that have shown that precipitation has been decreasing [4]. The impact on businesses and industry will only increase as water shortage increases.

In urban areas, water restrictions may be used to force mandatory reductions in potable water use. This was the case in Gladstone in the early 1990's when industries were forced to make 25% reductions in their potable water use and were faced in 50% rationing before rains came [5]. The situation in South East Queensland under the current drought is equally damaging with Level 5 restrictions currently imposing a 25% water restriction on industries [6]. The Level 6 Restriction Guidelines have been drafted after rainfall failed to significantly improve the regional outlook in 2007. One of the main changes to industry under these restrictions is a focus on cooling tower efficiency [7]. While there has been some rain this winter in the Melbourne region adding to storages, there is only slightly more water than this time last summer (2006/07). This suggests that tighter restrictions could be on the horizon for the greater Melbourne region.

Similar situations are seen in rural areas, where industrial users compete with agricultural users for access to water. Concerns in the media have been with the potential impacts on the power industry with decreasing water availability and entitlements. This could be significantly damaging to urban industry if electricity supplies become disrupted.

Recycled water represents a reliable water supply even in time of drought. Recycled water systems are generally exempt from water restrictions. The use of recycled water also acts as positive publicity for companies when large water users are "outed" by the media. It should be noted that during drought the increase in water conservation across the catchment and the loss of rainwater that would normally enter the sewage system means that some volume is lost, however, this decline is rarely as significant as it is for potable and river water. Like other water sources, wastewater quality may also be impacted drought with TDS rising as a result of contamination, however this is not always the case [8].

In addition to the water saving benefit of wastewater recycling there are also the potential benefits of reduced disposal costs, reduced wastewater discharges to the receiving environment and a reliable continuous supply. There are also the costs and requirements of additional treatment and disposal of treatment by-products to be considered. All these factors should also be considered when assessing the feasibility of industry use of recycled water.

2.1.2 Environmental Benefits

The primary environmental benefit to using recycled water is the decrease in the pollution load on waterways by diverting treated wastewater. In the greater Melbourne region this is typically in the Port Phillip Bay and Bass Strait regions although there are some treatment plants that discharge to local river systems. The reductions can help to reduce the effect of algal blooms and bacterial populations in these waterways as well as contributing to an improvement in the aesthetic quality of the water

A secondary benefit is the potential use of water saved to go towards environmental flows on dammed rivers such as the Thomson and Yarra Rivers in Melbourne and the Barwon River in Geelong. If such a situation is possible increasing water flows will reduce pollutant levels via dilution as well as improving ecological outcomes in river systems.

2.1.3 Social Benefits

The main visible benefit of use recycled water instead of potable water is the increase in potable water available for public use. Most will focus primarily on the availability of water to drink and use around the home. It must be remembered however, that further impacts on quality of life will be seen through the release of water for recreational purposes. This will include some dams that are available for boating and jet skiing but must close when water levels are low. Where environmental flows are increased, riverside recreational activities such as fishing will be benefited.

One aspect that may be forgotten however, is the use of water on playing fields. Under current restrictions in Melbourne only 25% of playing fields may be watered using potable water. In Geelong, Bendigo, Ballarat and Wodonga playing fields may only be watered from non-potable sources. This may threaten amateur sports throughout the region and where competitions are cancelled there can be additional effects to health. Reducing the use of potable water potentially allows water for use in watering playing fields and improving quality of life for local residents.

2.1.4 Recycling in the Waste Hierarchy

The waste hierarchy (shown in Figure 2.1) is easily applicable to water use. Before considering recycling, the other components of the hierarchy should be considered. While this can help make financial savings it has the added benefit of ensuring that any contract entered into by your company does not result in the purchase of excess recycled water. This produces further savings, particularly where long-term contracts may be required. Local water providers can act as a starting point for information on some of these issues.

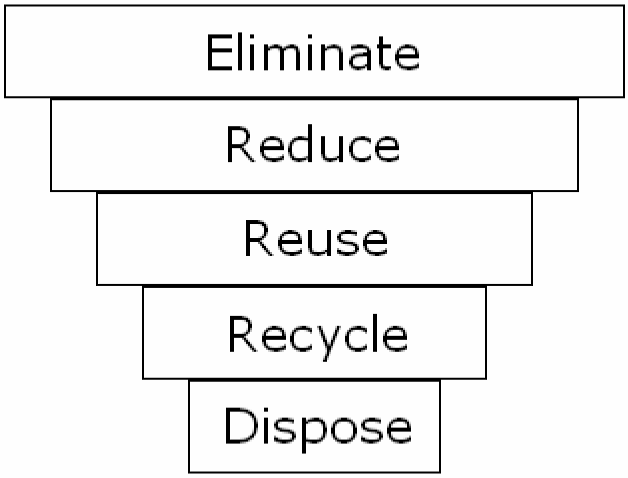


Figure 2.1. The waste hierarchy pyramid.

2.2 Water Quality

2.2.1 Introduction

The potential for reuse of treated sewage effluent in industry is a possible method of reducing the use of potable water by large industry users. In the Melbourne metropolitan area, industry uses around 27% of the total supply, with a higher percentage in the industrial west (43%) [9]. If this water were replaced with recycled wastewater, the potable water saving potential is substantial. However, the water quantity is not the only criterion appropriate in assessing the feasibility of such schemes and the quality of water, in addition to other social and environmental indicators, also needs to be incorporated in any assessment. This section of the report focuses on the quality of recycled water, the water quality requirements of industry for various end uses and the possible issues associated with replacement of potable supply with recycled water. With current supply of potable water to industry, the approach is of one high water quality for all end uses, a ‘one quality for all’. In this chapter the potential for application of a ‘fit for purpose’ concept, in which the quality of the water is matched to requirements for the end use, will also be discussed.

The quality of recycled water supplied to industry for a diverse range of end-uses needs to be well understood and assessed prior to implementing any reuse scheme. Recycled water can contain a wide variety of components, their presence dependent on each source of the recycled water and its treatment. Recycled water will contain chemicals from a wide range of sources including domestic, commercial, industrial, hospitals and the wide range of wastewater-producing institutions in the collection network. In addition, wastewater collected for recycling may also contain infiltrated groundwater from leaky collection networks and stormwater from cross connections or incorrect infrastructure installation. This potential wide range of inputs to the wastewater collection network implies a wide range of possible chemicals in recycled water.

2.2.2 Important Characteristics

Recycled water can be treated by a large variety of treatment options to provide water of a various qualities appropriate for different uses in industry. In Australia, water quality guidelines are based on a risk assessment and management approach to manage human health and environmental risks [2]. The first step of a risk assessment approach is to identify the hazards. In terms of water quality, these will be the parameters that may affect industrial processing operations in terms of corrosion, biocorrosion, scaling, staining, biofouling and other process impacts. In addition there are also impacts associated with human and environmental health. There are a wide range of parameters that are important when assessing the use of recycled water in industry. For ease of reference, the parameters can be broadly categorised into microbiological, physical and chemical as follows:

- Microbiological
    - Pathogens - Human health
    - Micro organisms causing biocorrosion
    - Micro organisms causing biofouling
- Physical
    - Colour
    - Temperature
    - Odour (Dissolved Oxygen and Biological Oxygen Demand)
    - Turbidity
- Chemical
    - pH
    - Hardness/alkalinity/salinity
    - Dissolved solids
    - Heavy metals
    - Nitrogen (nitrate and ammonia) and phosphorus
    - Residual organics
    - Silica
    - Suspended solids
    - Cations – sodium, potassium, calcium, magnesium
    - Anions – fluoride, chloride, sulphate, phosphate

There are also a range of known requirements in terms of water quality for various industry end uses and requirements are specific to each industrial process and different end uses will require different levels of treatment for recycled water. For example, where end uses have the potential for human contact (washing operations) or generation of aerosols (cooling towers) control of pathogenic micro-organisms is particularly important. Alternatively, control measures to reduce human exposure and contact may be a more cost-effective option.

2.2.3 Recycled water quality

The quality of recycled water is dependent on wastewater sources and level of treatment. Some examples of recycled water quality requirements are given in Table 2.1 and [1, 10], and at present there are different requirements for recycled water in each of the Australian states. These requirements only address human health and environmental water quality issues and do not necessarily incorporate some of the parameters that are important to wastewater reuse in industry. The more prescriptive state based guidelines are likely to be replaced by the risk management approach outlined in the National Water Recycling Guidelines [11]. This shift to performance based assessment is occurring and the Victorian guidelines for dual pipe recycled water systems [12] adopt this approach (Table 2.1)

Table 2.1. Recycled water quality guidelines for industrial uses

Parameter	Victoria Class A (contact)	Victoria Class A (dual pipe guidelines)	Victoria Class C (non contact)	Queensland Class A+ (contact)	Queensland Class C (non contact)
E.coli (cfu per 100 mL)	<10	<10	<1000	<1 (<10 95%ile)	<1000
Clostridium perfringens (per 100mL)	NG	Protozoa Median 6 log reduction from raw water	NG	< 1 (<10 95%ile)	NG
F-RNA bacteriophage (per 100mL)	NG	Viruses Median 7 log reduction from raw water	NG	< 1 (<10 95%ile)	NG
Somatic coliphage (per 100mL)	NG		NG	< 1 (<10 95%ile)	NG
Turbidity (NTU)	<2	NG	NG	<2	NG
BOD ($mg.L^{-1}$)	<10	NG	<20	20	20
Suspended solids ($mg.L^{-1}$)	< 5	NG	<30	5	30
pH	6 - 9	NG	6 – 9	6 – 8.5	6 – 8.5
Cl_2 residual ($mg.L^{-1}$)	1	NG	NG	0.2 – 0.5 (dual retic.)	NG
Total dissolved solids ($mg.L^{-1}$)	NG	NG	NG	1000	1000

NG – No guideline

Data on the quality of recycled effluent from the Melbourne Eastern Treatment Plant (ETP) is given in Table 2.2. Part of the effluent supplies the Eastern Irrigation Scheme which provides “Class A” recycled water from their new plant off Thompson Road, to the Sandhurst Club, Wedge Rd Reserve and other customers in the Cranbourne and Five Ways districts (Melbourne Water compliance report 2007).

Class A water is also produced at the Western Treatment Plant (WTP) in Melbourne for use in agriculture, open space irrigation and industry. The reported quality of the treated wastewater (Table 2.2) is different to that obtained from ETP and this may be due to the sources of wastewater, which includes a larger proportion of industrial waste compared to the primarily residential sources at ETP, and also because of the differing treatment methods.

Detailed review of literature and information collected from case studies, identifies a broader range of parameters which may affect the feasibility of recycled wastewater use in industry, compared to those given in Tables 2.1 and 2.2. These parameters will be further discussed in Section 2.2.4

Table 2.2. Melbourne Eastern (ETP) and Western (WTP) recycled water quality monitoring

Parameter	Units	EPA guidelines for industry use [13]	ETP Median [13]	ETP Maximum [13]	WTP Median [14]
Total Chlorine	$mg.L^{-1}$	*5*	5.0	5.7	-
Turbidity	NTU	*<2*	0.2	3.5	-
BOD	$mg.L^{-1}$	*<10*	0.0	5.0	<2
E.coli	$org.100mL^{-1}$	*<10*	0.0	0.0	0
SS	$mg.L^{-1}$	*<5*	1.5	14.0	5
pH	pH units	*6 - 9*	7.1	7.2	7.4
Ammonia	$mg.L^{-1}$	*no limit*	12.6	18.6	-
Nitrate	$mg.L^{-1}$	*no limit*	6.2	8.9	-
EC	$\mu s.cm^{-1}$	*no limit*	918.0	988.0	1900
Potassium	$mg.L^{-1}$	*no limit*	21.0	24.0	32.0
TDS	$mg.L^{-1}$	*500-1500*	458.0	511.0	1200
Total Nitrogen	$mg.L^{-1}$	*no limit*	21.0	21.0	21.0
Total Phosphorus	$mg.L^{-1}$	*no limit*	8.1	28.7	-
Sulphur	$mg.L^{-1}$	*no limit*	64.0	65.0	-
Viruses	FRNA	*<1*[1]	<1	<1	<2.5[2]
Sodium	$mg.L^{-1}$	*no limit*	100	110	290
Magnesium	$mg.L^{-1}$	*no limit*	9.4	11	26
Calcium	$mg.L^{-1}$	*no limit*	18.5	23	36
Potassium	$mg.L^{-1}$	*no limit*	20.5	25	32
Alkalinity	$mg.L^{-1}$	*no limit*	155	190	-
Aluminium	$mg.L^{-1}$	*5*	0.26	0.90	<0.05
Iron	$mg.L^{-1}$	*5*	0.32	0.79	0.085
True colour	PtCo	*no limit*	80	180	20
Arsenic	$mg.L^{-1}$	*0.1*	0.002	0.006	0.002
Manganese	$mg.L^{-1}$	*0.2*	0.044	0.055	0.064
Zn	$mg.L^{-1}$	*2*	*0.054*	0.18	0.017
Cadmium	$mg.L^{-1}$	*no limit*	-	-	<0.0002
Chromium	$mg.L^{-1}$	*no limit*	-	-	<0.006
Lead	$mg.L^{-1}$	*no limit*	-	-	<0.001
Mercury	$mg.L^{-1}$	*no limit*	-	-	<0.0001
Nickel	$mg.L^{-1}$	*no limit*	-	-	0.017
Chloride	$mg.L^{-1}$	*no limit*	-	-	430

1. Indicator of viruses, organisms per mL (or per 100 mL) with <10 equivalent to zero due to inaccuracies.
2. Value measured at Lagoon of recycled water prior to disinfection process with UV and Chlorine

2.2.3.1 Microbiological

The microbiological content of recycled water used in industry can impact on human health, or on the industrial process through biocorrosion and biofouling mechanisms. The concentration of pathogenic microorganisms in secondary treated wastewater is rarely monitored and the indicator organisms, Faecal coliforms, thermotolerant coliforms, *E. coli* (Table 2.2) and *F. entercocci* are usually used. Tertiary and other advanced treatment measures are used to reduce levels of pathogens in treated wastewater to allow the water to be used for unrestricted end uses. After this level of treatment monitoring for pathogens is undertaken to ensure the treatment system is removing pathogenic organisms as required. The main concern in recycled water systems will then become regrowth, particularly of opportunistic pathogens. Although these are still not well understood, Storey and coworkers [15] have shown that sufficient residual biocide will ensure regrowth will not occur to any significant degree.

Monitoring recycled wastewater for micro organisms that cause biocorrosion and biofouling is rarely carried out and none of the case studies investigated measured any specific micro-organism species which contribute to biocorrosion and biofouling. However, the monitoring of specific pathogenic species is sometimes undertaken with one study site in Queensland reporting on measurements of *Legionella* [16] and another in New South Wales on Reovirus and Enterovirus [17].

Bacteria and viruses in recycled water may be resistant to disinfection processes due to shielding from larger particles [18, 19] and so other quality parameters, such as suspended solids, are important in assessing microbiological quality.

2.2.3.2 Physical

The colour of recycled wastewater can be in issue for use in industrial applications, specifically when used as process water as the colour can impact the quality of the product i.e. paper production (see the Mondi Paper case study in Chapter 4). If the colour is organic in origin this may promote microbiological growth and biocorrosion. Colour may also affect the user perception of recycled water. This is likely to be more of an issue in residential and higher contact end uses.

Temperature has a direct impact on corrosion rates, higher temperature leading to increased corrosion. Temperature also affects the solubility of recycled water components and will influence the rate of microbiological activity. Recycled water from large scale schemes, will be relatively constant in temperature, depending on storage and retention times in the treatment train.

Odour can be caused by sulphate compounds which are subject to anaerobic conditions, forming H_2S. This may be an issue in industrial processes where water is stored for a long period of time, allowing anaerobic conditions to occur. The development of anaerobic conditions will be related to the microbiological activity, the concentration of biological organic matter (usually measured by BOD) and the dissolved oxygen (DO) content of the water. Microbiological activity due to high BOD will lead to low DO and anaerobic conditions.

Recycled water turbidity gives an indication of the clarity of the treated water and is also correlated in most circumstances to suspended solids concentration. Turbidity alone is not necessarily a good indicator of impact on industrial processes and operations as information on the cause of turbidity is required. For example, if turbidity is related to high inorganic content then issues of fouling and scaling are important. However, if related to organic content then the issues of biofouling and biocorrosion are more relevant.

Suspended solids are those greater than 0.45 µm and can be inert inorganic material, organic material or a combination of both. Suspended solids in recycled water can be deposited on surfaces in the process or foul filtration media, the former also providing a 'seed' for microbiological growth. As with turbidity the nature of the suspended solids, organic or inorganic, is important in assessing the potential impact on industrial processes.

2.2.3.3 Chemical

pH is an important parameter in most water based industrial processes as it can affect the rate of chemical reaction, the solubility of constituents and can impact corrosion and scaling. Alkalinity and acidity are related to pH but are fundamentally different. Alkalinity is a measurement of water's ability to neutralize acids or a measure of the buffering capacity. Conversely acidity is a measure of the systems ability to neutralise alkalis. The pH, however, is the measurement of the concentration of hydrogen ions in water. Water can have a high pH, but a low alkalinity and be regarded as unstable. Alkalinity and acidity will affect pH stability. Alkalinity can influence the formation of metal carbonate complexes and so result in increased metal dissolution.

Water hardness, usually expressed as $mg.L^{-1}$ $CaCO_3$, is a measure of the mineral content of water, usually calcium and magnesium, but may also include iron, aluminium or manganese. Hardness is affected by pH and temperature and would impact industrial processes through scale formation. The Langelier Saturation Index (LSI) is linked to hardness and indicates the scaling tendency for a particular water, a positive index indicating a scaling tendency and negative index, non-scaling. There are a number of other indices, parameters and ratios that are used to assess the corrosivity of water and these are summarised by Asano and coworkers [20].

The salinity is important when assessing application of a wastewater stream to land. Salinity is determined by measuring the Electrical Conductivity (EC) or the total dissolved solids (TDS). EC can be used to estimate TDS. The potential detrimental effect on plants and soils of high salinity wastewaters is often measured by the Sodium Adsorption Ratio (SAR) which gives a comparative ratio of sodium, calcium and magnesium ions.

In addition to being a measure of salinity, the TDS content of a recycled wastewater can also impact industrial process performance and can affect thermal performance and corrosion. In cooling tower applications, TDS can affect the wood components of the cooling tower in both wet and dry conditions [21]. Because solids become concentrated in cooling tower water, there is little scope for using recycled wastewater as make-up unless it has a much lower conductivity than the cooling tower blow-down composition.

A recent review of domestic wastewater quality reveals there is a large array of metals which may be present in recycled wastewater [22] and different metals will have different impacts on industrial processes. The main metals that are monitored in recycled water are: aluminium, iron, manganese and zinc and the semi-metal arsenic. Aluminium and iron can form scale deposits when combined with phosphate or other anions. Aluminium, iron and manganese can also affect the operation of ion exchange resins and electrodialysis membranes, causing fouling and reduced capacity. The free zinc ion in solution is highly toxic to plants, invertebrates and some vertebrate fish. Arsenic is also a highly toxic element which combines readily with both organic and inorganic ions.

Nitrogen, in the forms of nitrate and ammonia, can have significant impacts of industrial processing. Ammonia can have significant corrosion impacts particularly with copper and copper alloy components of an industrial process [21] and may cause stress corrosion cracking in these materials. Ammonia also forms complexes with metals resulting in increased solubility and metal release. Nitrogen compounds are also required for biological growth and so may stimulate growth of biofilms. Ammonia will also interfere with the formation of free chlorine residual, forming chloramines with any free chlorine in the system.

Phosphorus compounds stimulate biological growth and combined with calcium as calcium phosphate is one of the most common forms of scale. Orthophosphate can react with copper to form copper phosphate complexes that coat pipes and equipment. Ammonia, nitrate and phosphorus concentrations of recycled water are well documented as recycled water has been used for agricultural and irrigation end uses.

Residual organics in wastewater can have a number of impacts on industrial processes. As organic compounds contain a carbon source they are a precursor to microbial growth and slime formation. They can also cause scale formation and in certain applications i.e. boilers, and can cause foaming.

Silica, SiO_2, is rarely monitored in recycled water but is an important parameter when assessing the impact on industrial processes. Silica forms scale, with the propensity for scale formation being dependent on both temperature and pH.

Sulphates can impact industrial processes by causing scaling and through corrosion of concrete structures. The presence of sulphates can lead to the formation of hydrogen sulphide, which also causes corrosion and generates odours. Sulphate can also interfere with the formation of cupric hydroxide scales, thus increasing the potential for metal release.

Chlorine and fluorine molecules and compounds in recycled water aid in corrosion and other processes. Chlorine can cause wood delignification and failure and chlorides can cause corrosion in steels and stainless steels and increased metal release due to complexation with certain metals. Chlorine is also used as a disinfectant and is usually required as a residual in recycled water to ensure minimal microbial growth. Fluoride has an affinity for iron oxide and can soften previously hard pipe scale or iron oxide in steel pipes and tanks. This softened scale can then be mobilised in the industrial process causing downstream problems and exposing the surface to further corrosion. Fluoride can also combine with calcium forming a common scaling compound. Any of the recycled water components which increase the electrical conductivity of water can increase the corrosivity of the water.

Table 2.3. Microbiological water quality requirements for international industry case studies

Case study	Reference	Bacteria	Viruses	Other
Chevron, El Segundo, USA	[23]	Non stated	Non Stated	Non Stated
Exxon Mobil, Torrance, USA	[24]	Non stated	Non stated	Non stated
ARAMCO, Riyadh, Saudi Arabia	[25]	Non stated	Non stated	Non stated
Palo Verde, Arizona, USA	[26]	Non stated	Non stated	Non stated
Chevron, Richmond, USA	[27]	Total coliforms	Non stated	Non stated
Irvine Water District, USA	[28]	Total coliforms	Non stated	Non stated
Eraring, NSW	[17]	Total Coliforms Faecal coliforms Faecal streptococci	Reovirus Enterovirus	Non stated
BP, Bulwer Island, QLD	[16]	Heterotrophic plate count	Non stated	Total Legionella count
BlueScope, Port Kembla, NSW	[29]	Coliforms	Viruses	Parasites

2.2.4 Industry water quality requirements

The requirements from industry for recycled water quality vary depending on the industry type, the unit operation or process for which the water will be used and on the location.

2.2.4.1 Microbiological

Overseas studies (USA and Saudi Arabia) rarely include the full range of microbiological parameters in industry specifications for recycled water (Table 2.3), and usually only include coliform monitoring. It is not clear if this is because these parameters are pre-specified in more general recycled water quality guidelines or if the indicator organism is sufficient for proof of quality. Australian data generally contain requirements for bacteria, viruses and sometimes protozoa and parasites. None of the case study sites reviewed required testing or monitoring for specific micro organisms causing biocorrosion or biofouling, although BP at Bulwer Island requirements include < 10 $cfu.mL^{-1}$ total Legionella count [16].

Bacteria are unlikely to survive in suspension in an ultra pure water environment as they require nutrients such as nitrogen, phosphorus and other micro nutrients and salts to maintain their viability. However, they may form biofilms in this environment.

2.2.4.2 Physical

Colour is seen as an important parameter in pulp and paper, petrochemical and coal, chemical and cement industries (Table 2.4). In the case study sites investigated, colour was not identified as a water quality requirement for cooling or boiler water but was in textile industry requirements [30, 31] and pulp and paper industry [32]. Temperature was not identified as a water quality requirement in any of the case study sites investigated. However, data from Asano and coworkers [20] state temperature requirements for boiler feed, cooling water, pulp and paper and primary metals industries.

Odour itself is rarely monitored or a requirement for any industry application, although the Rawhide Energy Station in Fort Collins does use water for recreational purposes in a lake and it is required that the water does not contain objectionable quantities of algae or odour. However, sulphate is included in water quality requirements for most industries, although data for the pulp and paper industry is not clear with the some references not including this parameter (Table 2.5) and others, such as the Mondi paper mill in Durban, South Africa, reporting sulphate levels, suggesting this parameter is important in this industry application.

Turbidity is identified as a water quality requirement for boiler feed and cooling water (Table 2.5) as it is often used as a surrogate for suspended solids content. Other industries where this parameter is a water quality requirement include the textile industry and tanning operations.

Table 2.4. Typical water quality requirements for various industrial processes

Industry	Process	Parameter												Ref
		pH	Hardness ($mg.L^{-1}$)	LSI	Turbidity ($mg.L^{-1}$)	SiO_2 ($mg.L^{-1}$)	Alkalinity ($mg.L^{-1}$)	Mn ($mg.L^{-1}$)	HCO_3 ($mg.L^{-1}$)	Ca ($mg.L^{-1}$)	Mg ($mg.L^{-1}$)	TDS ($mg.L^{-1}$)	EC ($\mu S.cm^{-1}$)	
Pulp and paper	Mechanical pulp	6-10						0.1						WPCF (1989) in [33]
	Chemical unbleached	6-10	100			50		0.5		20	12			
	Bleached	6-10	100			50		0.05		20	12			
Petrochemical and coal		6-10	100			50		0.05		20	12			WPCF (1989) in [33]
Chemical		6.2-8.3	250			50	125	0.1	128	68	19	1000		WPCF (1989) in [33]
		6 - 9	350			60	500		480	75	30	1000		[20]
Cement						35		0.5				600		WPCF (1989) in [33]
		> 3.0					1000	500	400	2000	2000	2000		[34]
Textiles	Sizing suspension		5			25		0.05				100		WPCF (1989) in [33]
	Scouring bar and dye		5			25	400	0.01				600		
Boiler water Operating pressure range	1.0 - 4.8 MPa	8.8 - 9.0				10	100	0.1	120	0	0			[35]
	4.8 - 10.3 MPa	8.2 - 10	0.0			< 0.7	40.0	0.01	48	0	0			
	10.3 - 34.4 MPa	8.8 - 9.2				0.01	0.0	#	#	#	#			
Boiler water Operating pressure range	1.0 – 1.2 MPa	8 – 10	1.0		5	10	100	0.1	120	0	0	500		[20]
	4.8 – 10.3 MPa	8.2 – 9.2	0.1		0.5	0.1	40	0.01	50	0	0	200		
	10.3 – 34.4 MPa	8.2 – 9.2	0.07		0.05	0.01	0					0.5		
Cooling water (AUS)		7 - 8 7 - 7.5[a]	140 - 180									3000	1200	[36]
Circulating cooling water with inhibitors		7 - 8.3 7 - 7.5[b]	500 1000[c]	-0			80-400					2000	1200	[36]
Freshwater makeup for recirculation			130			50	20	0.5	25	50		500		[20]
Brackish water once through			6250		100	25	115			520		35000		[20]
Cooling tower water (Marley)			800	0-1		150	100 - 500					5000		[21]
Cooling tower Once through	Brackish water	6.0-8.3	< 6250			< 25	< 115		< 140	< 420		< 35,000		[35]

Controlled by other treatment
a - for light metal alloys
b - light metals
c - with stabiliser addition
WPCF - Water Pollution Control Federation

Table 2.4 (cont). Typical water quality requirements for various industrial processes

Industry	Process	Parameter										Ref.
		Cu (mg.L^{-1})	Fe (mg.L^{-1})	Cl (mg.L^{-1})	F (mg.L^{-1})	TSS (mg.L^{-1})	Colour (Pt Co)	SO_4 (mg.L^{-1})	NO_3 (mg.L^{-1})	NO_2 (mg.L^{-1})	COD (mg.L^{-1})	
Pulp and paper	Mechanical pulp		0.3	1000			30					WPCF (1989) in [33]
	Chemical unbleached		1	200		10	30					
	Bleached		0.1	200		10	10					
Petrochemical and coal			0.1	200		10	10					WPCF (1989) in [33]
Chemical			0.1	500		5	20	100	5			WPCF (1989) in [33]
			0.1	500	5	5	20	100				[20]
Cement			2.5	250		500	6.5 - 8.5					WPCF (1989) in [33]
				360		2000		600				[34]
Textiles	Sizing suspension		0.3			5						WPCF (1989) in [33]
	Scouring bar and dye		0.1			5		250				
Boiler water Operating Pressure range	1.0 - 4.8 MPa	0.05	0.3			5						[35]
	4.8 - 10.3 MPa	0.05	0.05			0				0.7[d]	< 5	
	10.3 - 34.4 MPa	0.01	0.00			0						
Boiler water Operating pressure range	1.0 – 1.2 MPa	0.05	0.3			5					5	[20]
	4.8 – 10.3 MPa	0.05	0.05			0					0.5	
	10.3 – 34.4 MPa	0.01	0.01			0					0	
Cooling water (AUS)			0.3	300		50		500				[36]
Circulating cooling water with inhibitors			0.3	300 50[a]		50		500		200- 700		[36]
Freshwater makeup for recirculation			0.5	500	500	100		200			75	[20]
Brackish water once through					19,000	2500		2700			75	[20]
Cooling tower water (Marley)				455[b] 910[c]				800		300[e]		[21]
Cooling tower Once through	Brackish water			< 1900		< 2500		< 2700				[35]

a - for austenitic steel
b - for galvanised steel
c - for stainless steel
d - as NH_4-N
e - as nitrate

Table 2.5. Recycled water metal quality requirements for selected industrial case studies

Industry	Ref	Aluminium ($mg.L^{-1}$)	Iron ($mg.L^{-1}$)	Manganese ($mg.L^{-1}$)	Zinc ($mg.L^{-1}$)	Other
Refinery, USA	[27]	0.4	0.1	0.07	0.06	Cu, Pb, Na, K, Ma, Ca, B
Nuclear, USA	[26]					Na, Ca, Mg
Refinery, Australia	[16]	< 0.001	< 0.01			Cu, Hg
Steel, Australia	[37]	< 0.1	< 0.05	< 0.05		K, Na
Textile, USA	[31]		0.08	< 0.1	0.28	Na, Hg, Cu, Cr, Mg, Ca

2.2.4.3 Chemical

pH is an important parameter in many industry processes as it can affect the rate of reaction and chemical solubility. In addition, pH can affect the propensity for scaling or corrosion. As a result of these potential impacts, pH is a water quality requirement for the majority of industries (Table 2.4). Whilst pH requirements are not stated in Table 2.4 for the textile industry, changes in pH could affect dyeing operations and case study site data does include pH as a water quality parameter [30, 31].

Alkalinity of water will affect the pH stability and so is also included in most industries where pH water quality requirements are made. As water hardness is also linked to pH and alkalinity this parameter is also included for most industries. Increased hardness will increase scale formation and so relatively low limits are imposed in boiler applications as compared to chemical or cooling water uses.

Although silica is rarely monitored in recycled water, all industries reviewed in this report include a silica water quality parameter (Table 2.4) due to its propensity for scale formation, which is dependent on both temperature and pH. The range of silica concentrations varies for the different industries, with high pressure boiler applications requiring a high quality (0.01 $mg.L^{-1}$)

Salinity of recycled water used in industry is measured as electrical conductivity or total dissolved solids. The majority of industries use TDS rather than EC as a water quality requirement (Table 2.4) although it is usually derived from an (easier) EC measurement. This is true in other case study data for a range of industries in Australia and the USA.

Requirements for metal concentrations in recycled water varies by industry and metal. For example water quality requirement in boiler feed water for copper less than 0.05 $mg.L^{-1}$ whereas manganese requirements range between 0.01 $mg.L^{-1}$ for textiles and boiler water to 500 $mg.L^{-1}$ for cement industry. Of the metals monitored in recycled water (aluminium, arsenic, iron, manganese, zinc), arsenic does not appear in any required water quality guidelines in industry. Lead, mercury and chromium are monitored in refinery and textile applications.

Water quality requirements for some nitrogen species (nitrite, nitrate and ammonia) exist for certain industries (Table 2.4), with the chemical, petroleum and coal products industries [20] specifying nitrate levels and cooling and boiler water having nitrite specifications. Most case study industries also have a requirement for ammonia. Phosphorus is usually measured as total P, phosphate or orthophosphate (USA).

Some case study sites include total organic carbon (TOC) as a water quality parameter [23, 26] and others use biochemical oxygen demand (BOD) [24, 29] both of which will provide an indication of residual organic matter. COD is a requirement for some industry applications (boilers and cooling,Table 2.4) but will not necessarily provide a good correlation to organic content.

Required suspended solids concentrations in boilers, textiles, petrochemical and coal and pulp and paper industry are low, less than 10 $mg.L^{-1}$. Cooling water and cement industries have less stringent requirements.

Anions can impact corrosivity of a recycled wastewater and chloride water quality requirements are apparent for most industries except boiler feed. Chlorine concentrations are also specified as this acts as a residual disinfectant, reducing the potential for microbial survival and growth. Fluoride can also be included in required water qualities i.e. for chemical and cooling water (Table 2.5).

2.2.5 Benefits and issues

There are a number of challenges regarding recycled water use in industry, the primary one being matching recycled water quality with industry requirements in a 'fit-for-purpose' approach. The above review shows that water quality monitoring requirements for recycled water do not necessarily match those required by industry, as industry generally requires more detailed analysis.

Recycled water quality should also be compared to the current water that is supplied to industry as changes in water quality parameters may impact on industrial processes. This is particularly important in industries where water is recirculated such as in evaporative cooling towers or in irrigation as it could result in greater water demand. Significant differences in water quality can lead to an increased blowdown rate in cooling towers and boilers with the knock-on effect of greater chemical treatment requirements to maintain the same conditions. This can effectively eliminate any triple bottom line benefits reached by using recycled water. This was observed in the case of the Chevron petroleum refinery in Richmond, California, despite the success of other Chevron plants [38].

Table 2.6 shows the general potable water qualities in the Greater Melbourne region with the focus on industrial regions. In terms of cooling towers, the Melbourne region is considered to achieve 10 cycles of concentration as a maximum [36] (for a better understanding of cycles of concentration please see Section 3.1). Tertiary treated recycled water (Class A contact uses) typically gives five cycles of concentration leading to greater water consumption, whereas MF/RO quality water will generally give a higher number of cycles. In Melbourne, the potable water in the more industrial western suburbs is of higher dissolved solids content (Table 2.6) as the region relies on raw water in the Sugarloaf Reservoir. For this reason substitution with recycled water in this region may be more successful. However, recycled water in this region is of higher total dissolved solids concentration than the ETP and higher than the existing supply (Table 2.2 TDS WTP recycled water 1000$mg.L^{-1}$, Table 2.6 mean TDS potable water ~ 107/100 x 640 = 685 $mg.L^{-1}$) because of the higher concentration of industry in the catchment and the saline aquifer in this region. In addition to recycled water quality, the industry discharge water quality requirements also need to be included in any assessment of the feasibility of recycled water use. If use of recycled water costs the industry in terms of additional solid or liquid waste discharge, this needs to be incorporated into the overall analysis.

Table 2.6. Comparison of potable water qualities in Greater Melbourne

Parameter	Units	City West Water [39]					Yarra Valley Water [40]		South East Water [41]				Barwon Water [42]	
		General			Altona	Footscray	Tullamarine	Broadmeadows	General			Dandenong	Lovely Banks	Highton
		Min	Max	Mean	Mean	Mean	Range	Range	Min	Max	Mean	Mean	Range	Range
Free Chlorine	mg.L^{-1}	0	0.85	0.1	0.05	0.06	0.01-0.45	0.02-0.28				0.09		
Alkalinity	mg.L^{-1} as $CaCO_3$	10	13	12	11	11			12	18	15			
Aluminium	mg.L^{-1}	< 0.01	0.08	0.02	0.02	0.02			0.02	0.09	0.05		< 0.01 - 0.047	< 0.01 - 0.031
Ammonia	mg.L^{-1}								0.003	0.01	0.006			
Calcium	mg.L^{-1}	7.1	8.9	7.4	7.6	7.6			2.9	7.1	4.9			
Chloride	mg.L^{-1}	13	16	15.4	16	16			6	8	7			
Colour	Pt/Co (CWW, BW), HU (SEW)	< 2	7	2	2	2						5.9	< 1 - 20	< 1 - 19
Conductivity	uS.cm^{-1}	55	140	107	114	113			7	72	54			
Copper	mg.L^{-1}	< 0.004	0.032	0.008	< 0.004	0.015	0.004-0.140	0.011 - 0.150	0.002	0.66	0.04		0.003 - 0.17	0.004 - 0.07
Fluoride	mg.L^{-1}	0.7	1.08	0.9	0.9	0.9			0.61	1	0.88		0.07 - 0.1	0.07 - 0.09
Hardness	mg.L^{-1} as $CaCO_3$	23	29	26	27	27	11 - 18	11 - 16	12	20	16		30 - 100	30 -37
Iron	mg.L^{-1}	< 0.02	0.24	0.02	0.02	0.02	0.03 - 0.17	0.03 - 0.12				0.06		
Magnesium	mg.L^{-1}	1.6	2	1.8	1.9	1.9			0.9	1.4	1.2			
Manganese	mg.L^{-1}	< 0.01	0.03	< 0.01	< 0.01	< 0.01			0.001	0.034	0.007		< 0.002 - 0.014	< 0.002 - 0.036
Nitrate	mg.L^{-1}	0.84	1.37	1.18	1.2	1.24			0.041	0.2	0.11			
pH	units	7	9.7	7.5	7.6	7.4	7.0 - 7.4	7.0 - 7.5				7.3	7.4 - 8.7	7.1 - 8.3
Potassium	mg.L^{-1}	1	1.2	1.1	1.1	1.1			0.6	0.8	0.7			
Silica	mg.L^{-1}	5.2	6	5.6	5.7	5.6			5.5	7.7	6.6			
Sodium	mg.L^{-1}	6.7	9.3	8.2	8.9	8.3			3.9	5.6	4.7			
Sulphate	mg.L^{-1}	7	12	10.5	11	12			1	2	2			
TOC	mg.L^{-1}	1.3	1.9	1.5	1.5	1.4			1	2	1.5			
Total Phosphorus	mg.L^{-1}	< 0.003	<0.003	0.003	< 0.003	< 0.003			0.006	0.09	0.016			
TDS	mg.L^{-1}	57	70	67	69	68			24	70	47			
Turbidity	NTU	0.1	9.6	0.6	0.4	0.5	0.50-1.20	0.40-1.40				0.6	< 0.1 - 4.6	< 0.1 - 1.1

Altona/Footscray covers the main industrial regions of Altona, Laverton, Newport and Yarraville in the City West Water district.
Tullamarine/Broadmeadows covers the main industrial hub in the north of Melbourne including Coolaroo, Campbellfield and Broadmeadows.
Lovely Banks includes the Corio region of Geelong, while Highton includes Moolap and Point Henry.

2.3 Health Concerns

2.3.1 Introduction

One of the primary concerns expressed about the use of recycled water is the potential effect on human health. This comes from the perceived health risks associated with recycled water in the form of endocrine disruptors such as hormones and pharmaceuticals as well as pathogens that are commonly found in sewage. The following is a discussion of the actual health risks associated with recycled water use for non-potable purposes and ways to reduce these risks. There are two main categories of health risks that are generally associated with recycled water: chemicals of concern and pathogens. Though both are considered in the following discussion, pathogens ultimately represent the greatest risk in the industrial use of any water due to the acute nature of the risk. This risk is essentially eliminated where the Australian and Victorian guidelines are followed in the establishment and running of the project.

2.3.2 Chemicals of Concern

Chemicals of concern refer to trace elements present in recycled water either from industrial waste products or from health related excretions. There are a number of classes of compounds in the chemicals of concern category, including mutagens and carcinogens. However, the two groups that are generally discussed in recycled water are endocrine disrupting compounds (EDCs), compounds that have an effect on the hormonal balance of an organism, and pharmaceutically active compounds (PhACs), compounds derived from pharmaceuticals that take part in the body chemistry of an organism. One of the main problems with chemicals of concern is the large number of potentially harmful compounds or compounds that are currently unknown that may have an impact.

It is generally accepted that wastewater treatment processes remove amounts of these compounds [43]. Research in Australian recycled water plants has suggested the undetectable amounts in water after tertiary treatment are further reduced by the microfiltration and reverse osmosis (dual membrane filtration) processes [44]. This is evidenced by detectable quantities in the RO brine. The trace level of most compounds of concern in recycled water in general suggests there is little risk to their presence in non-potable applications [45]. The unknown nature of the compounds do, however, raise some cause for concern [46] although this is a point of contention.

For all chemical of concern to have an effect, large quantities have to be consumed on a regular basis [43]. This would require someone to ingest copious amounts of recycled water over a long time period. In an industrial environment such a situation is unlikely to occur. Therefore the risk from chemicals of concern in the industrial use of recycled water may be considered minimal.

Phytotoxins may be of concern to industrial users, though not necessarily for their effects on human health. These are compounds that are toxic to plant life and include heavy metals, pesticides and salinity. Where recycled water is being considered for landscaping this could be an issue. Like other chemicals of concern high levels of treatment will remove these compounds and the risk should be low, however it is still present.

Table 2.7. Common pathogens found in raw sewage. Adapted from [2]

Pathogen Type	Common Pathogens
Bacteria	*Salmonella* *Campylobacter* Pathogenic *Escherichia coli* *Shigella* *Yersinia* *Vibrio cholerae* Atyipal *Mycobacteria* *Legionella* spp *Staphylococcus aureus* *Pseudomonas aeruginosa*
Viruses	Enterovirus Aednovirus Rotavirus Norovirus Hepatitis A Calicivirus Astrovirus Coronavirus
Protozoa	*Cryptosporidium* *Giardia* *Naegleria fowleri* *Entamoeba histolytica*
Helminths	*Taenia* (tapeworm) *Taenia saginata* (beef measles) *Ascaris* (round worm) *Trichuris* (whipworm)

2.3.3 Pathogens

Pathogens are biological agents that cause illness in their host. Table 2.7 lists the more common examples of pathogens present in raw sewage. These fall largely into four main classes of pathogens: bacteria, viruses, protozoa and helminths [47]. In raw sewage these tend to be enteric pathogens (meaning they are common in the intestines of humans and therefore present in sewage), however recycled water may also contain opportunistic pathogens (meaning they take advantage of favourable breeding conditions and can be found in almost any location where conditions are right). In general, although enteric pathogens are threats to human health, their nature means that their source is well known and they can be easier to control. Opportunistic pathogens on the other hand can often enter a system after disinfection techniques, via soil or air, and present a greater, unknown threat.

To determine pathogen concentrations and effects, indicator organisms and reference pathogens are used respectively. Comparison of indicator organism concentrations before and after treatment serves to act as a guide to reduction effectiveness (most commonly defined as a log reduction that is to say how many order of magnitude the concentration has decreased) across the entire class. Reference pathogens on the other hand have been established by the Australian Guidelines [2] to assess the consequences of exposure and assist in determining the appropriate level of reduction required by the treatment process.

The four classes of pathogens and their indicator and reference organisms are discussed below:

2.3.3.1 Bacteria

Bacteria are the most common pathogens. They are unicellular organisms that can breed independently of the host. Bacteria are able to reproduce in multiple host types meaning they are not exclusive to humans and can be spread through animal hosts. This means there are a number of possible vectors for the spread of bacteria. Typically quite large populations are required for infection. They are largely enteric in nature and their populations can be effectively reduced using disinfection as part of a wastewater treatment program. They can never be fully removed however, and some biocide (in the form of a chlorine residual or other chemical discussed in Section 6) must be used to ensure the population does not re-establish [43]. Some opportunistic bacteria are also a concern. These are typically of greatest importance in industrial applications due to their association with common procedures, for example *Legionella* species in cooling towers [21] and *Klebsiella* species in paper manufacturing [48].

Table 2.8 shows the typical log reductions in pathogenic species from various treatments. From this it can be seen that bacterial removal is effective with membrane filtration, reverse osmosis and biocidal techniques such as chlorination, ozonation and UV disinfection. These will focus on enteric bacteria reduction and will most likely be in place at the treatment plant providing the recycled water. However, as was previously noted, bacteria do not require a host to multiply and opportunistic bacteria may enter the water through other sources. This means that some on site precautions may be required to ensure that regrowth does not occur. For further details on this see Section 2.3.6.

The presence of bacteria in wastewaters is typically measured using faecal coliform counts or *E. coli*. The reduction of these common enteric bacteria is believed to be an effective measure of the reduction of bacteria in general. The reference pathogen for bacteria, according to the Australian guidelines, is *Campylobacter* [2]. This is due to its being the most common cause of bacterial gastroenteritis in Australia.

2.3.3.2 Viruses

Enteric viruses are the smallest of the pathogens. They are highly contagious, only requiring a small number to cause infection (10 viral particles are often enough [43]). They have a narrow host range, meaning viruses found in birds will not easily jump to humans. They are also unable to replicate outside the host. This means that disinfection processes can reduce a virus to levels below that required for an infectious dose and that the population will not re-establish. Consequently, where an effective disinfection programme is in place at the recycled water source, viruses should not pose a significant risk. This view is supported by the World Health Organisation's assessment of pathogen risks in recycled water [47]. Having said this the more significant health effects from viral infection and lower infectious doses leads to greater log reduction requirements by the Australian Guidelines [2]. This in general means that viral risks dictate the degree of treatment and disinfection required in recycled water.

Virus removal can be effective with options such as dual media filtration, reverse osmosis and ozonation (Table 2.8). As was noted previously, as long as the tolerable risk is achieved at the recycled water source, no significant risk will exist at the end use because viruses need a host to replicate.

Table 2.8. Indicative log reductions for various treatment processes. Adapted from [2]

Treatment	Indicative Log Reductions						
	E. coli	Bacterial Pathogens	Viruses	Giardia	Cryptosporidium	Clostridium perfringens	Helminths
Primary Treatment	0 - 0.5	0 - 0.5	0 - 0.1	0.5 - 1.0	0 - 0.5	0 - 0.5	0 - 2.0
Secondary Treatment	1.0 - 3.0	1.0 - 3.0	0.5 - 2.0	0.5 - 1.5	0.5 - 1.0	0.5 - 1.0	0 - 2.0
Dual Media Filtration (w/coagulation)	0 - 1.0	0 - 1.0	0.5 - 3.0	1.0 - 3.0	1.5 - 2.5	0 - 1.0	2.0 - 3.0
Membrane Filtration	3.5 - > 6.0	3.5 - > 6.0	2.5 - > 6.0	> 6.0	> 6.0	> 6.0	> 6.0
Reverse Osmosis	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0	> 6.0
Lagoon Storage	1.0 - 5.0	1.0 - 5.0	1.0 - 4.0	3.0 - 4.0	1.0 - 3.5	-	1.5 - > 3.0
Chlorination	2.0 - 6.0	2.0 - 6.0	1.0 - 3.0	0.5 - 1.5	0 - 0.5	1.0 - 2.0	0 - 1.0
Ozonation	2.0 - 6.0	2.0 - 6.0	3.0 - 6.0	-	-	0 - 0.5	-
UV light	2.0 - > 4.0	2.0 - > 4.0	> 1.0 adenovirus, > 3.0 enterovirus, hepatitis A	> 3.0	> 3.0	-	-
Wetlands (surface flow)	1.5 - 2.5	1.0	-	0.5 - 1.5	0.5 - 1.0	1.5	0 - 2.0
Wetlands (subsurface flow)	0.5 - 3.0	1.0 - 3.0	-	1.5 - 2.0	0.5 - 1.0	1.0 - 3.0	-

The presence of specific viruses in wastewater can be determined but it is expensive. A more common approach is to use faecal coliforms as an indicator of when viruses might be present and to take corrective action accordingly. This is because the test for faecal coliforms is easier, cheaper and more reliable than virus analysis. The reference pathogens as outlined in the Australian guidelines are rotavirus and adenovirus [2].

2.3.3.3 Protozoa

Protozoa are unicellular organisms, distinguished by the presence of a nucleus and outer membrane. Outside a host they exist as dormant cysts or oocysts that activate once in the right conditions in a host. The main host is man, although some can activate in other animals. The most common species are *Entamoeba histolytica*, *Giardia lamblia*, *Giardia intestinalis* and *Cryptosporidium parvum* [43]. These species cause gastrointestinal illnesses. They are highly infectious requiring as little as 10 (oo)cysts for infection to occur. In terms of their inactivation however, they are the least understood of the pathogens.

Due to their large size, filtration techniques are often best for reducing protozoa levels as indicated by Table 2.8, UV irradiation has also been found effective in inactivating (oo)cysts and is currently used for this purpose by Melbourne Water at Western Treatment Plant. Chemical disinfection (chlorination and potentially ozonation) on the other hand is less effective than with other pathogens. As with other pathogens the focus of removal is on the recycled water source.

In the past faecal coliform counts were used to determine the efficacy of removal of (oo)cysts, however research has shown that there is little correlation between coliform kills and (oo)cyst kills [49]. Cyst counts are now more commonly performed, but recent investigations have suggested that this may not be a reliable indicator as between 75 and 97% of cysts after sewage treatment are incapable of activating [50, 51]. Consequently, (oo)cyst counting will lead to a high number of false positive events. However, the large rate of (oo)cyst deaths in wastewater treatment plants means that protozoa are not considered a significant threat in recycled water [50].

As noted above (oo)cyst counts of *Giardia* or *Cryptosporidium* are typically used as an indicator for protozoa. By the Australian Guidelines the reference pathogen is *Cryptosporidium parvum* as it is less easy to remove than *Giardia* protozoa [2].

2.3.3.4 Helminths

Helminths are parasites such as hook worm, round worm and whip worm that reside in the stomach and intestines of a host. They generally have complex life cycles, requiring intermediate hosts to activate. The three previously mentioned are of greatest concern as they have no intermediate host [43]. They are classified as the greatest risk in using recycled water by the World Health Organization [47] although their occurrence and removal through filtration and detention treatment systems (see Table 2.8) limits their impact in Australian recycled waters.

Helminths are rarely tested on a regular basis in Australian recycled waters. Typically they are removed by filtration techniques or pond detention. In Victoria checks are generally performed to ensure that the treatment techniques effectively remove helminths on start up. They should not pose a significant threat to industrial applications, however they are of concern for agricultural use and details of the specific treatment processes of a site should be sought where a product could end in agricultural reuse. In terms of reference pathogen, the Australian Guidelines state that *Cryptosporidium parvum* is an appropriate measure for helminths as well as protozoa.

Table 2.9. Victorian EPA guidelines for pathogen levels in recycled water [1, 52].

Classification	Requirements
A	< 10 *E. coli* per 100 mL Viruses: 7-log reduction from raw sewage to recycled water[1] Protozoa: 6-log reduction from raw sewage to recycled water[1] *< 1 virus particle in 50 L*[2] *< 1 viable helminth egg in 1 L*[2] *< 1 protozoa in 50 L*[2]
B	< 100 cfu per 100 mL Helminth reduction for cattle grazing
C	< 1,000 cfu per 100 mL Helminth reduction for cattle grazing
D	< 10,000 cfu per 100 mL

[1]According to the Guidelines for Dual Pipe Water Recycling Schemes. This is more commonly used for the definition of Class A water in Melbourne
[2]According to the Guidelines for Use of Reclaimed Water

2.3.3.5 State and National Guidelines

The Victorian and Australian guidelines [1] focus primarily on the health effects of recycled water use and any consideration of this issue should be focused around the most current version of these guidelines.

There are some differences between the two current documents the most important being the setting of biological targets. The 2003 Victorian guidelines and associated documents [1, 52, 53] provide four classes recycled water based around biological targets. These are listed in Table 2.9. It is important to note that the virus, protozoa and helminth levels are all extremely low for Class A water. These will not reproduce outside the host and will consequently pose a minimal health risk. Bacteria on the other hand are able to reproduce and represent a very real health risk in the water. The class of water is typically related to bacterial removal and the health risks increase for Class B and C waters. These waters typically must be limited in their exposure to humans but recent laws allow for their use where significant controls are in place. Users should refer to the EPA guidelines "Supply of Recycled Water for Drought Relief" for information on controls for specific uses [53].

The 2006 Australian Guidelines (Phase 1) [2] on the other hand ask for each user to perform a quantitative risk assessment aimed at producing "fit for purpose" water. This will target a reduced potential for pathogenic infection below a tolerable risk threshold of 10^{-6} Disability Adjusted Life Years (DALYs). Overall the guidelines are designed to allow for greater flexibility in water treatment and use options. However, there is an element of complexity for an industrial user. Where a number of generalizations for residential uses are available, the guidelines state that the risk for industrial uses must be calculated on a case-by-case basis. This is particularly difficult in the case of exposure volumes and frequency of a number of items of plant, mainly aerosol-producing plant. An investigation of the literature has been unable to find any established data along these lines. Consequently, the Victorian Guidelines may provide a useful starting point prior to a more in depth assessment of quality using the Australian Guidelines.

2.3.4 Aerosols

2.3.4.1 Aerosol Formation and Risk
Anything that causes turbulent motion of water has the potential to produce an aerosol. In industry and commercial situations equipment that can cause this includes, but is not limited to:

- Cooling towers
- Dust suppression equipment
- Washing hoses and nozzles
- Wet milling and grinding equipment
- Cooling sprays
- Faucets and showerheads
- Toilets
- Fountains and water features

Aerosols represent a major route of transmission for pathogens in recycled water systems, due to both enteric and opportunistic pathogens. Bacteria entrapped in these aerosols are able to be inhaled and ingested by humans in the drift area where the bacteria then have the ability to cause infection. Where the received water meets the Victorian and Australian Guidelines, the appearance of pathogens will be due to regrowth and those that entered the system subsequent to disinfection. This is not necessarily due to the use of recycled water and is certainly not limited to it. As previously noted typically large numbers of bacteria are required for infection. For enteric pathogens these are typically not seen in recycled water. Most enteric pathogens will present only very minor risks where tertiary effluent (Victorian Class A) water is used due to their low levels. Access controls should be put in place wherever secondary effluent (Victorian Class B or Class C water) is used where there is a chance of human contact (see the current Victorian Guidelines [1] and the Australian Guidelines [2]). This is particularly important where aerosols are formed.

The most common pathogens that will cause infection through aerosols are *Legionella* and *Klebsiella* although other microbes such as poliovirus and heptatitis have also been seen in aerosols [49]. These are both opportunistic pathogens that cause respiratory infections. Their sources can vary with *Legionella* being present in numerous water sources and also able to spread through aerosols from neighbouring properties [54]. *Klebsiella* contamination is typically associated with contamination of water by dirt [48]. Importantly, they are not necessarily sourced from recycled water and are often seen in facilities using other water sources including potable water [55].

2.3.4.2 Controls
Control of pathogen spread through aerosols can be achieved in a number of ways. Reduction of aerosol formation is a possibility in some cases such as in cooling towers where drift reducers can be installed. However the main control will be using biocides. Where the correct treatment procedures are used the water should not present a risk. Typically residual chlorine content greater that 0.3 $mg.L^{-1}$ should be maintained in the water [56]. Where there is little to no stagnation in the water lines this will be provided by the water supplier. Where stagnation is unavoidable or where water is recirculated such as in cooling towers, further chlorination should be provided in the form of sodium or calcium hypochlorite or a similar oxidising biocide. It is strongly recommended that low level, continuous chlorination be used in these cases as shock chlorination can present a threat to some materials the water is likely to contact [21].

Table 2.10. Exposure reduction options and their related log reductions. Adapted from [2]

Control Measure	Effective Log Reduction
Withholding periods for irrigation of parks (1 to 4 hours)	1
Spray drift control (microsprinklers, anemometer systems, inward throwing sprinklers, etc)	1
Drip irrigation	4
Sub-surface irrigation	5 to 6
No public access during irrigation	2
No public access during irrigation and limited contact after (non-grass)	3
Buffer zones (25 to 30 metres)	1

The Australian Guidelines also specify techniques for reducing the potential risks of recycled water use in terms of limiting exposures. These are shown in Table 2.10 along with associated log reductions. They focus primarily on irrigation but can easily be extended to the use of sprays for washing and dust suppression.

Where secondary effluent (Victorian Class B or C recycled waters) are used that generate an aerosol an external environment, the Victorian guidelines outline a number of controls that should be put in place [1, 53].

2.3.5 Cross Connections

2.3.5.1 Risk of Cross Connection

Cross connections represent the other main health risk to recycled water use in industry. Though ingestion is the primary method for infection by enteric pathogens, the risk of this is low. Where cross-connection have occurred however, accidental drinking of recycled water will greatly increase the health risk. There have been three well publicised cross connection errors recently, two in the United States and one earlier in Australia. These are outlined below:

- Bangholme, Australia. On 19 March it was discovered that a kitchen in the Eastern Treatment Plant had been mistakenly connected to a recycled water pipeline [57]. The quality of this water is low, having a significant microbiological content. It does not leave the site in the condition it is in due to this content. An internal investigation by Melbourne Water identified 22 people displaying symptoms of infection including gastro-intestinal illness. The cross connection seems to have occurred through a plumbing error.
- Cary, North Carolina, USA. Four houses using recycled water (equivalent to Victorian Class A or tertiary effluent) for irrigation were cross connected in July 2007. It was discovered during a routine depressurization of the recycled water system. The standard checks, including inspection of the connections prior to the house being sold failed to pick up the mistake. The investigation suggested that the meters may have been switched after inspection.
- Chula Vista, California, USA. A business park, home to two food companies among others, was incorrectly connected to recycled water (equivalent to Victorian Class A or tertiary effluent). The situation went undetected for two years. The recycled water in the Otay district was provided as a blend until recently and the decreased water quality at the business park sparked concerns in June-July 2007 although the

situation wasn't revealed until August 2007. The two food outlets have since gone out of business due to a lack of custom. The investigations raised questions over the inspector for the site who was recently indicted on bribery charges.

What is important to note about the three cases above is that the problems centred on human error. This is something that cannot be avoided in any situation involving multiple pipelines. The University of New South Wales also suffered from a cross connection incident when the recirculated water system (used for cooling within a building) was incorrectly connected to a number of potable water taps. This risk is always present in large industrial facilities. Importantly, the risk of health impacts from a cross connection incident will be low where high quality water (Class A or better) and effective management controls are in place. Significant quantities of high quality recycled water (MF/RO or Class A) would be required before any real effect is seen [43]. Lower quality water (Class B and C) may present a health risk if consumed where appropriate biological controls have not been utilized. However, people's perception of the water is very different. In all three cases people have reported (generally retrospectively) gastrointenstinal illnesses. Though these claims may be justified, there is also a degree of paranoia that results from the discovery that the drinking water was not what the drinker believed and there is no way to confirm the problem one way or the other. (In the case of the Chula Vista cross-connection, investigation of the recycled water quality has said it meets Californian drinking water standards. This has not stopped a civil suit being filed against the Otay Water District by shop owners and customers). Consequently it is important to manage the risk of cross connection on a site effectively.

<u>2.3.5.2 Recommended approaches to cross connection prevention.</u>

Ensuring a non-potable water system is free from cross connections can be performed using a two-pronged approach: differentiation of the recycled water system and the water; and system tests to ensure the water is what it is. It is also worth mentioning that there is a certification course for plumbers with regards to recycled water run by the local water provider. The Plumbing Industry Commission in Victoria also has guides to recycled water plumbing.

2.3.5.2.1 Differentiation

The most well known aspect of recycled water pipelines is the need for a colour differentiation from potable. The purple pipelines are standard throughout the world and a legal requirement in Australia [1]. Furthermore the marking of the recycled water pipelines and taps (with removable handles) as non-potable water is a legal requirement and can prevent accidental ingestion.

Some parts of the United States require that recycled water pipelines running in parallel to potable water lines be offset diagonally (ie both vertically and horizontally). This is believed to reduce the risk of accidental cross connection. In Victoria the only legal requirement is a separation of recycled water pipelines from potable of 100 mm above ground and 300 mm below [1]. Also there is a requirement that connections to recycled water taps and meters have different sized threads in order to minimise the possibility of cross connection. Other options that have been suggested to reduce the risk include:

- Using pipes of different sizes. Where the potable water system is not used for fire protection and can be made smaller, this has the added benefit of ensuring water quality is maintained. In general the long residence times of potable water in large pipelines reduces the water quality. Reducing pipe size decreases the residence time and provide better quality water.

- Dyeing of the recycled water as it enters a site. As well as clearly revealing where recycled water is flowing, this can mask any colour that may be present in the water where aesthetics are an issue. This will not be a solution to all cases, but could be useful in commercial buildings and some smaller industrial applications.

2.3.5.2.2 System Tests

Testing of recycled water systems can be typically performed in two ways. The first is a standard in most residential reuse schemes in the US and involves the depressurizing of the recycled water system once a year. A similar system can be used in an industrial application where the recycled water system can be depressurized during major plant shutdowns allowing for a thorough check of the system.

The alternative is more extreme but is under consideration in Cary after their recent cross connection problems. After a new property is connected to the recycled water system Cary officials will now test water directly from the tap for key properties. The main differentiating parameter in recycled water will vary with treatment conditions, however conductivity and chlorine residual are two key factors that generally vary. A similar simplified system may be achieved using conductivity or chlorine residual in industrial situations, with check being performed after major plumbing operations or plumbing where potable water systems were affected.

2.3.6 General Controls

The general control to protect human health in recycled water uses are guidelines outlining allowable uses based on the assessment of pathogenic health risks and barriers between existing pathogens and people. In general these are already in existence in most industrial applications. The main example where this is not the case is in aerosol formation that was discussed in Section 4. For all recycled water uses the main barrier will be disinfection using a biocide. As was previously noted where the chlorine residual imparted by the water provider is still above 0.3 $mg.L^{-1}$ at the end use no further treatment will be required [56]. Otherwise an additional biocide program will be required by the user.

In order for biocidal control to be effective, the dosage should be scientifically selected. A successful program will [58]:

- Know the target organisms
- Select the right biocide and their concentrations
- Perform a scientific determination of dosing frequency
- Monitor the control program
- Monitor attachment of micro-organisms to surfaces

In general oxidising agents are the most effective biocides as they act indiscriminately and organisms cannot build up a resistance to them [58]. They do, however, suffer from significant interferences reacting with any oxidisable substance such as organics. The main oxidising agents are:

- Chlorine. Chlorine is usually used as sodium hypochlorite, though calcium hypochlorite or chlorine gas are sometimes used. The issue of sodium salinity in sewers in the western region of Melbourne could make calcium hypochlorite a more appropriate choice where the calcium can be tolerated. Alternatively chloramination may be an option. It is highly non-selective and suffers major interferences from ammonia and organic nitrogen compounds. Its residual is easy to measure, but disappears somewhat quickly allowing for regrowth [58].

- Chloramination. Chloramines, formed through the reaction of chlorine with ammonia, are becoming more popular primarily due to their higher selectivity the chlorine. This means they are less corrosive to the environment in which they are used and have a longer lasting residual. However, as chloramine is less oxidising than chlorine it is slightly less effective and bacteria have been seen to develop a resistance [59].
- Ozone. The decomposition intermediates of ozone are particularly effective as a biocide. Unfortunately, ozone is not stable in water and will not maintain a residual to prevent regrowth. It also breaks down organics to short chained, oxygen-rich species that promote bacterial growth [58].
- UV radiation. This is most effective at 253.7 nm [58]. It lacks residual making it useful only where the system is located at the point of use to reduce the time for potential regrowth.
- Hydrogen peroxide. This is not effective in itself and must be used in conjunction with UV radiation to generate free radicals. It is effective against both bacteriacidal and sporicidal [58].

Oxidising agents can also present a threat to a number of materials such as steel and wood [56]. Consequently, large concentrations (such as those delivered during shock chlorination) should be avoided [21]. Continuous, low levels of oxidising agents are best. It is often also recommended that a second class of biocide be used to control micro-organisms in water as these suffer less from interferences and remain for longer periods in the water. These may include [49]:

- Biguanides. These compounds attack the membrane of a cell, rupturing the wall leading to death. Importantly they are fast acting and non-corrosive. They are commonly used in treating cooling water.
- Aldehydes. Typically formaldehyde or gluteraldehyde, they damage transport properties through the cell membrane and are also sporicidal. While gluteraldehyde is more effective it can only be used over a small pH range.
- Phenols. The compounds dissolve membranes that ultimately kill the cells. Their main drawback is that they are also harmful to humans.
- Thiol oxidizers. This class of compounds influence the structure of proteins. They are antimicrobial at high content, but only bacteriastatic at low content.

In general, while these compounds are sometimes used on their own, microbes are able to develop resistances to them and it is generally recommended that an oxidising agent also be used to reduce the population of resistant microbes [49]. Good practise has been shown to include both oxidising and non-oxidising biocides [25, 49].

2.3.7 Protocols for the Protection of Employee Health

There are a number of important steps that can be taken to ensure employee health and safety when using recycled water. These may vary depending on the different water qualities and their use and are generally outlined in the Victoria and Australian Guidelines [1, 2] (please refer to these documents for the most up to date protocols). These protocols should be communicated as part of an induction for all people (direct employees, contractors and visitors) entering a site that uses recycled water.

- People should understand what uses of the recycled water on site are acceptable and what are not. They should also be aware of the controls required and understand to check for pooling or ponding of water and ensure drift and runoff do no leave the site where recycled water is being used.
- Food, drink and cigarettes should not be consumed where recycled water is used.
- After using recycled water workers should wash their hands immediately particularly before eating, drinking, smoking or leaving the site.
- All wounds should be covered with a waterproof dressing when working with recycled water.
- Any skin rashes or illnesses should be reported to a supervisor who will in turn report to an OH&S specialist for investigation of the incident.
- Workers with dermatitis, chronic illnesses or weakened immune systems (either due to illness or medication) should assessed by a medical professional before using or working in the vicinity of recycled water.
- Where low quality recycled water is used or treated onsite, immunization may need to be considered against particularly harmful viruses such as hepatitis. Note that this is only an issue for water that is considered Class D or lower in quality. Such water cannot be directly used in industrial applications and will require further treatment. Workers in the building where this treatment is performed are the only ones required to undergo immunization.
- All recycled water taps should be labelled as being recycled and non-potable. There should also be signs prominently displayed around the site indicating that recycled water is used on the site.
- All employees should be made aware of procedures to report incidents or problems related to the use of recycled water. There should also be encouragement to report incidents.

2.3.8 Animal and Livestock Health

Although this report does not consider the agricultural industry, some industrial users may produce products that go to support this industry. There are a number of facilities in the Greater Melbourne region that process chicken and stock feed as there are in regional Victoria. Regional Victoria is also host to a number of pet food producers. There are also companies that produce products for pets that have the potential to be consumed such as toys and toiletries (flea baths, shampoos etc). Consequently the potential effects to animals should be briefly considered.

While the Victorian Guidelines do take animal health into some account it is generally only in terms of knock on effects to humans.

There are a number of other pathogens that may be present in raw sewage and therefore recycled water. These are unlikely to be present in quantities similar to human-specific pathogens, however. Also, some pathogens that effect humans may also be a concern for other animals, for example *Giardia lamblia* is also capable of infecting cats and dogs [60]. The main difference between human and animal infection would be in the dose-response values. It should be noted that the Australian Guidelines do not consider animal health in their risk assessment, but have the potential to be extended. It may be appropriate, therefore, to consider the health implications of products targeted to animals, using the

Australian Guidelines as a template, particularly for products that may be consumed.

Two of the more noteworthy animal based diseases are discussed in the following sections.

2.3.8.1 Beef and Pork Measles

Beef measles are the intermediate state on the life cycle of *Taenia saginata* or tape worm. The eggs may be eaten by cattle where the immature tapeworm works it way through the intestinal walls where it reaches the blood stream. It then reaches the muscles where, over a period of time, a cyst forms. If the cyst still containing a viable tapeworm is eaten by a human the tapeworm will fully develop. While there is no noticeable affect to the health of cattle, any cattle suffering from beef measles cannot be sold for slaughter.

The equivalent in pigs is pork measles. Similar cysts are formed as part of the lifecycle of *Taenia solium* and that lifecycle is essentially the same as for *T. saginata* with human consumption leading to infection. Consequently that same set of risks exists. The main difference is the severity of human infection. While T. saginata brings moderate health consequences, T. solium can lead to serious neurological effects. As with cattle, pigs suffering from pork measles cannot be sold for slaughter.

Taenia saginata is a helminth and, as such, the eggs are quite large and are relatively easily removed by sedimentation and filtration techniques. Lagoon retention in particular is considered very effective [61]. In Australia a 25 day retention time is generally required for *T. saginata* and is considered the equivalent of a 4-log reduction [2]. However, in order to manage the significantly more severe effects that *T. solium* has on human health, federal government regulations mean recycled water cannot be used to water pigs and pig fodder [2]. As a result any process where the product goes to consumption by pigs cannot use recycled water.

2.3.8.2 Bovine and Ovine Johne's Disease (BJD and OJD)

BJD and OJD are tuberculosis-like infections by the bacteria *Mycobacterium paratuberculosis*. The diseases are considered particularly harmful to agriculture as they are not easy to detect initially, the inoculation period can be more than three or four years [62], and are therefore able to infect a large portion of a herd or flock virtually undetected. There is no known cure and BJD and OJD are generally fatal. The bacteria typically spread through faecal contamination. Importantly this includes water that may pass through the site. It has also been associated with humans [63]. It is possible therefore for *M. paratuberculosis* to be present in recycled water supplies.

One of the major concerns with *M. paratuberculosis* is its ability to survive a number of treatment and disinfection processes in particular chlorination [63]. Consequently a recycled water quality that meets the Australian Guidelines with respect to human health may not with respect to BJD. A similar risk analysis to that provided in the Australian Guidelines should be applied to recycled water for animal health where appropriate.

2.4 Corrosion

2.4.1 Introduction

Corrosion is a physicochemical process where a metal interacts with its environment resulting in changes to the metal properties [64] and often loss of material to the surrounding environment. This causes unwanted wear, reducing the performance or lifetime of equipment or structures. Furthermore, the oxidised metal particles can become suspended in water as metal oxides or salts and alter colour, taste, pH or in some cases cause water toxicity. Corroded surfaces also increase the surface roughness of metals and can facilitate bacterial re-growth.

Most corrosion is caused by oxygen dissolved in the water reacting with metallic materials. It is influenced by the composition of the water, the environmental conditions and the material involved and can take a number of forms.

When considering the use of water in an industrial process, electrolytic corrosion is the major process. Electrolytic corrosion occurs where there is a potential difference between two sections of metal that are electrically connected. This can occur on a single piece of metal where one section of the metal acts as the anode while the other acts as the cathode. By this process the anode is oxidised by the generalised half reaction:

$$M \rightleftharpoons M^{z+} + ze^- \qquad -1$$

where M is the metal, e^- are electrons and z is an integer. As it results in the release of electrons, corrosion rates can be measured using current densities. The production of M^{z+} can lead to a number of products both soluble and insoluble and the importance of this will be discussed later. As part of the electrolytic cell, the electrons liberated from the oxidation must be used in a reduction at the cathode. The cathodic reactions can take three broad forms. The most common is the reduction of dissolved oxygen to produce hydroxide or hydrogen peroxide:

$$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^- \qquad -2$$

$$O_2 + 2H_2O + 2e^- \rightleftharpoons 2H_2O_2 \qquad -3$$

This obviously relies on the diffusion of dissolved oxygen to the surface of the metal.

Corrosion can also occur in the presence or absence of oxygen producing hydrogen by the half reaction:

$$2H^+ + 2e^- \rightleftharpoons H_2 \qquad -4$$

In general this reaction is much slower, unless the water is very acidic [59] or the metal is very reactive, for example aluminium or magnesium.

The final corrosion possibility is the cementation reaction which involves reduction of a dissolved metal ion in the water resulting in corrosion of the structural substrate and deposition of the reduced form of the reactive ion. This takes the generalised equation:

$$X^{x+} + xe^- \rightleftharpoons X \qquad -5$$

$$Y \rightleftharpoons Y^{y+} + ye^- \qquad -6$$

where X is the soluble metal ion and Y is the substrate. This will occur where the corroding metal substrate is more reactive. A pertinent example to industrial water is the presence of dissolved copper in steel plant. In this case the steel (Fe) is more reactive and will be displaced by the copper by the overall reaction:

$$Fe_{(s)} + Cu^{2+} \rightleftharpoons Fe^{2+} + Cu_{(s)} \qquad -7$$

Table 2.11. Galvanic series for some metals and alloys. Adapted from [59] and [64]

Noble	Titanium
(likes electrons)	Monel
	Silver
	Inconel
	Nickel Copper
	Brass
	Nickel
	Tin
	Lead
	Lead-tin solder
	Iron alloys
	Iron Steel
	Cadmium
	Aluminium
	Zinc
(likes water)	Magnesium
Base	Magnesium alloys

Hence, it is important to ensure that the presence of dissolved copper in industrial water is low. The presence of copper is difficult to avoid completely as it can enter the water as a corrosion product where copper or yellow metal piping, fittings or plant are used. A rough guide to reactivity and potential displacement reactions can be found in the galvanic series shown in Table 2.11. The table provides an indication of the risk of corrosion of metals used in combination. When dissimilar metals are used, one will act as a cathode and the other as an anode in a galvanic cell and the less noble metal will corrode. The further apart in position two metals are, the larger the difference in potential and the risk of corrosion.

Corrosion is described as general corrosion when it occurs relatively evenly across a surface. This is due to a switching effect whereby slight changes in the local water chemistry or in the surface can switch a crystallite from a cathode to an anode and back. The surface appearance is either clean or covered with corrosion products depending on whether they are soluble or insoluble.

More important however, is the more aggressive localised corrosion. This is brought about through permanent concentration variation between two points. An example of such a situation is for a partially immersed metal. In this situation reactions will deplete dissolved oxygen from around the metal. Near the water-air interface however, oxygen can be readily replaced while the conditions at lower depths will remain predominantly anaerobic. Following Nernst's law, such a situation will lead to an electrochemical potential difference between the two locations. Where the difference is great enough corrosion will be induced. Essentially any situation in which oxygen can more readily diffuse to a site has the potential to lead to corrosion. A similar situation to that described above can be seen for a water droplet or small pool on a metal. Alternatively, situations in which oxygen cannot penetrate to a section of a metal's surface can also lead to corrosion. This is the case of under-deposit corrosion due to scaling or the formation of biological films, hence the importance of reducing both of these factors. Certain mechanisms of corrosion will also set up concentration cells. These are described in Section 2.3.2.

As was noted earlier, corrosion can lead to either a soluble or insoluble product. A soluble product will diffuse away from the metal surface and drive the corrosion reaction further, however this is not common. Typically an insoluble product, generally an oxide or hydroxide will form. In irons and steels, the solid ferric oxides and hydroxides tend to be porous and poorly adherent. This allows for further corrosion to occur as water can reach the iron or steel surface further promoting the reactions. For some metals such as stainless steel, titanium and aluminium, the oxide film that is formed completely covers the metal surface and leads to a phenomenon known as passivation. In this situation corrosion is slowed to about 5 orders of magnitude below the metal's normal corrosion rate [59]. The metal is essentially protected from corrosion. This passivation need not occur from oxides, but may also be induced using other anions added to the water. For example, orthophosphate is commonly added to cooling towers as iron phosphate to promote the formation of a passive film protecting iron and steel surfaces from corrosion [23].

When corrosion rates (or current) are observed as a function of potential (as shown in Figure 2.2), passivation is seen (where it occurs) once a specific potential is reached. If the potential is increased further, reactions will again be witnessed. This region is known as the transpassive region. In general the reactions in the transpassive region are not associated with the metal but with oxygen production from the oxidation of water. However, in some situations such as on chromium and stainless steel, it actually represents a change in the corrosion mechanism and further corrosion occurs. The shift to more positive potentials that leads to corrosion on these passivated surfaces is known as ennoblement and is of particular importance to microbially influenced corrosion (MIC).

An important aspect of corrosion reactions is polarization. This is essentially the slowing of corrosion reactions due either to a build up of product at the anode (anodic polarization) or a depletion of reactants at the cathode (cathodic polarization). It is possible for certain chemicals or microorganisms to reverse this trend. This is termed depolarization and results in an increase in corrosion rates. The case of oxygen diffusion at the water-air interface described earlier is an example of cathodic depolarization. The formation of a complex by a corrosion product and its removal from the metal surface is an example of anodic depolarization. To reduce corrosion rates both of these situations must be avoided.

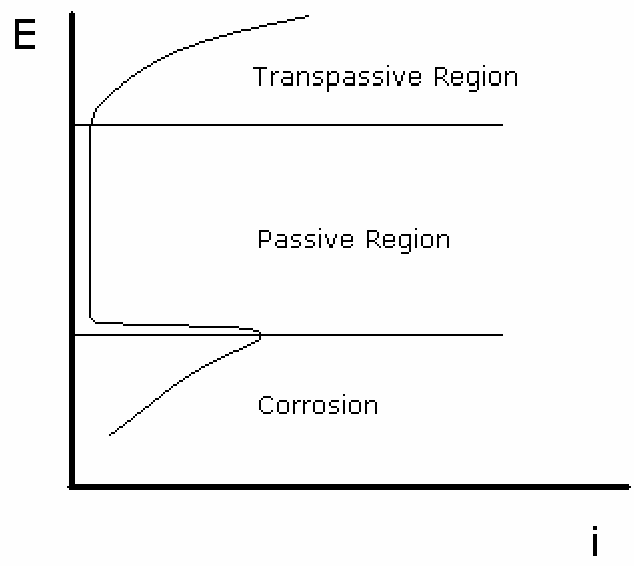


Figure 2.2. Plot of the potential versus current of an anode in a corrosion process showing passivation and the transpassive region.

2.4.2 Corrosion Mechanisms

2.4.2.1 Pitting and Crevice Corrosion

Pitting and crevice corrosion are localised corrosion that arise due to the action of aggressive ions, particularly chloride. They are influenced by a large number of factors, including temperature, pH and chloride concentration [65]. Pitting typically occurs on passivated metals where a localised breakdown of the passive film has occurred. This could be for mechanical reasons or due to deposits and fouling.

Crevice corrosion on the other hand occurs in tight gaps under gaskets, fittings, deposits and films where oxygen cannot easily diffuse. Crevice corrosion is insidious because it occurs in inaccessible spaces and may not be noticed until there is a failure.

Once a pit or crevice has started to form the composition of the pit or crevice changes dramatically with a higher chloride concentration and lower pH due to the hydrolysis of the dissolving metal that makes the environment in the pit more aggressive and helps to establish a concentration cell. This is coupled with the cathodic oxygen reduction reaction that occurs outside the pit or crevice increasing the external pH, facilitating the formation of precipitates when the pit or crevice solutions diffuse to the bulk. Importantly it is very difficult to repassivate a section of metal once pitting has started and corrosion will likely continue to breakthrough, although chemical cleaning may be used to remove all corrosion products and establish a passive surface.

Certain conditions will increase the likelihood of pitting corrosion – see Section 2.4.3. Of these, one in particular is important with regards to recycled water. The presence of oxidising agents in the water will increase the possibility of pitting [66]. Even mild oxidising agents are a potential risk. If the recycled water is more oxidising than the current supply then the risk of pitting will also increase.

Table 2.12. Ions associated with stress corrosion cracking in some common metals. Adapted from [67].

Metal	Ion	Concentration	Temperature
Carbon Steel	OH^-	High	High
	NO_3^-	Moderate	Moderate
	CO_3^{2-}/HCO_3^-	Low	Moderate
Strong Steel	Cl^-	-	Low
	S^{2-}	-	Low
Austenitic Stainless Steel	Cl^-	High	High
	OH^-	High	Very High
Martensitic Stainless Steel	Cl^-	Moderate	Low
Copper Alloys	NH_3/NH_4^+	Low	Low
Titanium Alloys	Cl^-	High	Low
Aluminium Alloys	Cl^-	Low	Low

2.4.2.2 Stress Corrosion Cracking

Stress corrosion cracking results from a combination of a corrosive environment and residual and/or applied tensile stress in a metal. How the process is initiated is not fully understood although embrittlement of the metal at a structurally weaker point is often implicated. Once a crack tip has formed, the establishment of an oxygen concentration cell and the subsequent corrosion couple with the tensile stress would assist in the continual growth of the crack. This eventually results in catastrophic failure of the metal.

The most common example and one that is pertinent to recycled water, is the effect on copper and its alloys of ammonia that is seen to accelerate stress corrosion cracking. This has been seen at concentrations as low as 2 $mg.L^{-1}$ [23]. Consequently in cooling systems it is generally best to remove ammonia either by stripping or using biological nitrification. This is practised in the refineries in Los Angeles that use tertiary effluent as cooling water [68]. Table 2.12 contains a list of common metals and the ions thought responsible for stress corrosion cracking. The table has been adapted from [67] and does not explain what a high concentration would entail, however manufacturer recommendations in cooling towers typically allow chloride concentrations between 400 and 910 $mg.L^{-1}$ in systems where stainless steel of unspecified grade is used [21], anything above this level therefore would be considered high.

In terms of recycled water, high quality water produced using reverse osmosis should not present a significant threat due to the deionised quality of the water. However, this needs to be qualified as some alloys, such as Ni-Cr-Fe alloys, undergo stress corrosion cracking in high purity water [69].

Adoption of any water source, including tertiary treated water (Class A), will need to take into consideration the ions of importance to the metallurgy of the system and the adoption of appropriate corrosion management. As noted earlier, ammonia is a serious problem for copper and must be removed. Similarly chloride should be considered a potential threat to aluminium and carbonate to carbon steels (at moderate temperatures). Other metals require high concentrations and although the concentrations should be checked on a case-by-case basis, it is unlikely that they will pose a threat.

2.4.2.3 Hydrogen Embrittlement
Hydrogen, as a result of its small size, can dissolve into just about any metal to some extent. The diffusion is also fast in ferritic steel. Importantly the ease of dissolution and diffusion is higher at points of high stress where pathways may be dilated. Though it is not fully understood, once hydrogen has entered the metal at these points the metal becomes more brittle eventually leading to cracking, often quite rapidly.

Hydrogen can be generated at the surface of a metal electrochemically as a product of cathodic corrosion reaction. Therefore reducing the acid corrosion of a metal should help to reduce hydrogen embrittlement.

2.4.3 Drivers of Corrosion

The corrosion reaction and its rate are affected by a number of parameters, such as electrolyte conductivity, buffering capacity (alkalinity – especially CO_3^{2-} and PO_4^{3-}), and inorganic ions, especially Cl^-, and SO_4^{2-}, pH, dissolved oxygen concentration, temperature and water velocity. The effects of these parameters are summarised in Table 2.13.

2.4.3.1 Electrolyte Conductivity
While it is possible to use thermodynamics to calculate a theoretical corrosion potential, there are a number of factors that will also influence potential in a practical situation. These are termed overpotentials as they increase the potential difference required. One of these is the concentration overpotential that is related to the diffusion of species to the metal surface and contributes to the cathodic polarisation described in Section 2.3.1. In the current discussion the iR drop, or overpotential required to overcome resistance is more pertinent. As this resistance increases this overpotential also increases.

When using recycled water, the main difference when compared to potable is the water's conductivity. As the conductivity increases the iR drop decreases and corrosion will be accelerated. The conductivity change will be dependent on the level of treatment of the water. A tertiary treated water will typically have a conductivity up to ten times greater than the potable supply making corrosion more likely, using this water could result in a higher demand on corrosion control techniques although the recommended maximum conductivity of 4000 $\mu S.cm^{-1}$ [70] is unlikely to be exceeded. On the other hand the more highly treated MF/RO quality water will have an equal or lower conductivity making it less corrosive and therefore potentially extending plant life or allowing for reduced controls, provided other parameters such as buffering capacity are also controlled.

2.4.3.2 Buffering Capacity
The pH plays an important role in the corrosion process as it affects the solubility of corrosion products and dissolved ionic species to electrochemical reactions and hence the rate and type of scaling that occurs on the metal surface. The buffering capacity of water is its resistance to pH change by the addition of acid or base.

Buffering capacity is generally defined best by the alkalinity. A high alkalinity is equivalent to a high buffering capacity, often measured as the concentration of carbonates or bicarbonate in the water. Phosphate can be a major component of alkalinity of recycled wastewater [71].

Table 2.13. Impact of water quality parameters on metal corrosion [72]

Factor	Effect
pH	• Low pH may increase corrosion rate. • High pH may protect pipes and decrease corrosion rates for most metals • For brass where pH > 7.6 dezincification may occur.
Alkalinity (dissolved inorganic carbon)	• Can act as pH buffer, may help form protective coating on metal surfaces. • High alkalinity increases corrosion of copper, lead and zinc.
Dissolved oxygen (DO)	• Tends to increase corrosion rate. • Low DO can allow anaerobic conditions conducive to microbially-influenced corrosion.
Chlorine residual	• Increases metallic corrosion for copper, iron and steel if too high. • Reduces microbial corrosion.
Total Dissolved Solids (TDS)	• High TDS tends to increase conductivity and corrosion rate.
Calcium hardness	• Can form a protective layer of $CaCO_3$, but can also result in excessive scaling and crevice corrosion.
Chloride, sulphate	• High levels increase corrosion of copper, iron and galvanised and stainless steels.
Hydrogen sulphide	• Increases corrosion rates.
Ammonia	• Can increase solubility of some metals, e.g copper and lead. • Cause of stress corrosion of copper and copper alloys
Polyphosphates	• May reduce tuberculation of iron and steel, but can increase tuberculation of iron and steel at low dosages. • Increases solubility of lead and copper. • Reduces dezincification of brass. • Can revert to orthophosphate and form protective films.
Orthophosphates	• Forms protective films.
Silicate	• Sequesters ions and forms protective films. • Silicate solutions also contribute to increase pH.
Natural organic matter (NOM)	• NOM may decrease corrosion by coating pipe surfaces. • Some organics can complex metals and accelerate corrosion or metal release. • It also serves as feed for microbial activity
Iron or manganese	• Can precipitate and form a film in the interior of metallic pipes, the film can be protective • In hot water copper pipes Mn ≥ $0.03 mg.L^{-1}$ can promote pitting of copper through MnO_2 deposition [73]
Copper	• Deposits copper causing pitting in steels and zinc and/or Al coated steel
Magnesium	• May inhibit precipitation of protective calcite form of $CaCO_3$, instead favouring formation of more soluble aragonite $CaCO_3$.

Table 2.14. Quality of potable water and treated effluent in Melbourne

Parameter	EPA Limit	Units	ETP Median	ETP Maximum	WTP Class A (MW, 2007)	Melbourne tap water (YVW 2006)
Turbidity	*< 2*	NTU	0.2	3.5	2.4	0.1-4.3
pH	*6 - 9*	pH units	7.1	7.2		7-8.9
TDS	*500-1500*	$mg.L^{-1}$	458.0	511.0	1000	
Alkalinity	*no limit*	$mg.L^{-1}$	155	190		3-52

Source: http://www.topaq.com.au/waterquality/Apr-Jun2007.pdf, last assessed 10/08/2007 in [74], Melbourne 2006 (2004/05 Annual Monitoring Report to the Environment Protection Authority – confidential report) and YVW 2006 (Drinking Water Quality Report 2005-2006).

Corrosion reactions will bring about a change in the pH in water. Both the oxygen and acid cathodic reactions (reactions 2 and 4) will bring about a change in hydrogen ion or hydroxide ion concentration, increasing the pH at the cathode. At the same time any soluble metals formed at the anode/pit/crevice will hydrolyse, lowering the pH by the following reaction [66]:

$$M^{2+} + 2H_2O \rightleftharpoons M(OH)^+ + H^+ + H_2O \rightleftharpoons M(OH)_2 + 2H^+ \qquad -8$$

The associated pH change will be smaller in a more highly-buffered water whereby corrosion may take longer to establish. The lower pH near the anode can accelerate the corrosion process, so it is important that any potential pH changes can be buffered by the water.

In recycled water, alkalinity is highly dependent on treatment processes. Tertiary treated water has a relatively high alkalinity when compared to potable water as seen in Table 2.14 although this is largely attributable to phosphate.

More importantly water treated by reverse osmosis will have a very low alkalinity and buffering capacity. MF/RO treated water results in the removal of dissolved ions from water, decreasing its alkalinity and buffering capacity and producing a corrosive water for most metallic environments. This can be overcome by mixing the RO product water with an appropriate amount of hard water. This hard water may be taken from a raw water supply, groundwater or potentially an RO brine or bypass stream. Alternatively chemical addition can also be adopted. A possible composition of adjusted RO water is alkalinity 40 $mg.L^{-1}$, pH 7.8 - 8.0 that may be achieved using lime and carbon dioxide dosing. Stabilisation of RO water via chemical addition is often practiced in centralised treatment plants to protect the distribution system from corrosion.

2.4.3.3 Product Solubility

The ability of a corrosion product to become or remain soluble is of particular importance to corrosion rates. Corrosion resistance of a metal is usually achieved by the formation of an adherent protective (passive) film of corrosion products on the surface. If a product is soluble and able to diffuse from the electrode surface then the process remains in an active state and continues to corrode. Certain compounds are able to enhance this by chelating or complexing with the metal preventing the formation of what is generally an oxide film. The solubility of most common metal corrosion products increases at low pH, so pH and buffering are important controls. Chloride is one common anion that acts in this way preventing passivation of stainless steel, although high concentrations are needed. Generally chelating compounds are not found in largely quantities in recycled water so this should not be an issue.

Table 2.15. Limits for sulphate and chloride on particular metals to control corrosion. Adapted from [70].

Parameter	Metal	Limit (mg.L^{-1})
Cl^-	General	1500
	Copper	750
	316 Stainless Steel	1000
	304 Stainless Steel	200
SO_4^{2-}	General	2500
	Copper	1200

2.4.4 Control of Corrosion

Corrosion of metals tends to occur in most environments, however its rate can be controlled by proper management strategies. One way to control corrosion of metals is to ensure that there are no aggressive ions or compounds which may attack the metal. Table 2.15 gives some recommended concentrations for chlorides and sulphates in the presence of some important metals. These values are quite high (with the exception of 304 stainless steel) and are unlikely to be reached in most recycled waters, however each project must be considered on a case-by-case basis. It is important to note that even where these limits are exceeded other control methods can be used to ensure the integrity of equipment. These control techniques can be broadly sorted into two classes: physical control and chemical control.

2.4.4.1 Physical Control Techniques

2.4.4.1.1 Cathodic protection

Cathodic protection is based on the construction of a galvanic cell. When two different metals are immersed and in contact in an electrolytic solution, a galvanic couple is formed where the metal with the lowest potential undergoes accelerated corrosion. This principle is exploited for protection through sacrificial anodes or impressed current.

Sacrificial Anodes. A sacrificial anode is a metal purposely selected to provide a lower corrosion potential than the metal or alloy it is protecting. As a result it is preferentially oxidised, reducing the corrosion rate of the protected metal which acts as a cathode [75]. Common sacrificial anodes for steel include zinc, aluminium and magnesium.

Impressed current. The same protective effect can also be achieved through the application of a direct current from an external source to the metal that is being protected. A dc power supply is connected and direct current is passed between the structure and an inert anode (Pt/Ti is common). The continuous transfer of electrons to the metal being protected discourages corrosion [75].

2.4.4.1.2 Physical separation

The adoption of protective coatings, e.g polymeric, refractory coatings or naturally passivated coatings, can be adopted to isolate the metal from a corrosive environment and hence reduce corrosion. This system is commonly adopted in buried pipes which are externally wrapped in a layer of plastic to prevent intrusion of water or contact with moist soil and also for cement-mortar lined water mains. However, breach of the coating layer would result in fast localised corrosion. Cathodic protection can be applied to provide protection if the coating fails.

2.4.4.2 Chemical Control Techniques

2.4.4.2.1 Adjustment of pH
Adjustment of pH is adopted when dealing with cold-water corrosion to prevent the dissolution of protective layers. For galvanised pipe pH values between 7 and 8.5 prevent dissolution of protective oxides and carbonates of zinc. For brass a pH greater than 7.6 tends to favour corrosion, whilst for copper, corrosion of copper increases rapidly for pH < 7 (generalised corrosion and high dissolution). Chemicals such as lime, sodium bicarbonate and carbon dioxide are commonly used [72].

2.4.4.2.2 Film-forming chemicals
Phosphates and nitrites. Poly- and orthophosphates are commonly used as additives to reduce corrosion in metals, such as iron and galvanised steel as they form protective oxidised layer with the metal or the corrosion products [75]. Useful phosphates can be found in tertiary effluent and could provide some protection. Nitrites may be useful as anodic corrosion inhibitors in closed systems, but are susceptible to microbial attack and undergo rapid inactivation by oxidation.

Silicates. Silicates may form a thin layer over a corroded surface, whilst also increasing pH. They are a common corrosion inhibitor used for municipal water supplies to protect against corrosion of copper and steel, for point-of-use and for industrial processes. Typical dosages of 4-30 $mg.L^{-1}$ are generally applied to soft water, with higher dosages employed at higher temperatures and as hardness and TDS increase [72].

2.4.4.2.3 Corrosion-inhibiting chemicals
Azoles. Azoles form a protective sheath over specific metals. Often used in copper protection, they are commonly used at 1-5 $mg.L^{-1}$ for cooling towers. Common examples include tolyltriazole (TTA), mercaptobenzothiazole (MBT) and benzotriazole (BZT), however they can be degraded by halogen compounds, such as chlorine, generating odorous compounds [76].

Natural Organic Matter (NOM). A range of NOM compounds, including humic and fulvic acids, have been identified to provide some corrosion protection for metals such as iron, zinc coatings and unprotected steel [72]. On copper there is no consensus as to effect with some suggestions NOM accelerates corrosion [77] and others suggesting it inhibits it [76]. The molecular weight and the polarity of NOM compounds is believed to increase the thickness and density of the corroded layer by delaying carbonate precipitation and retarding the oxidation process [72]. The presence of NOM in recycled water may act beneficially in preventing corrosion therefore.

2.4.4.3 Materials selection
The selection of materials of construction is a key factor in achieving the best performance from plant to be used in contact with recycled water. A balance needs to be set between practicability and cost of the competing approaches of water treatment and materials selection. For example, components made from type 304 stainless steels may need to be replaced by type 316 or higher to give acceptable performance.

2.4.5 Final Word

Although this document has provided general information regarding the factors that influence corrosion in water, recycled water and each specific application needs to be individually assessed for its likely performance in a particular environment. Specialised corrosion consultants may be engaged for this purpose. The corrosion of each alloy system can be the subject of an individual chapter or an entire book.

Proponents wishing to investigate use of recycled water need to have a thorough understanding of all components of their plant and equipment and the corrosion potential of the recycled water in question.

Whilst awareness is required, recycled water has been adopted in industrial applications worldwide in a range of industries from metal forming to energy production to pulp and paper.

2.5 Microbially Influenced Corrosion

2.5.1 Introduction

Corrosion processes can be enhanced or suppressed by the presence of microbes. This can occur through the acceleration of the kinetics of corrosion or through the modification of the chemistry of the surface layer of the metal and the surrounding aqueous environment. Microbially influenced corrosion (MIC) occurs through the presence of microbes in a biofilm. The formation of such a film cannot be avoided – most chemical plants already contain a biofilm at start up and engineering advances have yet to generate a surface that can prevent microbial adhesion [78]. More importantly, while studies of corrosion rates for individual microbial species have been performed, evidence shows that multifloral corrosion (corrosion in a film containing multiple microbial species) is significantly faster due to synergistic interactions between the microbes, their metabolites and the metal and corrosion products [79]. Other abiotic components of a biofilm (such as the polymeric matrix that supports the film and enzymes that can function abiotically) may also aid in accelerating the corrosion rates.

The main issue with biofilms (or sessile microorganisms) is that they are far more stable then their planktonic counterparts. This comes from the extra protection afforded by the matrix of the biofilm. It is generally accepted that a level of biocide two or three orders of magnitude higher is required to be effective in biofilms when compared to planktonic species [78]. This makes biofilms almost impossible to destroy and the focus of any biocide program is instead on control.

Also of significance is the anoxic (oxygen-free or depleted) nature of portions of the biofilm. While the outer surface of a biofilm will be aerobic, the inability of oxygen to penetrate into the denser inner layers means that anaerobic pockets become common, particularly near the metal surface. This is significant as one of the largest groups of species responsible for MIC, the sulphate-reducing bacteria, are anaerobic.

Favourable conditions for the growth of biofilms include warm aerated waters such as those present in cooling towers, and water where there can be a buildup in nutrients. This can occur in areas of pipework, for instance, where some stagnation occurs and there is an increase in deposited organic matter [80]. This results in the depletion of chlorine residuals typically used to control microbiological growth, especially when combined with large residence times. This is not so much a function of the water composition but more a function of the engineering of the plant. While some categories of recycled water will have a higher nutrient content than potable water, they will not necessarily be more susceptible to microbiological growth. It is the buildup of the nutrients that will play a more important role.

2.5.2 Generic Mechanisms of MIC

The presence of a biofilm on a metal surface can lead to MIC. The nature of biofilms means they will not be uniform. Some regions will be thicker than others as some will have greater access to the nutrients on which they can grow. This also means the species in parts of the film will vary depending on the local physical conditions and the chemistry of the surroundings. One common mechanism for MIC is the establishment of an oxygen concentration cell [81]. This comes about when one section of a biofilm utilizes large amount of dissolved oxygen significantly depleting the concentration in the surroundings. This means some sections of the metal surface will have much lower concentrations of oxygen present leading to a difference in electrochemical potential. Where this difference becomes great enough, corrosion reactions will occur [82].

An alternative explanation of the influence of the biofilm on corrosion is that it allows the formation of an occluded cell in which an aggressive chemical environment can develop due to the hydrolysis of corrosion products that are formed as a result of oxygen reduction outside the biofilm.

Similar to the oxygen concentration cell, cells can be established with particular metallic species, particularly where the microbes can utilise the metallic ion or compound as part of their metabolic pathways. In this respect iron concentration cells can be established by iron-reducing or oxidising microbes.

All bacteria secrete extracellular polymeric substances (EPS) when forming biofilms. The EPS aid the survival of the microbes by sequestering nutrients and acting as protection from potentially harmful chemicals such as biocides [78]. Importantly, EPS contain a number of complex compounds, such as polysaccharides, as well as some abiotic enzymes that can participate in corrosion reactions [79]. Polysaccharides in particular are able to chelate with metal ions such as copper [83] and iron [84]. The chelation chemistry significantly changes the corrosion cell potential and typically allows for greater corrosion rates. Enzymes such as oxido-reductase have also been implicated in speeding corrosion reactions [83]. Some bacterial species will secrete large amounts of EPS when forming biofilms and are therefore considered greater risks. Some of the genuses in this higher risk category include, *Clostridium*, *Flavobacter*, *Bacillus*, *Desulfovibrio*, *Desulfotomaculum* and *Pseudomonas* [83].

2.5.3 Specific Mechanisms of MIC

2.5.3.1 Sulphate-Reducing Bacteria

Sulphate-reducing bacteria (SRB) are strictly anaerobic and therefore only appear in an anoxic section of a biofilm [85]. They are the most studied of the microorganisms that cause corrosion as they are the most often implicated. The *Desulfovibrio* family is considered the most damaging with the main offenders being *D. desulfuricans* and *D. vulgaris*. Table 2.16 contains a list of other SRBs and their general habitats. It is important to note the species are not necessarily associated with wastewater, but can enter any water from external sources.

Table 2.16. List of common sulphate-reducing bacteria and their traditional habitats [86]

Species	Habitat
Desulfovibrio	
D. africanus	Well Water
D. desulfuricans	Soil
D. furfuralis	Pulp and paper waste
D. salexigens	Sling mud
D. vulgaris	Soil
Desulfotomaculum	
Dtm. nigrificans	Soil
Dtm. orientis	Soil
Desulfococcus	
Dc. biacutus	Anaerobic digestor sludge
Dc. multivorans	Sewage digestor

SRB cause corrosion through the metabolic reduction of sulphate to hydrogen sulphide while oxidising organics or hydrogen. In anaerobic conditions, abiotic corrosion of metals is believed to occur using the cell reaction:

$$M^0 + nH^+ \leftrightarrow M^{n+} + \tfrac{n}{2}H_2$$

The role of hydrogen in the process has led to the theory that the consumption of hydrogen ions shifts the equilibrium towards its production and thereby increases the iron corrosion rate [87]. An alternative hypothesis has suggested that the M^{n+} species is removed through its precipitation with sulphide. This sulphide is typically non-passivating. The consumption of the corrosion product will drive the corrosion reaction to produce more Fe^{2+} and therefore increase the rate of corrosion [87]. Regardless, the presence of sulphate-reducing bacteria will drive the corrosion reactions at a faster rate.

Interestingly, sulphate-reducing species have also been implicated in the reduction of iron with some species, such as *D. desulfuricans*, believed to be more active in reducing ferrous species than sulphate [87]. Iron-reducing bacteria are discussed in Section 2.4.3.3.

Though mild steels are generally considered to be the target of attack by SRB, there are a range of metals and their alloys that are potentially under threat. Metals that are susceptible to attack include the full range of steels (carbon based and stainless), copper, nickel, zinc, lead and their alloys [83]. Typically, the non-passivating nature of the sulphide film and the corrosivity of the sulphide ion lead to the accelerated corrosion.

An example in which SRB represented a significant issue is the potable water supply in Johannesburg, South Africa [88]. This water typically has a high sulphate content as a result of the mine wastes from sources upstream of the main dams. The high sulphate content coupled with problems with the treatment program leaving large quantities of organics led to growth of *D. desulfuricans* in the distribution system. The Rand Water Board reached the conclusion that imposing a 50 $mg.L^{-1}$ limit on sulphate in water reduced the corrosion risk from SRBs.

2.5.3.2 Iron-Reducing Bacteria

Iron-reducing species are of great concern. This category includes *Desulfovibrio desulfuricans* [87] and *Shewanella putrefaciens* (previously known as *Pseudomonas putrefaciens* and *Altermonas putrefaciens*) [89]. These species accelerate corrosion of steel by reducing Fe^{III} oxides to their more soluble Fe^{II} counterparts. This has the effect of removing some of the protection afforded to the metal by the presence of the iron oxides and by allowing the soluble species to diffuse from the surface, further driving corrosion [89].

2.5.3.3 Iron-Oxidising Bacteria

Iron-oxidising bacteria oxidise Fe^{II} species to Fe^{III} that then deposits as an oxide. Common members include the genuses *Gallionella*, *Leptothrix* and *Sphaerotilus* [90] along with *Acidithiobacillus ferrooxidans* [91] and *Ferrobacillus ferrooxidans* [92]. The deposition of these oxides occurs as tubercles, sheaths of material that initial surround the microbe. The nature of these tubercles makes it difficult for oxygen to diffuse to the lower metallic surface. This in turn leads to the establishment of a oxygen concentration cell and encourages corrosion. This type of corrosion typically appears as pitting and can lead to perforation/breakthrough. These species also concentrate chlorides in iron- or (in the case of *Leptothrix*) manganese chlorides. These salts are able to act similarly to dilute hydrochloric acid in accelerating corrosion [90].

Biocorrosion is not limited to steels and may occur in most metals except titanium and the noble metals [90]. On one case of aluminium corrosion a slightly different mechanism has been proposed by which deposited Fe^{III} acts as a chemical oxidant for the aluminium corrosion reaction resulting in pitting of the metal [92].

Stainless steels are widely used in corrosive industrial applications, are also prone to crevice and pitting corrosion under similar under-film conditions to those that are linked with MIC. Some of the corrosion issues associated with stainless steels are covered in a useful WSAA Fact Sheet [93].

In the mining industry in Western Australia, pitting has been seen in stainless steel piping used in a dewatering facility that was associated with iron oxidising bacteria [94]. The water contained a high concentration of chlorides and little organics and few bacteria were detected around the corrosion site. The cause was traced to *Gallionella ferruginia*.

2.5.3.4 Manganese Oxidising Bacteria

Manganese oxidising bacteria are of particular concern to stainless steel and include species such as *Leptothrix discophora* and *Siderocapsa treubii* [95]. They can have a similar corrosion mechanism to iron oxidising bacteria in that they create tubercles of MnO_2 that can lead to the establishment of an oxygen concentration cell. Similarly they can also concentrate chlorides as manganic chloride that has a hydrochloric acid-like ability for accelerating corrosion [90]. Of greater importance however is the ennoblement of stainless steel. The deposition of MnO_2 on the stainless steel surface moves the corrosion cell potential on the stainless steel from the passive region to the transpassive region, allowing for destructive oxidation (that is, corrosion) to occur. To bring about the corrosion there must be a source of manganese present in the water. Keeping the concentration of this species in recycled water low should eliminate the impact of this type of MIC.

2.5.3.5 Organic Acid Secretors

A large number of bacteria secrete organic acids as their fermentation product. Though these acids may not be particularly corrosive on their own, the concentrations that may be induced in, or under, a biofilm can give rise to dramatic differences in pH between the bulk water and the metal surface. Coupled with this is the fact that the presence of the film will prevent action of corrosion inhibitors. These two effects will lead to a drastic increase in corrosion rates. Typical acid secretors include *Acetobacter aceti* [96] and *Lactobacillus delbruckii* [59].

2.5.4 Control

Control of MIC can take two approaches. The first is to limit the nutrient or compound that is metabolised by the bacteria and thereby remove the corrosion threat. This can be effective in the case of SRBs where removing the sulphate can reduce the overall corrosion [88]. If this is the case then limiting the concentrations of sulphate, nitrate and ferrous and manganous ions will help in limiting the corrosion rate. This is not always possible however, particularly in the case of the metal ions where abiotic corrosion will result in the release of these ions into the water.

Another related approach is to limit the assimilable organic carbon (AOC) in the water. These are the short organic compounds used by most bacteria to generate energy. Some water treatment techniques, such as ozone treatment, have the effect of increasing the AOC content of water [80]. Where ozone treatment is used, some adsorption technique to remove organic carbon should be employed to compliment the technique. However, in some situations this is not possible or practical. Also the problem with microbial control is typically not the nutrient content in the water, but the content where there is accumulation. Therefore another control method is generally used to prevent significant microbial growth.

The second approach to controlling biological growth and MIC is the use of biocides. While biocides cannot kill every organism that may be present in water and are far less effective against biofilms, they are useful in controlling population growth. This control will help minimise the effect of MIC even when the other conditions may be favourable. Typically water is treated using chlorination (addition using chlorine gas, sodium or calcium hypochlorite or chlorine dioxide) prior to its being provided by a water supplier. In the case of recycled water, to ensure an almost zero health risk large chlorine residuals are left in the water (when compared to the potable supply) to ensure there is adequate biocide available before the water is used. However, in large industries or areas of a plant where the water is stagnant or recycled extensively, this chlorine residual may be lost and further biocide may be required. Also the presence of organics in the water will consume chlorine removing its protection at a greater rate and requiring replenishment.

Biocides can be separated into two main classifications: oxidising and non-oxidising. In general, while oxidising biocides are highly effective and microbes should not develop a resistance to them, they will decompose quite quickly removing long-term protection. Non-oxidising biocides on the other hand tend to be more stable, providing significant long-term protection. They also suffer from less interference. The main drawback to their use however is the ability for microbes to develop immunity. If the immune population grows significantly, all biological control of the system may be lost. The results can be quite dramatic [25]. It is generally recommended therefore that a biocide program uses both oxidising and non-oxidising biocides in order to be most effective [25, 58].

2.5.4.1 Oxidising Biocides

The most common oxidising biocide is chlorine. It may be used in the form of chlorine gas, chlorine dioxide or hypochlorite. While sodium hypochlorite is the typical chlorination compound used, others such as calcium hypochlorite may be of greater value due to the high sodium contents often witnessed in wastewater streams and the greater ease with which calcium can be removed. This is particularly important in the west of Melbourne where salinity is a problem in the sewage system. Chlorination is pH dependent becoming less effective as the pH decreases. More importantly it is a non-selective oxidant meaning it will oxidise any material available particularly organics [58]. It also reacts with ammonia. The loss of chlorine over time is one of its most significant drawbacks. However, it is inexpensive, easy to use and relatively reliable. The residual is also easy to measure meaning online monitoring and further addition can be simple. Chlorine is generally recommended in any biocide treatment regime [58].

Other halogens may also be used as biocides with bromine sometimes used in cooling tower treatment programs. They operate in a similar way to chlorine, where their lower volatility is an advantage, however they are slightly less oxidising and therefore less effective.

Ozone is gaining popularity in treating water as it does not leave the harmful disinfection by-products (DBP) that chlorination can produce [58]. However in non-potable applications DPB are less of a concern. It is actually the decomposition intermediates of ozone that are biocidal [58]. While these are effective they are not stable in water meaning the residual does not remain much beyond the point of application. Also ozone treatment leads to an increase in AOC and increases the likelihood of biological regrowth [80]. Removal of these compounds after ozonolysis is important. Ozone does have the advantage of also removing colour by breaking down organic colour-causing compounds [97].

Addition of ammonia with chlorine leads to the formation of chloroamines, which are also used as an oxidising biocide. The reactivity of chloroamines is lower than that of chlorine, which means that it usually retains a residual concentration in the water for a longer period of time and for this reason it is used in distribution systems with long residence times. However, its lower reactivity compared to other oxidising biocides means that other disinfection processes (eg. UV disinfection) are often used to provide the initial disinfection of the water, while the chloroamines are used to maintain disinfection within the distribution system. Chloroamination is also used to prevent biofouling in some membrane systems, as the lower oxidising strength is less detrimental to the membranes.

UV radiation is also popular. However its efficacy is reduced if the water quality is not high; that is, if there is a high level of solids able to scatter the radiation or chemical compounds able to adsorb it [58]. It also lacks a residual meaning regrowth after treatment is inevitable. It is more typically used in conjunction with hydrogen peroxide or followed by chlorination to provide a residual. The peroxide radical generated by the UV radiation is a very effective biocide. However its residual is short lived leading to the possibility of regrowth.

Table 2.17. Common non-oxidising biocides in industrial use sorted by their primary biocidal action.

Electrophiles	Lytic Agents	Protonophores
Isothiazolones	Quaternary ammonium compounds	Weak acids
Heavy metals	Biguanides	Parabens
Copper	Phenols	Pyrithiones
Silver	Alcohols	
Carbamates	Surfactants	
Bronopol		

2.5.4.2 Non-oxidising Biocides

There are a large number of non-oxidising biocides that are available for use. They differ greatly in mechanism relying on passing through or destroying the microorganism's membrane by acting on a specific target location. The mechanisms of many non-oxidising biocides, though well-studied are not particularly well-known and may actually comprise multiple mechanisms. For example, the isothiazolone 5-chloro-n-methylisothiazol-3-1 (CMIT) is known to oxidise thiol groups in proteins that ultimately influence enzymatic function interrupting metabolic pathways and limiting growth leading to cell death [98]. However, there have also been suggestions that CMIT may also react with amine groups in proteins with similar effect [99]. CMIT also appears to effect DNA synthesis within the microbe [99]. In general however, classes of biocides are associated with a particular action.

Table 2.17 contains a list of common industrial non-oxidising biocides and their primary action. Electrophiles act by oxidising or reacting with the thiol or amine groups of proteins inhibiting specific functions and ultimately leading to cell death. Lytic compounds act by damaging the membrane of the cell ultimately resulting in the leakage of intracellular components and eventually death. Protonophores prevent the movement of protons across the cell's membrane preventing production on important compounds such as adenosine triphosphate (ATP). What is important to note is that these compounds will act on specific sites. It is possible for mutations to occur and for microorganisms to develop resistance simply by closing the pathway that was originally available to the biocide. In doing this it is possible for cross resistance to develop, that is to say that the resistance will not just stop the biocide that had been used but potentially other biocides that used similar pathways. It is important that any resistant population be killed to ensure the biological control can be maintained [58]. For this reason it is generally recommended to use both oxidising and non-oxidising biocides to help control the growth of biofilms [25, 58].

2.5.4.3 Film Removal

The other main chemical treatment used against biofilms aims to remove the film. This is typically performed using a surfactant such as quaternary ammonium compounds. The aim of such compounds is to remove microorganisms from the protection afforded by the biofilm and make them more susceptible to biocide attack [58]. A secondary process is to remove the inactivated microbes from the film [100]. Though quaternary ammonium compounds often fulfil this role due to the fact they also possess biocidal activity, their efficacy has come under attack [100]. Regardless the use of a surfactant to help remove the film is strongly recommended [58].

2.6 Perceptions and Company Image

2.6.1 Introduction

One of the concerns often expressed by companies considering taking recycled water is the image of the company and its product. The primary concern is the potential impact on sales of product made using recycled water. A lack of understanding in the general public and media particularly can fuel concerns that even if the water is not in contact with the product the consumer will view it as tainted. Consequently there is often a focus on the negative. However, it is possible to take the use of recycled water and put a positive light on it to improve the company image and show a practical approach to environmental performance. This is particularly important in the major Australian cities with the current concerns about water consumption and the willingness of the media and government to "out" the large water users [101].

2.6.2 Consumer Perceptions

When considering recycled water it is vital to understand the effect the use will have on potential product sales. This in a lot of cases will be negative. There is much discussion in the literature and media about the "yuck" factor of recycled water. This is a psychological aversion to recycled effluent that results from people association of sewerage with contamination. It is particularly strong in drinking recycled water. With most opposition voiced through "toilet to tap" advertising campaigns. A study into the psychological affects of drinking recycled water from a number of sources and from eating foods grown with recycled water showed 20% suffered a feeling of disgust for each use despite the fact respondents were actually drinking potable water for each test [102]. This problem is not easy to overcome.

Of more significance to industrial use of recycled water comes from the reasons behind the aversion named the law of contagion [103] or law of sympathetic magics [104]. This psychological principle states when something that is perceived as contaminated comes into intimate contact with another object, that object is then perceived as contaminated. Recycled water has been in contact with raw sewage and is therefore perceived as contaminated, resulting in the "yuck" factor. Any further objects touched by this recycled water can also be perceived as contaminated although the perceived level of contamination may be decreased. Consequently any product made with recycled water runs the risk of being perceived as contaminated by the consumer.

Investigations into public acceptance have typically revolved around the potential use of recycled water to supplement drinking water supplies. Though these cannot be directly related to industrial use there are some important trends that are worthy of mention:

- Public acceptance is strongly tied to the intimacy of the use with the consumer [102]. That is to say the closer the use comes to a person, the more likely they will be opposed to it. Drinking will be strongly opposed followed by cooking and washing laundry while watering a garden is less likely to be a problem. The same can be inferred in product use. The use of recycled water to make car parts or computer chips is less likely to be an issue that the use of recycled water to make tinned fruits or packaged vegetables. The use of recycled water to make newsprint will be less opposed than the use to make facial tissues. The use of recycled water to dye carpets will be more acceptable than the use of recycled water to dye clothing. This does not say people will be strongly opposed to the use, it just provides a relative scale on which opposition can be measured.

- Public acceptance will decrease when a recycled water use is salient [105]. While people may be accepting of the use of recycled water for drinking when the questions is posed theoretically, as the use enters into reality public acceptance can drop significantly.
- Public acceptance of recycled water is directly related to trust [106]. This is probably the most important aspect of recycled water use. The public will be more accepting of recycled water where they feel the proponents (the government, water authority and end user in industrial reuse scenarios) can be trusted. This will also mean that the process by which the project advanced should be open and transparent so people can understand how the decision process occurred. In reality this applies to all projects where a person can perceive an impact to himself or herself.
- Public acceptance of recycled water may be changing over time [107]. This is also an interesting issue as current trends suggest a decrease that may be related to the negative publicity recycled water tends to generate and the level of trust people have in water authorities, government agencies and large corporations. It has yet to be addressed to any significant degree in the literature, but as noted may be related to the level of trust people have in the environmental performance and their review of responsibility of the relative agencies involved. It may also be related to the level of water stress, with recycled water demand probably increasing in times of water hardship. The link may therefore be somewhat tenuous.
- Public acceptance is related to knowledge. This is an obvious relationship, and may be addressed using education and community outreach. However, the success of these programs in overcoming the “yuck” factor may be limited, as this feeling is psychological in nature and cannot be considered the result of a “rational” decision. The Australian Guidelines for Recycled Water contains a chapter devoted to the development of community outreach and education programs [2].

Studies into the public acceptance into the use of recycled water for various industrial uses have been performed in the past (1960s and 1970s) [108]. Importantly, these studies were also performed in the United States and therefore won’t be entirely relevant to a current Australian market. More recent Australian surveys tend to focus on acceptance for domestic or irrigation purposes rather than industrial uses. However, some conclusions can be drawn from these older studies.

Table 2.18 shows the percentage of respondents who objected to a range of recycled water uses, including industrial uses. What is important to see from these values is the higher percentage objection with different scales of the same use. For example the use of recycled water in the manufacture of canned vegetables is of equal objection to its use in cooking. This is due to the higher degree of human contact or ingestion between the recycled water product and the consumer. Other uses where the link to human exposure is low, such as air conditioning or cooling are rated low, even though there may be health risks involved. As will be noted later union opposition to the use of recycled water for fire fighting was the primary reason for the Illawarra Recycled Water project stalling for almost a year [109]. In general it must also be kept in mind that there may be exceptions to these perceptions due to local sensitivities and projects are best analysed on a case by case basis.

Table 2.18. The percentage of objection to certain uses of recycled water taken from the 1960s and 1970s in American markets [108].

Use	% Objection
Food Preparation in Restaurants	57
Drinking	53
Preparation of Canned Vegetables	49
Cooking	49
Swimming	22
Home Laundry	20
Manufacture of Tissues	20
Commercial Laundry	18
Irrigation – Dairy	16
Irrigation – Processed Foods	16
Irrigation – Vineyards	15
Commercial Air Conditioning	9
Electronics Plant Process (Wash) Water	7
Toilet Flushing	6
Industrial Cooling	3
Industrial Air Conditioning	2
Fire Fighting	2

Using this data it is possible to determine where public acceptance will have a significant impact on the potential sales of a product, *regardless of where the water is used*. In industries where the level of acceptance is low, the understanding of processes by media and the public will not necessarily aid in the level of acceptance. Use of recycled water in a cooling process for instance, though it does not contact the product, will not necessarily be viewed in a different light from an instance where the water does contact the product. This will result in a high likelihood of consumer backlash where it is understood recycled water has been used. Consequently it is strongly recommended that processed food and beverage, pharmaceuticals and cosmetic and toiletry manufacturers not use recycled municipal wastewater in the manufacturing process (Note that it is not legal for food and beverage manufacturers to use water other than potable water [110]).

It could be speculated that other industries may be relatively safe from potential backlash if the trends in Table 2.18 are followed. Two that may be of interest to note are the paper and textile industries. From Table 2.18 tissue manufacture is subject to a relatively high level of opposition. This statement could be widened to include other forms of paper, but with reduced opposition levels. Though there is some opposition, this has not prevented paper and tissue manufacturers from successfully operating with recycled water in Japan, the United States and South Africa [30, 111-113]. Branding may also have a significant impact on consumer confidence in a product. It was noted in a study of facial tissues that the brand name was more important to the consumer than the use of recycled water [108]. If the manufacturer is entirely open about the use and does not seek to hide it or aspects of it, the trust generated should increase the acceptance of the use and therefore the product. It should be possible to turn a potentially negative situation around and stress the environmental significance of what is being done. This has been achieved in irrigation uses by taking a proactive approach of informing the public and emphasising the positives of the use [114].

2.6.3 Employee Perceptions

Maintaining a positive image to the use of recycled water onsite is also a very important issue. Negative images or publicity can halt a project similar to community objections halting potable recycling schemes. One very potent example of this is the BlueScope Steelworks in Port Kembla [115-117]. In this instance the union for the New South Wales fire brigade refused to fight fires at the site due to the use of recycled water in the plants fire control system. Citing potential health effects a protracted industrial action was fought between the union and the New South Wales government, during which time the plant was provided with potable water, while the recycled water was sent to ocean outfall. The union was asking for indexed death and disability benefits for financial protection if they got sick using the water [118]. The issue was eventually resolved by arbitration from the Industrial Relations Commission.

Industries in Chennai, India similarly faced opposition from workers when switching from potable to recycled water. In this instance education programs were used to assure the workers the water was safe [119].

In general, employee concerns are going to be with the safety of the water. Keeping employees on side will require open and transparent communications from management particularly focusing on this issue. It should be remembered there are two primary health concerns with recycled water: trace compounds (eg endocrine disrupting compounds and pharmaceuticals) and pathogens (eg bacteria, viruses, protozoa). Due to the way in which industrial water is used, workers would only be at risk to exposure from pathogens. Where a Class A or greater recycled water is used, there should be no risk as these waters are considered pathogen free. Class B and C will be disinfected, but should still be treated with caution and will require some controls and barriers.

When taking recycled water, a thorough communication strategy between management and the workforce should be undertaken. The main part of this would encompass:

- Communicating exactly what the water is, where it will be used and what health controls are in place (sometimes, due to the nature of the water used initially, no further controls will be needed, alleviating most concerns).
- Explain how production is likely to be affected by the use of recycled water.
- Determining worker concerns and addressing these concerns.
- Communicating to report issues and how issues will be resolved during operation.

Further ideas and issues may be found in the Australian Guidelines [2]. It is important that, at all times, the communication is two way and open. This will ensure that employees will feel confident that the changes made onsite will not affect them.

2.6.4 Marketing Considerations and Company Image

2.6.4.1 Marketing – Defensive Response

As a drought becomes more severe in nature, the media will focus more on water use and large water users. The process of “outing” large water users is a very real threat. It was performed recently in Sydney by the Sydney Morning Herald [101] and the Top 200 have been publicly listed in Melbourne (this process will be repeated every financial year). This process may tarnish the name of the big water users unless they can present a defence of their use. In the case of Sydney, BlueScope, Qenos, Caltex and the coal terminals in Wollongong and

Newcastle were named as some of the largest users and those that were increasing their use, such as Centennial Coal's Tahmoor coal mine were particularly focused on. In this case, BlueScope was able to successfully defend itself due to its use of recycled water and the fact this was still included in the figure as it was purchased from Sydney Water. The plans underway at Caltex and the Port Waratah Coal Terminals were likewise able to help in their defence. In Melbourne the driving force for Qenos' water projects has been to move out of the top potable water users [120].

The negative stigma attached to appearing on such a list of large water users is significant. One way to ensure a positive public image is to try moving down this list as much as possible. Using recycled water is one way to implement this.

2.6.4.2 Marketing – Proactive response

The growth of the environmental movement in the 1980s and 1990s has placed environmental issues on the public agenda. As part of this, consumers are looking more to companies they purchase from to behave responsibly on environmental and social issues. This has led to a growth in the use of green marketing or green advertising, that is marketing that emphasises the green qualifications of a product or company. Examples can be easily found in the media daily. For instance petroleum giant BP has pushed its environmental credentials recently. Interestingly part of this campaign has seen the BP logo associated with a flower and have shifted the focus of the acronym BP to "beyond petroleum." The aims of BP's campaign have been to emphasise its investigation into other fuel sources and to highlight the sustainable way in which it recovers petroleum and other products. The main question however is whether such campaigns are successful.

As has been noted is Sections 2 and 3 trust is of great significance when approaching environmental issues and cannot be ignored in respect to green marketing. Green marketing during the 1990s was plagued with issues of unproven, inconclusive or unrealistic claims [121]. This led to what has been perceived as a backlash against products using green advertising. This is now being challenged and the current belief is that all companies benefit financially from green marketing strategies.

Crane [121] divided green marketing strategies after the perceived backlash into 4 groups:

1. Passive greening. This is essentially a reactive or defensive approach. Greening and marketing are driven only by pressure from external groups such as activists or government organisations. In terms of recycled water use passive greening is investigation of recycled water to prevent the negative publicity of being names as a large potable water user as outlined in Section 4.1
2. Muted greening. This is a proactive approach where environmental change is initiated within a company that is not driven by external pressures. It is characterised by its advertising methods. The product is not marketed as environmentally friendly (there will be nothing on the packaging), but information on the product and the company, such as pamphlets and media releases, will emphasise environmental issues. This approach is often supported by the literature. Mathur and Mathur [122] recommend that advertising to enhance a company's image should be moderated and focus on communicating environmental facts. Thogersen [123] also cautions against strong environmental marketing due to the nature of media attention and the more hostile environment such marketing faces. Recycled water is often used as part of muted greening campaigns by industry with

information of the water use available through press releases and environmental reports, but not necessarily in heavy use during advertising.

3. Niche greening. This proactive marketing approach highlights the environmental benefits of a product during its advertising and aims to target the environmentally conscience consumer. This type of marketing can benefit significantly from recycled water use. An example is the Rocky Point Cogeneration Plant on the Gold Coast, Queensland, a biomass fuelled power station that uses recycled water. These campaigns are generally highly focused on a small consumer market and are not particularly prevalent at the present time.
4. Collaborative greening. This marketing strategy tends to overlay one of the other three approaches. It focuses on working with other groups or organisations (including competitors) to build a strong environmental position. This could be in the form of certification from an NGO that is viewed as more trustworthy due to its impartiality or could take the form of pressuring suppliers to move towards more environmental, sustainable practises. In this respect the supply of recycled water to a particular region, such as in the Kwinana Water Reclamation Plant, can provide opportunities for all three green marketing techniques.

In terms of risk, muted greening is the lower risk approach, but with no guarantee of success. Niche marketing, is higher risk but can result in greater financial return where correctly managed, while passive greening suffers at least some negative impact before a knee-jerk response can be made. When benefits of recycled water are highlighted, they should focus on benefits specific to the case in question. That is they should not just state the pollution loads are reduced, but where they are reduced. Possible benefits to consider are:

- Potable water used is now available for drinking
- Decreased pollution loads at sewage discharge points, greening the local environment
- Maintaining groundwater levels to ensure other users have access, to prevent seawater intrusion or simply to ensure sustainable water practises
- Reuse of a valuable public resource, reducing ecological footprint.

One other point of interest is the naming of a project. This will have an effect on how it is perceived. Singapore's NEWater project has used its brand to successfully market the product and provide a cleaner, more acceptable image for the product. In terms of industrial projects, one of interest is the project to expand the recycled water available to Chevron's refinery in Richmond, California [124]. This has been dubbed the Richmond Advanced Recycling Expansion, or RARE for short. This name is perfect for the San Francisco Bay area as water is a rare resource needing to be imported from other parts of the state. Emphasising this has served to emphasise the benefits of the project and is therefore a positive for both the water providers (East Bay MUD) and Chevron.

The financial impact of green marketing has been heavily studied and trends have shown an increase in profitability for both large and small businesses [125]. In terms of purchase intentions, it has been shown that focusing on environmental performance can be more effective than focusing on price [126]. Stock price index has also been shown to be largely unaffected by green strategy announcements when using a muted strategy, although a niche strategy can see a slight dip depending largely on company size [122]. The most recent studies have shown that there is a competitive advantage to be gained from employing environmental practises [125] and the use of recycled water could be an important part of this.

2.6.4.3 Recognition and Awards

One other positive way to use recycled water for the benefit of a company's public image is in recognition programs and awards such as the savewater! Awards and the Banksia Environmental Awards. These programs are very useful to enter as the proponents will investigate what is being done and how to further improve. Some awards, such as the Telstra Business Awards claim to benefit the entrants by making them look at what they are doing in detail, often showing areas where efficiency can be improved along the way. Putting all the information of a company in one place also benefits the operators as a more accurate picture of the company can be found. Importantly these awards provide a free and positive marketing platform for the winners and the runners up regardless of their focus.

Some of the awards of interest include:

A. savewater! Awards
(http://www.savewater.com.au/)
Identifies products, organisations and individuals who have demonstrated innovation and commitment to deliver efficient water usage. Winners receive:

- Prestigious savewater!® trophy and framed certificate
- Acknowledgement (corporate name and logo) in media advertisements on announcement of awards
- 12 month use of the savewater! award® winner logo
- Case study on savewater.com.au, Australia's leading source of water conservation information and advice (sympathetic to confidentiality issues)
- Media and publicity opportunities following the announcement of winners (where appropriate)

B. Banksia Environmental Foundation Awards
(http://www.banksiafdn.com/)
The Banksia foundation was founded to support and recognize members of the community, including companies, that have made a significant contribution towards the environment. There is a Water category that can be awarded to a company or business that has enhanced or conserved freshwater and marine environments (this could be though the reduction of pollution to waterways). There are also categories for climate (reducing greenhouse gas emissions) and sustainability (minimising ecological footprint). Presents a positive nation-wide marketing opportunity.

C. Premiers Sustainability Awards
(http://sustainabilityawards.vic.gov.au/)
These awards recognise individuals and businesses that have made a substantial effort towards reducting their environmental impact. Presents a positive state-wide marketing opportunity.

D. Local Council Business Awards
Some local councils (e.g. Wyndham City Council) have business awards that extend from small business to large corporations headquartered in their region. Schemes that benefit the local community may be recognized and provide potential local marketing opportunities for winners.

E. Australian Business Awards
(http://www.businessawards.com.au/)
The awards support organisations that are committed to business excellence. There are awards in a number of categories including: Environmental Responsibility; Corporate Social Responsibility; Innovation; Design; and Community Contribution. Presents a positive nation-wide marketing opportunity.

F. Telstra Business Awards
(http://www.telstrabusinessawards.telstra.com/)
Through extensive promotion and publicity, the Awards enable businesses to promote their achievements to the broader community, including the media, potential customers and new partners. Categories are based on the size of the business. Presents a positive nation-wide marketing opportunity.

G. Grow Me the Money
(http://www.growmethemoney.com.au/)
This is a rewards program rather than awards. By joining the project and performing environmental initiatives, businesses can earn points. These points can be redeemed to obtain support from consultants, training and education and access to resource-efficient products. The recognition program has four levels that can be used by members for 12 months. Increasing through the levels requires commitment to the program. The program will also help by providing intensive media coverage of the efforts made by members.

CHAPTER 3 Specific Considerations – End Uses

The following chapter is a discussion of significant water end uses. The focus is on the common industrial uses of cooling, boiler feed (steam generation), and washing, although some other minor processes are also considered. Importantly, although there is some information in Section 3.9 about specific process uses such as water in the paper/pulp and textile industries, these have not been considered in as great a detail due to the complexity and the number of industries involved.

The focus of each subchapter will be on addressing typical concerns with recycled water in the specific end use, identifying problem areas and suggesting solutions. There is also a discussion of the inherent benefits in the use of recycled water for the application under consideration.

3.1 Cooling Water

3.1.1 Introduction

In industrial processing, water is typically used to cool streams and condensers. While air can be used it is highly inefficient and expensive, as a result water is unlikely to be replaced in this role. In heavy industry 50 to 90% of the water used onsite can go towards cooling streams. Cooling also represents the most common use of recycled water with 90% of recycled water in industry going to cooling makeup [127].

There are two main types of cooling water: once-through cooling and recirculating evaporative cooling. Once-through cooling takes cool water from a cold source circulates the water through the system once (where it takes the heat from the process streams and/or condensers) and returns it to the cold source. In order to maintain the low temperature of the cold source and the necessary flow rates of the cooling system, the cold source must have a very large volume (See Figure 3.1a). Typically it is a bay, lake or river depending on the location. Artificial lakes are sometimes created for such cooling systems using recycled water [128]. The environmental impact of once-through cooling, in particular the discharge of warm, contaminated water into sensitive marine environments in the case of seawater is resulting in increasing pressure on companies to phase out this type of cooling [129].

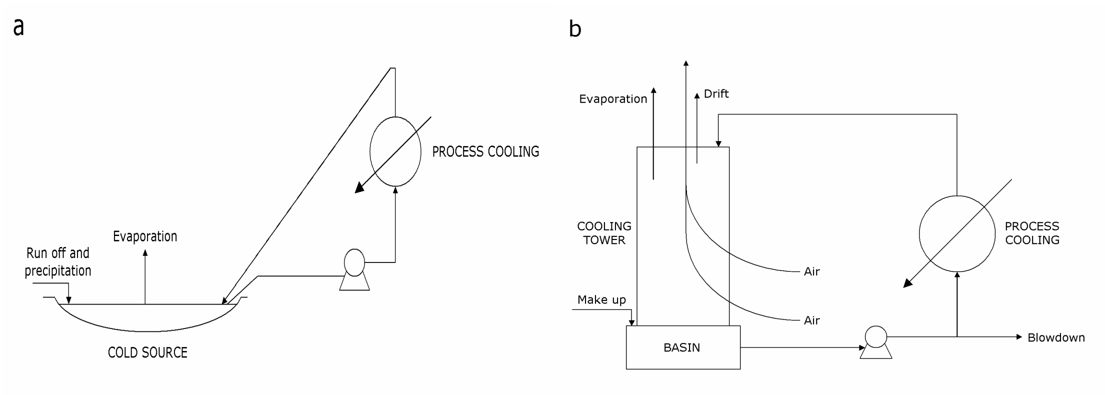


Figure 3.1. Depiction of (a) once-through cooling and (b) recirculated cooling.

Recirculated evaporative cooling recirculates the water through the cooling system numerous times. Cooling of the heated water is achieved in cooling towers. In these the water is passed through the tower from top to bottom while air is drawn through in a counter current direction. The evaporation of a portion of the water efficiently lowers the temperature of the surrounding water (the evaporation draws heat energy from its surroundings). This also requires additional water in the form of makeup to be added to the system on a regular basis. Water may also leave the tower in the form of drift, that is water in aerosol form leaving with the steam plume from a tower. Modern cooling towers are constructed in such a way as to minimise this from occurring. While drift will take dissolved constituents in the water with it, evaporation will not. The concentration of constituents in the water will increase as evaporation occurs and more is introduced through the makeup water. To combat this water is bled from the circuit periodically or constantly. This is termed blowdown. The water balance of a cooling tower is shown in Figure 3.1b.

The ratio of the evaporation to blowdown rates gives what is termed the cycles of concentration [56]:

$$\text{Cycles} = 1 + \frac{E}{B + D}$$

Where E is the rate of evaporation, B is the rate of blowdown and D is the rate of drift. Essentially multiplying the concentrations of constituents in the makeup stream by the cycles of concentration will give their approximate concentrations in the recirculating water (and the blowdown stream). So where the evaporation and blowdown rates are equal, the tower is operating at 2 cycles of concentration and the concentrations of species in the circulating water is twice that of the makeup. Controlling the cycles of concentration through the blowdown rate is used to help control scaling and corrosion issues by preventing concentrations of target species rising above critical levels. The achievable cycles of concentration are a function of input water quality. In Sydney, Melbourne and Canberra 10 cycles of concentration is achievable with reticulated drinking water, while in Adelaide, Brisbane and Perth 5 tends to be the maximum [36].

3.1.2 Important Characteristics

The effect that water will have on the cooling system will depend on the materials used in the construction of the heat exchangers, pipework and the tower itself. In general these are made of carbon steels, copper or copper alloys (particularly admiralty brass). There is also a possibility that the setup will be made of stainless steel or titanium where particularly corrosive waters have been previously used (such as in once through seawater cooling). Each of these will be subject to corrosion that can be accelerated by the presence of certain species. The problems with corrosion are discussed in section 3.1.3.1.

Typical construction of a cooling tower uses the metals described above, however some of the larger ones may be constructed using concrete that will also suffer from the effects of corrosion. This corrosion will depend on the porosity and the type of reinforcement used. This is discussed in Section 3.1.3.1. Wood is also typically used in cooling tower construction. The deterioration of wood represents a significant problem when it comes to the lifespan of a cooling tower. Influences on wood deterioration are discussed in Section 3.1.3.2.

As well as the materials used in the construction of the towers, the packing used in the cooling tower is also of significance. It is important that material can pass through the tower without being trapped in the packing and fouling the system. The threat here comes from suspended solids and biological growth.

3.1.3 Potential Problems and Solutions

3.1.3.1 Corrosion

Where copper and copper alloys are used one of the main concerns is ammonia. Catastrophic failure of copper-based components through stress corrosion has been reported at concentrations as low as 2 $mg.L^{-1}$ of ammonia [23]. In lower quality recycled water, such as tertiary treated recycled water used in Chevron's El Segundo refinery, nitrification is important in order to convert the ammonia to nitrate [23]. There are a number of examples (for example, Saudi Aramco's refinery in Riyadh, Saudi Arabia [25]) where nitrification has been found to occur in the cooling tower basin and the ammonia levels in the recirculating water are kept low. This has the added benefit of generating acid and reducing alkalinity in situ, and at least one site using secondary treated recycled water has practised adding ammonia to the feed to generate enough nitric acid to prevent scaling in the cooling system [130]. While this approach has been successful, others relying on in situ nitrification have had trouble controlling the nitrification process sufficiently leading to either significant scaling or biological growth [25]. Nitrification as a pre-treatment process would be more appropriate allowing for control away from the point of end use and providing greater plant protection.

Chlorides are also a significant issue in regards to corrosion due to its ability to accelerate the process either through complexing with the dissolved metals preventing passivation or generating local acidity. Significantly this is also a problem for reinforced concrete. The Palo Verde Nuclear Plant outside Phoenix, Arizona has reported a significant decrease in the life of the cooling towers since switching to recycled water [26]. This was due to the use of a porous concrete and uncoated reinforcing bars (rebars) in their towers. This will be overcome by using a less porous concrete and epoxy-coated rebars coupled with a barrier on the concrete to prevent permeation of species. In general, the chloride content should be controlled using the blowdown rate.

A general indicator of corrosivity of a water is the total dissolved solids (TDS) content. Higher TDS means higher conductivity and greater potential for corrosion. TDS can be reduced by some pretreatment depending on the quality of the water provided. Importantly, the TDS should not be too low as the water can lose the ability to buffer pH changes and this can, in turn, lead to greater corrosion. This is an issue that has been faced with the use of high quality water treated by microfiltration and reverse osmosis in some Australian sites [8, 29]. In Kwinana this has been overcome through the blending of the product water with a small amount of groundwater to increase the TDS [131]. A similar result may be achievable using a small amount of RO brine or the original recycled water prior to microfiltration, or lime and carbon dioxide to a specified pH and alkalinity.

3.1.3.2 Wood Deterioration

Wood is still commonly used in the construction of cooling towers and is at risk from chemical, physical and biological attack. Chemical attack is probably the most significant is terms of recycled water, not from the water itself, but from the treatment regimes. Delignification of wood occurs in the presence of oxidising agents and alkaline conditions [56]. Delignification results in the dissolution of lignin in the wood, leaving predominantly cellulose that can be easily washed away by the cascading water. This results in a thinning of the wood. It occurs predominantly in the flooded basin of the tower where wood is in constant contact with the water. In order to prevent the chemical deterioration of wood it is important to maintain a chlorine residual of less than 1 $mg.L^{-1}$ (preferably 0.3 to 0.7 $mg.L^{-1}$) and a pH below 8 [56]. It is highly recommended to use non-oxidising biocides in conjunction with a low chlorine residual in cooling towers containing wood.

Biological attack comes from organisms that convert and consume the cellulose component of the wood. This can be on the surface of the wood or internally. The organisms responsible are common air- and water-borne organisms and cannot be prevented from entering the system [56]. Surface rot occurs predominantly in flooded portions of the tower and is not as serious as internal rot that occurs in areas that are not in constant contact with the water. Both organisms can be controlled using biocides as described in Section 3.1.3.4. It is also best to routinely monitor the wood. The use of recycled water will not affect the rate of biological attack on wood.

Physical deterioration of wood arises predominantly from high temperatures changing the structure of the wood and parts of the wood adjacent to iron nail or fixtures. Deposits such as oil can also support the growth of surface rot organisms. As with biological attack, the use of recycled water should not significantly impact the rate of physical deterioration of wood.

3.1.3.3 Scaling

The most common forms of scale are calcium phosphate, silica and calcium sulphate, with calcium carbonate, calcium fluoride, magnesium silicate and iron phosphate sometimes contributing. The actual scale that forms is dependent on the composition of the feed water. When the concentration of a salt passes its solubility limit it will precipitate from solution. This presents a number of problems. The first is the blockage of packing in the cooling tower if the particles are large enough or are able to agglomerate. It is also possible for these particles to attach to the sides of pipes and the tower, particularly where a biofilm is present, leading to an increased rate of fouling. Furthermore, the solubility of many of these species decreases with increasing temperature, meaning they are more like to precipitate on the surface of the heat exchangers leading to poorer heat transfer efficiencies.

Scaling is really only a major problem in secondary and tertiary effluent, although blow-down is an essential component of cooling tower operation. MF/RO treatment leads to high quality water where the concentration of scale forming species is very low leading to low blowdown rates. Three techniques may be used to overcome scaling problems. Scaling can be controlled by pH adjustment. Typically calcium salts are more soluble at lower pH. By recirculating the water at a low pH it is possible to operate at higher calcium and phosphate levels than would be otherwise achievable. The use of antiscalants is a common control technique. Chelating agents, such as EDTA, are used to sequester the metals responsible for scale. Threshold inhibitors, such as short chain polyacrylates, retard the rate of crystal formation as the crystal is forming, causing it to redissolve [56]. Surfactants or dispersants may also be used as antiscalants. These prevent agglomeration of particles and to try to release particles on metallic surfaces of pipes and heat exchangers. The third way to control the onset of scaling is to control the concentration of the scaling species in solution. This can be done either as a pre-treatment or by controlling the cycles of concentration.

The scaling species of particular concern is normally phosphate as many of the phosphate scaling products precipitate as temperature increases making heat exchanger surfaces particularly susceptible. Calcium is also a problem, however its removal is difficult requiring ion exchange, reverse osmosis or electro dialysis reversal [56]. The biological removal of phosphate during typical sewage treatment reduces the phosphate content below the level of concern [56], however some sites perform further phosphate reduction using cold lime treatment. This process involves the increasing the pH to about 11 using lime ($Ca(OH)_2$). This results in the precipitation of calcium phosphate, calcium carbonate and magnesium salts as well as the removal of silica and hydroxyapatite [56].

As with corrosion enhancing species, cycles of concentration can be used to control the maximum concentration of scaling species in the recirculating water. If there is a concern with the level of a scaling species in the recycled water, decreasing the cycles of concentration by increasing the blowdown rate will be an option where all else fails.

3.1.3.4 Biological Growth

There are three significant problems with microbial growth. Firstly, the organisms adhere to surfaces forming deposits and interfere with heat transfer in the cooling systems [132]. There is also an increased corrosion potential due to the formation of corrosive by-products or the shielding of surfaces from corrosion inhibitors leading to under-deposit corrosion [88]. Such occurrences can be difficult to remove once established [88], although they can be controlled and further growth prevented [133]. Finally, there can be increased energy requirements due to the increased fluid frictional resistance [58].

There are two main factors that assist biological growth, microbes and the nutrients that support them [134]. In general the presence of microbes in the reclaimed water should be minimal due to the requirements imposed by regulatory bodies on its use [134]. The problem arises from the introduction of micro-organisms from external sources from airborne dusts and aerosols and in the ability of these micro-organisms to reproduce. It is generally accepted that biofilms exist on all surfaces and problems associated with biofouling control come not from the influx of micro-organisms, but from the increase in nutrients available to them [78].

These nutrients can take a wide variety of forms, but in general they are organic compounds in the water [78]. Some inorganic nutrients can include sulphates (eg *Desulfovibrio desulfuricans* was a biocorrosion issue in the sulphate-rich potable water of Johannesburg [88]), phosphates and nitrates (lead to the growth of algae where light is also present such as in cooling towers [78]). Probably the most significant biocorrosion source is from the *Desulfovibrio* genus. In recycled water, limiting the build up of potential nutrients is one way of controlling the problem. More important however is the use of biocides. Successful biocide programs are based around multiple biocides, including one oxidising biocide to ensure tolerance does not become and issue, coupled with biodispersants to remove the micro-organisms from the biofilms and increase the efficacy of the biocide [58]. Experiences at the Aramco refinery in Saudi Arabia have shown that, for lower quality recycled water, a more aggressive biocide regime, using an oxidising biocide, is required to ensure the smooth operation of the plant [25]. Where a tertiary treated recycled water is being used, industry often increases the biocide by 20% to ensure no fouling is encountered until a more scientific study of the case can be made and more reasonable levels used [23]. It is generally recommended not to use shock treatment to give a high residual, but longer chlorination times giving lower residual as these are more effective [21, 25] and safer for wood structured cooling towers [56].

3.1.3.5 Aerosols and Drift

In a case specific to evaporative cooling systems and cooling towers, concerns are often raised over drift and the potential for pathogens in the aerosols that may be present in drift [135]. This is also a concern of the surrounding community as has been highlighted in submissions concerning the Metcalf Energy Centre [136]. For cooling towers, probably the greatest concern is *Legionella*. Typically associated with air-conditioning cooling towers [55], there have been cases of Legionnaires' Disease outbreaks due to industrial cooling towers [54]. In general all these cases have been attributed to poor maintenance procedures and lack of biocide in the water to limit the growth of *Legionella*. *Legionella* is an opportunistic pathogen, not enteric (those pathogens commonly found in sewage), and is present in all water sources. It can enter a cooling tower as an aerosol from surrounding facilities or through any available water supply. Having noted this there have not been any reported cases of *Legionella* outbreak that was traced to the use of recycled water and a properly maintained cooling tower should not be the cause of a *Legionella* outbreak regardless of the water source [21].

There are considerable concerns about the possible presence of other pathogens in aerosols, in particular viruses. Studies into this have been performed by the Metcalf Energy Centre (a power station using reclaimed water as cooling water in California). These studies have shown no threats in the aerosols produced from their cooling towers [136].

3.1.3.6 Foaming

The formation of foams in a cooling tower is generally considered only an aesthetic concern. However if the foaming becomes severe enough the spread of the foam outside the cooling tower can be a serious issue [26]. The main cause of foaming is surfactants present in the water. The use of biodegradable detergents in most household and commercial applications means there is little threat from these compounds as there is little to no surfactants generally seen in the treated wastewater [137]. Naturally occurring surfactants may be found in the water as a product of algae death (and to a lesser degree as a metabolic product). While biological growth was discussed in Section 3.1.3.4, algae are particularly prevalent in cooling towers where light is able to enter. Restricting daylight through the use of covers will help decrease the potential for an algal bloom onsite and therefore decrease the risk of foaming. Surfactant contamination due to algae can also occur at the sewage treatment plant. While this is rare it is important to keep in mind if a foaming event occurs. The general practise with regards to foaming is to add an antifoaming agent (reduces the surface tension) when foaming is seen. No other action is required.

3.1.3.7 Discharge Water Quality

In a number of cases where recycled water is due to replace potable water, the quality of the blowdown is very important. These sites, such as Chevron's Richmond refinery [138] and the power stations involved in Queensland's Western Corridor Project [135], discharge their effluents into environmentally sensitive waterways and have pre-existing licensing agreements with the environmental authorities. In order to maintain these agreements, no increase above the levels specified in the agreements in terms of contamination of the recycled water would be accepted. Where it is not possible to direct the waste stream to the sewer, two possibilities remain: reducing the cycles of concentration and thereby increasing the blowdown rate and makeup volumes; or using a quality of recycled water that is equal to or higher than that of the water currently used as part of the license.

3.1.3.8 Manufacturer Recommendations

It must also be recognised that cooling tower manufacturers will also have water quality requirements with regards to the circulating water. This is particularly important in cooling towers that are still covered by a warranty in that exceeding these levels could void the warranty. There is wide variation between manufacturers as a result of different construction materials and different levels of acceptable risk. The recommendations of four companies are shown in Table 3.1. In general the quality requirements are not particularly high, and where there is a concern increasing the blowdown and reducing the cycles of concentration is an option.

3.1.4 Inherent Benefits

3.1.4.1 Tertiary Treated Recycled Water

The use of tertiary treated recycled water in cooling towers has two main advantages. The first is the presence of a low, but significant level of phosphates. While this may present a scaling problem, control of pH will alleviate this concern. A far greater impact is the corrosion protection phosphates offer carbon steels [23]. This occurs through the formation of a passive iron phosphate film on the surface of the steel protecting and substantially slowing the rate at which oxygen can diffuse to the surface. In some cases, such as the Chevron refinery in El Segundo and the Exxon Mobil refinery at Torrance, the amount of phosphate present in the tertiary effluent is high enough to require no further addition of a carbon steel corrosion inhibitor [23].

Another benefit from the use of tertiary treated recycled water comes from the nitrification process, whether this is as part of a pre-treatment or if it occurs naturally in the cooling tower's basin. The nitrification process will produce nitric acid that works as a mild steel corrosion inhibitor and an antiscalant, due to its acidic properties [130]. While this will not completely remove the need for additional scale control, both in terms of pH and dispersant, it will decrease the reliance somewhat.

Table 3.1. Manufacturer recommendations for circulating water quality.

Parameter	Superchill [36]	Marley [21]	BAC [21]	EVAPCO [21]
pH	7 to 8.3; 7 to 7.5 for light metals	6.5 to 9	7 to 9	6.5 to 8.0
Langelier Saturation Index	0	0 to 1	-	-
Hardness ($mg.L^{-1}$ as $CaCO_3$)	500; 1000 (with stabilizers)	800	30 to 500	50 to 300
Chlorides ($mg.L^{-1}$)	300; 50 (for austenitic steels)	455 galvanised steel; 910 stainless	125	200 galvanised steel; 400 stainless
Sulphates ($mg.L^{-1}$)	500	800	125	-
Iron ($mg.L^{-1}$)	0.3	-	-	-
TDS ($mg.L^{-1}$)	2000	5000	1000	10000
TSS ($mg.L^{-1}$)	50	-	-	-
Conductivity ($\mu S.cm^{-1}$)	1200	-	-	-
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	80 to 400	100 to 500	500	50 to 300
Nitrites ($mg.L^{-1}$)	200 to 700	-	-	-
Silica ($mg.L^{-1}$)	-	150	-	-
Ammonia ($mg.L^{-1}$)	-	10 to 25	-	-
Chlorine ($mg.L^{-1}$)	-	0.4 continuous; 1 shock	-	-
Nitrates ($mg.L^{-1}$)	-	300	-	-

3.1.4.2 MF/RO Treated Recycled Water

While MF/RO treatment requires greater energy and equates to greater running costs it does provide substantial benefits due to its low chemical content. Experience has shown that a significant reduction in all chemical treatments can be achieved when using the higher quality water [131]. This would go towards offsetting the costs to produce the water. Additionally, the higher quality of water generally allows for an increase in the cycles of concentration, greatly reducing the quantity of makeup water required, further reducing chemical treatment and water costs [68, 131].

3.1.4.3 General

Previous studies have shown that cooling systems are rarely optimised [21]. As part of any transfer to recycled water it is strongly advised to employ a consultant or specialist to advise on any changes to the water treatment regime in place for the system. Such cooling tower audits in the past have been able to suggest improvements resulting in significant savings for sites involved, even before considering the use of recycled water. A cooling tower audit as part of any transfer to recycled water has the potential to identify further areas for reducing costs.

3.1.5 Some Examples

3.1.5.1 Eraring Power Station, Hunter Valley, New South Wales

The Eraring Power Station located near Lake Macquarie in the Hunter Region of New South Wales is a 4 by 660 MW coal-fired power station [139]. It has been accepting recycled water, in the form secondary treated recycled water from the Dora Creek STP since 1995 (see Table 3.2 for the minimum water quality requirements). Eraring treat the water onsite using microfiltration (coupled with sodium hypochlorite disinfection) and reverse osmosis (see Table 3.3 for the minimum water requirements at this point in the process) to generate a high quality recycled water primarily for boiler feed, but it is also for makeup to some recirculating evaporative cooling systems. Approximately 1 $ML.day^{-1}$ of this treated water is used in the cooling system [139].

The Eraring treatment has been upgraded twice since 1995 to increase its capacity and Eraring have witnessed significant savings (around $1m a year) from the use of recycled water [140]. In twelve years of the use at Eraring, no operational problems have been reported [141].

Table 3.2. Maximum values of specific water quality parameters required of the treatment plant influent by Eraring Power [17].

Parameter	Maximum Value
BOD ($mg.L^{-1}$)	50
NFR ($mg.L^{-1}$)	50
Faecal coliform ($cfu.mL^{-1}$)	1000
Phosphorus ($mg.L^{-1}$)	15
Chloride ($mg.L^{-1}$)	180
Sulphate ($mg.L^{-1}$)	100
Silica ($mg.L^{-1}$)	10
Ammonia N ($mg.L^{-1}$)	15
Total Oxidised N ($mg.L^{-1}$)	15
Total Hardness ($mg.L^{-1}$ as $CaCO_3$)	150
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	150
Sodium ($mg.L^{-1}$)	130
Magnesium ($mg.L^{-1}$)	15
Calcium ($mg.L^{-1}$)	35
Temperature (°C)	28
pH	9.0
Al^{3+}/Fe^{3+} to P ratio	2.5:1

Table 3.3. Main quality requirements of water used in the cooling towers at Eraring [17].

Parameter	Maximum Value
Suspended Solids ($mg.L^{-1}$)	1
Silt density index	3
Reovirus (in 100 mL)	nil
Enterovirus (in 100 mL)	nil
Total coliforms (in 100 mL)	10
Faecal coliforms (in 100 mL)	1
Faecal streptococci (in 100 mL)	1

3.1.5.2 Chevron refinery, El Segundo, California, USA

The Chevron petroleum refinery in El Segundo (Los Angeles), California is a large facility capable of processing 270,000 barrels of crude a day. It has been accepting recycled water in the form of nitrified Title 22 water (that is, tertiary treated recycled water that has undergone additional biological nitrification to reduce the ammonia content) since 1995 from the West Basin Municipal Water District (see Table 3.4 for the water qualities). The site accepts 27 $ML.day^{-1}$ and receives no further treatment aside from chemical addition [23].

The quality of the recycled water has allowed Chevron to maintain the 4 to 5 cycles of concentration previously used with potable water. The presence of phosphates in the feed water has resulted in a reduction of the amount of steel corrosion inhibitor used. Overall Chevron saves $2.3m a year in water costs and has reduced its chemical treatment costs by 15% [142]. They have reported an overall improvement in the operation of the cooling system [142].

Table 3.4. Average and worst quality water received by Chevron El Segundo for use in their cooling towers [23].

Component	Average Value	Maximum Value
Conductivity ($\mu S.cm^{-1}$)	1240	1840
pH	7.6	7.8
Hardness ($mg.L^{-1}$ as $CaCO_3$)	143	214
Calcium ($mg.L^{-1}$)	41	67
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	78	133
Total Phosphate ($mg.L^{-1}$)	5	7.7
Ammonia ($mg.L^{-1}$)	< 0.5	1.3
Chloride ($mg.L^{-1}$)	215	302
Sulphate ($mg.L^{-1}$)	124	294
Nitrate ($mg.L^{-1}$)	84	116
Nitrite ($mg.L^{-1}$)	< 0.5	0.7
Silica ($mg.L^{-1}$)	19	27.6
TOC ($mg.L^{-1}$)	8.3	8.9
COD ($mg.L^{-1}$)	22	41

Table 3.5. Quality of water received by Rawhide Energy Station from Fort Collins prior to treatment [128]

Parameter	Value
Dissolved O_2 ($mg.L^{-1}$)	2.5
BOD_5 ($mg.L^{-1}$)	20
Coliform ($cfu.100mL^{-1}$)	1500
TSS ($mg.L^{-1}$)	20
Ammonia ($mg.L^{-1}$)	9-18
Nitrate ($mg.L^{-1}$)	1
Phosphate ($mg.L^{-1}$)	2-3.5
TDS ($mg.L^{-1}$)	400
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	125-210
pH	7

3.1.5.3 Rawhide Energy Station, Fort Collins, Colorado, USA

The Rawhide Energy Station in Colorado is a 250 MW coal-fired power station. It has been using recycled water for once through cooling since 1984. The recycled water is sourced from nearby Fort Collins and passes through an aluminium sulphate flocculation-clarification process and filtered in anthracite charcoal filters before being discharged into the 19 billion litre Hamilton Reservoir [128, 143]. The Hamilton reservoir is an artificial lake specifically created to provide cooling water for the Rawhide Energy Station. The phosphorus removal process is not associated with any technical concerns, but is instead aesthetically based aimed at reducing the potential growth of algae in the lake [128]. The use of the lake is beneficial as it allows the high level of suspended solids to settle before drawing the cooling water.

The lake was filled at a rate of 30 to 34 $ML.day^{-1}$ and operates with a 14 $ML.day^{-1}$ supply of makeup water (rainfall and runoff to the reservoir is insufficient). The power station itself uses approximately 930 $ML.day^{-1}$ of water from the reservoir for its cooling needs [128]. After one pass through the cooling system, the water is returned to the lake. The water quality as received from Fort Collins is shown in Table 3.5.

3.1.6 Suitable Water Qualities

In general secondary or tertiary treated recycled water with little to no treatment is acceptable for use in cooling systems, either once through or recirculating evaporative. Treatment in the USA is typically to a tertiary level, possibly with some nitrification or phosphate removal, while MF/RO treated recycled water is more common is Australia due to its concurrent use with higher quality processes such as boiler feed.

In terms of individual parameters, ammonia, alkalinity, phosphate, silica, TSS and TDS are considered critical due either to their corrosive nature or their ability to form deposits and scale. As noted above however, tertiary treated recycled water generally meets the low levels required for these parameters.

3.1.7 Best Practice

Where tertiary treated recycled water is due to be used nitrification may be necessary to reduce the ammonia content to less than 2 $mg.L^{-1}$ in the makeup water where copper based alloys are in use [23]. For greater control this nitrification should take place prior to entering the cooling tower system. Phosphate reduction or pH adjustment may be required where it exceeds 20 to 25 $mg.L^{-1}$ in the circulating water to minimise the chance of scaling [23].

For any quality of water, dechlorination with sodium bisulphite may be required where high levels of residual chlorine are present. Where the cooling tower is a wooden structure it is important that the chlorine level be reduced to less than 1 $mg.L^{-1}$ [56]. Where high levels of nutrients are present, an aggressive biocide program using a constant low level of oxidising biocide and additional non-oxidising biocide should be pursued.

A cooling tower audit by a cooling tower specialist is strongly recommended before transferring to recycled water. This will ensure an appropriate use of any chemicals for water treatment and the appropriate setting of the cycles of concentration. This will in turn result in a smoother transition to the new water source.

3.2 Boiler Feed Water

3.2.1 Introduction

In industrial systems, heating is often performed using steam. Steam also may be used to do mechanical work, such as drive turbines in power stations. Generation of steam can make up a significant portion of the water intake of petrochemical plants and represents the second largest water use (after cooling) in power stations.

In a steam generation plant (see Figure 3.2), water, regardless of its source, first undergoes some pre-treatment to remove salts that have the potential to generate scale or lead to deposits. This pre-treatment generally occurs through reverse osmosis or via ion exchange. After pre-treatment water passes through a deaerator where oxygen is removed and an oxygen scavenger is added to reduce the possibility of corrosion. From here the internal treatment chemicals are added. These are used to control scaling, corrosion and foaming and are described in more detail in Section 3. The economizer or pre-boiler utilises energy from various plant processes (eg the hot blowdown from the boiler) to heat the water before it enters the boiler, thereby saving energy.

The boiler is the most significant part of the setup as it is here that the steam is generated. The generation of the steam leads to a loss of pure water from the system. This in turn means that an increase in the concentration of contaminants in the water is inevitable. To combat this water is bled off, either intermittently or continuously, to reduce the buildup of solids in the system. This stream, known as the blowdown, must be minimised to ensure the overall efficiency of the boiler. A rate of 10% of the rate of evaporation has been set as an absolute maximum by the Australian Standards [144], the aim should be much lower than this. Consequently the water entering the boiler must be of very high purity to accommodate low blowdown rates and high degrees of concentration.

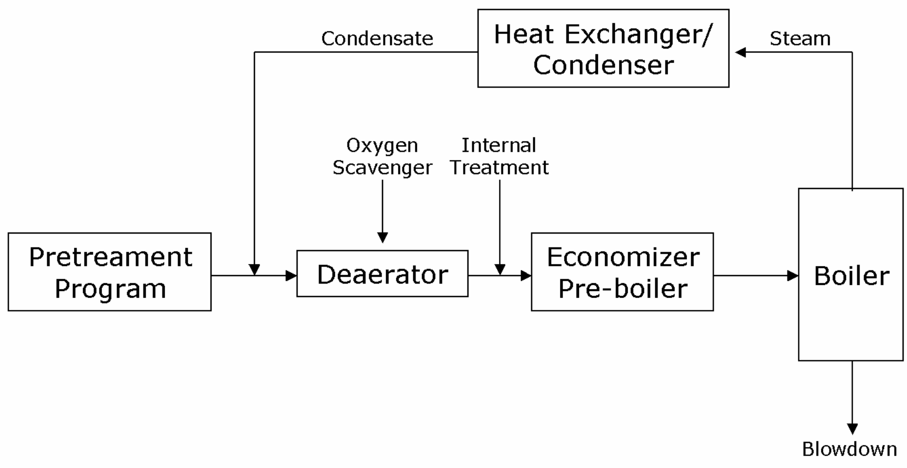


Figure 3.2. Generalised flow sheet of a boiler system.

The heat provided to a boiler can come in two main forms: hot gases from combustion reactions; or electric elements. Most industrial boilers generate heat from the burning of coal or oil and the transfer of heat from the flue gases to the water. It is also possible to heat electrically using an element. In these boilers, the heat transfer area is significantly lower and the potential for scale to form and its impact are both greatly increased [56].

The steam generated in the boiler is then sent to the processing section of the plant where it is either used as a source of heat or to perform mechanical work before being condensed and returned for recycling at the head of the deaerator.

Recycled water treated to an MF/RO quality has been successfully used for boiler feed in a number of operations in Australia and around the world with no reported problems [141, 142, 145]. Before using a new water source, however, it is important to take into account its effect on all of the components that make up the circuit.

3.2.2 Important Characteristics

The main purpose of a boiler is the generation of steam for use throughout the plant. The steam formed is conveyed throughout the site generally in carbon steel piping, while yellow metal or stainless steel condensers may be used [56]. One important thing to note is the high temperatures of the system and the increased corrosion rates this entails. It must also be kept in mind that volatile materials in the boiler feedwater will also go through this system. These gases, such as CO_2, SO_2 and H_2S are highly corrosive particularly in the presence of steam.

The purity of the steam produced in terms of liquid and solid content is also of significance, particularly where the steam is used to drive moving parts such as turbines. The potential for deposition or erosion of these parts is high where the steam becomes contaminated. Maintaining steam purity through the use of high quality feedwater is imperative.

3.2.3 Potential Problems and Solutions

3.2.3.1 Corrosion

The production of high purity steam in a boiler leads to significant concentration of contaminants in the boiler water. As was noted earlier this can be controlled through the use of periodic or continuous blowdown removing some of the highly contaminated water. This high level of concentration of contaminants can, however, lead to significant problems with respect to corrosion and deposition. In general the higher the operating pressure of the boiler, the worse the potential problem is [146]. This is complicated by the increased corrosion rates witnessed as a result of the higher temperatures in the boiler and pre-boiler in particular. In general very high purity water should be used, with significantly low levels of dissolved solids. Table 3.6 shows the recommended levels of the American Society of Mechanical Engineers (ASME) [56]. The concerns with feedwater concentrations are corrosion in the preboiler and deaerator as well as in the boiler itself.

The most significant problem with respect to corrosion in boiler systems comes from dissolved gases, primarily oxygen. This comes about for two main reasons. Firstly, it is directly responsible for corrosion. Most corrosion reactions require the presence of oxygen to occur. The high temperatures present in the boiler and in the steam infrastructure only help to accelerate this. Secondly, and perhaps of greatest significance, is the effect that oxygen has on the destruction of passivating films typically used to protect steel and copper in boiler systems [56]. These reduced oxide films are the primary defence against corrosion in boiler and steam systems. The presence of oxygen in the water or steam will fully oxidise these films resulting in loss of the passivation and increased corrosion rates. Deaeration is a must in boiler system, regardless of the water source. The use of an oxygen scavenger such as sodium sulphite for low pressure systems and hydrazine for high pressure systems is also of importance. Both of these compounds are corrosive to copper and its alloys, however, and must be used with great care [147]. With regards to recycled water, the presence of dissolved oxygen should not be significantly different to potable water where the water has undergone adequate pre-treatment (ie softening and deaeration).

The formation of other gases, such as CO_2, SO_2, NH_3 and H_2S, are also of considerable concern in a boiler due to the corrosion threat they pose. High alkalinity in the feedwater can lead to the formation of significant amounts of CO_2. This gas is particularly corrosive to steels in the presence on steam [134]. NH_3 is corrosive to copper and its alloys [23] and can be present in the water as ammonia or ammonium salts. SO_2 and H_2S also present a problem from the decomposition of sulphite and sulphate compounds. In general these compounds must be removed from the water before use. In a MF/RO treatment regime, followed by a polishing stage using either a second RO pass or an ion exchange softening, recycled water should meet the required criteria. Lower grade recycled water however, will have elevated levels of NH_3, SO_2 and CO_2 and are therefore not suited for this application without MF/RO equivalent pre-treatment.

Table 3.6. American Society of Mechanical Engineers Recommended Water Qualities for Modern Industrial Boilers [56].

Parameter	Drum Operating Pressure							
	0 to 2.07 MPa	2.08 to 3.10 MPa	3.11 to 4.14 MPa	4.15 to 5.17 MPa	5.18 to 6.21 MPa	6.22 to 6.89 MPa	6.90 to 10.34 MPa	10.35 to 13.79 MPa
	0 to 300 psig	301 to 450 psig	451 to 600 psig	601 to 750 psig	751 to 900 psig	901 to 1000 psig	1001 to 1500 psig	1501 to 2000 psig
FEEDWATER								
Dissolved O_2 (before scavenger addition) ($mg.L^{-1}$)	0.04	0.04	0.007	0.007	0.007	0.007	0.007	0.007
Total Iron ($mg.L^{-1}$)	0.1	0.05	0.03	0.025	0.02	0.02	0.01	0.01
Total Copper ($mg.L^{-1}$)	0.05	0.025	0.02	0.02	0.015	0.015	0.01	0.01
Total Hardness ($mg.L^{-1}$ as $CaCO_3$)	0.3	0.3	0.2	0.2	0.1	0.1	Not detectable	
pH	7.5-10	7.5-10	7.5-10	7.5-10	7.5-10	8.5-9.5	9.0-9.6	9.0-9.6
Chemicals for preboiler protection	use only volatile alkaline materials							
Non-volatile TOC ($mg.L^{-1}$)	1	1	0.5	0.5	0.5	0.2 or lower		
Oily Matter ($mg.L^{-1}$)	1	1	0.5	0.5	0.5	0.2 or lower		
BOILER WATER								
Silica ($mg.L^{-1}$)	150	90	40	30	20	8	2	1
Total Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	350	300	250	200	150	100	Not detectable	
Hydroxide Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	Not specified						Not detectable	
Specific Conductance ($\mu S.cm^{-1}$)	3500	3000	2500	2000	1500	1000	150	100

The potential for acid corrosion in the boiler is also high. In general the pH must be maintained above neutral to prevent the possibility of this form of corrosion [56]. A moderate level of alkalinity is generally required. This cannot be in the form of carbonate/bicarbonate due to the potential for the formation of corrosive CO_2 gases. The typical calcium carbonate salts used would also represent a scaling threat. The use of sodium hydroxide and amine based buffers is a more common approach [56].

Under deposit corrosion is also a significant issue as the water environment under a deposit can be significantly different (and generally more corrosive) than the properties in the bulk water. See Section 3.3.3.2 for a discussion of deposit formation issues.

High total dissolved solids will, of course lead to a greater corrosion rate, though in any boiler water feed TDS should be at a significantly low level.

3.2.3.2 Deposits and Scale

The concentration factor of contaminants in a boiler, the high temperatures of the water and the localisation of the evaporation also leads to high potential for deposition and scaling in a boiler system [56]. Scaling can be particularly destructive leading to increased heat loads to achieve the same heat transfer and can lead to the rupture of a boiler. Crystallization in boilers tends to be slower and therefore a more structure and tenacious scale forms that is resistant to most physical and chemical cleaning techniques [56]. Also once scale starts to form, the restriction of water circulation in the boiler can further accelerate its formation [56].

Scale can take a number of forms based around calcium, magnesium, silica, aluminium, iron or sodium salts [56]. Low content of these salts in feedwater is important meaning MF/RO treatment is generally a minimum. Scale can be controlled using either sodium phosphate (this precipitates calcium and magnesium salts in the boiler, but can only be used at low pressure) or by solubilising the salts using chelating agents. In general, however, the use of chelating agents can help control scale formation for all salts except iron [56]. Low iron content is important along with the use of polymers to assist in the dispersion of any iron salts that will precipitate.

Sludge deposition can occur from the precipitation of salts in the bulk of the boiler, or from the presence of suspended solids. Again the use of MF/RO treated wastewater, the use of a polymer dispersant and employing a satisfactory blowdown rate should control the accumulation of sludge in the boiler.

3.2.3.3 Steam Purity (Foaming and Carryover)

Further plant operations using steam can be significantly impacted by a poor quality of steam. This poor quality arises from carryover, which is liquid and solid components being carried with the steam into other sections of the plant. Carryover occurs to some degree in all boilers and it is only the extent and the effects of carryover that can be reduced.

The carryover of solids from the boiler entrapped in water droplets is a particular concern to the operation of mechanical parts such as turbine, where erosion or fouling can occur. The higher the TSS of the feedwater, the greater the amount included in carryover. Dissolved salts can also be an issue as they can precipitate from the water droplets and can significantly increase corrosion. Table 3.7 shows the recommended water qualities and the associated steam purity for a range of different boilers and emphasises the need for high purity feedwater, particularly for high pressure boilers.

Perhaps the only real difference that may be seen between recycled water and potable water is the potential for foaming. The formation of bubbles in the boiler greatly increases the rate of carryover as the bubbles will be able to overcome the measures typically used for carryover prevention. The threat from foaming comes from a number of sources including high alkalinity, high dissolve solids content (particularly of sodium and potassium salts [127]) and from oils and organics [134]. High alkalinity and TDS as discussed previously, must be reduced in a boiler system and the use of MF/RO should be sufficient for this task. The main threat in recycled water comes from the presence of surfactants in the form of detergents or algal breakdown products in recycled water and fatty acids that can undergo saponification in the alkaline conditions of the boiler. However, the increasing use of biodegradable detergents has lessened the threat from this source while natural surfactant production from algal cell breakdown can be controlled by covering storage tanks and reservoirs to minimise algal growth. Typical biological treatment and MF/RO should also reduce the levels of organics present in recycled water. While some increase in foaming has been seen in cooling systems using recycled water treated to a secondary level [26, 56] this has not been significant and the further reduction achieved with MF/RO treatment should virtually eliminate this effect although some small, neutral surfactant molecules may pass through the membranes. If foaming is detected, use of an antifoaming agent can significantly reduce the effect of carryover in a boiler.

Table 3.7. Recommended water tube boiler limits and the associated steam purities as suggested by the American Boiler Manufacturers Association [56].

Parameter	Drum Pressure										Once Through Boiler
	0 to 2.07 MPa	2.08 to 3.10 MPa	3.11 to 4.14 MPa	4.15 to 5.17 MPa	5.18 to 6.21 MPa	6.22 to 6.89 MPa	6.90 to 12.41 MPa	12.42 to 16.20 MPa	16.20 to 17.93 MPa	17.94 to 20.00 MPa	> 9.65 MPa
	0 to 300 psig	301 to 450 psig	451 to 600 psig	601 to 750 psig	751 to 900 psig	901 to 1000 psig	1001 to 1800 psig	1801 to 2350 psig	2351 to 2600 psig	2601 to 2900 psig	> 1400 psig
TDS ($mg.L^{-1}$)	700-3500	600-3000	500-2500	200-2000	150-1500	125-1250	100	50	25	15	0.05
Total alkalinity ($mg.L^{-1}$ as $CaCO_3$)	140-700	120-600	100-500	40-400	30-300	25-250	variable				N/A
TSS max. ($mg.L^{-1}$)	15	10	8	3	2	1	1	N/A			
TDS in steam ($mg.L^{-1}$)	0.2-1.0	0.2-1.0	0.2-1.0	0.1-0.5	0.1-0.5	0.1-0.5	0.1	0.1	0.05	0.05	0.05

Table 3.8. Recommended boiler water and boiler feedwater purities in AS3873-2001. The recommendations are for boilers with pressures up to 2.0 MPa [144].

Parameter	Boiler Type			
	Water-tube	Fire-tube or shell	Electrode	
			Low voltage	High voltage
FEEDWATER				
Hardness max. (mg.L^{-1} as $CaCO_3$)	10	5	3.5	5
pH	8.5-9.5	7.5-9.5	8.0-9.0	8.0-9.0
Dissolved O_2 max. (mg.L^{-1})	0.05	0.05	0.03	0.05
Iron + nickel + copper max. (mg.L^{-1})	0.05	0.06	Fe < 1	-
Total solids; alkalinity, silica (mg.L^{-1})	Must be maintained so TDS in boiler can be below the specified level, and blowdown less than 10% of the evaporation rate		400	50
Bound CO_2 max. (mg.L^{-1})	25	25		
Oil	Not detectable (< 1 mg.L^{-1})		-	-
BOILER WATER				
Sodium Phosphate (mg.L^{-1} as Na_3PO_4)	50-100	50-100	As per manufacturer's recommendations	
Caustic Alkalinity (mg.L^{-1} as $CaCO_3$)	300	350		
Total Alkalinity max. (mg.L^{-1} as $CaCO_3$)	700	1200		
Silica max. (mg.L^{-1})	< 0.4 of the caustic alkalinity or < 150 mg.L^{-1}			
Sodium sulphite (mg.L^{-1})	30-50	30-70		
Volatile oxygen scavenger (mg.L^{-1} as N_2H_4)	0.1-1.0	0.1-1.0		
TSS max. (mg.L^{-1})	100	100		
TDS (mg.L^{-1})	2000	3000		

3.2.3.4 Requirements of national standards and manufacturers

The quality of boiler feedwater and boiler water is also often set by national standards. The guidelines in the Australian Standards (AS3873-2001) are shown in Table 3.8 [144]. These are an absolute minimum for the safe operation of the boiler and the standards are only for low pressure boilers. In general the manufacturer will specify more pure water [148]. There is no set recommendation however due to variation in the boilers and variation in the feedwater. It is generally best to discuss any variation in the quality of feedwater with the boiler manufacturer to ensure their requirements are adequately met. However, in general, the use of MF/RO treated recycled water to feed a demineralization plant prior to entering a boiler will give a quality of water similar, if not better than, the potable supply.

3.2.4 Inherent Benefits

In general, MF/RO treated recycled water will be of higher purity than potable water and of significantly higher purity with respect to groundwater. This has two potential impacts. Low pressure boilers may be able to take the MF/RO water with no further pre-treatment, as has been seen in the case of the Californian refineries [145]. While high pressure boilers will generally require some form of pre-treatment to further reduce salinity, the maintenance and regeneration costs of an RO or demineralization plant will be significantly reduced through the use of higher purity water [140, 142]. This should result in a significant saving.

3.2.5 Some Examples

3.2.5.1 Eraring Power Station, Hunter Valley, NSW

The Eraring Power Station located near Lake Macquarie in the Hunter Region of New South Wales is a 4 by 660 MW coal-fired power station. It has been accepting recycled water, in the form secondary treated recycled water from the Dora Creek STP since 1995 [140] (see Table 3.9 for the minimum water quality requirements). Eraring treat the water onsite using microfiltration (coupled with sodium hypochlorite disinfection) and reverse osmosis (see Table 3.10 for the minimum water requirements at this point in the process) to generate a high quality effluent primarily for feed to the demineralization plant and ultimately boiler makeup. Approximately 1.5 $ML.day^{-1}$ of this treated water is sent to the demineralization plant [17].

Table 3.9. Influent parameters to the Eraring treatment plant [17].

Parameter	Maximum Value
BOD ($mg.L^{-1}$)	50
NFR ($mg.L^{-1}$)	50
Faecal coliforms ($cfu.mL^{-1}$)	1000
Phosphorus ($mg.L^{-1}$)	15
Chloride ($mg.L^{-1}$)	180
Sulphate ($mg.L^{-1}$)	100
Silica ($mg.L^{-1}$)	10
Ammonia ($mg.L^{-1}$)	15
Oxidised N ($mg.L^{-1}$)	15
Hardness ($mg.L^{-1}$ as $CaCO_3$)	150
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	150
Sodium ($mg.L^{-1}$)	130
Magnesium ($mg.L^{-1}$)	15
Calcium ($mg.L^{-1}$)	35
pH	9
Al^{3+}/Fe^{3+} to P ratio	2.5:1

Table 3.10. The minimum quality requirements of water after reverse osmosis for Eraring Power Station [17].

Parameter	Maximum Value
Suspended Solids ($mg.L^{-1}$)	1
Silt density index	3
Reovirus (per 100 mL)	nil
Enterovirus (per 100 mL)	nil
Total coliforms (per 100 mL)	10
Faecal coliforms (per 100 mL)	1
Faecal streptococci (per 100 mL)	1

The demineralization plant uses an ion exchange resin to reduce the hardness of the water. After switching from potable water to recycled water Eraring has found that less regeneration and replacement of the resin is required due to the higher quality of the water [140]. The Eraring treatment has been upgraded twice since 1995 to increase its capacity and Eraring have witnessed significant savings (around $1m a year) from the use of recycled water. In twelve years of the use at Eraring, no operational problems have been reported [141].

3.2.5.2 BP refinery and the Bulwer Island Cogeneration Plant, Brisbane, Qld

The BP petroleum refinery at Bulwer Island in Brisbane has a capacity of 85,000 barrels a day. It has been accepting recycled water, in the form of MF/RO treated effluent since 2000 (see Table 3.11 for the minimum water quality requirements). This water is used to produce 55 MW of steam at the Bulwer Island Cogeneration Plant [149]. The treated water passes through a demineralization plant using ion exchange resins to reduce the hardness of the water before it enters the boiler system. The project (as part of the Queensland Clean Fuels Project) won the 2001 Australian Construction Achievement Award [149].

The only problem noted to date has been difficulty in imparting some hardness and buffering capacity to the RO product water to reduce the water's corrosivity. This is recognised, however, as not being particularly significant [8].

Table 3.11. The quality requirements for water entering the Bulwer Island refinery and Cogeneration plant and the actual water qualities [16].

Parameter	BP Requirement	Actual Quality
pH	6.8-7.2	6.8-7.2
Conductivity ($\mu S.cm^{-1}$)	60-120	80-100
Turbidity (NTU)	< 0.1	0.02-0.1
Free Chlorine ($mg.L^{-1}$)	0.3-0.5	0.3-0.5
Ammonia ($mg.L^{-1}$)	< 1.0	0.04
Total N ($mg.L^{-1}$)	< 2.0	1.5
Phosphorus ($mg.L^{-1}$)	< 0.2	< 0.2
TOC ($mg.L^{-1}$)	< 1.0	< 1.0
Aluminium ($mg.L^{-1}$)	< 0.01	< 0.01
Chlorides ($mg.L^{-1}$)	< 40	11
Copper ($mg.L^{-1}$)	< 0.001	< 0.001
Iron ($mg.L^{-1}$)	< 0.01	< 0.01
Fluoride ($mg.L^{-1}$)	< 0.1	< 0.1
Mercury ($mg.L^{-1}$)	< 0.001	< 0.001
Heterotrophic Plate Count ($cfu.mL^{-1}$)	< 1000	< 100
Legionella ($cfu.mL^{-1}$)	< 10	< 10

Table 3.12. Water quality requirements for the boilers of two of the Los Angeles refineries [145].

Parameter	Mobil, Torrance (average)	Chevron, El Segundo (max)	
		Low Pressure	High Pressure
Conductivity (µS.cm^{-1})	50	-	-
TOC (mg.L^{-1})	0.7	-	-
Ammonia (mg.L^{-1})	1.9	-	-
Silica (mg.L^{-1})	1	1.5	0.1
Sodium (mg.L^{-1})	6.8	-	-
Chloride (mg.L^{-1})	3.2	-	-
Nitrate (mg.L^{-1})	0.2	-	-
Nitrite (mg.L^{-1})	0.3	-	-
TDS (mg.L^{-1})	-	60	5
Hardness (mg.L^{-1} as $CaCO_3$)	-	0.3	0.03
Bicarbonate (mg.L^{-1})	-	27	3

3.2.5.3 Chevron refinery, El Segundo, and Mobil refinery, Torrance, California

The petroleum refineries in and around Los Angeles have been using recycled water for cooling since 1995 and for boiler feed since 2000 [142]. The West Basin Municipal Water District provides designer recycled water for specific uses in this region of which two are used as boiler feedwaters. Table 7 shows the minimum requirements of the two refineries. Low pressure boilers at El Segundo and the demineralization plant at Torrance use secondary treated recycled water that has undergone MF/RO treatment by West Basin. In this way significant cost reductions have been achieved through fewer demineralization regenerations with no loss in protection of the boiler [142].

El Segundo's high pressure boilers are fed with water that has been treated to the same level, and then further treated with a second RO pass further reducing salinity and hardness. The two pass RO water is sold at a more expensive rate than potable water [142], however some savings are made through an increase in the cycles of concentration used in the boilers (from approximately 10 to 50) and through a 80-90% reduction in the energy required for water treatment on site (this represented millions of dollars) [142]. An improvement in the protection of the boiler has also been noted. The use of recycled water significantly reduced the operating costs of the refinery.

3.2.6 Suitable Water Qualities

Boiler feedwater must be of high purity. Only RO treated water will meet the requirements. For high pressure boilers, this water will then need to be further polished to reduce hardness in a similar way to potable water. Low pressure boilers may be able to directly use RO treated wastewater, however this must be assessed on a case by case basis. If only lower quality water is available, MF/RO treatment should be provided by the user before demineralization. As a minimum the water must meet the Australian Standards (outlined in Table 3). The aim of any plant, however, should be to meet the ASME recommendations outlined in Table 1. Where the steam generated is used to do mechanical work or where the integrity of the steam conveyance system is imperative the high quality requirements of the ABMA outlined in Table 2 should serve as a guideline.

3.2.7 Best Practice

As noted in the previous section, recycled water for demineralization plant or boiler feed should be RO treated. High pressure boilers must undergo some hardness reduction through the same technique that was employed for potable water (eg, ion exchange demineralization or a second RO pass). In general this quality water feed will be higher than that provided by potable water and it may be possible to increase the cycles of concentration or to decrease the reliance on demineralization regenerations. Where RO water is provided, some blending with a harder water may be required for other applications to increase the buffering capacity of the water and thereby decrease it corrosivity.

Where lower quality water is provided, it has been found more economic to treat secondary treated recycled water directly via microfiltration and reverse osmosis as opposed to treating to a tertiary level first.

3.3 Water for Washing

3.3.1 Introduction

Wash and rinse water is used in a large variety of applications for cleaning a large number of materials. Washing can be divided into three broad categories:

- Quality control (washing of a starting material, product or in intermediate stages of production to prevent cross contamination). This requires a moderate to high quality water to prevent cross contamination issues.
- Pollution control (scrubbing of gases to remove particulates and water soluble gases). This generally only requires a low quality water as there is little human exposure and no contamination problems.
- General housekeeping (washing of plant, vehicles, floors, palettes, surfaces etc). This requires moderate quality water with a focus on being microbiologically clean due to the potential for human exposure.

Each of these uses carry their own set of risks, for example washing as part of a housekeeping routine brings with it a high level of human contact not seen in pollution or quality control situations, while the level of trace contamination is of greater concern in quality control uses.

3.3.2 Important Characteristics

The most important part of a cleaning/washing system is the delivery of the water and, more specifically, the nozzle and pump used to make the delivery. In housekeeping washing applications, the parameter of greatest importance is the droplet impact and, as a result, high pressures are typically used. The smooth operation of the high pressure pump in such a situation is of critical importance. To ensure this a clean, solids free supply of water is necessary. In pollution control applications it is the spray area and droplet size that is of greatest importance. This means that the design of the nozzle cannot be compromised and must be protected from deposit formation and corrosion. These issues are discussed in Sections 3.3.3.2 and 3.3.3.3.

When considering the use of recycled water, the nature of the material being washed is also of importance. Water is often used to wash surfaces such as a factory floor, palettes and plant. This water tends to be transitory and risks are typically low, however where washdown occurs frequently it may become important to consider the affect that cleaning will have on the material itself.

3.3.3 Potential Problems and Solutions

3.3.3.1 Biological Growth and Health Concerns

One of the main concerns in the use of recycled water for washing is the potential impact on human health. In housekeeping based washing, such as vehicle, road and floor washing, human contact with water is inevitable and the potential for biological infection must be eliminated. Biological growth also represents an operational concern in the form of microbially influenced corrosion and deposit formation in pipes and delivery devices.

The potential for the formation of aerosols containing pathogens makes health issues vital in water for washing applications. Tertiary treated recycled water, Class A in the current Victorian system, is generally considered biologically safe and would therefore be an appropriate quality. However, availability of tertiary treated recycled water is sometimes an issue, and the Victorian Guidelines have been amended to allow secondary treated recycled water to be used after disinfection and with specific access controls in place [150]. This is consistent with the Australian Guidelines that aim to determine the level of disinfection and controls required to produce a recycled water that is “fit for purpose.” More information can be found in the Health Section (Section 2.3). Importantly, where a water meets the Australian Guidelines, the water should be safe for its intended use. Microbiological regrowth may occur where long residence times or stagnation occurs. This can be overcome by instituting a biocide program utilising an oxidising biocide as a minimum.

To prevent a potential build-up of biomass in the delivery system, particularly around any spray nozzles, it is important to maintain a low level chlorine residual in the water. If water is stored on site before use, it is important to check and maintain the chlorine residual, dependent upon the final use. Generally shock chlorination is discouraged as the high levels of chlorine can be corrosive. Importantly, where recycled water is in a water supply system that is not heavily used, flushing the pipes to prevent stagnation and biological growth is important. A procedure should be setup to ensure that stagnant water does not stay in the lines once the chlorine residual has dissipated.

In pollution control situations the large surface area present in a scrubber due to the filling/packing can help provide a surface for biological growth. The potential extent of growth will be dependent on the nature of the scrubber. Growth in chemical and particulate scrubbers has the potential to decrease its efficiency and when left uncontrolled has the potential to irreparably damage the unit. Control of biological growth should be maintained with a biocide program, particularly where there is a large degree of internal recycling of the water. In biological scrubbers, biocide must be avoided particularly where the biological system is constructed rather than naturally evolved. In wet biological scrubbers MF/RO quality water would be recommended with chlorine removal using sodium bisulphite performed onsite.

3.3.3.2 Corrosion and Erosion

The most significant corrosion issue will result from the metallurgy of the delivery system. High ammonia content could result in increased corrosion of copper and copper alloy piping. Where it is feasible to do so on site, treatment with a copper corrosion inhibitor such as tolytriazole will increase the life of the piping. Biological nitrification prior to use onsite is also an option if a holding tank is used. In both cases this would be feasibility based and the increased maintenance that would be required for copper piping in this application may not be significant enough to warrant such treatment.

Carbon steel pipes may also be more susceptible to corrosion using tertiary treated recycled water due to the potentially higher conductivity, however some advantage can be gained when using a tertiary treated recycled water. The phosphate levels in this water will provide some corrosion protection to carbon steels and consequently corrosion problems will decrease [142].

Highly treated water, that is to say MF/RO treated water, may present corrosion issues in piping due to the low alkalinity and buffering capacity of the water. While there is increased protection to most metals due to a lack of ions such as chlorides that can increase the corrosivity of water, the loss of buffering capacity can allow significant pH variation and therefore drive corrosion reactions. Where this is an issue, mixing the recycled water with a small amount of hard water, such as groundwater or a somewhat saline waste stream, is a suitable solution to the problem [131].

Microbially influenced corrosion (MIC) is also a significant issue. Biofilms will always exist on surfaces no matter how microbially pure the influent water may be. The potential for corrosion from such films is high where adequate precautions are not taken. Probably the greatest threats are sulphate reducing bacteria, such as *Desulfovibrio desulfuricans*, and iron oxidising bacteria, such as *Acidithiobacillus ferroxidans*. Decreasing the possibility of corrosion from microbes by preventing their growth takes two forms: restricting nutrients and biocidal control. Typically recycled water carries a high chlorine residual that, where there is no stagnation in the system, should be sufficient for biological control. Where water is stored and the chlorine residual is compromised a biocide program may be required. As was described in Section 3.3.3.1 biocidal control is best achieved with a continuous low level chlorination giving low chlorine residual to control the potential for biological growth, while maintaining protection against the corrosion and deterioration threat of chlorine and other oxidising agents. To help control the growth of the organisms, while control of organic content is one solution, control of the species that directly leads to the corrosion provides added protection. A low level of sulphate in the water (less than 50 $mg.L^{-1}$ [88]) is desirable to reduce the possibility of MIC.

The potential for corrosion to a washed surface, particularly where air drying is used must also be considered. The high TDS value (at least with respect to potable water) in tertiary treated water (typically the conductivity is 10 times that of potable water [38]) will lead to increased corrosion rates. This is a problem for washed surfaces where the TDS can provide a more conductive electrolyte to help establish a cell during drying. Where the surface must be protected a final rinse with a lower TDS water would be recommended. In vehicle washing for instance, it is sometimes recommended that the final wash use potable water [151] or RO treated water [152] (though this may be driven more for aesthetic reasons as described in Section 3.3.3.5). It must be noted however that this is not always recommended and vehicles are commonly washed with tertiary treated recycled water with no significant side effects [153].

Where high pressure is used as part of the cleaning process, suspended solids removal is important. Particles greater than 10 µm in size have the potential to cause significant damage to high pressure pumps through erosion [154]. Removal of suspended solids should be effectively achieved through the sewage treatment process to produce a tertiary treated recycled water and, consequently, should not represent a significant issue.

3.3.3.3 Deposits

The formation of deposits and scale are of greatest significant around the nozzle of a spray system. Though this is significant in washing for housekeeping purposes, it is of greater significance to the pollution control devices due to the greater need for control of dispersion and spray area. Suspended solids should not be an issue from tertiary treated water and higher. Secondary treated recycled water however may require some further treatment in the form of filtration to reduce the suspended solids level.

Biological growth and deposits can also threaten to disrupt nozzles in wash systems. Biocide treatment, as described in Section 3.3.3.1, is important to prevent biological fouling of the nozzles.

Scaling also presents a potential issue in nozzles and pipework, particularly where higher temperatures are encountered, such as in flue gas scrubbers. Scale can take the form of calcium phosphate, silica, calcium sulphate and calcium carbonate normally, with magnesium silicate and iron phosphate also a possibility [134]. The main scalants generally become less soluble at higher temperature, meaning the greatest risk comes at the nozzle in scrubbers, while the delivery pipework is under less threat. Recirculated cleaning and scrubbing systems are also under threat due to the concentration increase that occurs, although this should be controlled through the correct setting of the blowdown rate. Secondary treated recycled water represent a significant scaling threat without phosphate removal where higher temperatures are encountered (this threat is minimal at lower temperature). Where a recirculated system is used it is strongly recommended that phosphate removal be performed on these classes of water. Biological nitrification of recycled water will generate nitric acid that will help control scale to a degree, but where the threat is high addition of antiscalant (a chelating agent and dispersant/surfactant) would be recommended. Tertiary treated recycled water and above should be acceptable to these purposes.

3.3.3.4 Wood Deterioration

In terms of wood deterioration, only delignification is a significant issue for wash water. Delignification is generally only an issue where the wood is in constant contact with water [56], however repeated exposure and soaking of the water onto a wooden surface could present a problem. Delignification occurs when an oxidising agent, in recycled water this is typically in the form of chlorine or bromine, attacks and dissolves the lignin that holds the wood together. This leads to a thinning of the wood as the lignin dissolves and the remaining cellulose is washed away. It is a significant problem in alkaline water where the chlorine residual exceeds 1 $mg.L^{-1}$ [56]. Where a wooden surface or structure is washed regularly or will have a long exposure time to the recycled water, chlorine removal through the use of sodium bisulphite may be necessary. Where water is stored on site and some oxidising biocide added, continuous low level chlorination is more effective than shock chlorination where delignification is an issue.

3.3.3.5 Aesthetic Issues

In some applications the final appearance of the washed surface and the appearance of the water can be a significant issue, for example in professional carwashes. In such situations high quality water will undoubtedly be required.

Where water is used for cleaning and a customer is able to see the water, it is important that the water appear clean [152]. Colour will be an important issue in such a system. Removal of colour from tertiary treated water can occur through the use of activated carbon treatment or chemical oxidation (using hydrogen peroxide or ozone for example). Alternatively, the use of higher quality MF/RO treated water is an option. While it is possible to mask the colour of the water using a water soluble dye, this will not be appropriate to this situation.

Another aesthetic issue is the appearance of spots or beads on the washed surface. This can result from a higher level of dissolved solids in the water [152]. Where spots are considered an issue the final rinse should be performed with high quality water. The International Carwash Association recommends all final rinses on vehicles be performed with MF/RO treated water [152].

3.3.3.6 Contamination Potential

Washing of plant, particularly internally, has the potential to carry contaminants over to the process. As this process typically has a high level of human exposure, a tertiary treated recycled water should be used. This should have low levels of the chemical contaminants, but this will be dependent on the source water. For example sewage from industrial regions can contain high levels of heavy metal contaminants such as lead. Thorough removal of these contaminants would occur with MF/RO treatment, so this should be less of an issue. However where tertiary treated recycled water is used and there is concern about low level contaminants in the plant and potentially the final product it may be advisable to provide a final rinse in potable or MF/RO water.

In biological terms, tertiary treated recycled water presents little threat. However, the washing of plant used in the manufacture of products for human or animal consumption with this water in not recommended because there is a low risk. There is also a public perception risk associated with such practises. In keeping with the Australian Guidelines, the end use of a washed product and the potential for ingestion should be considered as part of the risk assessment process.

The washing and rinsing of raw materials, the product or intermediate stages of production may also carry a risk of cross contamination. This risk is very much process and product dependent. For example in the semiconductor industry, intermediate rinses should only be performed with MF/RO quality water due to the potential for interference by contaminants and corrosion. In generalised terms where the product will potentially be used in an activity related to consumption (for example in ceramic plate production or cutlery production) a final rinse in high quality MF/RO or potable water may be appropriate. For other uses where human contact will follow the rinse a tertiary treated recycled water is more suitable, while secondary treated recycled water may be used where some controls on the use of the product are in place (for example in making car parts prior to assembly).

3.3.3.7 Drift and Drainage.

By the current Victorian EPA regulations, recycled water cannot be allowed to enter the environment after use, regardless of class [1]. This is partly to avoid personal and environmental health problems, but is primarily due to the fact that it would represent a discharge and an EPA license would therefore be required. Where washing is occurring outdoors a buffer is recommended between the use of a recycled water spray, nearby watercourses and other developments. For Class C water a 100 m buffer zone is required for flood or high pressure sprays from the nearest watercourse [1]. This decreases to 50 m for low pressure sprays. As the quality of water improves this can be decreased, but no specifications exists in the recycled water guidelines. Also spray and drift should not escape beyond the boundary of the premises. For Class A water it is acceptable for the wetted area to extend to the edge of the premises, though this is not recommended. A buffer zone of 50 and 100 m exists for Class B and C waters respectively [1]. It is possible to reduce these buffer distances through the use of adequate controls as outlined in Chapter 7 of the Victorian EPA Guidelines for the Use of Reclaimed Water [1] and this must be approved on a case by case basis.

The effect of the Australian Guidelines is similar to the above with certain control measures required to make the water "fit for purpose." These are not generalised like the Victorian Guidelines, however, and are assessed on a case-by-case basis. The controls will be pre-determined as part of the approval criteria for taking the water, and will ensure a negligible risk to human health and the environment.

A final important part of the Victorian Guidelines regards the pooling of water on a site. The potential health and environmental risks this poses means all possible attempts must be made to prevent pools of recycled water forming.

3.3.3.8 Foaming

There are two main foaming impacts that could occur from using recycled water: unwanted foaming and lack of foaming. Unwanted foaming will be an issue in applications such as scrubbers where foaming may impact the efficiency or can lead to unwanted escape from the system. The main concern here is organic and surfactant contents. The use of biodegradable detergents in households and biological treatment in sewage treatment plants has reduced the risk of unwanted foaming; however foaming may still be witnessed in tertiary treated recycled water [26, 155]. Generally the system should be monitored for foaming and treated with an antifoaming agent where it is identified.

A lack of foaming in some housekeeping applications will result from the higher hardness of recycled water reducing the effectiveness of surfactants. Where the hardness of the water used is high additional surfactant should be used.

3.3.4. Inherent Benefits

3.3.4.1 Secondary and Tertiary Treated Recycled Water

This quality water has two potential technical benefits. The first is the presence of a low, but significant level of phosphates. While this could be a scaling threat, it is unlikely where the correct steps are taken. More important is the fact that phosphates offer carbon steels some corrosion protection [142]. This occurs through the formation of a passivating iron phosphate film on the surface of the steel protecting substantially slowing the rate at which oxygen can diffuse to the surface. It is possible that the presence of phosphate in a system can provide wholly adequate protection with no further user input into the system.

Another benefit from the use of tertiary treated recycled water comes from the nitrification process, where this is a part of a pre-treatment process. Nitrification will produce nitric acid that works as a mild steel corrosion inhibitor and an antiscalant, due to its acidic properties. While this will not completely remove the threat of scale it will provide a small amount of greater protection.

3.3.4.2 MF/RO Treated Recycled Water

The treatment processes that produce MF/RO quality water will result in a water quality that is better than that witnessed in a potable supply. This produces a number of benefits including:

- A reduction in blowdown from any recirculating processes such as scrubbers
- A decreased requirement for surfactants due to the lower water hardness
- A much lower risk of cross contamination issues

- Lower demineralization requirements (less ion exchange resin regenerations) where ultrapure water is required such as in semiconductor manufacture
- Greater aesthetics control and no requirement for a final potable water rinse

3.3.5 Some Examples

3.3.5.1 Queensland Alumina Ltd. (QAL) Refinery, Gladstone, Queensland

The QAL alumina refinery in Gladstone is the largest in Australia. It generates 3,700,000 tonnes per year of alumina using the Bayer process [156]. As part of this process alumina is leached from bauxite using caustic before it is precipitated in its more pure form. The residue from the leaching stage is known as red mud and is contaminated with caustic. Before disposal this caustic must be recovered by washing the red mud. This is typically the most water intensive process of the alumina refining process.

Since 2002 QAL has been accepting 6.5 $ML.day^{-1}$ of disinfected secondary treated recycled water from the Calliope River STP [156]. This water is used for washing the red mud with the only further treatment being chlorination to reduce the risk of biofouling. No problems have been reported with the introduction of recycled water to the site and the use of recycled water has proved profitable to the company, with no managerial desire to return to the potable supply once water restrictions were lifted [5]. The project has received significant recognition winning the Gladstone Regional Environmental Excellence Award in 2003 and receiving a high commendation in the Queensland Division of the 2003 Engineering Excellence Awards (Engineers Australia) [5].

3.3.5.2 Big Bend Power Station, Apollo Beach, Florida

The Big Bend Station is a 1,800 MW coal-fired power plant. It has been using 760 $kL.day^{-1}$ of tertiary treated recycled water since 1984 as a feed to the flue gas desulfurization scrubber [127]. This has been continually upgraded, using 3 $ML.day^{-1}$ in 1995 [157] and currently using 7.6 $ML.day^{-1}$ [158]. The facility is supplied by two regional wastewater treatment plants [159]. The only water quality requirements specified were chlorine residual above 0.1 $mg.L^{-1}$ at point of use and turbidity below 5 NTU [127] (the actual water qualities achieved are shown in Table 3.13). The scrubber operates by mixing the recycled water with lime that is then sprayed into the flue gases. It has been operating at an efficiency of 95% since its 1995 upgrade and operates for 200 days before plugging (as a result of the gypsum formed in the process) becomes an issue, though this is primarily due to the unique design of the scrubber [157]. The gypsum that forms as part of the desulfurization process is refined to wallboard quality gypsum for sale.

Table 3.13. Water qualities provided to the Big Bend Power Station in Apollo Beach for use in the desulfurization scrubber [158].

Parameter	South County WWTP	Falkenburg WWTP
pH	7.5	7.2
Conductivity (µS.cm^{-1})	920	1085
Faecal coliforms (cfu.100mL^{-1})	< 1	< 1
Chloride (mg.L^{-1})	155	129
TDS (mg.L^{-1})	601	708
Sulfate (mg.L^{-1})	97	127
Ammonia (mg.L^{-1} as N)	< 0.1	< 0.1
Organic N (mg.L^{-1})	0.7	0.8
Nitrate (mg.L^{-1})	0.55	0.5
Total N (mg.L^{-1})	1.6	1.3
oPhosphate (mg.L^{-1})	0.13	0.33
Sodium (mg.L^{-1})	83	127
Copper (mg.L^{-1})	< 0.001	0.003
Zinc (mg.L^{-1})	0.057	0.053

Table 3.14. Water quality of the wash water used at the Gucheng Depot of the Beijing Metro [160].

Parameter	Beijing Metro
Odour	Not objectionable
pH	8.47
COD (mg.L^{-1})	13
BOD_5 (mg.L^{-1})	2
LAS (mg.L^{-1})	0.14
SS (mg.L^{-1})	5
Bacteria (counts.mL^{-1})	0
Coliforms (counts.L^{-1})	< 3

LAS = Linear alkylbenzene sulfonate (a surfactant)

3.3.5.3 Gucheng Depot, Beijing, China

The Gucheng Depot is part of the Beijing Metro system. It accepts 20 to 30 ML of recycled water daily that it treats further onsite for use in washing trains [160]. The treatment process also recycles significant quantities of used wash water. The treatment process uses contact oxidation and biological carbon adsorption to treat the water. The quality of the product water is shown in Table 3.14.

3.3.6 Suitable Water Qualities

In general acceptable water qualities for washing processes will start at secondary treated recycled water, where no human exposure will occur and range up to MF/RO being heavily dependent on the application.

- For housekeeping based washing (where high pressure water is used or where a spray is used in the presence of workers) tertiary treated recycled water should be the aim, although secondary treated recycled water may be allowable assuming state and national regulations are met.
- For pollution control based systems such as scrubbers secondary treated recycled water should be sufficient, though some phosphate and ammonia reduction may be required to reduce scaling and copper corrosion respectively.

- For quality control type applications secondary treated recycled water may be acceptable, but more often tertiary treated recycled water will be the minimum, with MF/RO water only recommended for sensitive applications such as electronics. In many cases it may be advisable to use a MF/RO quality water or potable water to perform a final product rinse in such applications.

3.3.7 Best Practice

Best practise is process dependent and hence there will be a need to investigate each application individually. Some generalizations can be provided however.

Before replacing potable water with recycled water in any application it is always best to check with the manufacturer any of their water quality recommendations for the unit. This is especially the case for scrubbers that are designed to meet individual needs [161].

For pollution control, secondary treated recycled water is recommended and tertiary treated recycled water should be considered the absolute maximum quality where this is the only use. The water used may need some phosphate removal (using a cold lime technique for instance) where scaling is an issue. Where copper is being used nitrification to remove ammonia is also strongly recommended. All applications using secondary treated recycled water should be restricted in terms of human exposure and it should be ensured that some chlorine residual is maintained.

For quality control secondary treated recycled water is acceptable although tertiary treated recycled water may be more appropriate. The main concern will be cross contamination which can be controlled by providing a final rinse using potable water. Where a material sensitive to contamination is being washed MF/RO quality water is recommended. Again secondary treated recycled water water should only be used where the Australian Guidelines can be met. This may also extend to the product meaning products that go directly to a consumer may be best washed with tertiary treated recycled water or higher, or receive a final potable water rinse before sale.

For housekeeping uses tertiary treated recycled water should be the aim although secondary treated recycled water is acceptable where suitable controls are used and the Australian Guidelines are met. Depending on the nature of what is being washed a final wash with potable water may be required if MF/RO water is not used (though this is generally for aesthetic reasons).

In general, if stagnation of the water is likely it may be necessary to provide further chlorination to the water. Where wood is being exposed to the water low level chlorine residual (0.2 to 0.5 $mg.L^{-1}$) is required. Where water is provided with a high chlorine residual some reduction may be required using sodium bisulphite.

3.4 Water for Transport and Separations

3.4.1 Introduction

One common use of water in mineral-based industries is transport and separations, although the practise is not limited to these industries. Transport of mineral via slurries is often practiced where transport by rail or road is not possible due to difficulties in terrain or the disruption that would occur to neighbours is significant. Under these conditions efficient use of a slurry transport and dewatering system, particularly where the water can be internally recycled may be justified.

Mineral processing and separations are also highly water intensive. Crushing and grinding processes will use water to prevent raising dusts, while separation processes use water as a medium in which to aid the separation. Typically these separations are driven by gravitational forces such as in hydrocyclones and flotation systems, with the light stream rising and the heavy stream sinking. Additionally some are targeted separations using surface properties to selective float a desired product. Both of these water-based separation systems may be targets for recycled water use.

3.4.2 Important Characteristics

In slurrying processes, the most important characteristic is the ability to recover the product in a clean form once it reaches the end. This is normally done using filtration it is important that the water used does not interfere with this process meaning solids free water is of the utmost importance. This is discussed in Sections 3.4.3.1 and 3.4.3.4.

Most separation processes rely on gravity, however surface interactions will also play a part potentially interfering through unwanted agglomeration or peptization. Density and viscosity of the water may also play a role in settling times and thereby affect the efficiency of a separation. However these are not likely to be particularly significant when going from potable or surface water to recycled water. Some of these issues are discussed in more detail in Section 3.4.3.2.

Finally the materials that hold the slurry and the separation plant will also be important. Loss of slurry due to pipeline failure will be a significant financial loss to a company in terms of product and will likely incur fines from government bodies such as the EPA and DSE in Victoria. As such corrosion and fouling protection will be important. These issues are discussed in Sections 3.4.3.3 and 3.4.3.4.

3.4.3 Potential Problems and Solutions

3.4.3.1 Product recovery

In the transport of a material via a slurry, the recovery of the material in a form that can be used at the end point is essential. The main problems that can occur are via contamination or interference in the recovery procedure.

Contamination may be eliminated through washing of the solids after recovery although surface active species are not always removed by this process. The materials most commonly transported in slurry form are minerals and ores and further processing generally involves washing prior to treatment. Consequently contaminants would be removed in these further processing stages by washing with moderate to high quality water. This means that while tertiary treated wastewater would be desirable, secondary treated waters may also be acceptable for use as transport water depending on the degree of turbidity.

The main concern with product recovery would be with suspended solids. Filtration is a common technique used to dewater a slurry. Suspended solids in the water would also be caught by the filter. Though this leads to a contamination issue, as noted earlier further processing is likely to minimise this threat. More importantly some solids will interfere with the filtration process leading to blockages that may be more difficult to remove. Though this is highly unlikely and can be dealt with by a relatively minor increase in maintenance, in some cases it may present an issue.

In terms of water qualities, tertiary treated recycled water should not present a problem in this regard. Though secondary treated recycled water may present a concern, filtration of the water, using rapid sand filtration for instance, should be sufficient to eliminate the threat of filtration interference or solids contamination.

In rare instances where product recovery is performed using evaporation techniques, the quality of water will be of significance. Comparison would be needed between the recycled water and current water source. Tertiary treated recycled water may be higher in dissolved solids, but may be comparable to some ground water sources. Where dissolved solids are a serious issue, MF/RO quality wastewater should be sought.

3.4.3.2 Issues with separations

In general wet separations in monometallic or bulk concentrate situations, such as flotation, are fairly robust and will not suffer from any significant interference [162]. Properties of the water such as density and viscosity should not vary significantly enough to generate any interference. One issue may arise in the form of surfactants and the possibility of foaming. The use of biodegradable surfactants and their destruction by general wastewater processing techniques essentially eliminates the potential threat from the synthetic versions of these compounds. Naturally occurring surfactants may enter the recycled water system as the result of algal breakdown products. Controlling the biological growth is therefore import. Methods for doing this are outlined in Section 3.4.3.4, however, an additional control for algae could be to cover open reservoirs and tanks to prevent the ingress of sunlight which helps algae to thrive. This would have the added benefit of reducing evaporative losses from the system.

The main issues will come with selective separation processes where a particular ore is targeted for flotation or depression for example copper ore may be selectively removed from an ore also containing zinc, with zinc removed in a second stage. These selection processes focus on surface chemistry and therefore interferences will come from ions and molecules that interfere with surface reactions. As was noted earlier, surfactants should not present a significant issue in recycled water, however the presence of some ions and organics will. Table 3.15 shows some of the important ions of concern and the effects they may have. In general though, it is advised that tests be performed using the available water to determine any effects that may be seen. This is recommended for any water and should be carried out regularly to account for any variation that may be seen.

Table 3.15. Potential ions/compounds of concern in selective flotation and their effects [162]

Component	Effect
Cu^{2+}, Fe^{2+}, Pb^{2+}	Undesired activation/flotation of sulphide minerals
S^{2-}	Undesired depression of sulphide minerals
Alkaline earth ions (Mg^{2+}, Ca^{2+} etc)	Lower grade of sulphide concentrate obtained, lower recovery of oxides
Primary amines	High adsorption at fine particles causes slime flotation

3.4.3.3 Corrosion

Corrosion problems can mean a significant financial loss for a company where water is used as a transport medium over large distances. Though corrosion will also be affected by external factors such as the soil conditions where the pipe is laid, or atmospheric conditions where the pipeline is above ground, control of corrosion from the carry water is also important. This corrosion will depend significantly on the metallurgy of the pipe. In general the higher conductivities of tertiary and lower grade recycled waters may result in higher corrosion rates. On some metals, particularly carbon steels, this will be tempered by the presence of low but significant concentrations of phosphates in the water.

Additional threats may come to systems using copper. Ammonia is particularly corrosive to copper, with contents of 2 ppm being implicated in stress cracking [23]. Where copper is used it may be advisable to reduce the ammonia content if it is above this level. Biological nitrification is practiced in industrial situations in the United States to reduce the ammonia content of water used in copper based heat exchangers [23]. This may be a relatively inexpensive solution. Alternatively the addition of a copper corrosion inhibitor, such as tolytriazole is a common solution.

While it is not recommended for this use (as the quality is significantly greater than required) MF/RO treated recycled water is also considered corrosive as it is not buffered, leading to drastic localised pH variation accelerating corrosion. This should not be a significant issue, however, as impurities should enter the water and induce some hardness as part of the slurrying or mineral processing procedure. Where this is perceived to be an issue, mixing the water with a trivial amount of hard water (groundwater or an RO brine stream) will provide the necessary buffering protection.

A major concern in pipelines for transport will be microbially influenced corrosion (MIC). Corrosion processes can be accelerated by the presence of microorganisms. Formation of biofilms on surfaces cannot be avoided and, consequently MIC is a serious concern. The main source of corrosion will be the byproducts formed by species such as *Acidithiobacillus ferroxidans* and *Acidithiobacillus thiooxidans*. These species are particularly prevalent in the presence of some sulphide ores. Control of MIC can be achieved in two ways, limiting the amount of nutrients reaching the micro-organisms and controlling the population of micro-organisms. Control of microbial populations can be achieved through the use of biocide. Recycled water will be disinfected and contain a chlorine residual to achieve this. However, recirculating water and the long residence times that are particularly seen with water used for transport will lose this protection. Consequently, the addition of further biocide typically using chlorination (either direct use of chlorine or indirect use by sodium or calcium hypochlorite or chlorine dioxide) will be required to minimise the further growth of bacteria in the pipes. At the same time it is beneficial to reduce the content of some of the feedstocks that will ultimately be converted to corrosive products. Typically this means reducing the sulphate content of the water. It has been recommended to reduce sulphate content in water to less than 50 $mg.L^{-1}$ in order to avoid corrosion problems [88]. In minerals applications this may be difficult and greater care to control microbial populations may be the only reasonable response.

3.4.3.4 Biological growth

As was noted in Section 3.4.3.3, biological growth induces a greater corrosion threat. Biological growth will also lead to the formation of deposits that can interfere with the flow of water through the pipes in transport as well as separation processes. Consequently limiting the presence of microbes in water is important. In general, all water sources will undergo some disinfection before supply, although secondary treated recycled water will have some microbial content. Importantly, recycled water is provided with a chlorine residual that will prevent the further growth of micro-organisms that are present. The main drawback is that this residual decays over time and must be replenished. In transport systems where water is recirculated and large residence times are expected this is particularly important. Maintaining a constant moderate level of chlorine residual through the addition of sodium or calcium hypochlorite is recommended over shock chlorination [21] (occasional additions of large concentrations) as this will mean greater corrosion stability for the system. For longer pipelines, chloramination may be more appropriate due to its longer residual time.

3.4.4 Inherent Benefits

One of the significant benefits to using recycled water in transport is the corrosion protection offered by the presence of phosphates. Although phosphate contents are often lowered during the wastewater treatment process a small, but significant content remains. On carbon steels this phosphate will help form a passivating layer and thereby reduce the threat of corrosion. This is particularly useful for the protection of pipelines.

One additional benefit, particularly to separation processes, is the consistency of recycled water. Though there are often different opinions in relation to the consistency of potable water as compared to recycled water [38, 142], other water sources may be less reliable in the composition. Seasonal variation in river flows will lead to some variation in composition. Greater control and optimization of the separation processes may be obtained using a recycled water source therefore. This would need to be assessed on a case-by-case basis.

3.4.5 Some Examples

3.4.5.1 Cadia Valley Operations, Orange, New South Wales

Newcrest's Cadia Valley Operations (CVO) are New South Wales' largest gold mining operation. In excess of 560,000 ounces of gold and 61,000 tonnes of copper were recovered from the mines last financial year [161]. As part of the operation, copper concentrate is transported from the site in slurry form to Blayney where it is dewatered before loading into sealed containers and railed to Port Kembla for transport overseas for smelting. Location of the site is an consideration that in the past has ruled out the extension of the rail line from

Blayney and although road transport is an option, the quantity required could cause disruptions to the local community [162]. It was therefore decided to transport concentrate to Blayney where it would be dewatered to go by rail to Port Kembla. The water from the process is returned to the site for use in dust suppression and processing.

Mineral separation also occurs as part of CVO principally by flotation after crushing and grinding. This is used to separate gold and copper minerals from the ore as well as produce concentrate containing copper minerals and elevated gold levels.

As part of planning for the operation, CVO recognised the need for secure long term water supplies. As part of its water management strategy, CVO approached the local cities with a proposal to secure treated effluent water for use in the processing facilities. The result was a pipeline from Orange City Council that would provide the site with at least 10 $ML.day^{-1}$ of tertiary treated recycled water [162]. This ultimately provided two thirds of the makeup water required by the site [163] and was also used initially to help fill the dam that provides another significant portion [162]. To date the only problem that has been noted with the use of recycled water is the occasional presence of insoluble fibres that cause interference at the dewatering stage [164]. This has been determined to be only a minor matter that occurs rarely. In the flotation circuits, Newcrest perform regular flotation tests with the water and to date no problems have been recorded [164]. CVO is currently investigating the possible importing of recycled water from Bathurst to further decrease reliance on surface water sources and improve water supply reliability [164].

3.4.5.2 Fosterville Gold Mine, Bendigo, Victoria

The Fosterville Gold Mine owned by Perseverance Corporation has been operating with recycled water since 2005. The mine produces about 90,000 ounces of gold a year from sulphide ores [167]. 5 $ML.day^{-1}$ of tertiary treated recycled water is provided by Coliban Water for all mineral processing on site [168], including the main separation technique, flotation. The site also uses biological oxidation to facilitate the carbon-in-leach process. To date Fosterville have not reported any problems related to the use of recycled water onsite [169].

3.4.6 Suitable Water Qualities

Suitable water qualities will be process dependent, but in general are recommended to be secondary or tertiary treated recycled water. Although MF/RO treated water could be used its quality is significantly higher than what would typically be required. In transport where contamination and recovery are concerns tertiary treated recycled water should be sufficient for the process and a higher quality wash at the destination significantly reducing water use. Where significant further processing of a mineral is going to occur after transport then a secondary treated recycled water will be sufficient.

For separations, where selective separation of a particular ore is required, tertiary treated recycled water is recommended in order to decrease interferences. For other processes based around size separation, however, secondary treated recycled water (maybe with some filtration) should be sufficient.

3.4.7 Best Practice

Best practise will be heavily process dependent. As a generalization though, filtered secondary treated recycled water or better and chlorination would be required for transport using a slurry. Where no significant processing of the material being transported occurs at the destination, then tertiary treated recycled water may be more appropriate. Washing of the product at the destination will use a higher quality water.

For unimetallic and ore concentration separation processes based around weight and size, filtered secondary treated recycled water would be considered best practise. Multicomponent selective separations may need tertiary treated recycled water. In all separations cases laboratory tests on the suitability of the water for the particular separation process being used should be conducted regularly to determine the effects of any variation in the water quality.

3.5 Process Water

3.5.1 Introduction

In industry, processing water is used in a range of applications including reduction of friction and control of wear in rubbing parts, heat transfer, dust control and suppression, dyeing, finishing and washing products and raw materials (for a discussion of water for washing see Section 3.3), rinsing of plant, solvent for liquor, lubrication emulsions, acid dilution and pollution control (eg. wet scrubbers).

A number of such applications can be found across a range of industries, with some common quality concerns across industries, e.g. corrosion and health risks, but often applications are industry specific and so are the quality requirements to minimise detrimental impacts to products and processes.

In this section, typical process water applications for a range of industries will be evaluated. Due to the large variation in industrial processes and water qualities, not every industry could be investigated. Furthermore, although quality specifications for the industry can be specified in regards to pH, TDS and conductivity, the requirements generally assume that levels of organics and other contaminants will not interfere with the process and the same microbiological requirements that apply to all other applications explored in chapters will be applicable.

The following discussion should not be considered definitive for any industry assessed. When considering the use of recycled water in a process expert advice should be sought.

3.5.2 Metal processing

Metal processing occurs at two major levels, large scale metal processing and metal forming, e.g. steel industry, and at specialty fabrication, e.g. car parts manufacture, metal sheeting, etc.

Water use in the steel industry fulfils three main purposes, material conditioning, air pollution control and heat exchange medium. The last application includes use in boilers and heat exchangers that are covered in other chapters. It also constitutes the largest sink of water in the industry with up to 75% of the water intake used in heat transfer [170]. Metal processing applications can also consume a significant amount of water. The combined water requirements for material processing and heat removal for typical processes such as cold rolling, hot rolling and plate milling are up to 11.7, 32.5 and 37.8 kL.tonne^{-1} respectively (see Table 3.16). The industry typically sources its water from potable mains, surface waters, groundwater and recycled water, depending on source availability. Typical processes in the industry include casting, rolling and metal finishing. In the casting process, liquid steel is continuously poured into moulds to be cast into shapes (slabs, blooms, billets) so that it can be rolled. As cast steel leaves the mould and starts to solidify, water sprays assist in the cooling process [171]. As part of the rolling process, the cast metal is machined through a set of rollers into the desired shape, to refine its strength and impart the desired mechanical properties. The rolling process can be undertaken using a hot or cold rolling process. In hot rolling, metal billets are rolled whilst still hot, while in cold rolling the steel part is cleaned with acid and then rolled at rapid speeds with the aid of lubricants to reduce friction [172]. The finished product can be delivered as produced in the rolling stage or undergo further processing (hot forming, cold forming, tooling, etc) and finishing [172], which can include the addition of plastic, metals or paint coatings to the final product.

Table 3.16. Typical water consumption for steel industry applications. Adapted from [170]

Process Area	Material conditioning	Air pollution control	Heat Transfer	Recycled/Reused fraction
Cokemaking	0.8 kL per ton coke	0.9 to 1.1 kL per ton coke	30 to 32 kL per ton coke	0% (newer plants may recycle cooling water)
Boilers for converting coke oven gas, tars, and light oils.			150 to 450 kL per ton coke	Varies depending on age of boilers
Sinter Plant	0.08 to 0.11 kL per ton sinter	3.4 to 3.8 kL per ton sinter	0.8 kL per ton sinter	80%
Blast Furnace	0.4 to 0.8 kL per ton molten iron	3.0 to 3.8 kL per ton molten iron	9.5 to 11.4 kL per ton molten iron	90%
Boilers for Converting Blast Furnace Gas			75 to 230 kL per ton molten iron	Varies depending on the age of boilers
Basic Oxygen Furnace	0.4 to 0.8 kL per ton liquid steel	3.0 to 3.8 kL per ton liquid steel	9.5 to 11.4 kL per ton liquid steel	50%
Direct Reduced Iron Processes	0.26 to 0.30 kL per ton iron	negligible	0.8 to 0.9 kL per ton iron	~80%
Electric Arc Furnace	negligible	negligible	7.6 to 9.5 kL per ton liquid steel	80%
Continuous Caster	negligible	negligible	11.4 to 13.2 kL per ton cast product	70%
Plate Mill	3.8 to 7.6 kL per ton plate	negligible	26 to 30 kL per ton plate	30%
Hot Strip Mill	1.5 to 2.3 kL per ton hot rolled strip	negligible	26 to 30 kL per ton hot rolled strip	60%
Pickling	0.11 to .0.15 kL per ton steel pickled	0.30 to 0.38 kL per ton steel pickled	0.08 to 0.11 kL per ton steel pickled	70%
Cold Rolling	0.19 to 0.38 kL per ton cold-rolled strip	negligible	9.5 to 11.4 kL per ton cold-rolled strip	90%
Coating	0.23 to 0.26 kL per ton coated steel	4 to 40 L per ton coated steel	4.5 to 6.8 kL per ton coated steel	80%

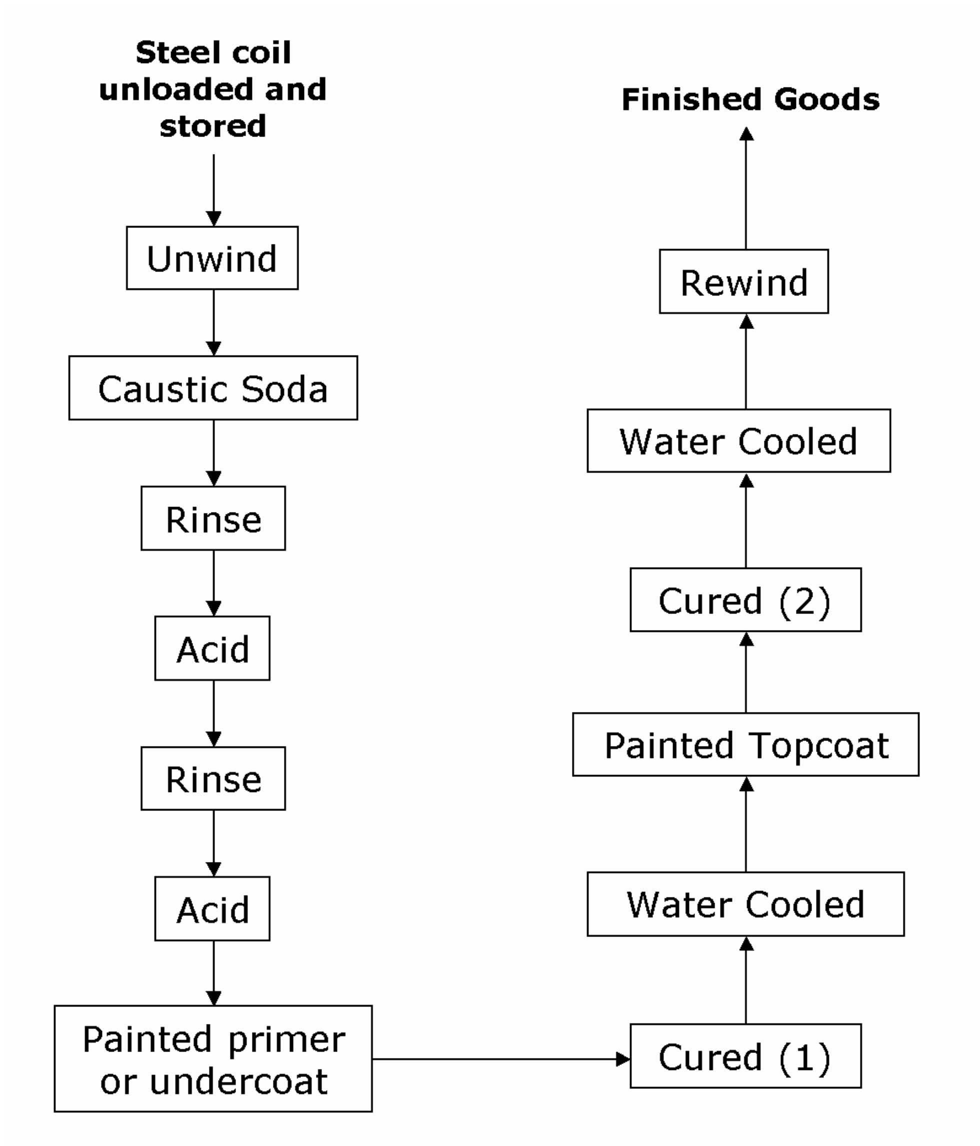


Figure 3.3. Diagram of the finishing process of a steel product [173]

Finishing for application of a protective layer or for further painting requires surface cleaning and preparation. This is achieved using processes such as solvent cleaning, alkaline cleaning, washing, etc, which involves immersion in baths of acid or caustic solutions followed by rinse stages to remove contaminants (e.g. corrosion residues, debris). Additives are sometimes added to the baths to aid the process, e.g. organic brighteners are used to promote a smooth surface layer. During such stages, the water quality needs to be of the highest purity and close to deionised quality (EC < 10 - 15 $\mu S.cm^{-1}$) to avoid blemishes to the plated surface [174-176]. The concentration of organic compounds and metal contaminants also needs to be controlled to avoid interference with other processing additives [176]. An example of the typical finishing process train for steel coil is shown in Figure 3.3.

Water used for the preparation and washing of finished products e.g. for forming and rolling of plates and later stages requires strict controls of dissolved solids and salts to prevent adverse interactions with the finished product. In refined applications, such as electroplating, metal parts have to undergo a range of finishing stages (solvent cleaning, alkaline cleaning, washing, etc) to leave a protective layer onto a metal part or in preparation for further painting. In such cases, the recycled water quality requirement is for high purity water close to deionised quality (EC < 10-15 $\mu S.cm^{-1}$) to avoid blemishes to the plated surface [175, 176].

Processing of metal via rolling mills utilises oil emulsions for lubrication and reduction of friction. The emulsions are prepared to a specific pH and deviation of water quality from the pH can break down the emulsion and slow down production [177].

Suitable water qualities in the metal processing industry are very dependent on application. In general, secondary or tertiary treated recycled water may be acceptable. For sensitive processes however, such as hot rolling, electroplating and finishing, MF/RO quality recycled water may be required.

3.5.2.1 Example: Bluescope Steelworks, Port Kembla, NSW

Bluescope Steel has a 15 year contract with Sydney Water for the supply of 20 million litres of recycled water per day to the Port Kembla Steelworks and Springhill Works, in Illawarra, New South Wales. The steel works uses a mix of MF/RO treated recycled water and raw water from Avon Dam in a ratio of 55:45 [171]. The water is used in a range of processes including, cooling hot coke and metal, cooling tower makeup, process water for cleaning and rinsing strip, steam generation for heating purposes, dust suppression and washing [29, 171]. The recycled water quality is required to comply with limits for health (bacteria and virus counts essentially zero), chlorides (< 20 $mg.L^{-1}$), ammonia (< 1 $mg.L^{-1}$), hardness (0 to 20 $mg.L^{-1}$) and pH (6.5 to 8.5) [177].

3.5.3 Electronics industry

The electronics industry produces printed circuit boards, semi-conductors, compact discs, cathode ray tubes and so on. It requires high quality water for rinsing and washing of components during the manufacturing stages [178]. The range of operations conducted includes multiple stages of removal of solvents and residues. Some of the more common processes are:

- Washing and cleaning. Water is used in the preparation of solutions for removal of oil, grease, cooling fluids, removal of residues from the production and mechanical shaping process and ends up with a range of surfactants, inorganic acids, alkali, corrosion inhibitors, complexing agents, phosphates, borates, etc.
- Etching. Products are etched and residues removed by passage through acid aqueous solutions containing corrosion inhibitor, brighteners, etc.
- Layer deposition/removal. Parts are washed to remove excess layers from galvanic, lacquering, wet or dry coating techniques. The rinse water produced will contain a range of chemicals including organic acids and bases, surfactants, organic solvents and developers, inorganic chemicals such as acids, salts, metals, complexing agents and wetting agents.

Any compounds that can cause corrosion or interfere with the conductivity of the product also need to be controlled. The process requires ultra pure water with TOC levels of less than 0.0003 – 0.0004 mg of $C.L^{-1}$, which is lower than that of potable water [178], and removal of organic and inorganic metal contaminants.

Therefore the water is generally treated by activated carbon and reverse osmosis to produce ultra pure deionised water.

In general, the electronics industry can only accept MF/RO treated recycled water, followed by deionisation in a similar way to the potable water supply. The principle benefit from using the high quality water is a decrease in the deionisation costs as shown in the example below. A lower quality recycled water can be accepted provided MF/RO treatment is provided onsite. In this case, a secondary treated recycled water is generally considered more economic than tertiary treated water [124].

3.5.3.1 Example: Sony Display Device, Singapore

Sony uses recycled water in the production of cathode ray tubes for televisions and computer monitors. The tertiary treated recycled water from Jurong Industrial Water Works is mixed with internal wastewater streams and treated using microfiltration and reverse osmosis before being deionised [179]. Significant savings have been made by Sony on demineralization costs and a potable water saving of 40% has been achieved [179].

3.5.4 Paper and Pulp industry

In paper and pulp applications process water is subject to high temperatures, moderately acidic pH (often pH 4-6 for white paper) and high electrolyte concentrations that can aggravate the corrosion potential of the water on equipment. The pH is controlled by the addition of alum, sulphur dioxide, sulphate and sulphuric acid. The use of closed water circuits is increasing in the paper mill industry resulting in a high concentration of salts and organics in the recirculating water. The presence of chloride ions in process sections, such as the suction press roll and the headbox, can aggravate the severity of corrosion as chloride accumulates in crevices located in sites that are difficult to examine [180].

Sprays are used for application of water over the paper in the paper machine. The spray water needs to have low TSS and control of ionic species to avoid precipitation and scaling in pipes and nozzles. Suspended solids should not be an issue from tertiary treated recycled water and higher. But secondary treated recycled water may require some further treatment in the form of filtration to reduce the suspended solids level. Biological growth and deposits can also threaten to disrupt nozzles in wash systems and biocide treatment can be important to prevent biological fouling of the nozzles [181].

The main concerns of poor water quality in the pulp and paper industry are:

- Biological growth. This can lead to clogging of plant, odours, the texture and uniformity of the product paper and human health. Preventing this requires control of COD and nutrients and a biocide (3 $mg.L^{-1}$ residual chlorine is generally best, although SAPPI, South Africa use 0.8 $mg.L^{-1}$ to control microbial growth).
- Scaling and corrosion. This requires control of silica, aluminium (alumina), hardness and TDS levels. Use of scale and corrosion inhibitors is also useful.
- Final product quality. Problems with colour can occur with iron, manganese and microorganisms in the water, while brightness is compromised by suspended solids.

Table 3.17. Major water quality parameters of concern for paper manufacture at Mondi [32]

Parameter	Significance
Conductivity	Corrosion
Colour	Product Colour
Residual Cl	Control of microorganisms At > 1 $mg.L^{-1}$ interferes with dyes
Chloride	Corrosion Affects starch Needs to be less than 80 $mg.L^{-1}$
Iron	Colour, bleaching
Sulphate	Scale and deposits Needs to be less than 80 $mg.L^{-1}$
Manganese and copper	Colour, bleaching
Oil/Soap/Grease	Foaming
TOC	< 5 $mg.L^{-1}$ for fouling of resins
E. coli	Health
Total Aerobic Bacteria	Filamentous slime (biofouling by *Sphaerotilus natans*)

If phosphate is not removed, secondary treated recycled water represents a scaling threat where higher temperatures are encountered (this threat is lesser at lower temperature). Where a recirculated system is used it is strongly recommended that phosphate removal be performed. Biological nitrification of recycled water will generate nitric acid that will help control scale to a degree, but where the threat is high addition of antiscalant (a chelating agent and dispersant/surfactant) would be recommended. Tertiary treated recycled water and above may be suitable for these purposes.

The control of TDS and colour are two major considerations for recycled effluent according to experiences from paper plants such as Mondi Paper and SAPPI ENSTRA, South Africa, which use recycled water from STPs. The solids content of the water can be reduced by flocculation, sand filtration and colour by activated carbon towers to prevent staining of the final product. Chlorine addition to produce a chlorine residual of 0.8 $mg.L^{-1}$ at the point of use minimises the attack of chlorine onto the paper, whilst controlling microbial growth. The major parameters of concern are shown in Table 3.17.

The general water quality requirements for the paper/pulp industry would mean a minimum of tertiary treated recycled water with colour removal. It would also be recommended to ensure the chlorine residual does not exceed 1 $mg.L^{-1}$. If need be, this can be reduced using sodium bisulphite or a similar agent.

3.5.4.1 Example: Mondi Paper, Durban, South Africa

The Mondi Paper papermill in the Durban suburb of Merebank has been operating on recycled water since 1972 [111]. Since 2001 it has been receiving 47.5 $ML.day^{-1}$ of water from the Durban Water Recycling Plant (DWRP). This water takes the form of tertiary treated recycled water that has undergone ozonation and passed through activated carbon to reduce the colour [97] (initially colour present in the recycled water from dyehouse effluent was an issue for Mondi [111]). As a result of the DWRP Mondi has reduced its water tariff by 44% [97].

3.5.5 Textiles

Manufacture and preparation of textiles is generally performed using wet processing (Figure 3.4). The process operations consist of pre-treatment, dyeing, printing and finishing.

- Pre-treatment: singeing, carbonising, solvent wash, desizing, caustic kier boiling, bleaching, mercerising, gumming, washing and rinsing;
- Dyeing: water is used in washing and rinsing operations and also in the preparation of dye and treatment liquor;
- Printing: includes washing and rinsing operations;

In the dyeing process a batch of fabric is rolled between two rollers through a dye liquor, or looped over the winch reel, dropped in the dye liquor and repeatedly folded stirring the dye (for woollens and synthetics). Application of enzymes, soil repellents, surfactants and silicone compounds is often adopted as a finishing process.

Process water is required for the majority of the unit processes adopted as fabric and yarn undergo multiple cycles of washing and rinsing during production. The process water may need to be pre-treated for the removal of impurities present in surface, ground and recycled waters such as calcium, magnesium, iron and manganese carbonates, phosphates, nitrates and chlorides. The water is then mixed with chemicals suited for each process operation. For instance, acids are used in acidic dyeing processes for synthetic fibres and blends, for pre-treatments of cotton and as pH regulators in finishing processes (pH 4.5 to 6) [182]

Corrosion and scale control are also important considerations as process water is led through pipes or tubes to the machines and salts are used in reactive dyeing processes.

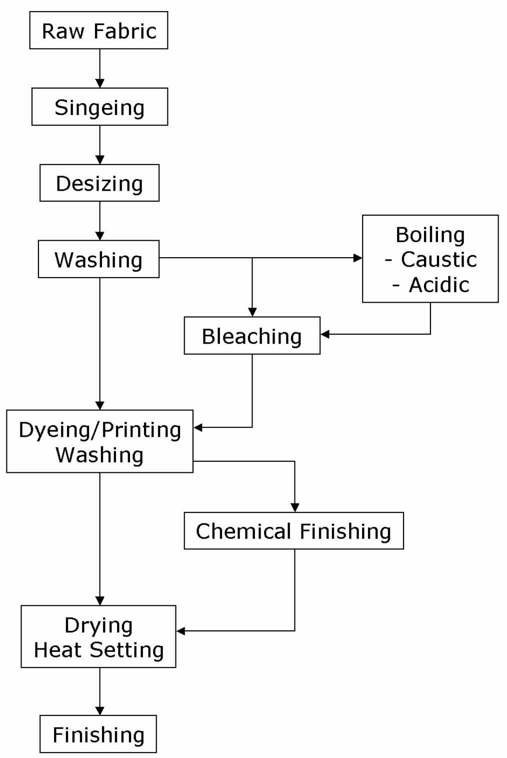


Figure 3.4. Example of wet processing of textiles [182]

The water source's turbidity, colour (in the form of iron and manganese salts and organic dyes) and high hardness should be avoided. In addition nitrates and nitrites can interfere with the dyeing process and should be considered for each dye formulation [182]. Addition of thiosulphate to neutralise free chlorine can also be usedul as it reduces the risk of fabric bleaching.

In general, for textile processing tertiary treated recycled water with colour removal would be the minimum. Chlorine should also be completely removed using sodium bisulphite or a similar agent. An important benefit to using tertiary treated recycled water is the greater buffering capacity it affords [183]. This in turn can lead to better control over the dyeing process. This is highlighted in the example below.

3.5.5.1 Example: Tuftex of California, Los Angeles, California

Tuftex of California is the largest carpet manufacturer on the west coast of the USA. They have been using a tertiary treated wastewater (3.8ML.day^{-1}) in their dyeing process since about 1994 [183]. Both the dyebecks and continuous dyeing processes are used onsite. The source of recycled water was specifically chosen to be low in ammonia, iron and manganese. A small amount of treatment is performed onsite, primarily sodium thiosulphate addition to remove the residual chlorine prior to dyeing (there is a water provider operated chlorination station also on the property to reduce biological growth due to the system having a large residence time). While minor formulation changes have been needed, the overall chemical costs were reduced. This included a 10% reduction in buffering compounds due to the higher buffering capacity inherent in recycled water [183]. The redyeing rate has also dropped from 5% using potable water to 3% using recycled [183]. This is believed to be due to greater consistency in the quality of supply. There have not been any reports of loss in product quality from consumers.

3.5.6 Final remarks

Overall the requirements of process water will be highly dependent on specific industry processes and applications. Requirements vary widely, from the metal finishing and electronic industry that require ultrapure water, to the mineral processing industry that can easily adopt secondary treated recycled water of any composition provided health risks are mitigated.

Within entities in the industry, process design and operational requirements can also vary. Hence, the process requirements need to be considered on a case by case basis.

3.6 Fire fighting

3.6.1 Introduction

Potable water has traditionally been used for fire fighting. In the combat of fire, water can be provided for fire suppression via continuous supply through external sources such as hydrants and tankers, or early intervention via sprinkler systems.

In each application, ensuring the continuity of supply, suitable flow rates and hence pressure are essential for effective operation. This has resulted in the adoption of minimum pipe diameters and operating pressures in water supply infrastructure for fire fighting purposes.

The adoption of recycled water as a source of water for firefighting purposes has been observed in a number of municipal, commercial and a few industrial applications around the globe driven mainly by scarcity of potable water supplies [20].

Use of the highest class recycled water for fire fighting purposes or unrestricted uses is allowed by water recycling guidelines in the majority of Australian jurisdictions (NSW, Vic, SA, QLD, ACT) and also overseas, e.g. in the state of California, USA and in Singapore [184].

3.6.2 Important Characteristics

Recycled effluent adopted in industrial applications needs to be treated to quality requirements that aim firstly to mitigate health risks and ensure safety of public and firefighters; and secondly to minimise detrimental impacts to the plant equipment and processes and the environment.

3.6.2.1 Water quality

In addition to operational issues, the main concern in regards to the use of recycled water for fire fighting purposes is the health risk it can pose due to direct ingestion and exposure to sprays or inhalation of aerosols by fire fighters and/or by any personnel that might be in the area.

When recycled water is used in open applications that can result in human exposure, e.g. dust suppression and fire fighting, the minimum quality required is often the highest possible, class A or class B. In Victoria, in face of water scarcity, use of class B water can be allowed in special circumstances (when no other alternative sources are available), for example in the combat of bushfires, provided prior approval is obtained from the relevant water authority. Similarly in Los Angeles tertiary treatment with disinfection is the minimum requirement for firefighting structural fires and secondary treatment with disinfection for non-structural fires [50].

The classification stipulates the maximum allowed level of microorganisms, biological oxygen demand, suspended solids, turbidity, pH range and in addition chlorine residual for Class A. Microorganism levels are important due to the risk that they can pose to humans during firefighting. Turbidity, pH and suspended solids are factors that can affect the effectiveness of disinfection processes and chlorine residuals impact on the potential for microorganism re-growth. After treatment, the risks posed by the presence of pathogens, viruses, protozoans and endotoxins in class A and B water were deemed negligible. Additionally , the microbial quality of recycled water was considered better than or at least equivalent to that of surface waters, which are often used for firefighting [184]. An illustration of the quality requirements in Australia is shown in Table 3.18.

Table 3.18. Recommendations for recycled water quality (Adapted from [184])

State	Class	Micro-organisms	Turbidity (NTU)	pH	Chlorine residual ($mg.L^{-1}$)	BOD/SS ($mg.L^{-1}$)	Reference
Vic	A	• *E. coli* < 10 in 100 mL; • Helminths < 1 in 1 L; • Protozoa < 1 in 50 L; • Viruses < 1 in 50 L • Viruses: 7-log reduction from raw sewage to recycled water[1] • Protozoa: 6-log reduction from raw sewage to recycled water[11]	< 2	6 – 9	≥ 1 (or equivalent disinfection)	< 10 / 5	[1]
	B	• *E. coli* < 100 in 100 mL		6 – 9		< 20 / 30	
ACT		• < 10 cfu in 100mL (med)	< 2 (prior to disinfection) Maximum 5	6.5 – 8.0 (90% compliance)	≥ 1 after 30 min or equivalent disinfection		[185]
QLD	A+	• *E. coli* < 1 cfu in 100 mL (med), < 10 cfu in 100 mL (95th-%ile); • *Clostridium perfringens* < 1 cfu in 100 mL (med); < 10 cfu in 100 mL (95th-%ile); • F-RNA < 1 pfu in 100 mL (med) < 10 pfu in 100 mL (95th-%ile) • *Somatic coliphage* < 1 fu in 100 mL (med) < 10 fu in 100 mL (95th-%ile)	< 2	6 – 8.5 (for chlorine disinfection) 6 – 9.2 (other disinfection)	0.2 – 0.5 (dual reticulation) or as per risk assessment for other uses.		[10]
NSW	A	• *F. coliforms* < 1 in 100 mL • Coliforms < 10 in 100 mL (95th-%ile) • Viruses < 2 in 50 L • Parasites < 1 in 50 L	< 2	6.5 – 8.0	Schemes without disinfection by chlorine require approval from EPA and Department of Health.		[186]
TAS	A	• Thermotolerant coliforms < 10 in 100 mL (med)		5.5 – 8.0		BOD < 10 Nutrient, toxicant and salinity control	[187]
National		• < 10 cfu in 100 mL	< 2	6.5 – 8.5	≥ 1	SS < 5	[188]

1. From the Dual Pipe Water Recycling Scheme Guidelines [52].

3.6.3 Potential Problems and Solutions

3.6.3.1 Microbial risk

The perceived presence of pathogens in recycled water is one of the major concerns in recycled water used in firefighting. Mitigation of such risk can be achieved by conventional primary and secondary treatment of wastewater followed by advanced filtration and disinfection. At such treatment levels the health risk is considered minimal as pathogens, toxins and nutrients which can harbour favourable conditions for micro-organism growth are controlled [184]. In addition, maintaining a residual disinfectant level in the recycled water is also recommended for storage and distribution requirements to prevent the growth of opportunistic pathogens.

In addition, adoption of multiple barrier approaches are also recommended to minimise the risk of exposure. These can include: quality control at the treatment plant, differentiation and identification of recycled water infrastructure (e.g. purple pipes, taps, hydrants) and signage and design for non-standard fittings to prevent cross-connections or inadvertent access to access points by non-authorised personnel.

In Los Angeles where recycled water for firefighting has been used in vigour for a number of years, risks are minimised by implementing procedures and controls to safeguard the performance of the water recycling plant, including real-time monitoring of the recycled water as it leaves the plant and enters the network and also procedures to ensure early detection and intervention if any problems are detected [50]. Hydrants and connections are also differentiated and marked to inform the population and the community of the use of recycled water and prevent access by non-authorised personnel [20].

3.6.3.2 Reliability of supply

Besides water quality, ensuring reliability of supply is another major factor for consideration in the provision of recycled water. This requires the provision of adequate storage capacity in excess of daily needs and also the adequate sizing of recycled water infrastructure to accommodate the flow requirements for firefighting (larger pipe diameter). A number of municipalities in the USA adopt recycled water for fire fighting, including Irvine Ranch, San Francisco (California) and St Petersburg (Florida) [134].

In the case of dual pipe provision for fire fighting from a centralised location appropriate infrastructure sizing is required. Provision of recycled water for fire fighting via hydrants in municipal networks, has been implemented in Altamonte Springs and St. Petersburg, Florida, USA, each housing respectively 75 and 308 hydrants serviced by recycled water, however such schemes can be restricted by the cost of infrastructure, the distance to the source and the supply capacity [20]. In St. Petersburg, the recycled water network is only used as a back-up for firefighting in case pressure mains fail.

Whilst in the case of stand alone systems, infrastructure costs are often lower as provision is addressed with the use of balance tanks on individual lots to ensure adequate supply for fire fighting purposes [20]. Under such circumstances, sizing of the tanks, storage space and energy requirements become essential to ensure reliability of supply. For example, in the city of Burbank the tank that provides recycled water for firefighting to commercial buildings is located at an elevation that allows gravity flow during energy outages [50].

3.6.3.3 Infrastructure considerations

Water quality can impact the materials adopted in the firefighting infrastructure and the system lifetime. Hence consideration of potential impacts is required in the design and operation needs of the distribution infrastructure.

As with potable water, maintenance programs including periodic flushing are required for removal of sediments and prevention of extended residence times that can lead to water aging, and biological growth. This is particularly important for indoor fire systems.

A wide range of sprinkler designs are available in the market [189]. Materials used in the manufacture of firefighting sprinklers and the associated transport systems include steel, often galvanised, copper piping, cement lined cast iron and plastic [190]. Australian Standards for firefighting sprinklers require resistance to ammonia, salt sprays, sulphur dioxide and moisture on sprinkler systems as a standard requirement [191]. Their design is based on the adoption of potable water and the impact of residence time and the potential for growth of slime, clogging and microbial corrosion caused by long residence times of alternative water sources in the sprinkler system needs to be evaluated on a case-by-case basis to assess minimum water quality requirements for TDS, suspended solids, Langelier index and minimisation of corrosion and scaling.

This can also be mitigated by sprinkler design. Sprinklers are designed as wet, dry and combination systems [189]. Wet sprinkler systems hold water in the lines at all times, releasing it upon activation, whilst dry systems are pressurised with air and kept empty until sensors detect a fire, which activates an actuating valve outside the buildings and allows the ingress of reclaimed water to the system. After fire suppression, the sprinkler is drained, minimising the occurrence of stagnant water pockets. In California, where recycled water can be used for firefighting, the Sanitation Districts of Los Angeles County recommends the adoption of ‘dry’ type sprinklers to minimise any risks of clogging and microbial corrosion in the lines or the sprinkler heads [50].

3.6.3.4 Requirements of national standards and manufacturers

Contaminant levels stipulated in the National Australian guidelines on the use of recycled water in firefighting are based on the assumption of a maximum ingestion of 1 L of water per fire fighter per year and assumes that any pre-treatment will obtain a removal of 6.5 logs for viruses, 5.3 logs for *Campylobacter* and 5.1 logs for *Cryptosporidium* [2]. Such requirements can be achieved through conventional primary and secondary treatment methods followed by tertiary filtration and disinfection stage as often adopted to produce Class A effluent [184]. If recycled water is used for supply of indoor fire sprinklers, additional treatment may be required depending on the sprinkler design and material of construction, as control of TDS may be required. Current standards for firefighting equipment allow the use of non-potable water sources subject to approval by water authorities and government agencies [189].

Requirements for Class B effluent are less detailed, but authorisation for adoption requires approval by the relevant water authorities on a case-by-case basis.

Table 3.19. The minimum quality requirements of water after reverse osmosis for Eraring Power Station [17].

Parameter	Maximum Value
Suspended Solids ($mg.L^{-1}$)	1
Silt density index	3
Reovirus (per 100 mL)	nil
Enterovirus (per 100 mL)	nil
Total coliforms (per 100 mL)	10
Faecal coliforms (per 100 mL)	1
Faecal streptococci (per 100 mL)	1

Table 3.20. Minimum quality requirements for recycled water at the Sydney Olympic Park

Parameter	Maximum Value
Chlorine residual (mg/L)	0.5
Turbidity (NTU)	2
Viruses (per 50 L)	2
Parasites (per 50 L)	1
Total coliforms (per 100 mL)	10
Faecal coliforms (per 100 mL)	10
pH	6.5-8.5

3.6.4 Inherent Benefits

Recycled water can often be the only reliable supply in areas affected by water scarcity.

3.6.5 Some Examples

3.6.5.1 Eraring Power Station, Hunter Valley, NSW

Treated recycled water is used as make-up water for the fire fighting system in the Power Station. The same water is also adopted for domestic requirements, wash-down and auxiliary cooling. The required water quality is given in Table 3.19

3.6.5.2 Sydney Olympic Park, Homebush, NSW

Wastewater from the Sydney Olympic Park undergoes advanced biological treatment and UV disinfection. This is followed by further treatment in the WRAMS treatment facility (continuous microfiltration and chlorination) for use in other applications and fire-fighting. The minimum water requirements are given in Table 3.20.

3.6.5.3 City of Livermore, California

The city of Livermore uses reclaimed water treated by MF/RO for the protection of airport hangars and a wholesale warehouse house. Recycled water was adopted because the potable water system could not provide sufficient pressure [20].

3.6.5.4 Puente Hills Gas-to-Energy Power Plant

A 500,000 gallon reclaimed water storage tank connects to a cooling tower reservoir in the power plant and serves the associated landfill and its fire system [50]. The recycled water generated at San Jose Creek Water Reclamation plant undergoes primary sedimentation, biological oxidation and clarification as secondary treatment and tertiary filtration and chlorination [192].

3.6.5.5 Bonelli County Regional Park, California

The recreational area of 205 acres has a fire system that is supplied by a 5 million gallon reservoir of recycled water placed at an elevation to ensure flow during power outages.

3.6.6 Suitable Water Qualities

Class A, A+ or class B subject to approval.

3.6.7 Best Practice

Treatment of effluent to class A or class A+ via tertiary treatment. Provision of suitable storage capacity.

Acceptance of recycled water for firefighting in Australia has encountered resistance from the firefighters union due to concerns with the potential risk to firefighters. Similar concerns have been expressed in the USA, and in response the Sanitation District of Los Angeles County developed a protocol to address its utilisation in consultation with major stakeholders including firefighting departments [47]. A similar Standard Operating Procedure is in the final stages of development in Victoria with support from both the Metropolitan Fire and Emergency Services Board and the Country Fire Authority.

3.7 External use

3.7.1 Introduction

Water is used in a range of external industrial applications and activities such as:

- Dust control at construction sites,
- Landscape irrigation and water features.
- Building, kerb and pavement washing,
- Washing of vehicles, floor and yards.

The major concerns when recycled water is used for these applications relate to human and animal health risks due to the potential for close contact with the recycled water and environmental impacts on soils, surface waters, biota, air due to run-off and direct application. Whilst the application of water for landscape irrigation may be a small percentage of water use in industry, the benefits of a green landscape for both employees and the company image, should not be overlooked.

The risks and impacts associated with industry applications for external water use will be similar to those for other non-industrial uses. For example, data and information on the use of recycled water for agricultural or municipal uses can be used comparatively. Information on the issues and barriers associated with water recycling in the car wash industry can be used for comparison to vehicle washing, floors and yards (see Section 3.3).

3.7.2 Important Characteristics

When recycled water is used in unrestricted applications that can lead to human contact, e.g. dust suppression, water features and irrigation, recycled effluent needs to be treated to ensure that the health risk is minimised. This is similar to the production of aerosols in washing applications (see Section 3.3), although a lower quality can be used dependent on site specific conditions and control measures [1]. Control measures may include application times, mode of application, fencing and withholding periods [1]. In addition to human health risks, it may also be necessary to investigate the nature of items being washed (see Section 3.3) as different qualities of recycled water may have impact on materials in vehicles or surfaces.

Where recycled water is to be used for irrigation or other environmental purposes the impacts of the recycled water quality on the soils, plant life, groundwater and other surface waters will need to be assessed. For irrigation, water should be applied at a rate that does not exceed the plant's water or nutrient needs and should maintain soil conditions for optimum plant growth or yield [1]. Use should also protect groundwater and other surface waters, avoid structural changes to the soil and avoid air contamination from sprays or aerosols. Some of these factors can be controlled by careful selection of the irrigation application site by ensuring appropriate soil type, limited slope, assessment of groundwater reserves and also by incorporating climatic conditions in the calculation of application rates [193]. Water, nutrient and salt balances should also be carried out. Design of the application system is also important in minimising both human health and environmental risks and drip, sub surface, spray irrigation or low pressure sprinkler systems are recommended.

3.7.3 Potential Problems and Solutions

3.7.3.1 Pathogens and health risk

The primary concerns when recycled water is used for washing, irrigation and other external uses are the potential for human contact and impact on human health. There is the potential for accidental ingestion of the treated wastewater or inhalation of aerosols produced during application of the treated wastewater.

Table 3.21. Issues for consideration in water quality used for general purpose and irrigation [194]

	Key Issues
Soil	Root zone salinity Soil structural stability Build-up of contaminants in soil Release of contaminants from soil to crop and pastures
Plants	Yield Salt tolerance Specific ion tolerance Foliar injury Uptake of toxicants in produce for human consumption Contamination by pathogens
Water resources	Deep drainage and leaching below root zone Movement of salts, nutrients and contaminants to groundwaters and surface waters
Important associated factors	Quantity and seasonality of rainfall Soil properties Crop and pasture species and management options Land type Groundwater depth and quality

In applications where there is a high potential for aerosol generation or human contact, Class A water should be used. This may be achieved by use of tertiary treated water with pathogen reduction, to obtain a water quality of: < 10 *E. coli* per 100 mL; <1 helminths per litre; < 1 protozoa per 50 litres; and < 1 virus per 50 litres. There are additional requirements for other water quality parameters as follows: Turbidity < 2 NTU, < 10 $mg.L^{-1}$ BOD, < 5 $mg.L^{-1}$ SS, pH 6 – 9 and a 1 $mg.L^{-1}$ chlorine residual (or equivalent disinfection).

In irrigation applications the microbiological component of recycled water will also need to be controlled, as there is the potential for biofilm growth in the irrigation system that may cause blockages and irrigation system failure. Low levels of residual chlorine may be used to control this but the impact on plants and soils should be considered.

3.7.3.2 Environmental impact

Water used for irrigation or landscaping requires consideration of its potential impact on groundwater, surface waters and plant life (see Table 3.18). Guidelines for irrigation water are presented in the ANZECC/ARMCANZ 2000 Australian and New Zealand Guidelines for Fresh and Marine Water Quality [194].

Application rates and salt and nutrient levels also need to be considered to ensure minimal environmental impact. Application rates should be calculated to ensure adequate supply of water but no over application. Soil moisture sensors can be used to control application rates and aid in the automation of irrigation systems.

Salt levels in treated wastewater can affect both plant growth and soil characteristics. Sodium, magnesium and calcium concentrations are used to calculate the Sodium Adsorption Ratio (SAR), a factor often used in assessing the applicability of wastewater to irrigation applications. Municipal effluent typically has a SAR of less than 8. Minimal removal of sodium, calcium and magnesium occurs in primary and secondary wastewater treatment, but tertiary treatment may provide some removal dependent on the process used. Electrical conductivity is also often used to assess potential impact of recycled wastewater on soils and plants, with an EC of > 8.1 $dS.cm^{-1}$, indicating an extreme salinity rating and a water unsuitable for plant irrigation.

Recent work suggests that the potassium concentration should also be incorporated in this ratio, as potassium can have similar long term detrimental effect on soils as sodium [195]. However, potassium is an essential plant macronutrient, unlike sodium. The metals concentrations for wastewater used for irrigation should also be assessed, as these compounds can have detrimental impacts on soil structure and plant growth. The ANZEC and ARMCANZ guidelines [194] state trigger values for aluminium, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium and zinc in irrigation effluent in long term use.

The application rates of nitrogen and phosphorus should be calculated to ensure no overapplication and subsequent pooling, runoff and contamination of groundwater or surface waters or plant toxicity issues.

3.7.4 Inherent Benefits

In the current climate of water scarcity and water restrictions, recycled water offers a more secure supply, compared to collected rainwater. An advantage of using recycled water for irrigation purposes is that nutrients, nitrogen and phosphorus are utilised and are generally beneficial to plant growth. Class A water does contain low but significant levels of phosphates and nitrates.

Using recycled water for maintaining green open space and other irrigation applications has the benefit of improved visual aesthetics, impacting positively on employee and general public perceptions of an industrial site.

3.7.5 Some Examples

There are few examples of use of scheme recycled water for irrigation purposes in industry outside agricultural applications, which are not being addressed in this study. CH2 in Melbourne is an example of a commercial premises where sewer mined effluent is being used for irrigation,. Case studies for washing purposes can be found in Section 3.3.

1. Cadia Valley Operations (Newcrest Mining), Orange, NSW

- Gold and copper mine and mineral processing plant
- Uses a mix of water with 2/3 being RW from Orange
- Water used in all processing including dust suppression, flotation processes, leaching etc, but not in the mine itself.

2. CH2, Melbourne City Council building, Melbourne, Vic

- Wastewater mined from sewer
- Treated via ceramic filter and RO
- Treated water used in combination with collected rainwater for irrigation of vertical gardens on north facade, cooling, toilet flushing, street washing and open spaces

3. Werribee Technology Precinct

- Open space watering
- Washdown for Melbourne University Vet School
- Future supply to Hoppers Crossing Pumping Station for pump gland lubrication and motor cooling.

3.8 Personal uses

3.8.1 Introduction

Personal uses allowed for recycled effluent cover non-potable applications such as toilet and urinal flushing and potentially clothes washing. The volumes of water used in these applications in industry may be low compared to water needs of the industrial process. In commercial or office building these end uses can be significant with up to 37% use for domestic and bathroom reported by Sydney Water and 31% reported in a Californian study [196]

The primary concern for use of recycled water for these end uses is that of human health, as there is potential for direct contact. In addition there are aesthetic issues of staining and colour as recycled water may contain some colour compounds and also the impacts on appliances and their components.

3.8.2 Important Characteristics

When recycled water is used in unrestricted applications that can lead to human contact, such as toilet flushing and clothes washing, Australian guidelines state that it needs to be treated to ensure that the risk to health is minimised. This requires treatment to class A or A+ (QLD), with a residual disinfection.

Water demand for these applications will be related to the number of employees, the numbers of fixtures and the type of fixture i.e. single or dual flush. For these systems dual reticulation is required so there is one system for drinking water to supply basins and another to supply the recycled water. Generally the installation of this dual reticulation system is best done during building construction as the cost of retrofitting can be prohibitive. There are guidelines and codes relating to the installation of dual reticulation systems particularly in the prevention of cross connections [52, 197] (see also Section 2.2.5). Appropriate signage should be in place to ensure users are aware that recycled water is being used.

3.8.3 Potential Problems and Solutions

3.8.3.1 Pathogens and health risk

For most states in Australia there is the requirement to treat recycled water to Class A standard via tertiary treatment and residual disinfection for indoor uses. The treatment technology should provide a pathogen reduction to achieve: < 10 *E. coli* per 100 mL; <1 helminth per litre; < 1 protozoa per 50 litres; and < 1 virus per 50 litres. There are additional requirements for Turbidity < 2 NTU, BOD < 10 $mg.L^{-1}$, TSS < 5 $mg.L^{-1}$, pH 6 – 9, 1 $mg.L^{-1}$ chlorine residual (or equivalent disinfection).

There are also requirements for quality control monitoring [1] which include weekly analysis of pH, BOD, SS, *E. coli* and continuous monitoring of turbidity and disinfection efficacy (eg chlorine residual). This would be performed at the sewage treatment plant, and potentially onsite, by the recycled water provider.

3.8.3.2 Aesthetic impacts

Recycled water can be coloured and this may reduce the acceptability for end uses such as toilet flushing and may impact the quality of the wash when used for laundry purposes. There may also be issues associated with use of recycled water in different appliances, dependent on their materials of construction.

3.8.4 Inherent Benefits

Toilet facilities are often centrally located in office and commercial buildings, located on the same location on each floor. This configuration allows shorter pipe runs and common supply systems.

3.8.5 Some Examples

5.1 Sydney Olympic Park (http://www.naiad.net.au/?q=node/54)
5.2 Commercial office buildings: Council House 2
(http://www.naiad.net.au/?q=node/27)

CHAPTER 4 Case Studies

The following chapter contains a selection of case studies on the use of recycled water by industry. For a full list of industrial users of recycled water see Appendix A. Although the focus of the chosen case studies is on Australian use, there are also some international case studies included. Also, although they were not the focus of this report, there are some case studies related to internal recycling of water in industries where recycled water from a sewage treatment plant cannot be used. These case studies aim to highlight the success with which different qualities of recycled water can be used in various applications. Also, any potential pitfalls that the industrial user may encounter are outlined here.

CASE STUDY

BlueScope, Port Kembla, NSW, Australia

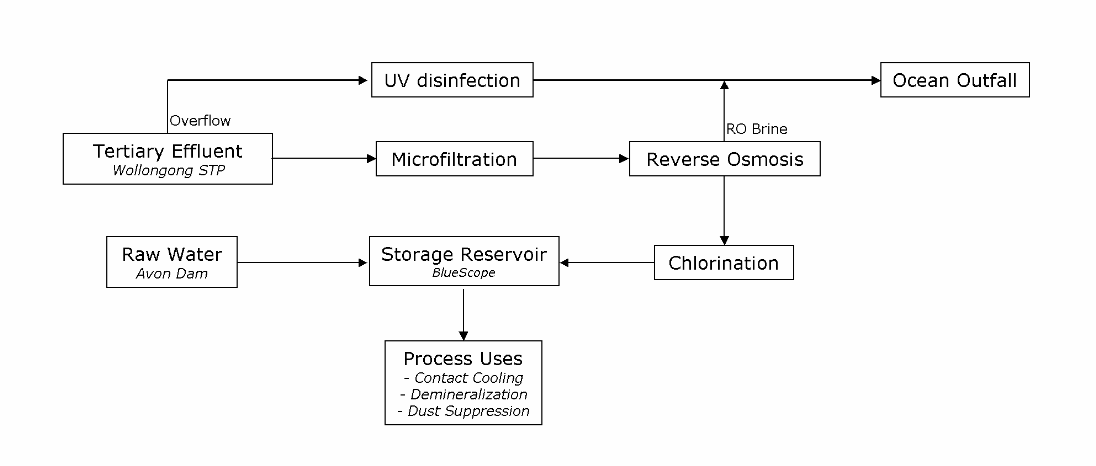
Introduction

- The BlueScope steelworks in Port Kembla, south of Wollongong, has an annual steel production of approximately 5 million tonnes. The steelworks has been operating on the site since 1928.

Problem Description

- BlueScope is the largest user of potable water in the Sydney Water operational area. Significant water reduction had been made due to the drought in 1992 due to the imposition of restrictions. However due to the nature of steel making it appeared unlikely that any further reductions could be made internally.

Process Flow Diagram



Solution Adopted

- In 2002 the Illawarra Wastewater Strategy was announced whereby Sydney Water would consolidate the Port Kembla, Bellambi and Wollongong sewage treatment plants into one facility treating 60 $ML.day^{-1}$. A portion of this effluent would be treated using microfiltration and reverse osmosis to produce 20 $ML.day^{-1}$ of high quality water for use on the BlueScope site [29].
- Due to the limited amount of recycled water available, this water would be mixed with raw water from the Avon Dam in a ratio of 55:45 to ensure an adequate water supply [29]. The typical water qualities of the recycled water are shown in Table 1.

Table 1. BlueScope requirements for the recycled water and average values for the first year's operation [37]

Parameter	BlueScope Requirements	Actual Values
Adenovirus (MPNIU)	< 1	nil
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)		8.9
Aluminium ($mg.L^{-1}$)		0.01
Ammonia ($mg.L^{-1}$)	< 1	0.02
$CBOD_5$ ($mg.L^{-1}$)	< 1	< 2
Chloride ($mg.L^{-1}$)	< 20	8.8
Chlorine Residual ($mg.L^{-1}$)		1.6
Conductivity ($mg.L^{-1}$)		50
Cryptosporidium	< 1	nil
E. Coli ($counts.100mL^{-1}$)	< 1	< 1
Enterovirus (MPNIU)	< 1	nil
Giardia	< 1	nil
Hepatitis A	< 1	nil
Manganese ($mg.L^{-1}$)		< 0.001
Nitrate ($mg.L^{-1}$)	< 4	0.27
Norwalk Virus	< 1	nil
Reactive Silica ($mg.L^{-1}$)		0.2
Reovirus (MPNIU)	< 1	nil
Rotavirus	< 1	nil
SS ($mg.L^{-1}$)	< 1	< 2
TDS ($mg.L^{-1}$)	< 85	33.9
Total Coliforms ($counts.100mL^{-1}$)	< 10	< 1
Total Hardness ($mg.L^{-1}$ as $CaCO_3$)	0 - 20	1.7
Total Iron ($mg.L^{-1}$)		< 0.01
Total N ($mg.L^{-1}$)	< 5	0.32
Total Phosphorus ($mg.L^{-1}$)	< 1	0.017
Turbidity (NTU)		0.1

Implementation

- The BlueScope site previously took raw water from the Avon Dam that was distributed by a separate reticulated system. The recycled water was added to this system. This meant no retrofitting was required by BlueScope of the site.
- Initially the high purity of the water was seen as a corrosion issue. This was not a significant concern for BlueScope as the water was mixed with raw water before use.
- The main problem faced by the project was opposition from the NSW fire brigade union. The industrial water supply was used for all fire fighting on site. A dispute arose between the NSW State Government and the union over the union's requirement for indexed death and disability benefits as protection in case one of their members became sick from contact with the water. The dispute lasted for more than a year after the completion of the project during which time recycled water was sent to ocean outfall while potable water was used onsite.

Economic Justification

- BlueScope and Sydney Water have entered into a 15 year contract for the supply of recycled water [29]. The situation is profitable, however no further information is available.

Environmental Justification

- The use of recycled water at BlueScope has decreased the annual use of water from the Avon dam by 20%, freeing more water for potable uses and environmental flows.
- There has also been a 40% reduction in the discharge of sewage to the Wollongong marine environment reducing the pollution load. This has been further spurred by the consolidation of three STPs into a single plant equipped with an ocean outfall in order to produce the quantity of water required by BlueScope.

The Future

- Plans are currently underway to expand the recycled water project to provide between 35 and 50 $ML.day^{-1}$ of recycled water to BlueScope to virtually eliminate their reliance on water from the Avon Dam.

CASE STUDY

BP & Bulwer Island Cogeneration Plant, Bulwer Island, Qld, Australia

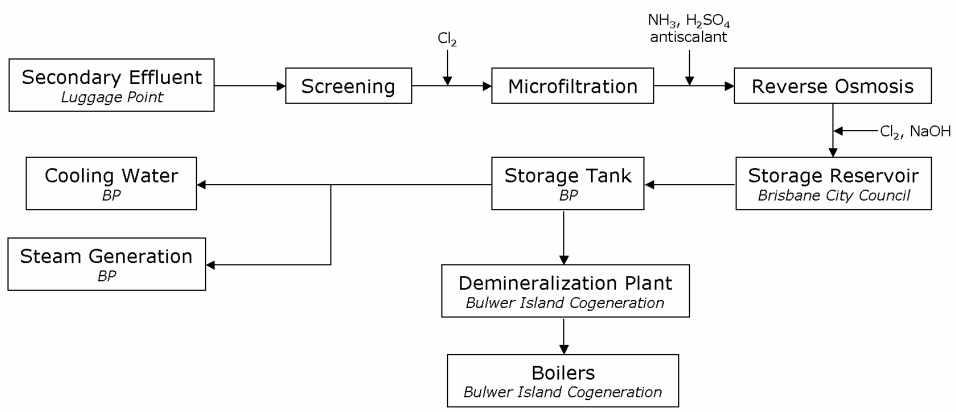
Introduction

- The refinery on Bulwer Island in Brisbane was established in 1965 and has undergone a number of upgrades to reach its current production level of 88,000 barrels a day.
- The most recent expansion came as part of the Queensland Cleaner Fuels project saw the building of a hydrogen fuels production facility (owned by BOC) and a cogeneration plant (a joint venture between Origin Energy and ATCO) for the refinery.

Problem Description

- The upgrade to BP's refinery as part of the Cleaner Fuels project meant a tripling in the site's demand for water. This could not be easily met by the local potable water supply from Brisbane Water.

Process Flow Diagram



Solution Adopted

- To satisfy the water demands for the site and in keeping with Brisbane City Council's wish to use fit for purpose water 10 to 14 $ML.day^{-1}$ of MF/RO treated water from the Luggage Point STP is provided to BP. The water qualities required by BP and achieved initially from the plant are shown in Table 1.

Table 1. BP requirements and actual quality achieved by the Luggage Point Project [16].

Parameter	BP Requirement	Actual Quality
pH	6.8-7.2	6.8-7.2
Conductivity (µS.cm^{-1})	60-120	80-100
Turbidity (NTU)	< 0.1	0.02-0.1
Free Chlorine (mg.L^{-1})	0.3-0.5	0.3-0.5
Ammonia (mg.L^{-1})	< 1.0	0.04
Total N (mg.L^{-1})	< 2.0	1.5
Phosphorus (mg.L^{-1})	< 0.2	< 0.2
TOC (mg.L^{-1})	< 1.0	< 1.0
Aluminium (mg.L^{-1})	< 0.01	< 0.01
Chlorides (mg.L^{-1})	< 40	11
Copper (mg.L^{-1})	< 0.001	< 0.001
Iron (mg.L^{-1})	< 0.01	< 0.01
Fluoride (mg.L^{-1})	< 0.1	< 0.1
Mercury (mg.L^{-1})	< 0.001	< 0.001
Heterotrophic Plate Count (cfu.mL^{-1})	< 1000	< 100
Legionella (cfu.mL^{-1})	< 10	< 10

Implementation

- Problems with implementation were minor from BP's point of view. Initial problems at Brisbane Water's reclamation plant led to some contaminants in the water initially.
- The main issue came from the alkalinity of the water being too low, presenting a potential corrosion problem. This problem has disappeared over the life of the plant as the RO membranes age.
- No operational problems within the BP site are known.

Economic Justification

- The treatment plant and water delivery system cost $20m. Other economic details are considered confidential.

Environmental Justification

- The principal environmental justification is the reduction in the pollution load in the Brisbane River and Moreton Bay as a result of the greater level of treatment of the water and the reduced sewage discharges.
- Also of significance is the reduction in potable water usage that is of great importance to the Brisbane region due to the severe water shortage currently occurring.

Recognition

- The recycled water project received recognition as part of the Queensland Cleaner Fuels Project that won the Australian Construction Achievement Award 2001.

CASE STUDY

Cadia Valley Operations, Orange, NSW, Australia

Introduction

- The Cadia Valley Operations near Blayney in New South Wales is operated by Newcrest Mining and is New South Wales' largest gold mining operation and consists of the Cadia Hill open pit mine, the Ridgeway underground mine and the Cadia ore processing plant.
- Its main products are gold and copper in a sulphide concentrate, producing approximately 560,689 ounces of gold and 61,120 tonnes of copper in concentrate in the 06/07 financial year.
- Concentrate containing copper minerals and gold is transported to Blayney as slurry, dewatered and transported in closed containers by train to Port Kembla.
- The Cadia Hill mine and processing plant have been operational since 1998 and the Ridgeway mine opened in 2002. The projected life of the Cadia Hill and Ridgeway mines was 15 and 18 years respectively.
- Plans are currently underway to start mining a new area. This Cadia East project will extend the life of the operation by a further 20 years.

Problem Description

- During the development of the mine proposal it was apparent that surface water in the region alone would not be sufficient to meet the needs of the project for a secure long term water supply.
- Increasing environmental restrictions meant that the Orange City Council would accrue additional costs for sewage discharge into the local river system from the EPA.

Process Flow Diagram

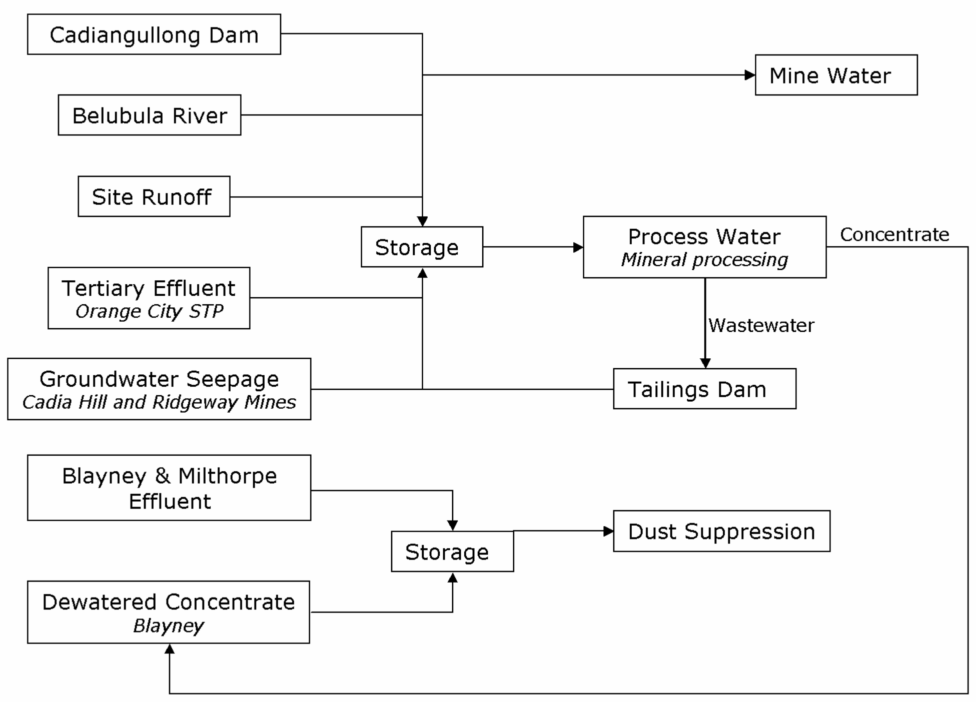


Table 1. Breakdown of water sources for the Cadia Valley Operations

Source	Volume ($ML.day^{-1}$)	Percentage
Cadiangullong Dam	2.8	6
Belubula River	3.45	7
Rainfall Projections	1.1	2
Blayney Effluent	0.06	0.1
Orange Effluent	12.8	27
Internal Recycle (tailings and dewatering facility returns)	27.2	57

Table 2. Water quality requirements specified by CVO to Orange City Council

Parameter	Value
BOD ($mg.L^{-1}$)	15
TSS ($mg.L^{-1}$)	20
Oil and grease ($mg.L^{-1}$)	10
pH	6.5 - 8.5

Solution Adopted

- The water solution for the Cadia Valley Operations was to diversify the water sources. The breakdown of water sources from a recent publication are shown in Table 1. The plant performs a significant amount of internal recycling with water from the tailings dam recycled to the process water and water from the return pipeline after dewatering of the copper concentrate in Blayney used for dust suppression and processing.
- The values shown in Table 1 have varied significantly as a result of drought and decrease supplies to the surface water and recycled water.
- Water is also sourced from river supplies with the two main sources being the Belubula River and the Cadiangullong Dam (built and owned by Cadia).
- The largest external water supply was taken from the Orange City Council's sewage treatment plant (the water is equivalent to Victoria's Class A recycled water). This initially provided about two thirds of the site's make-up water.
- Table 2 shows the water quality required by the site. This water is used in all mineral processing stages. It is not used in the mines in order to reduce the exposure of workers to the water. Also recycled water from Blayney and Milthorpe is added to the Blayney return pipeline and used for dust suppression and processing.
- The recycled water receives no further treatment.

Implementation

- As part of the implementation, beyond the standard water testing performed by Cadia, flotation tests are also performed. To date no issues have been identified.
- In terms of recycled water use no significant problems have been reported, although Newcrest have noted that the presence of inert fibres occasionally impacts on filter performance.
- In terms of water management, Cadia has suffered a negative impact due to the recent drought, despite the diversity of water sources. The lack of rainfall in New South Wales has meant that the surface water sources have been drastically reduced and the Orange effluent water volumes have decreased (this is due to the combined effect of lack of stormwater entering the Orange sewage system and the general decrease seen as a result of restrictions). Importantly, the quality of the recycled water was not impacted by the decrease. This left Cadia with several options,

including finding new water sources, increasing on-site storage capacity (longer term contributor) or reducing production. Negotiations with the Orange City and Cabonne Shire Councils has resulted in a solution where Cadia's requirements can be met for the short term using water previously used for recreational purposes in Orange, and from a disused quarry in the Cabonne Shire.

Economic Justification

- Cadia paid $1 million up front for access to the recycled water from Orange City council for the life of the mine.
- Cadia also paid the capital and pay operational costs for the infrastructure to deliver the recycled water to the site.
- Though this may have been done at less expense using river water; as was demonstrated during the drought, access to this water may be restricted (despite paying for access to the water at the height of the drought Cadia was only able to access 50% of its high security and none of its general security entitlements) and may impact operations.

Environmental Justification

- The large use of recycled water (both internal and external) has meant that Cadia could continue to provide environmental flows to the Belubula River.
- The use of recycled water has also been beneficial for the Macquarie River near Orange with a significant reduction in the nutrient load.

The Future

- The Cadia East project, may entail an increase in the processing rates and thereby water use. A range of secure long-term water supply options are being investigated including:
  - Pumping recycled water from Bathurst
  - Increasing the size of the on site water storage.
  - Obtaining water form the now flooded Browns Creek mine (near Blayney)

CASE STUDY

Chevron Refinery, El Segundo, Ca, USA

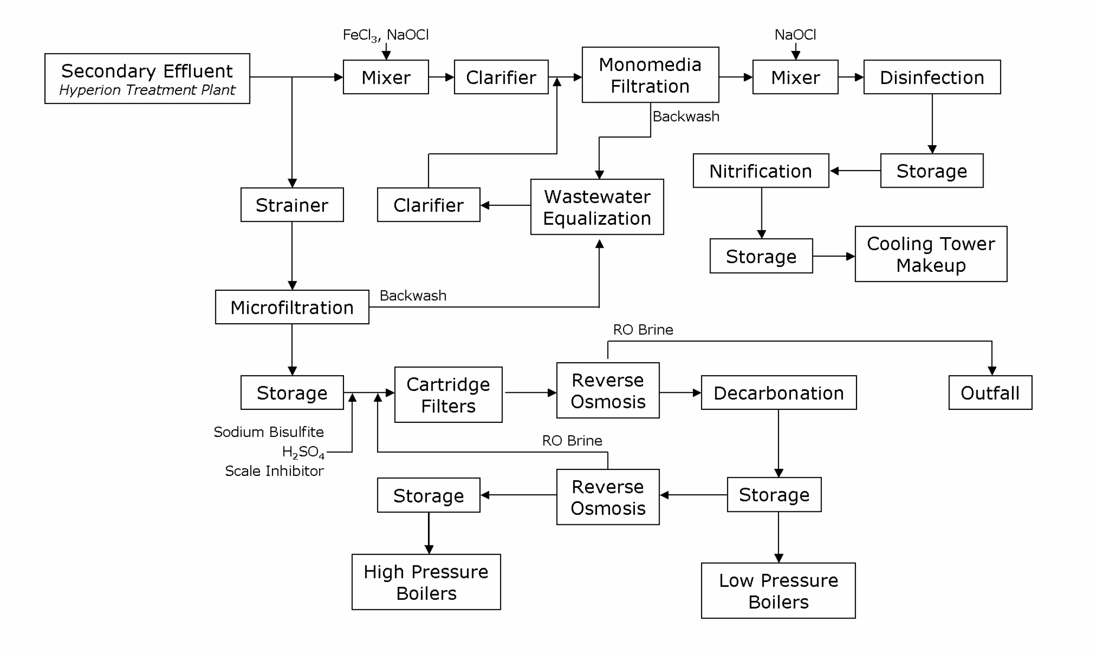
Introduction

- The Chevron petroleum refinery located in El Segundo, Los Angeles, has an operating capacity of 270,000 barrels per day. It has been operating on the site since 1911 and focuses its production on transport fuels (petrol, diesel and aviation fuel).
- Since 1995 the site has used recycled water for cooling towers. In 2001 the site also began accepting recycled water for boiler feed.

Problem Description

- Los Angeles is heavily reliant on imported water from the Colorado River and water sources in the Sierra Nevada, with only moderate levels of groundwater available.
- The Colorado River supply in particular is under increasing demand as it provides water to a large number of west coast cities.
- In Los Angeles, the petroleum refineries are large users of water, primarily groundwater. Reducing this use will free groundwater for potable use and reduce the city's reliance on imported water.

Process Flow Diagram



Solution Adopted

- The local water district, West Basin Municipal Water District, has undertaken to encourage recycled water use in industry by providing "designer" water. Essentially this means West Bain provides six different types of recycled water to customers, of which Chevron uses three.
- Secondary effluent from the Hyperion Treatment Plant is treated to a tertiary level at West Basin's water reclamation plant. This water is sent to a satellite treatment plant at the refinery where it undergoes nitrification to reduce the ammonia content. 19 ML.day^{-1} of the nitrified Title 22 water is used by Chevron for cooling purposes (see Table 1 for qualities).

Table 1. Quality of the nitrified tertiary effluent used by Chevron in their cooling towers.

Constituent	Mean	Maximum
Conductivity (µS.cm^{-1})	1240	1840
pH	7.6	7.8
Hardness (mg.L^{-1} as $CaCO_3$)	143	214
Ca (mg.L^{-1})	41	67
Total alkalinity (mg.L^{-1} as $CaCO_3$)	78	133
Total Phosphate (mg.L^{-1})	5	7.7
Ammonia (mg.L^{-1})	< 0.5	1.3
Chloride (mg.L^{-1})	215	302
Sulphate (mg.L^{-1})	124	294
Nitrate (mg.L^{-1})	84	116
Nitrite (mg.L^{-1})	< 0.5	0.7
Silica (mg.L^{-1})	19	27.6
Total Organic Carbon (mg.L^{-1})	8.3	8.9
Chemical Oxygen Demand (mg.L^{-1})	22	41

Table 2. Quality requirements for the boiler feed water at the Chevron, El Segundo refinery

Component	**Low Pressure**	**High Pressure**
Silica (mg.L^{-1})	1.5	0.1
TDS (mg.L^{-1})	60	5
Hardness (mg.L^{-1} as $CaCO_3$)	0.3	0.03
Bicarbonate (mg.L^{-1})	27	3

- Secondary effluent is also treated using a microfiltration and reverse osmosis train at the reclamation plant. Water treated with one RO pass is sent to the low pressure boilers at Chevron, while water treated with two RO passes goes to the high pressure boilers. This represents 16.3 ML.day^{-1} with 10 ML.day^{-1} going through the two pass RO system. The water qualities specified by Chevron are shown in Table 2.
- Chevron provides no further treatment other than its own chemical addition for corrosion, scale and biological protection.

<u>Implementation</u>

- The use of nitrified Title 22 water has meant that Chevron has maintained the cycles of concentration for the cooling towers previously used onsite.
- For the boiler system the cycles of concentration have been significantly increased from 10 to 50.
- Steel corrosion inhibitor use has dropped significantly due to the presence of phosphates in the water.
- No problems have been reported at the site, in fact reports claim that both the cooling and boiler systems appear to be running with greater protection.

<u>Economic Justification</u>

- Chevron have seen a $2.3m decrease in cooling water costs from taking recycled water, and a 10% decrease in water costs associated with boiler feed despite the higher costs of the water.
- Chemical treatment costs have decreased by 15 and 75% for the cooling towers and boilers respectively.
- There has also been an 85% reduction in the costs of energy onsite representing savings in the millions of dollars.

Environmental Justification

- The use of recycled water has reduced the pollution load from sewage discharge into Santa Monica Bay.

Recognition

- The boiler feed project won a Public Officials for Water and Environment Reform Award in 2001 for Chevron and the West Basin WMD.

The Future

- Chevron is currently planning an expansion of the El Segundo site. As part of this it has requested access to larger volumes of nitrified Title 22 water from 2009. West Basin is currently investigating the feasibility of expanding their recycled water operations.

CASE STUDY

Chevron Refinery, Richmond, Ca, USA

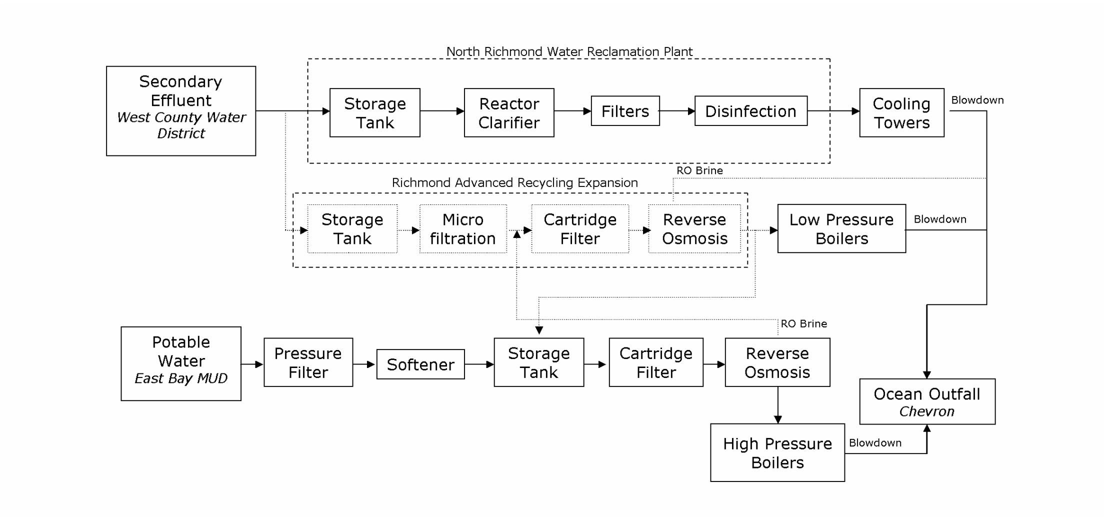
Introduction

- The Chevron petroleum refinery located in Richmond, California on the shore of San Francisco Bay has an operating capacity of 240,000 barrels per day, making it the largest refinery in the Bay area.
- It has been operating on the site since 1902 and focuses its production on transport fuels (petrol, diesel and aviation fuel) and lubricants.
- Since 1996 the site has used recycled water for cooling towers and plans are underway to upgrade the facility to take recycled water as boiler feedwater by the end of 2008 [124].

Problem Description

- The size of the Chevron refinery at Richmond means it used a large amount of potable water in an area prone to low rainfall and drought.
- In times of low rainfall, the local water district, East Bay Municipal Utilities District (EBMUD) was required to import water from other districts. A reduction in reliance on the recycled water was required to free up potable water for the district and reduce the reliance on imported water.

Process Flow Diagram



Solution Adopted

- To reduce the refinery's reliance on potable water, EBMUD approached Chevron with a proposal to provide recycled water treated to a tertiary level (clarification, filtration and disinfection) for use in their cooling towers.
- The project was operational in 1996 and provided 11 ML.day^{-1} of cooling tower makeup water. This is currently being expanded, due to a refinery upgrade to 15 ML.day^{-1}. The average water qualities provided by EBMUD are shown in Table 1.
- The water receives no further treatment by Chevron.

Table 1. Average water qualities provided from the North Richmond WRP to the cooling towers at the Chevron Refinery.

Parameter	Value
Aluminium ($mg.L^{-1}$)	0.4
Boron ($mg.L^{-1}$)	0.5
Calcium($mg.L^{-1}$)	27.3
Chloride ($mg.L^{-1}$)	150
Chlorine Residual ($mg.L^{-1}$)	4.75
Total Coliforms (MPN per 100 mL)	< 2
Conductivity ($\mu S.cm^{-1}$)	1526
Hardness ($mg.L^{-1}$ as $CaCO_3$)	100
Iron ($mg.L^{-1}$)	0.1
Magnesium ($mg.L^{-1}$)	13.4
Manganese ($mg.L^{-1}$)	0.07
Orthophosphate ($mg.L^{-1}$)	2
pH	6.8
Potassium ($mg.L^{-1}$)	13.1
Sodium ($mg.L^{-1}$)	127
Turbidity (NTU)	0.6
Zinc ($mg.L^{-1}$)	0.06
Copper ($\mu g.L^{-1}$)	17.4
Lead ($\mu g.L^{-1}$)	9.9

Implementation

- When taking recycled water, Chevron and the water treatment contractor Nalco, made the following changes to the cooling tower operations and treatment regimes [38]:
  - Due to the higher conductivity of the recycled water (approximately 10 times greater) the cycles of concentration was reduced from 7 to about 4, meaning water use increased.
  - The presence of orthophosphate meant that the amount of steel corrosion inhibitor could be significantly reduced even taking into account the higher water use.
  - To control scale formation the concentration of dispersant/antiscalant used was doubled and the pH setpoint lowered. This means more acid and antiscalant are used.
  - The concentration of yellow metal corrosion inhibitor was maintained, but the lower cycles of concentration mean more is now used.
  - The chlorine setpoint was maintained, however the lower cycles of concentration has increased its usage.
- Chevron have noticed a greater variability in the quality of the water leading to some complications in controlling the water, however this has not been serious.
- To date the main problem witnessed by Chevron is a shorted life for the heat exchangers due to corrosion. This issue is still being addressed.

Environmental Justification

- The use of recycled water significantly reduces the pollution load in San Francisco Bay due to the redirection of the treated sewage.
- The decreased reliance on the local reservoir on the Mokelumne River means it is possible to release further water for environmental flows in autumn and winter if water supplies are adequate [198].

Table 2. The water quality requirements specified by Chevron for the RARE project. The values listed represent maximums [124].

Parameter	Low Pressure Boiler	High Pressure Boiler
Iron ($mg.L^{-1}$)	0.1	0.02
Copper ($mg.L^{-1}$)	0.05	0.015
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	30	5
Silica ($mg.L^{-1}$)	1.5	0.1
TDS ($mg.L^{-1}$)	60	5
Hardness ($mg.L^{-1}$ as $CaCO_3$)	0.3	0.1
TOC ($mg.L^{-1}$)	1	0.5
pH	6.0 - 7.5	6.0 - 7.5

<u>The Future</u>

- The justification for the project was significant enough for Chevron to expand the cooling water use.
- Plans are now underway for the construction of the Richmond Advanced Recycling Expansion (RARE) Water project that will provide 13 to 15 $ML.day^{-1}$ of MF/RO treated water for use as a boiler feed (shown in the process flowsheet). This will not provide all the water needs of the company with some makeup using potable water still required, but it does represent a significant reduction in the plant's reliance on potable water.
- As part of the new project, secondary effluent will be taken from the West County Water District's water pollution control centre and treated using a microfiltration membrane. This will be followed by reverse osmosis. After treatment the water will be sent to Chevron's existing RO treatment plant before being used in their boilers. The water quality requirements specified by Chevron are shown in Table 2. Pilot studies have shown that these quality requirements can be easily reached using the proposed system.

CASE STUDY

CSBP, Kwinana, WA, Australia

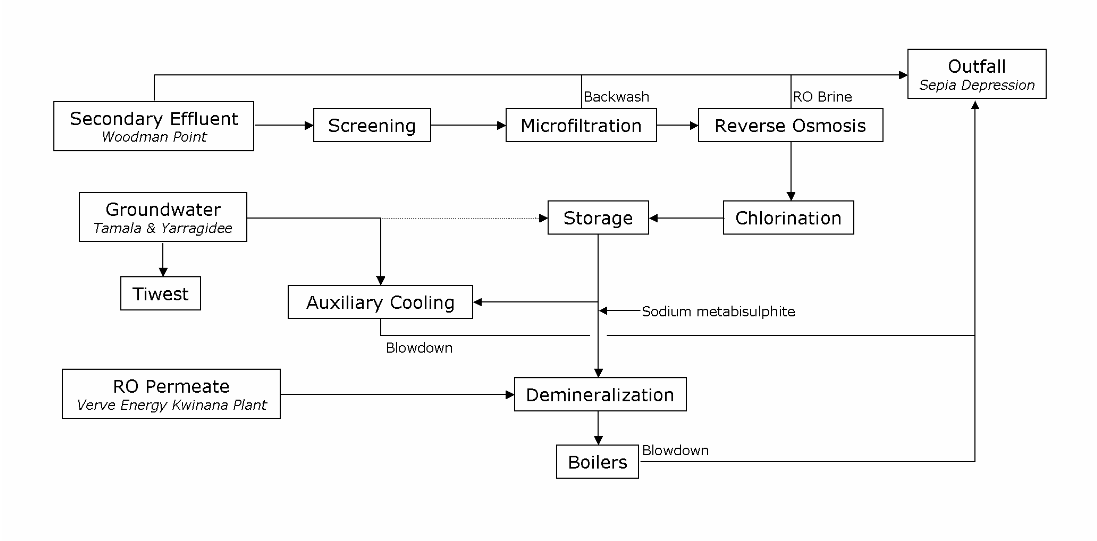
Introduction

CSBP is a chemical manufacturer that is part of the Wesfarmers group. It primarily produces fertilizers, but some explosives for the local mining industry are also manufactured. The Kwinana site has been operational since 1910.

Problem Description

Significant drought in the Perth region has lead to an increasing focus on water use by industry. Though the site primarily used groundwater, increasing demand on this source due to expansion of the Kwinana Industrial Area raised the issue of long-term water security. Also the groundwater quality is in a state of decline. Consequently, CSBP aimed to diversify its water sources and reduce its reliance on groundwater. The industrial symbiosis that exists in the Kwinana region creates a unique advantage in reaching this goal.

Process Flow Diagram



Solution Adopted

A significant portion of the water required by CSBP is now provided by the Kwinana Water Reclamation Plant owned by Water Corporation. This water is secondary effluent that has undergone microfiltration and reverse osmosis. CSBP mixes this water with a trivial amount of groundwater to increase the alkalinity and reduce the corrosivity of the water. The water is used in as cooling tower makeup and as a feed to the demineralization plant. Prior to use in the demineralization plant, CSBP treats the water with sodium metabisulphite to remove the residual chlorine. The recycled water feed to the demineralization plant is supplemented by excess RO permeate from Verve Energy's Kwinana Power Station.

Blowdown and waste water from other processes is sent to Water Corporation's Sepia Depression Ocean Outfall Line as part of the recycled water agreement. This service is provided by Water Corporation, provided the wastewater meets the WA EPA discharge requirements.

Implementation

CSBP has not noted any problems with the use of recycled water, although communications of equipment failures was highlighted as a problem initially. Chemical treatment requirements for the cooling tower and boiler have decreased significantly since the introduction of recycled water, partially offsetting the increased cost.

Economic Justification

The projects initiated by CSBP have not been performed for short-term gains. Taking recycled water ultimately costs CSBP more in running costs on top of the initial capital outlay. However the focus of the company is more long-term, with the recognition that with dwindling water supplies, expansion of the site would not be possible. This provides the economic justification for the project.

Environmental Justification

The main benefit for using recycled water is the reduction of cliffside discharges. All industries in Kwinana that agree to use recycled water are consequently able to use the Sepia Depression Ocean Outfall Pipeline to dispose of waste reducing the pollution load in the environmentally sensitive Cockburn Sound.

Recognition

- 2006 WA State Water Award (Community Partnerships)

CASE STUDY

Eraring Power, Hunter Valley, NSW, Australia

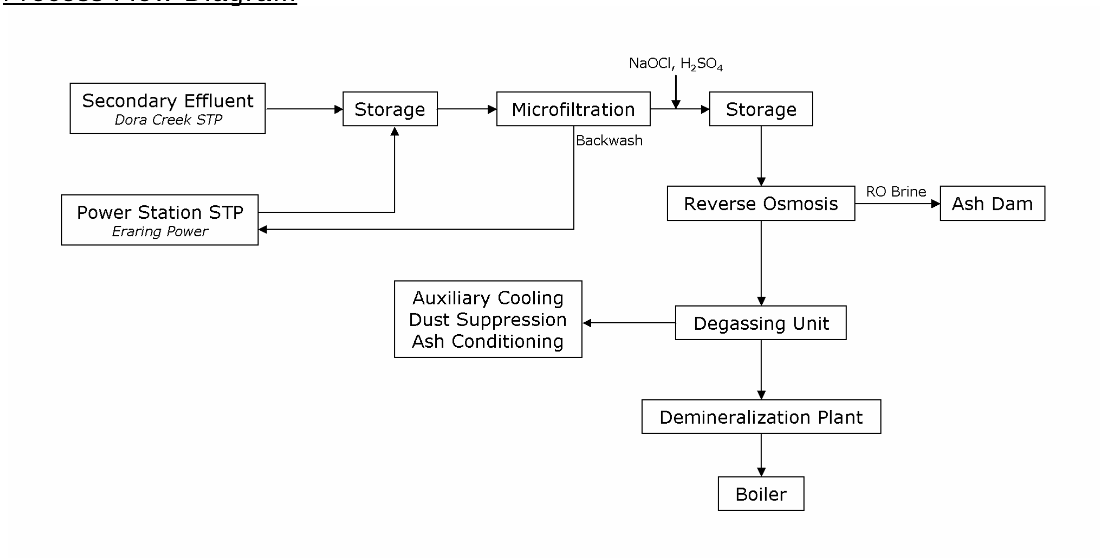
Introduction

- The Eraring Power Station on the shores of Lake Macquarie in NSW is a 4 by 660 MW power station providing a quarter of NSW's electricity needs.
- The facility commissioned its first unit in 1982 and reached its current state in 1984.

Problem Description

- Hunter Water, the local water provider, was upgrading the Dora Creek STP. As part of this upgrade a discharge pipe was to be built to allow for an ocean discharge. This pipe was due to run past the Eraring Power Station. To delay the cost of building the outfall Hunter Water approached Eraring's owners to gauge their interest in taking the water.
- Eraring at the time was in the process of reducing potable water consumption and the costs associated with it. Having already halved their water consumption, recycled water was the next obvious step.

Process Flow Diagram



Solution Adopted

- Hunter Water and Eraring Energy entered an agreement whereby secondary effluent from the Dora Creek STP would be provided to Eraring under a 15 year contract (see Table 1 for the minimum qualities).
- Initially this was expected to be 5 $ML.day^{-1}$, however by 2003 the plant was receiving 3.8 $ML.day^{-1}$. Part of the reason for this low volume was a decrease in supply due to drought and water restrictions reducing domestic water use.
- This water is treated by Eraring using a microfiltration and reverse osmosis system to produce 2.8 $ML.day^{-1}$. The focus of this system is on health protection as much as water purification (see Table 2 for the main water quality criteria.
- To date there have been no health issues with the water used at Eraring. The water is used for makeup to the auxiliary cooling system (1 $ML.day^{-1}$), demineralization plant/boiler feed (1.5 $ML.day^{-1}$) and dust suppression, washdown and ash conditioning (1.5 $ML.day^{-1}$).

Table 1. Water quality required by Eraring from the Dora Creek STP.

Parameter	Maximum Value
BOD ($mg.L^{-1}$)	50
NFR ($mg.L^{-1}$)	50
Faecal coliforms ($cfu.mL^{-1}$)	1000
Phosphorus ($mg.L^{-1}$)	15
Chloride ($mg.L^{-1}$)	180
Sulphate ($mg.L^{-1}$)	100
Silica ($mg.L^{-1}$)	10
Ammonia ($mg.L^{-1}$)	15
Oxidised N ($mg.L^{-1}$)	15
Hardness ($mg.L^{-1}$ as $CaCO_3$)	150
Alkalinity ($mg.L^{-1}$ as $CaCO_3$)	150
Sodium ($mg.L^{-1}$)	130
Magnesium ($mg.L^{-1}$)	15
Calcium ($mg.L^{-1}$)	35
pH	9
Al^{3+}/Fe^{3+} to P ratio	2.5:1

Table 2. The main water quality parameters required by Eraring after MF/RO treatment.

Parameter	Maximum Value
Suspended Solids ($mg.L^{-1}$)	1
Silt density index	3
Reovirus (per 100 mL)	nil
Enterovirus (per 100 mL)	nil
Total coliforms (per 100 mL)	10
Faecal coliforms (per 100 mL)	1
Faecal streptococci (per 100 mL)	1

Implementation

- The focus of Eraring has been on the protection of worker's health. As part of this the following protocols were adopted to ensure safe use of the water:
  - o Staff are educated and informed of the use of recycled water onsite. This includes visitor and contractor inductions.
  - o Staff at risk of contact with primary or secondary effluent are immunised against hepatitis A and B.
  - o All water outlets are signposted as to their water quality (reclaimed or potable).
  - o Separation of the potable and reclaimed systems was tested prior to the plant being commissioned.
  - o There is monthly biological testing performed on the recycled water. To date there have been no positive tests.
    - There have been no issues reported with the implementation and use of recycled water at the Eraring facility.

Economic Justification

- In 2003 it was estimated that Eraring saved US$986,500 on water costs and a further US$52,600 on reduced regeneration costs for the demineralization plant.

- The capital outlay for the project was $4,700,000 ($3.8m was the cost for the membrane plant) giving a 4 to 5 year pay back period for the project.

Environmental Justification

- The project significantly reduces the pollution load in Lake Macquarie and will defer the need for sewage disposal into a marine environment. Previously potable water was purchased from Hunter Water. This can now be made available for either domestic use or environmental flows.

Recognition

- Highly Commended, 1996 National Cleaner Production Award
- Highly Commended, 2006 Green Globe Award for Water Recycling and Conservation

The Future

- The upgrading of the Dora Creek STP is still underway and will continue to increase the volume of water available to Eraring. By 2010 3.75 $ML.day^{-1}$ is expected to be received for use by the plant.

CASE STUDY
Mildura Fruit Juices
Mildura, Vic, Australia

Introduction

- Mildura Fruit Juices Australia has been operating in Mildura since 1970.
- They have the capacity to process 150,000 Mtonnes of fruit annually.

Problem Description

- With extensive drought conditions throughout regional Victoria, reduction of potable water use at the Mildura site is a priority.
- A reduction in trade waste was also deemed beneficial and Mildura Fruit Juices worked with their staff, the Victorian EPA and the local water provider, Lower Murray Water, to achieve this aim.

Solutions Adopted

- Replacement of three water-cooled refrigeration condensers with air-cooled units.
- Installation of wastewater storage tanks. This helps with effluent adjustment and dilution (using evaporator condenser water) before discharge.
- Wastewater reuse for plant cleaning and washing
- Reuse of evaporator condensate water in on conveyors, peel washing and floor washing.
- These solutions reduce water use by 8 $kL.hr^{-1}$.

Implementation

- The water use over the past three financial years is shown in Figure 1. These give a clear reduction in water use over time (approximately 11% in 05/06 and 28% in 06/07).

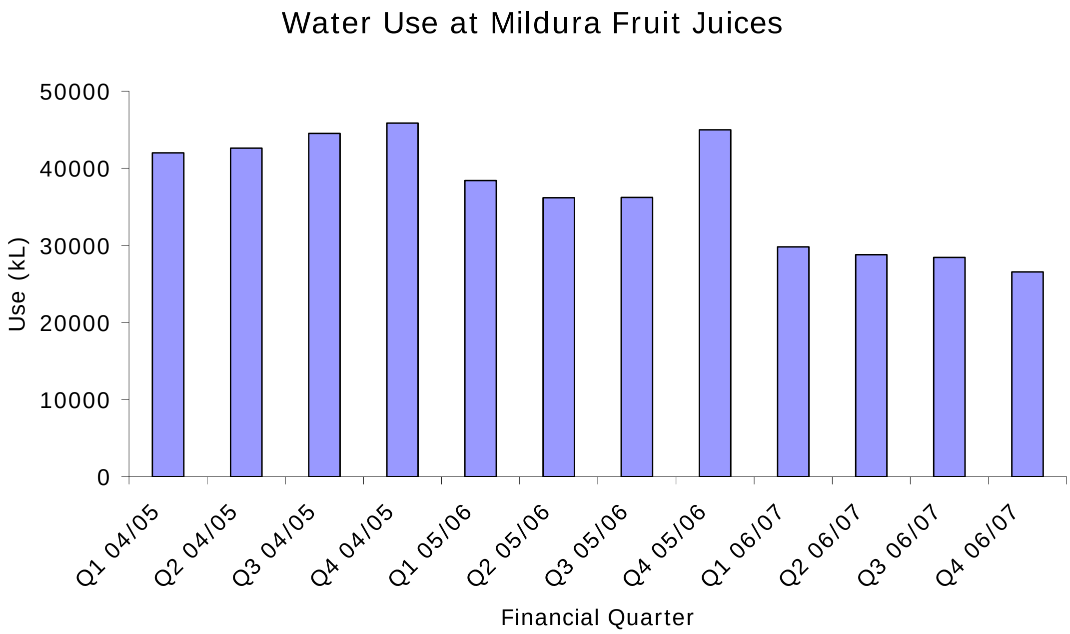


Figure 1. Water use at Mildura Fruit Juices over the past three financial years

Economic Justification

- The total costs for the above projects were $135,000.
- No details can be provided on savings or payback period.

Environmental Justification

- The project significantly reduces the amount of water used allowing for greater water security in the Mildura region.

The Future

- Mildura Fruit Juices has a 12 ML water reduction target for the 07/08 financial year.

CASE STUDY
Mondi Paper, Durban, South Africa

Introduction

- The Mondi paper mill in Merebank, Durban has been producing newsprint and fine paper since 1971.
- The plant consists of five paper machines and produces 220,000 tonnes a year of office paper, 77,000 tonnes a year of magazine paper and 227,000 tonnes a year of newsprint.

Problem Description

- Due to local water shortages, when the mill was in the planning stages the local water authority Durban Corporation (now eThekwini Water Services) required that Mondi use only recycled water for their water needs.
- Recycled water in the form of secondary effluent specially treated at the Southern Wastewater Treatment Works (SWTW). This plant only treated to primary before discharge to ocean outfall.
- During later expansions Durban Corporation felt that it was more economically sound to authorise expansion with the potable supply.
- In the 1990s the ocean outfall for the treatment works was reaching capacity and eThekwini was left with two options: constructing a second ocean outfall or treating the primary effluent to a higher level to allow cliff-side discharge of waste. Both of these options appeared expensive.
- At the same time Mondi was looking to decrease it potable water reliance and run the entire mill using recycled water.

Process Flow Diagram

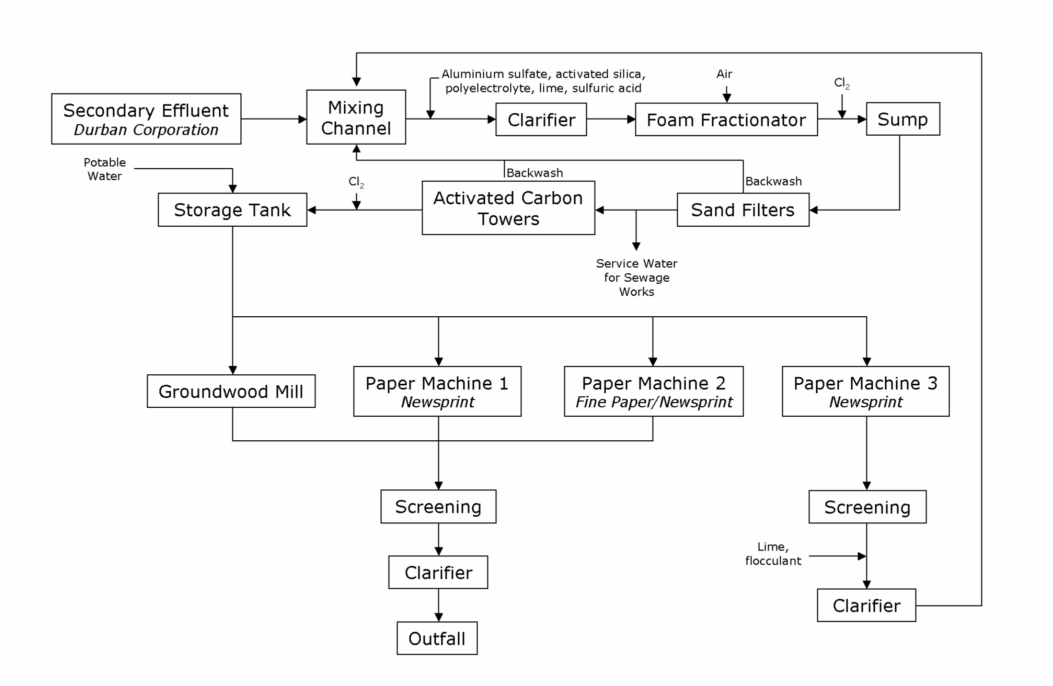


Figure 1. The original treatment process for Mondi Paper.

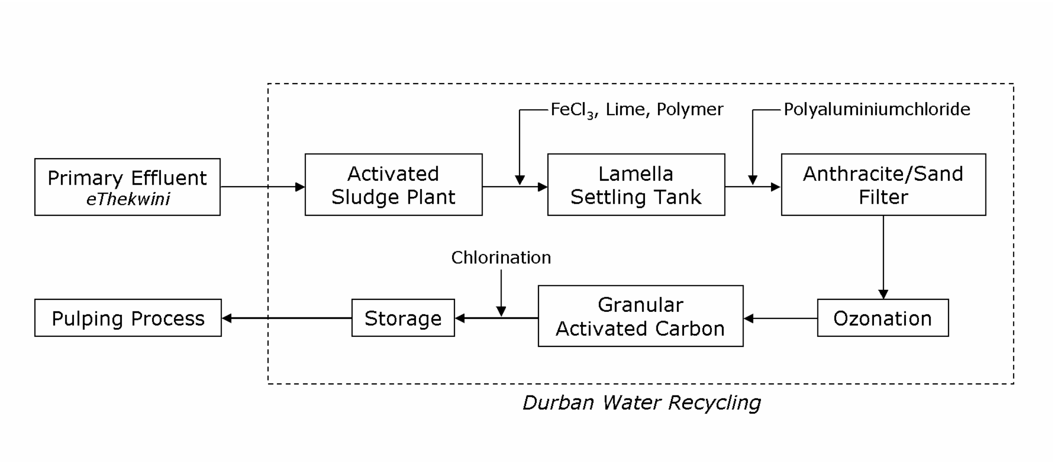


Figure 2. The treatment process provided by Durban Water Recycling for Mondi Paper since 2001.

Solution Adopted

- Recycled water started flowing to the Mondi paper mill in 1972. The mill was provided with 8 ML.day^{-1} of secondary effluent and provided its own tertiary treatment and colour removal.
- In 1976 when a third paper machine was added to the mill, the required water was made up using potable water as this was more economical to Durban Corporation. The treatment process is shown in Figure 1. The process consisted of a clariflocculation stage followed by a foam fractionator to reduce the solids content of the water. Subsequent sand filtration further reduced this. The activated carbon towers were used as a means of colour removal to prevent staining of the final product.
- When the third paper machine was added, Mondi performed little internal recycling as the water was heavily contaminated. Only the effluent from paper machine 3 was chemical free and deemed appropriate for recycling. This water was screened and sent through a clariflocculation process to remove any remaining pulp fibres. It was then returned to the head of Mondi's sewage treatment process.

- To meet the full needs of Mondi and surrounding industries and to delay the requirement for an increase to the Durban ocean outfall, eThekwini undertook to expand their recycled water supply.
- Since 2001 up to 47.5 ML.day^{-1} of tertiary recycled water has been provided to Mondi by the new Durban Water Recycling (DWR) project. This is a concession led by Vivendi water. Their treatment processes are shown in Figure 2. The primary difference between the original Mondi-operated plant and the DWR is the focus on colour removal. The use of the lamella settler, ozonation and activated carbon treatment all contribute to colour removal.
- Chlorination is performed to ensure a chlorine residual of 0.8 mg.L^{-1} at the point of use. This level should minimise the attack to the paper by chlorine.

Implementation

- One of the main issues with implementation of the plant was the source of water for SWTW. This was roughly equal portions industrial to residential. In particular the presence of colour in the water from textiles factories became an issue. Although the final water product was not coloured, the regeneration of the activated carbon towers had to be performed more regularly than originally planned. This issue was addressed by Durban

Corporation approaching the textile manufacturers to obtain a reduction in the colour of their discharge waters.

- One very positive point on the use of recycled water was the floods in early 1976. These resulted in damage to the potable water supplies and other Durban industries were forced to close. Mondi, however was safe from the resulting water crisis and was able to operate at full production through the use of recycled water.

Economic Justification

- The water tariff for Mondi has been reduced by 44% by taking water from the DWR plant. This does not need further treatment representing a major saving for the company.

Environmental Justification

- The use of recycled water significantly reduces the pollution load around Durban. More importantly, the recycled water project has ensured that cliff-side discharge of sewage can be avoided.

Recognition

- The following have been awarded to the Durban Water Recycling Project:
    - 2002 Piet Vosloo Award for technical achievement (Water Institute of Southern Africa)
    - 2001 National Award for technical excellence in civil engineering (South African Institution of Civil Engineering)
    - 2001 Visionary Client of the Year Award (South African Association of Consulting Engineers)

CASE STUDY

Murray Goulburn Co-operative Co Ltd., Leongatha, Vic, Australia

Introduction

- Murray Goulburn, Leongatha is a dairy company that produces a mixture of products including butter, spreads, creams, UHT products, milk, whey protein concentrate and lactoferrin.
- The company employs around 440 staff and is supplied by around 560 farms from 20 towns and communities.
- Annual sales are around AUS$1.6b
- The operations are critically dependent on water and the current drought situation is forcing the company to conserve and re-use water wherever possible.

Problem Description

- Not only is there a crucial water shortage but the company needs good quality potable water for obvious reasons. This is exacerbated by community concerns about comparative water use.
- The cooling water was seen as an obvious area to consider for the use of treated or reclaimed water. The quality requirements are shown in Table 1.

Process Description

- Approximately 300 $kL.day^{-1}$ of 2nd & 3rd effect cow water condensate is collected (this is water removed from milk in an evaporator during the production of condensed milk, milk powder and whey) and filtered via an RO membrane to remove fat proteins and lactose that may have been captured in the vapour section of the evaporator.
- The filtered condensate is stored in a 20,000 L storage tank and distributed to the cooling towers via a dedicated ring main.
- Prior to use, the condensate is disinfected with a Generox chlorine dioxide unit. It is expected that any condensate not within the quality specified above shall be disposed of via the waste water treatment plant.

Table 1. Quality requirements for cooling water at Murray Goulburn's Leongatha site.

Parameter	Value
Conductivity ($\mu S.cm^{-1}$)	< 400
Turbidity (NTU)	< 2
TSS ($mg.L^{-1}$)	< 5
BOD ($mg.L^{-1}$)	< 10
pH	6.0 - 8.0
Coliforms	nil
Heterotrophic colony count (HCC)	nil
Legionella	nil

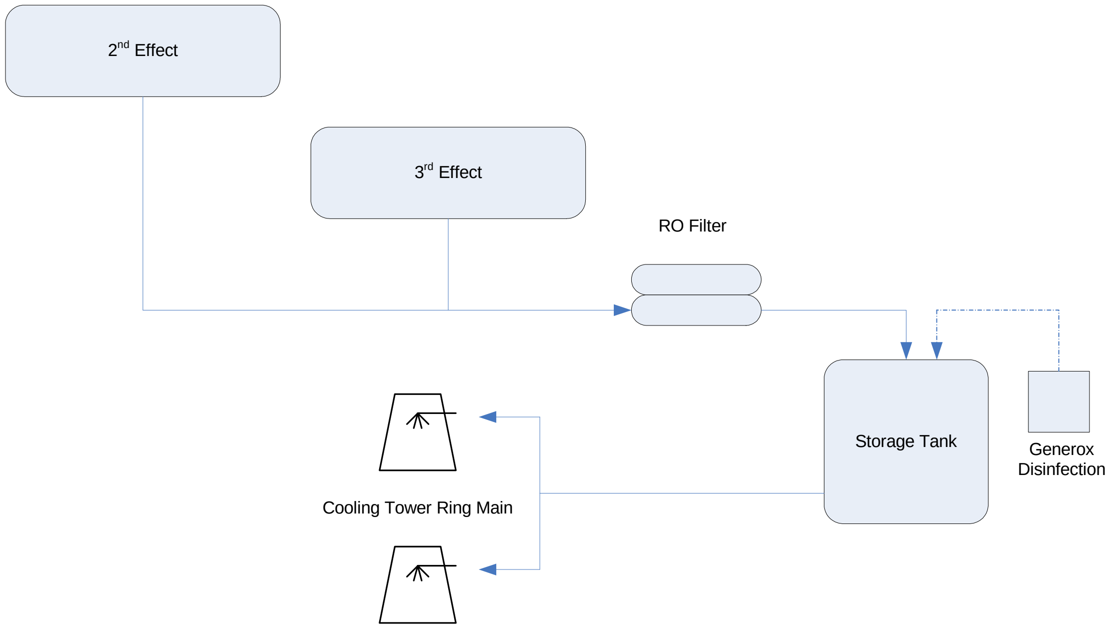


Figure 1. Condensate reuse process

Solution Search

- Murray Goulburn investigated several areas of production where water savings could be made including:
  - Reusing cooling tower blow down for dairy irrigation
  - Reusing cooling tower blow down as first stage truck wash
  - Evaporator condensate (as above) for cooling towers and boiler feed water
- The main problems encountered for reuse of water in the dairy industry includes:
  - Capital costs and incentives (unlike City West Water there does not appear to be any financial support offered by the local water administration, Gippsland Water)
  - Salt concentration (particularly sodium)
  - Transport/pumping costs
  - Cost to achieve Class A status with respect to microbiological control

Solutions Adopted

- Filtering and reusing condensate for cooling tower make-up was considered the most cost effective solution. It was also a relatively easy solution to the short term water needs of the site and only minor plant modifications where required.
- Currently approximately 500 ML of town water is saved per annum. This saving is the result of higher cycles of concentration achieved in the cooling tower due to the improved feed water quality.

Implementation

- To implement the project, the following plant modifications were required:
  1. Installation of a 20,000 L storage tank
  2. Installation of a ring main for the supply of make-up water to each cooling tower
  3. Installation of a Generox chlorine dioxide unit

Economic Justification

Estimated Town Water Saved	500 ML a year
Cost of Town Water	$1.08 per kL
Savings	$510,000 a year
Cost of Installation (Capital)	$200,000
Generox Treatment	$43,000
Cost of Condensate Water (@ $1.50 per kL)	$164,250
Costs for 1st Year	$407,250
Payback on Capital	0.4 years

Environmental Justification

- Reduced use of potable water will allow more water for the local community.

Recognition

- The local newspaper reported on the use of treated town water by the company and it was seen to be a very popular activity.

The Future

- The Murray Goulburn Leongatha site is currently implementing a 10-year plan that includes the installation of a ‘Water World’ or essentially a water recovery plant. This will dramatically increase the amount of water reused on site.

Further Information

1. Andrew Phillips – Drew Australia
2. Brian Jobling – Murray Goulburn, Leongatha

CASE STUDY

New Wave Leathers Pty Ltd
Toowoomba, Qld, Australia

<u>Background</u>

- The New Wave Leathers Group consists of three wet blue tanneries situated at Toowoomba QLD, Gunnedah NSW and Melbourne Vic.
- With a capacity of 60,000 hides per week, and a staff of around 300, the NWL group is a wholly owned subsidiary of Nippon Meatpackers Australia Pty Ltd (NMPA).
- NMPA provides employment to more than 3,000 Australians, and employs in excess of 26,000 people worldwide.
- New Wave Leathers Toowoomba, (NWLT) formerly known as Dixons Wetblue, (DWB) is situated in the northwest corner of the city adjacent to the local councils effluent plant and waste recycling center.
- At full capacity NWLT adds value to 25,000 cattle hides per week, by processing them to a stage where they can be sold to export markets and ultimately used in a wide range of end products, including shoes, handbags, automotive and furniture upholstery.

<u>Water Problem</u>

- Production tanneries use a lot of water but it is not necessary to use potable water for the washing of hides, tanning and some of the other processes.
- The Toowoomba plant has been used in an experimental sense to reduce potable water reuse and replace it with recycled water from the Toowoomba City Council (TCC) treated effluent. NWLT has been using treated effluent in the process for over thirty years

<u>Solution Adopted</u>

Three stages of water saving measures are available for NWLT. The first of these was implemented some time ago and the two remaining are currently underway (see The Future).

Stage 1 – Use of City Treated Effluent

- NWLT purchases around 7 ML of Toowoomba City Council's (TCC) treated effluent per week as a direct replacement of town water use.
- The incoming treated effluent is stored in a 3 ML dam, passed through a sand filter and held for use in 0.5 ML tanks.
- NWLT also purchases 0.5 ML of TCC potable, town water specifically for the manufacture of ice and factory amenities water.
- Used process waters are discharged to an on-site effluent treatment plant where they are screened for solids removal, equalized and oxidized in a 0.6 ML tank. They are then transferred to settling towers that feed two belt presses – the supernatant from the belt presses and the settling tower overflows are held in a 0.4 ML tanks and transferred to a dissolved air flotation (DAF) unit.
- Solids from the DAF are returned to the belt press and the supernatant is discharged to sewer.

- NWLT is looking into the further recovery of this treated liquid effluent stream for plant re-use.

Economic Justification
- Current liquid discharge costs to sewer cost around $600,000 pa and this would be drastically reduced to less than $50,000 pa.
- The company has already reduced water purchasing costs by utilizing TCC treated water.
- New operating costs would include two ultra-filtration units, one reverse osmosis unit, an evaporator, a crystallizer, chemicals, waste disposal, energy requirements, labour and depreciation estimated between $300,000 and $500,000 pa.
- It is anticipated that future trade waste charges will increase but this will be offset to a degree by the chloride and sulphate products from the RO unit.

Environmental Justification
- Replacement of potable drinking water with TCC treated effluent water is the main environmental advantage and this directly relates to the use in other areas of municipal treated effluents – Class A, B or C waters for industry.

The Future

Stage 2 – Waste Stream Segregation
- All non-chromium containing streams will be handled as per stage 1 (above).
- Chromium Recycle – The concentrated trivalent chromium stream from the processing vessels can be fed directly to a screened holding tank where grease and protein can be removed mechanically (to a high percentage). The remaining stream can be re-acidified with sulphuric acid, agitated and refrigerated. The resultant liquor can be transferred back into the tanning process.
- Floor Waste – The floor waste will be gravity fed to holding tank from where the following processing will be performed:
  - à screened agitated tank for pH adjustment
  - à settling tower with coagulant
  - à bottom solids to holding tank and to belt press
  - à supernatant to clarifier (DAF) à ultra-filtration à holding tank
  - à reverse osmosis à holding tank
  - à clean RO water to ice machine
  - à high solids from UF and RO to evaporator
  - à evaporator concentrate to crystallizer à crystals to process, sold or to landfill
- By segregating these waste streams, it is hoped that much cleaner bulk waste streams will be made available for recovery to a standard for normal process water.

Stage 3 – Further Water Recycling
- All post DAF liquids from Stage 1 and Stage 2 could be transferred to the 3 ML dam, put through sand and UF filters, fed to the 0.5 ML holding tanks and transferred back into the tanning process.
- The UF solids would go back to the dam.
- The 0.5 ML tanks would be topped up with TCC treated effluent as required by production.

Further Information

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CASE STUDY

OneSteel (formerly Smorgon Steel) Steelworks, Laverton, Vic, Australia

Introduction

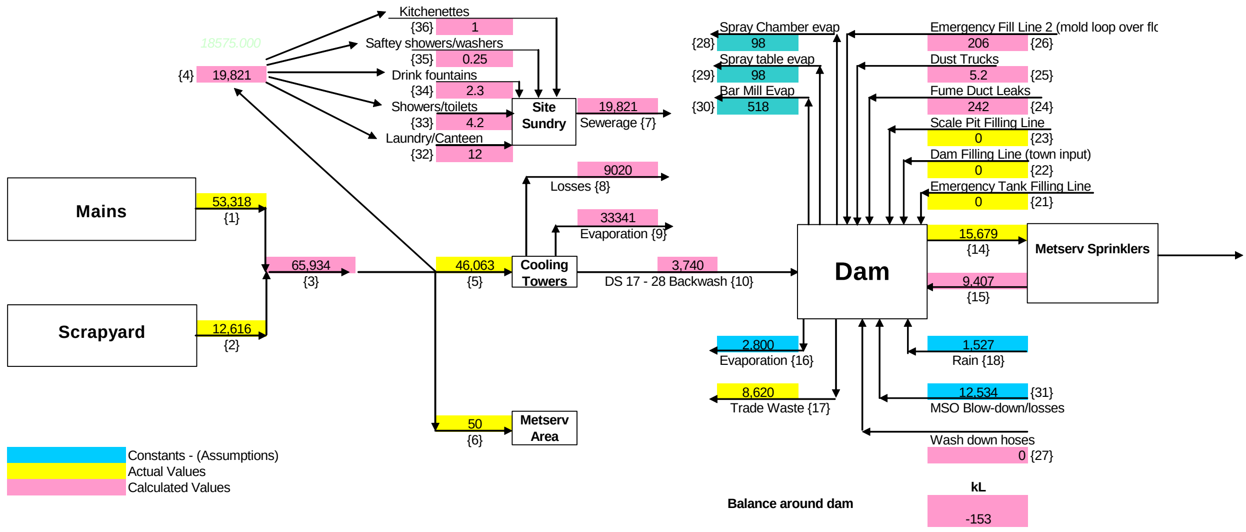
- The steel mill in Laverton was commissioned in 1983 by Smorgon Steel and generates steel rods and bar that are sold within the group for downstream processing.
- The site has a capacity to produce 700,000 tonnes of billet per annum from scrap steel
- In August 2007, the site became part of OneSteel following the merger of Smorgon Steel and OneSteel.

Problem Description

- Although, not a major cost input, water cost and consumption is a major consideration to OneSteel management. In particular, there have been ongoing efforts to reduce the amount of water required per unit of steel by focusing on water leaks, water quality and reuse.
- The Laverton site has been at the forefront of water monitoring and reduction for many years, and as such there is much data history available regarding the water in most applications across the site (cooling tower etc).
- Recently, a general water reduction target of 10% was set for the entire site. This target has bee one of the main drivers for projects such as Dam Water Reuse.
- 337kL.week^{-1} of potable water was used in a cooling system that utilizes contact cooling to quench the wire as it is drawn out. The water used here is given a very high suspended solid loading. As a large water use, this was targeted as a potential process for water reduction.

Process Description

- The Laverton Steel Mill operates as a zero-discharge site, with a dam being the final collection point for all the process water on site. Only during times of extremely high rainfall or other overflow events does dam water get sent to the sewer. Below is schematic of the water balance across the site showing the Dam as the main process water collection point.



Solution Search

- Options reviewed included improved filtration with in-line self cleaning filtration, improved water treatment chemistry and introducing a dam water shandy.

Solutions Adopted

- All of the above mentioned solutions were implemented.
- The introduction of the dam water shandy to the cooling system first commenced in early 2001. This was run through to early 2004 and then reoccurred again for a brief time in 2006 and 2007. On average 250 kL per week of dam water was mixed with potable water, giving a mix of 3:1. The actual percent shandy could vary depending on the condition/status of the level control system and water loss or bleed off rate.

Implementation

- After the installation of the make-up water pipes, introduction of the dam water was immediate. In each instance (01-04 and 06-07) the dam water supply was switched off because of excessive chloride build up in the 1-16 cooling system (see attached). The 1-16 cooling system has an upper chloride control limit of 300 ppm, which was regularly being breached during dam water make-up. In turn, this would increase the blowdown rate for the 1-16 system.

Economic Justification

Estimated tower water saved = 250 kL.week^{-1}
Cost town water = \$0.95.kL^{-1}
Total saving = \$238.week^{-1}
Estimated cost of installation = \$20,000 (unconfirmed)
Payback on capital = 2.5 years

Environmental Justification

- Lesser chance of overflow returning to the sewer system will ensure the site meets its zero-discharge policy.
- Reduced use of potable water will allow more water for the local community.

Recognition

- The project won the 2002 and 2003 savewater! Award.

The Future

- Without sufficient rainfall to dilute the chloride levels in the dam water it is unlikely that it will be used as cooling tower make up again. An alternate source of water (Class A) from Werribee would be more useful provided chlorides could be kept below 100ppm.

Further Information

Andrew Phillips – Ashland Water Technologies
Howard Richard – One Steel

CASE STUDY

Queensland Alumina Ltd., Gladstone, Qld, Australia

Introduction

- Queensland Alumina Ltd. (QAL) operates one of the world's largest alumina refineries in Gladstone.
- It has been operational since 1967 and produces 3.7 million tonnes of alumina per year, representing 10% of the worlds total alumina production [156].
- The refinery uses the Bayer process consisting of digestion (dissolution of alumina from bauxite), clarification of the liquor, precipitation, and calcination. The red mud left over after digestion needs to be washed to remove the caustic used to dissolve the alumina. This washing stage is the most water intensive process at the refinery [5].

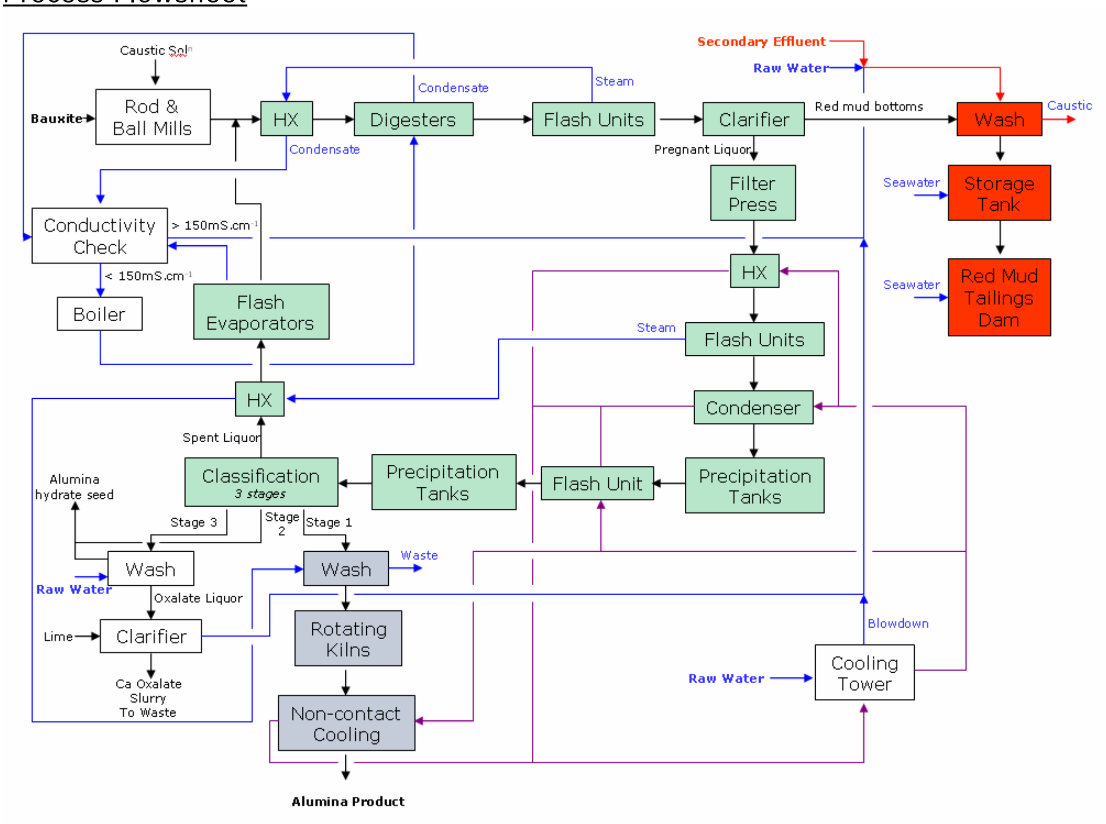
Problem Description

- In 2001/2 a severe drought threatened the water supply (Awoonga Dam) of the predominantly industrial region around Gladstone. The Gladstone City Council imposed a mandatory 10% reduction restriction on industry in April 2002. This was increased to 25% in November 2002 with the threat of 50% if rains did not fall before mid 2003.
- Through demand management and cleaner production practices QAL were able to meet the 10% reduction [156]. Meeting a 25% reduction, however, did not seem possible without cutting production at the site.

Process Description

- Initially QAL had four main water sources: raw water from the Gladstone Area Water Board's Awoonga Dam, seawater used to slurry, transport and neutralise red mud, water contained in the caustic solution used to dissolve the alumina in bauxite and water contained in the bauxite itself.
- QAL took a cascade approach to water use. Steam extracted from the process slurry in flash evaporators and coolers was used to heat streams, then the relatively pure condensate would be sent to the boiler or to washing operations.
- Cooling tower blowdown was likewise sent to washing applications (initially ash washdown of the coal used in the boiler).
- Washing of red mud (the solids remaining after the extraction of alumina) is the most water intensive process in the plant. In 2002, a total of 52 ML.day-1 of water entered the site [5]. Of this more than 12 ML.day^{-1} was lost as part of the last wash of the red mud [5].

Process Flowsheet



Solution Search

- Prior to the drought QAL had investigated some water saving opportunities that would be implemented when capital was available.
- In the initial stages of the drought the following were investigated [5]:
    1. Sending the water from the oxalate clarifier to the red mud wash
    2. Sending the cooling tower blowdown to the red mud wash
    3. Improving the availability of seawater pumps for neutralization and slurrying of red mud.
    4. Increasing the underflow concentration in the washing circuits
    5. Use of municipal effluent from Gladstone
    6. Treatment and recycling of onsite sewage effluent
    7. Increasing the degree of concentration in the calcium oxalate clarifier
- As the drought continued and restrictions became imminent further options were investigated including:
    8. Use of effluent from the Boyne STP and from the Boyne Aluminium smelter for red mud washing [156]
    9. Desalination using either reverse osmosis, distillation or vapour compression [5]
    10. Conversion of the cooling circuit to seawater [5]

Solution Adopted

- For the initial 10% restrictions, QAL implemented options 1 to 3 with great success. A 19% reduction in raw water use was achieved [5]. Attempts were also made to implement option 4, however this proved not to be possible.
- When 25% restrictions were implemented options 6 and 7 were implemented, however this would not meet the requirements imposed and QAL had to look at alternative water sources.
- Option 9 (desalination) was ruled out due to the time constraints [5].

- Option 10 was viewed as prohibitively expensive.
- Option 5 was implemented whereby secondary effluent from the Calliope River STP was used to replace raw water in washing the red mud [5].
- Results of the investigation into potential health effects showed that the high pH and temperature of the washing neutralised any pathogens that may be present [5].
- QAL established an agreement with the Gladstone City Council to take 6.5 $ML.day^{-1}$ of recycled water from the Calliope River STP [156].
- Overall these measures reduced raw water use by 29% [5].
- For the 50% restrictions, QAL concluded that the only option available was to retrofit the cooling system to take seawater (option 10). This would require significant capital investment, however with no other source available the only other option would be to reduce production at the plant which would see significant economic impact to the company, its suppliers and the surrounding community.

Implementation

- To allow for recycled water use a 8.5 km pipeline was built from the Calliope River STP, paid for by QAL at a cost of $8m. The wash water system at the site also required some minor retrofit work. A chlorination system was also installed to help QAL control microbial growth for health reasons and to prevent sliming and fouling of the pipelines [5].
- QAL has not reported any significant issues with the use of recycled water onsite. Despite the restrictions being lifted after rain reached the region, the savings made as part of the project have meant that the project continues and QAL operate at 70% of their 2002 water levels despite increases in production [5].

Economic Justification

- No figures can be provided as these are confidential, however the use of recycled water by QAL has been profitable for the company.

Environmental Justification

- Reduced water use from the Awoonga Dam ensured supplies could be maintained to the local community.
- A significant reduction in pollution load to the Calliope River has been achieved by completely rerouting the effluent to QAL. This is claimed to have contributed to Gladstone winning the 2002 Queensland's Tidiest Town award.

Recognition

- 2003 Gladstone Region Environmental Excellence Award.
- 2003 Engineering Excellence Awards, Highly Commended (Queensland Division, Engineers Australia).

The Future

- There has been renewed interest in synergy savings in Gladstone. There have been two main suggesetions:
    - Implementation of the Boyne water recycling project (option 8 from above that was abandoned due to the lifting of water restrictions). This has the possibility of reducing QAL's raw water use by 2 $ML.day^{-1}$ [156].
    - The use secondary effluent from the South Trees STP (about 5 km from the QAL site) for use in washing red mud. This would result in a 4 to 7% decrease in QAL's water usage [156].

CASE STUDY
Tiwest Joint Venture, Kwinana Pigment Plant WA, Australia

Introduction

- The Tiwest Kwinana Pigment Plant is located some 30 km south of Perth, Western Australia, and is the final stage of the Tiwest Joint Venture, the world's largest fully integrated titanium dioxide producer.
- The Kwinana Plant now produces in excess of 100,000 tonnes of titanium dioxide pigment per annum, in a range of grades suitable for a wide variety of national and international marketing requirements.

Problem Description

- Given Tiwest's status as one of the largest users of scheme water in Western Australia (until 2002 it was in fact the largest), and a significant user of groundwater, any improvements in efficiency of water use that the company can effect, have the potential to impact positively on water resources and the environment.
- The Kwinana site has, as a result, significantly improved water use efficiency of Metropolitan Integrated Water Scheme Water Supply (MISWSS), with the 1991 Tiwest consumption of 60.67 kL/tonne of finished pigment product (FPP) being reduced almost two thirds, to 20.05 kL/tonne FPP by year end 2005.

Process Flow Diagram

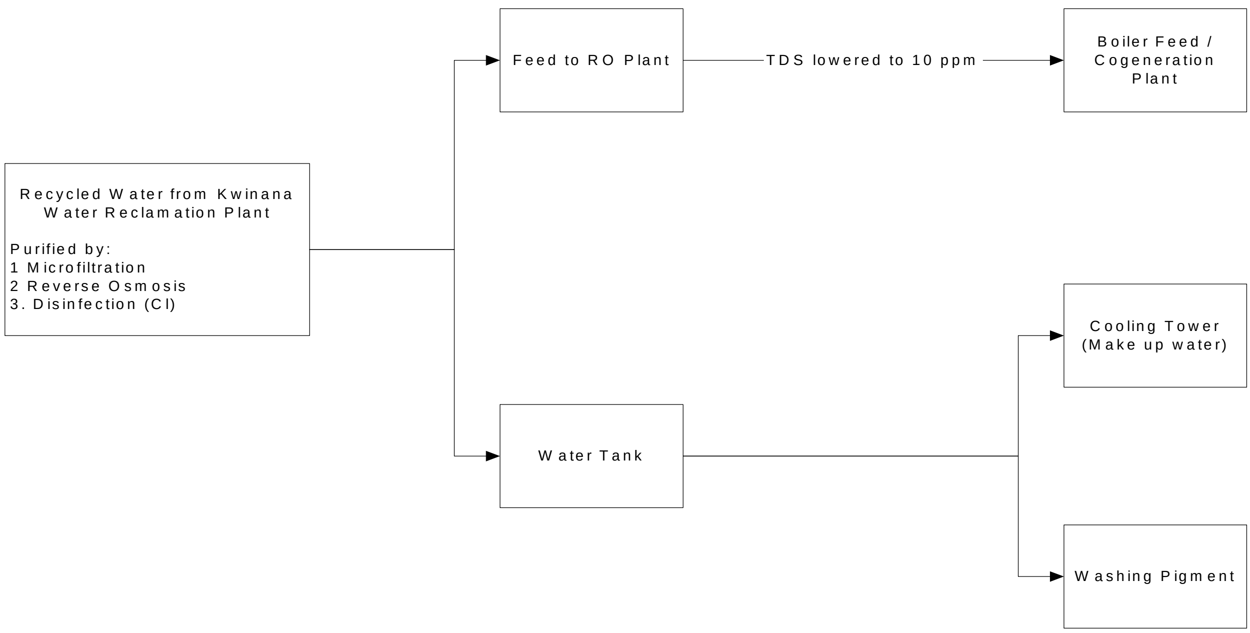
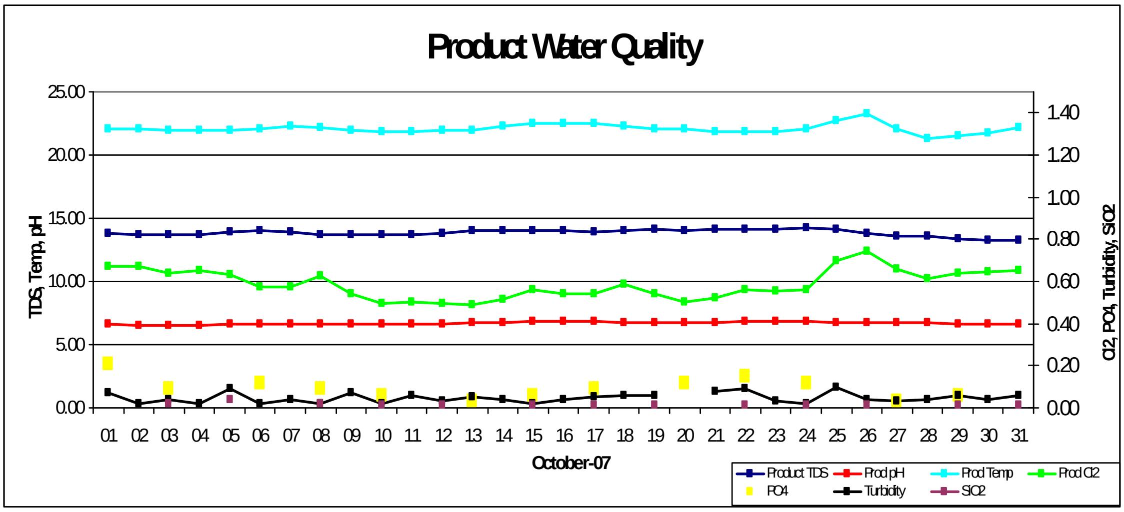


Figure 1. Quality of the recycled water as used by Tiwest Joint Venture at the Kwinana Pigment Plant.



Solution Adopted

- Tiwest is a long standing member of the Kwinana Industries Council (KIC), which was established in 1991 to promote and contribute to the sustainable co-existence of Kwinana industry, the community and the environment.
- Through its membership of KIC, Tiwest was involved with 'Waterlink', a program launched to improve water efficiency and contribute to environmental management in the KIA. This resulted in the construction of Kwinana Water Reclamation Plant (KWRP), which re-processes discharge water from the nearby Woodman Point Wastewater Treatment Plant for re-use by companies such as Tiwest, BP, CSBP, Wesfarmers and others. It also facilitates a reduction of industrial water discharged into the Cockburn Sound by accepting approximately 6 ML a day of wastewater from these operations.

Implementation

- Due to the low TDS content, recycled water has a tendency to increase the onset of corrosion.
- No problems have been reported at the plant at present. All pipes are made of carbon-steel with a steel, plastic lined water tanks.
- The increased Nitrogen concentration present as nitrates in recycled water was originally a concern for the operations. A study conducted by Tronox (parent company) was conducted prior to implementing its use within the processing plant.

Economic Justification

- The use of recycled water required a capital investment in the construction of KWRP and represents an ongoing financial cost to the operations of Tiwest. The use of recycled water is intended for community benefit only.

Environmental Justification

- The current water requirement for the processing plant stands at 8 $ML.day^{-1}$, with a current 2.2 $ML.day^{-1}$ sourced from the KWRP and a further 2.7 $ML.day^{-1}$ of ground water usage has significantly reduced the amount of scheme water used from the MISWSS.
- The KWRP project also allows industry to co-dispose of industrial waste water via the Ocean outfall pipeline which has also significantly reduced the industrial water discharge into the Cockburn Sound. This is a future opportunity for Tiwest.

Recognition

- Water Corporation, Certificate of Recognition as a Waterwise partner. CEPA Case Study 2007.
- Department of Water Government of Western Australia & Water Corporation. Highly Recommended. Category: Waterwise Business 2006.
- Department of Water Government of Western Australia & Water Corporation. Finalist. Category: Water Recycling.

The Future

- Tiwest Joint Venture is currently planning an expansion of the Kwinana Pigment Plant to produce 153,000 tonnes of titanium dioxide pigment per annum. This will increase the water consumption and could see the KWRP expanding its operations pending negotiations between the parties.
- In line with Tiwest's Environmental Policy, the Kwinana Pigment Plant will continue its commitment to significantly reduce the industrial water discharge into the Cockburn Sound.

CASE STUDY
Walt Disney World
Lake Buena Vista, Fl, USA

Introduction

- Walt Disney World (WDW) is a recreational resort containing four theme parks, two water parks as well as hotels, shopping, entertainment and recreational venues.
- WDW opened in 1971 and covers an area of 101 km^2.
- A separate local district, Reedy Creek Improvement District (RCID), was formed to provide municipal services.

Driving Force

- The environmental practices of the Walt Disney Company led to the pursuance of sustainable options at the WDW site from its inception. These have been increased over time.
- WDW have been using recycled water since 1971 and have been a zero-discharge site since 1990.

Solutions Adopted

- The site currently treats about 45 $ML.day^{-1}$ to a tertiary level equivalent. The treatment process uses a five stage Bardenpho treatment followed by clarification, deep bed sand filtration and chlorination. The important water quality parameters are listed in Table 1.
- The water is used onsite for a range of purposes including:
  - § Irrigation (640 ha)
  - § Cooling tower make-up (air conditioning)
  - § Vehicle washing (mostly buses – a fleet of 260)
  - § Street and pavement washing in theme parks
  - § Decorative fountains (select ones that avoid human contact)
  - § Fire suppression and fire fighting (where appropriate)
  - § Dust control
  - § Construction
- Since 1985 no new development has been planned without reclaimed water systems.
- During periods when irrigation demand is low, excess water is used for groundwater recharge via 85 rapid infiltration basins (these are man-made ponds constructed in a sand ridge of highly permeable soils). 20% of the basins receive water at any one time, and are then rested for 4 to 5 weeks allowing water to percolate 10 to 40 feet to the shallow groundwater table.

Table 1. Important water quality paprameters of treated wastewater at Walt Disney World

Parameter	Value
$CBOD_5$ ($mg.L^{-1}$)	1
TSS ($mg.L^{-1}$)	1
Total N ($mg.L^{-1}$)	2
Total P ($mg.L^{-1}$)	0.5

Implementation

- The only problem identified by RCID from the use of recycled water was corrosion of unprotected metallic pipe used in some irrigation sites. As pH adjustment was not an option and the use of metallic pipe was fairly low (most are PVC and lined ductile iron), WDW have not made any attempts to address the problem other than replace corroded pipes with PVC once they fail

Economic Justification

- Reedy Creek Improvement District sells recycled water at 80% of the rate of potable water.
- The value of reclaimed water to the user is increased significantly however as it is exempt from water restrictions that are currently affecting the central and south Florida regions.

Environmental Justification

- As a zero discharge site, the pollution load in Reedy Creek is significantly reduced.
- The groundwater recharge project, which provides approximately 19 $ML.day^{-1}$ (on an annual average), also provides water for the Upper Floridan Aquifer ensuring its long-term use as a water source for Florida communities.

Recognition

- WDW has been awarded:
    - 2005 WateReuse Association Customer of the Year
    - 2005 Florida Water Environmental Association Outstanding Reclaimed Water Customer
- RCID has also been awarded the 1995 and 2002 David W. York Reuse Awards from the Florida Water Environmental Association

The Future

- WDW and RCID plan on extending their water recycling efforts by enlarging the reclaimed water plant to 76 $ML.day^{-1}$. It is planned that this water will go towards replacing the last potable water used for irrigation onsite (about 160 ha).
- There are also investigations underway for increasing the treatment of recycled water (most likely via MF and UV irradiation) to augment a recreational lake onsite.
- The reclaimed water system is also on the cusp of requiring augmentation. RCID is investigating stormwater recycling, surface water use and aquifer storage and recharge options for the site.

CHAPTER 5 Conclusions

The general water qualities for specific end uses are shown in Table 5.1. It is important to note that these are guidelines and each site must be considered on a case-by-case basis. In general it is important to consider the current water quality in comparison to the recycled water quality for recirculated cooling uses as too low a quality could result in an increased water demand. A similar situation exists in any recirculated system.

The extra treatments outlined in Table 5.1 would, in some cases, still be necessary for potable or raw water and these should not act as discouragement. On the contrary, the demineralisation requirement of MF/RO quality water should be significantly reduced when compared to potable water. This means less regenerations would be necessary resulting in significant savings.

A number of uses will see potential benefits technically from the use of recycled water. The presence of phosphate will help protect steel systems such as cooling towers. The presence of nitrates and other nutrients in wastewaters are beneficial in irrigation projects.

Table 5.1. Fit for purpose water qualities for various end uses

Use	Treatment Level	Further Treatment Potentially Required
Cooling	Tertiary	Nitrification
Boiler	MF/RO	Demineralization
Wash - Housekeeping and Dust Suppression	Secondary	Subject to controls
	Tertiary	None
Pollution Control	Secondary	Ammonia and Phosphate reduction
Quality Control	Tertiary	Final rinse may need higher quality
Transport	Secondary	Filtration
Separation - Unimetallic	Secondary	Filtration, Flotation tests
Separation – Ore Selective	Tertiary	Flotation tests
Lubrication	Tertiary	
Fire Control	Secondary	Subject to controls
	Tertiary	
Irrigation - Restricted	Secondary	Subject to controls
Irrigation - Unrestricted	Tertiary	
Toilet Flushing	Tertiary	Aesthetic improvements
Textiles	Tertiary	Colour removal
Paper/Pulp	Tertiary	Colour removal
Electronics	MF/RO	Demineralization

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APPENDIX A
List of Global Recycled Water Projects

Owner	Operation	Location	Use	Quantity (ML.day^{-1})	Used Since
		AUSTRALIA			
Iluka Resources	Douglas Mineral Sands Project - Rutile Mining	Hamilton, Victoria	Mineral Separation		2007
Perseverance Corporation	Fosterville Gold Mine	Fosterville, Victoria	Mineral Separation, Mineral Processing	5	2005
Eraring Power	Eraring Power Station	Lake Macquarie, NSW	Cooling, boiler feed, dust suppression, ash conditioning	4.5	1995
BlueScope Steel	Steelworks	Port Kembla, NSW	Cooling, boiler feed	20	2006
Newcrest Mining Ltd	Cadia Valley Operations - Gold/Copper Mine	Blayney, NSW	Mineral separation, dust suppression	13	1998
Stanwell Corporation	Rocky Point Cogeneration Plant	Woongoolba, Queensland	Cooling		2002
BP	Petroleum Refinery	Bulwer Island, Queensland	Cooling, boiler feed	10-14	2000
ATCO/Origin Energy	Bulwer Island Cogeneration Plant	Bulwer Island, Queensland	Boiler feed		2000
New Wave Leathers Pty Ltd.	Tannery	Toowoomba, Queensland	Process (tannery)	1	1970s
InterGen	Millmerran Power Station	Millmerran, Queensland	Cooling		2003
Queensland Alumina	Alumina refinery	Gladstone, Queensland	Caustic recovery from red mud	6.5	2002
NRG	Gladstone Power Station	Gladstone, Queensland	Ash conditioning, dust suppression		2002
	Swanbank Power Station	Swanbank, Queensland	Cooling		2007
CSBP	Chemical (Fertilizer and Mining Compounds) Plant	Kwinana, Western Australia	Cooling, boiler feed		2006
HIsmelt	Pig Iron Foundry	Kwinana, Western Australia	Cooling, boiler feed		2006
Tiwest	Pigment Plant	Kwinana, Western Australia	Cooling, boiler feed		2006
Alcoa	Alumina refinery	Pinjarra, Western Australia	Bayer process		1999

Owner	Operation	Location	Use	Quantity (ML.day^{-1})	Used Since
		UNITED STATES			
Arizona Public Service	Palo Verde Nuclear Generating Station	Phoenix, Arizona	Cooling	210	1986
Salt River Project	K-7 Power Plant	Tempe, Arizona	Cooling	11.7	
Arizona Public Service	Redhawk Power Station	Arlington, Arizona	Cooling	14.8	2001
SCA	Tissue Mill	Flagstaff, Arizona	Process (Paper/Pulp)		2005
Chevron	Petroleum Refinery	Richmond, California	Cooling		1996
Chevron	Petroleum Refinery	El Segundo, California	Cooling, boiler feed	40	1995
ExxonMobil	Petroleum Refinery	Torrance, California	Cooling, boiler feed		1996
BP	Petroleum Refinery	Carson, California	Cooling, boiler feed		1999
Calpine	Metcalf Energy Centre	San Jose, California	Cooling		2005
Burbank Water and Power	Olive Power Plant	Burbank, California	Cooling	0.2	1967
Burbank Water and Power	Lake One Power Plant	Burbank, California	Cooling	0.2	2002
Burbank Water and Power	New Magnolia Power Plant	Burbank, California	Cooling	3.8-5.3	2005
Los Angeles County Sanitation District	Puente Hills Energy Recovery Plant	Whittier, California	Cooling, fire control	1.9	1984
Simpson Paper Company	Pomona Paper Mill	Pomona, California	Process (Paper/Pulp)		
Los Angeles County Sanitation District	Spadra Gas-to-Energy Plant	Pomona, California	Cooling	0.1	1991
Glendale Public Service	Grayson Power Plant	Glendale, California	Cooling	1.1	1979
Pacific Oroville Power	Oroville Cogeneration Facility	Oroville, Califonia	Cooling	0.2	1989
Northern California Power Agency	CT2 Project	Lodi, California	Boiler feed	0.3	1996
Calpine	Delta Energy Centre	Pittsburg, California	Cooling	29	2001
Calpine	Los Medanos Energy Centre	Pittsburg, California	Cooling		2001
Vernon Light and Power Department	Malburg Power Station	Vernon, California	Cooling		2002

Owner	Operation	Location	Use	Quantity (ML.day^{-1})	Used Since
	Royalty Carpet Mill	Irvine, California	Process (Carpet)		
Tuftex of California	Carpet Mill	Santa Fe Springs, California	Process (Carpet)		1993
Calpine	The Geysers Geothermal Power Station	Santa Rosa, California	Injection for steam production	42	2003
Mountainview Power Company	Redlands Power Station	Redlands, California	Cooling		2005
	California Street Landfill	Redlands, California	Dust Suppression		2004
Silicon Valley Power	Donald von Raesfeld Power Station	Santa Clara, California	Cooling		2005
Platte River Power Authority	Rawhide Energy Station	Wellington, Colorado	Cooling (once-through)	14	1984
Orlando Utilities	Curtis Stanton Energy Centre	Orlando, Florida	Cooling	38-42	1987
Tampa Electric Company	Big Bend Power Station	Apollo Beach, Florida	Desulfurization scrubber, cooling	7.6	1984
Vero Beach Municipal Utilities	Vero Beach Municipal Power Plant	Vero Beach, Florida	Cooling	7.6	1992
Ogden Martin	Lee County Power Plant	Fort Myers, Florida	Cooling	2.3	1994
City of Lakeland	McIntosh Power Plant	Lakeland, Florida	Cooling	23	1983
Southern Company	Oleander Power Project	Cocoa, Florida	Cooling	0.05	
Wheelabrator	McKay Bay Refuse-to-Energy Facility	Tampa, Florida	Cooling	2.3	1985
Progress Energy	University of Florida Cogeneration Facility	Gainesville, Florida	Cooling	1.5	1994
Progress Energy	Hines Energy Complex	Bartow, Florida	Cooling (once-through)	6.8	1995
Wheelabrator	North Broward Waste-to-Energy Plant	Pompano Beach, Florida	Cooling	3.8	1991
JEA	Northside Power Plant	Jacksonville, Florida	Cooling	3.8	
Tallahassee	Purdom Generating Station	St. Marks, Florida	Cooling	2.8	2002
Covanta Energy	Pasco County Resource Recovery Facility	Spring Hill, Florida	Cooling	0.8	1990s
Kissimmee Utility Authority	Cane Island Power Plant	Kissimmee, Florida	Cooling	8.7	1990s

Owner	Operation	Location	Use	Quantity (ML.day^{-1})	Used Since
Progress Energy	Intercession City Power Plant	Kissimmee, Florida	Scrubbed water	0.8	1990s
Wheelabrator	Pinellas County Resource Recovery Plant	St. Petersburg, Florida	Cooling	6.4	1990s
Disney	Walt Disney World	Lake Buena Vista, Florida	Vehicle Washing		1993
Chevron	Petroleum Refinery	Kapolei, Hawaii	Boiler feed	1.5	2000
Tesoro Hawaii Corporation	Petroleum Refinery	Kapolei, Hawaii	Boiler feed	1.25	2000
PSEG	Kalaeloa Cogeneration Facility	Kapolei, Hawaii	Boiler feed	1.9	2000
The Gas Company	Synthetic Natural Gas Plant	Kapolei, Hawaii	Boiler feed	0.2	2000
Alliant Energy	Energy Station	Clear Lake, Iowa	Cooling	4.9	2003
Sunflower Electric	Garden City Power Plant	Garden City, Kansas	Cooling	1.9	2007
Panda Global Services	Brandywine Power Plant	Brandywine, Maryland	Cooling	5.7	1997
Wheelabrator	North Andover Waste-to-Energy Plant	North Andover, Massachusetts	Cooling	2.5	1985
Millenium Power Partners	Power Station	Charlton, Massachusetts	Cooling	1.5	2004
Caledonia Operating Services	Caledonia Power Plant	Steens, Mississippi		1.9	2002
Nevada Power Company	Clark Power Station	Henderson, Nevada	Cooling	up to 10.2	
Nevada Power Company	Sunrise Power Station	Las Vegas, Nevada	Cooling	1.1	1990s
AES	Granite Ridge Power Plant	Londonderry, New Hampshire	Cooling	15	2002
PSEG	Linden Power Station	Linden, New Jersey	Cooling	45	2006
PSEG	Bergen Power Station	Ridgefield, New Jersey	Cooling	2.3	2002
PNM	Luna Energy Facility	Deming, New Mexico	Cooling	3.8	2007
Bronx Community Paper Company	Bronx Paper Mill	New York, New York	Process (Paper/Pulp)		
Covanta Energy	Lancaster County Resource Recovery Facility	Bainbridge, Pennsylvania	Cooling	2.3	1991

Owner	Operation	Location	Use	Quantity (ML.day^{-1})	Used Since
American National Power	Hays Energy Facility	San Marcos, Texas	Cooling	1.2	2002
	Cleburne Cogeneration Facility	Cleburne, Texas	Cooling		1997
Xcel Energy	Harrington Power Plant	Amarillo, Texas	Cooling	57	
Xcel Energy	Nichols Power Plant	Amarillo, Texas	Cooling		
Xcel Energy	Jones Power Plant	Lubbock, Texas	Cooling	19	
El Paso Electric	Newman Power Plant	El Paso, Texas	Cooling	9	1991
Suez Energy Resources	Ennis-Tractebel Power Plant	Ennis, Texas	Cooling	5.7	2001
Giant Industries, Inc.	Petroleum Refinery	Yorktown, Virginia	Cooling, fire control		2002
Old Dominion Electric	Marsh Run Generation Plant	Fauquier, Virginia	Cooling		2004
GE Energy	Fox Energy Centre	Kaukauna, Wisconsin	Cooling	3	2005
Pacificorp Energy	Wyodak Power Plant	Gillette, Wyoming	Boiler feed		
CANADA					
Petro-Canada	Petroleum Refinery	Edmonton	Hydrogen production, process steam for fuel desulfurization	5	2006
JAPAN					
Toyo Glass Company		Kawasaki	Cooling		
SINGAPORE					
Sony	Sony Display Device		Wash water in cathode ray tube production		1998
Systems on Silicon Manufacturing	Wafer plant		Wash water		2003
Panasonic Semiconductor	Semiconductor plant		Wash water		2005

Owner	Operation	Location	Use	Quantity ($ML.day^{-1}$)	Used Since
		UNITED KINGDOM			
Centrica Energy	Peterborough Power Station	Peterborough	Boiler feed, flue gas injection	1	2000
		SPAIN			
Repsol	Petroleum refinery	Puertollano	Cooling		1993
Enfersa	Fertilizer Plant	Puertollano			1993
		SOUTH AFRICA			
De Beers Group	Kimberley Diamond Mine	Kimberley	Wash water		
Mondi Paper	Merebank Paper Mill	Durban	Process (paper/pulp)	47.5	1972
SAPPI	Enstra Paper Mill	Enstra	Process (paper/pulp)	16	1940s
SAPPI	Cape Kraft Paper Mill	Cape Kraft	Process (paper/pulp)	1	
SAPPI	Port Elizabeth Paper Mill	Port Elizabeth	Process (paper/pulp)	2.5	
SAPREF	Petroleum refinery	Durban	Cooling		2001
City Power GHB	Kelvin Power Station	Johannesburg	Cooling		
Sasol Textiles	Merebank Textiles Mill	Durban	Process water (textiles)		2001
		SAUDI ARABIA			
Saudi ARAMCO	Petroleum refinery	Riyadh	Cooling		
		CHINA			
Huaneng Power International	Shandong Huaneng Power Plant	Shandong	Cooling		
North China Grid Company	Matou Power General Plant	Handan City, Hebei	Cooling		
		INDIA			
Chennai Petroleum	Petroleum refinery	Manali	Cooling		
Madras Fertilizers	Fertilizer plant	Manali	Cooling		