FRAMEWORK FOR DEVELOPING WATER REUSE CRITERIA WITH REFERENCE TO DRINKING WATER SUPPLIES

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FRAMEWORK FOR DEVELOPING WATER REUSE CRITERIA WITH REFERENCE TO DRINKING WATER SUPPLIES

Executive Summary

Objectives

The principal objective of this project was to develop a rationale for setting standards/guidelines for the safe reuse of wastewater for drinking water or to replace drinking water supplies based upon the pathway/risk end point. The rationale takes into account existing standards and criteria from different parts of the world and considers knowledge gaps. A draft framework was developed to guide the deliberations of an international Committee of Experts and enable them to critique the approaches and rationale and, thus, provide input for development of this document.

Conclusions

There is a range of regulations and guidelines for the safe reuse of wastewater for a number of purposes but which primarily relate to irrigation and groundwater recharge. Most of these regulations and guidelines follow a risk-based approach that considers the route and potential for exposure to contaminants in wastewater and the extent of treatment required for specific uses.

Although numerical standards are important, they cannot provide sufficient reassurance of safety on their own by simply providing lists of substances, or pathogens, with associated standard values against which to monitor.

There is a need for criteria that employ a broader approach to encompass treatment standards, treatment process controls and fail-safe systems, application standards and water quality standards suitable for a more comprehensive suite of wastewater uses.

The framework herein provides a consistent basis for the development of appropriate and verifiable standards and guidelines at local, regional and national levels. The framework takes into account the increasing complexity and need for reassurance of water reuse from simple irrigation to direct reuse as drinking water. The views of the Committee of Experts were incorporated into the final framework.

Benefits

The framework provides a basis for more widespread acceptance of the common practice of using treated and blended wastewater as a raw water source to be treated for drinking water and as a replacement for current uses of drinking water.

The framework provides a potential for significant environmental, social and economic benefits that should lead to savings in the development of water recycling and reuse projects by means of a sound scientific basis for standards and guidelines.

It also provides significant reassurance for suppliers and users as to the safety, and continuing safety, of recycled water through an auditable process to demonstrate that hazards potentially associated with wastewater have been identified and controlled.

For further information please contact UK Water Industry Research Limited, 1 Queen Anne's Gate, London SW1H 9BT quoting the report reference number

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1.1 The need for water reuse

Water demand globally has increased by a factor of four in the last fifty years. This is because of an increase in population and in standard of living with a consequential requirement for increased amounts of water for non-potable and hygiene purposes. In addition there has been an increase in water use in agriculture to increase productivity, particularly with the development of agriculture in areas of low rainfall. Unfortunately, it is not always possible to meet the higher demand as competition for water resources increases. In addition, climatic changes in the form of periods of prolonged drought have compromised many surface and underground water resources, even in areas not previously affected. Much of this places seasonal pressure on resources. Exploitation of groundwater close to coastal areas without due care can result in the intrusion of seawater into fresh water aquifers. In some circumstances pollution has also played a part in reducing the availability of high quality sources of water. Improvements in treatment processes have resulted in previously unusable resources being brought into use; however, solutions such as these can be costly and energy intensive.

Only a small fraction of drinking water that is supplied to domestic premises is used for drinking, cooking and hygiene. The remainder is used for a range of purposes for which drinking water quality is not necessary, including toilet flushing, watering gardens, laundry and car washing. On a global scale agriculture represents up to 60% of the total water demand while the requirements arising from increasing urbanisation such as watering urban recreational landscapes also creates a high demand. In Australia, an achievable target of 20% reuse of wastewater by 2012 has been set to highlight the importance of reuse and focus regional strategies. As water demands increase, the ability to meet them from sources that provide the basis for drinking water supplies is becoming increasingly difficult.

1.2 Alternative sources of water

As water resources become depleted, alternatives must be found to satisfy the demand, alongside demand management programmes. A number of alternatives may exist depending on the application. In some areas alternative fresh water sources are not readily available and in other areas while it may be possible to create new sources of water by building dams or developing new groundwater resources these are often limited and expensive both in cost and environmental impact. Conserving drinking water resources is increasingly important and one of the ways of achieving the goal of reducing the demand for drinking water is by exploiting an alternative source of water for uses that do not require the water to be of drinking water quality. For drinking water, the supply of bottled water for drinking and cooking purposes has been suggested as one means of conserving drinking water in times of water stress. The use of dual systems by which a small supply of water for drinking, cooking and basic hygiene is provided along with a less highly treated supply for other uses has been suggested. However, there are also potential disadvantages and problems associated with both, particularly the former, as well as advantages in reducing the demand for potable quality water.

Although treated wastewater has been an important means of augmenting river flows in many countries and the subsequent use of such water for a range of purposes constitutes indirect reuse of wastewater, it is becoming increasingly attractive to use reclaimed or treated wastewater more directly. In addition, reclamation of wastewater is attractive in terms of sustainability since wastewater requires disposal if it is not to be reclaimed.

1.3 Applications for reclaimed water

Reclaimed water can be used as an acceptable and safe substitute for many traditional uses of drinking water and water from sources that provide raw water for drinking water production. The place of reclaimed water in the water cycle is illustrated in Figure 1. Such uses can help conserve drinking water resources by replacing drinking water or water taken from drinking water sources and by enhancing drinking water sources such as reservoirs and groundwater. The developments in technology for wastewater and drinking water treatment have ensured that the indirect recycling that has been commonplace in many parts of the world for many years is not only safe but can be demonstrated to be safe. In addition, this technology can meet a range of new and emerging challenges from both microbial and chemical contaminants.

Treated wastewater may be used as an alternative source of water for irrigation in agriculture, which, as indicated above, is the single largest user of water in the world. It may be used as an alternative source of water for irrigation of golf courses and other green spaces, including those used for recreation in which individuals may come into contact with the ground. It may be used as an alternative source for irrigation of municipal gardens. It can be used to supplement artificially created recreational waters and for reclamation and maintenance of wetlands for which there can be a significant ecological benefit and a subsequent sense of benefit to the community. Its use in wetlands may also act as an additional treatment stage, helping to remove particulate material, nutrients and micropollutants prior to supplementing drinking water resources such as fresh water reservoirs. An additional use may be the direct supplementation of drinking water resources through groundwater infiltration and by adding it to surface water. It is even technically possible for it to be used as a direct drinking water source, although acceptability to the public may not yet be achievable.

Japan, amongst other places, uses a dual system in which highly treated wastewater is used for purposes such as toilet flushing, although great care is required to prevent cross connections with the drinking water supply. In addition there are many industrial applications for which suitably treated wastewater would be a replacement source of water. Reclaimed wastewater may also be substituted for drinking water for a variety of urban uses, including car washes and road and pavement washing.

Industrial applications include the provision of cooling water for evaporative condensers, boiler feed water and as a process water for the pulp and paper, chemical and petrochemical industries.

Clearly the application for which the water is to be used and the way in which it is to be applied will dictate the microbiological and chemical quality required. In addition, demand for reclaimed water will frequently vary during the year and alternative means of disposal or storage may be required when production exceeds demand.

For reuse, the water must, for many applications, be treated to a standard higher than that encountered in secondary treated effluent. Tertiary or advanced treatment is applied to reduce the chemical and microbial loads in the water to the extent that its use does not constitute an unacceptable health risk. Whilst it is possible to conduct health based risk assessments that will clearly demonstrate the safety of the proposed use, stakeholder and public acceptance is also essential if proposals are to become reality.

Figure 1. Diagram of example of potential reuse of reclaimed wastewater

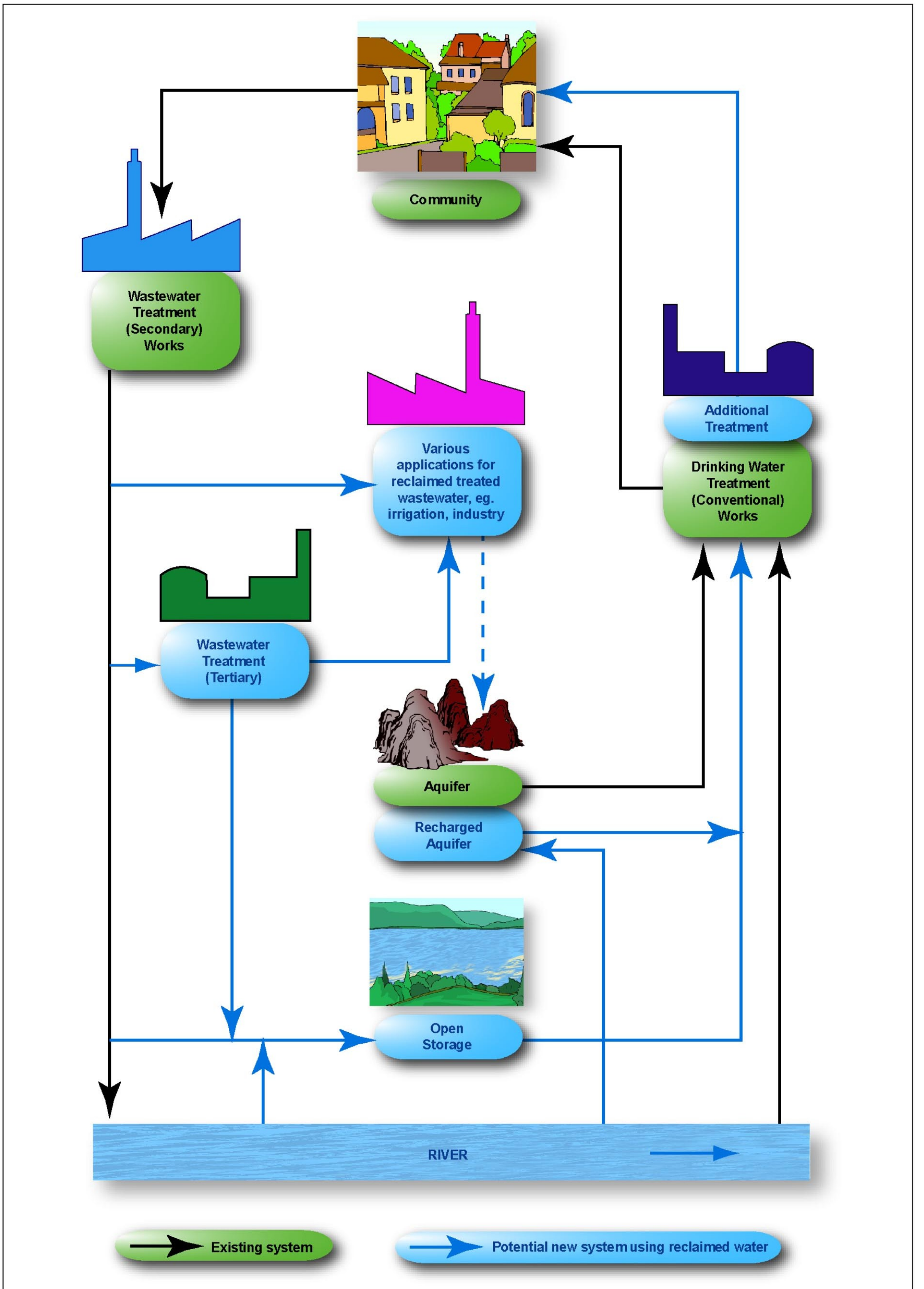
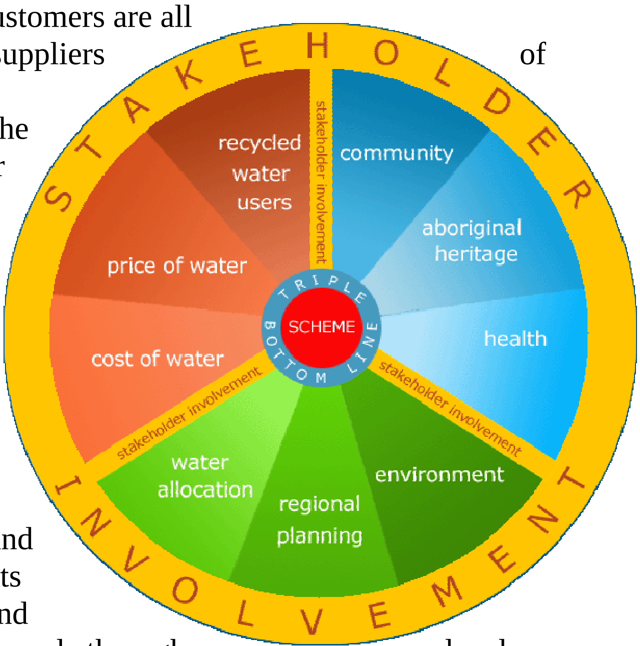


Figure 1 Diagram of example of potential reuse of reclaimed wastewater.

1.4 Public perception and acceptance of using reclaimed water

In developing all potential applications for replacing drinking water or water from drinking water sources with reclaimed water, it is essential that the stakeholders and consumers are comfortable with the principle and confident in its safety. Achieving public acceptance of a proposal is absolutely essential and no matter how technically sound and scientifically justifiable the proposals, public perception of the use of reclaimed water must be considered as a key component of any process.

The first stage of acceptance of the use of reclaimed water is the acceptance by the community of the need. In this case the use of reclaimed water becomes a solution to a problem and this, in turn, is an important driver of public perception. A second important consideration is the question of when does wastewater cease to become wastewater and become just another water resource. In this respect separating the reclamation phase and the application phase by dilution and storage either in a reservoir or in groundwater may be an important step in achieving acceptance, particularly when retention can be measured in weeks or months rather than days (Strang 2004). This approach has been used with considerable success in a number of circumstances where reclaimed water has been used to directly supplement drinking water sources in Singapore and the UK (Walker 2001). In addition a high degree of stakeholder involvement is a prerequisite for success. In this respect the public, the reclaimed water provider and their customers are all stakeholders along with environmental groups, suppliers of wastewater and drinking water services and regulators. Achieving public acceptance is not the subject of this framework but there are a number of parallel projects that have specifically addressed public acceptance and public perception. These include studies by the WateReuse Foundation (Haddad 2004, Hartley 2003, National Water Research Institute and Stratus Consulting Inc 2004, Resource Trends Inc 2004). Excellent examples for strategic planning and stakeholder involvement exist in Western Australia where priorities are agreed at stakeholder workshops, and options justified by triple bottom line assessments (economic, environmental and social benefits) and willingness to pay surveys. Project decisions are made through local stakeholder groups who are supported by environment and health regulators as well as NGO (Non-governmental organisations) stakeholder groups (Turner 2004).



1.5 Criteria and standards

An important part of the process of achieving public acceptability of water reuse is demonstrating that the water is safe. Even if advanced treatment is used, there is a need for criteria that can act as a benchmark against which to measure the safety of the final product within the context of the desired use. Such criteria also provide a technical benchmark for operators and for the development and deployment of treatment processes. These criteria may not be numbers relating to individual parameters but could be process standards. However, it is important that any criteria or standards are both scientifically sound and justifiable, that their derivation is transparent, all the options have been evaluated with the involvement of the stakeholders and the selected solution has the support of the stakeholders.

Guidelines and standards have been developed in many parts of the world; however, there is a need for a much wider agreement as to the criteria for both developing national or local standards and the approaches by which these can be achieved. UKWIR, Awwa Research Foundation (AwwaRF) and WateReuse Foundation commissioned this project to develop a consensus on criteria for water quality in reuse schemes and so further the potential for reuse of wastewater and provide a basis for discussion with regulators and potential users.

1.6 Objectives and specific tasks of the project

The following objectives were set for the project:

- Document existing standards for water reuse and their rationale/basis (public health and/or other parameters)
- Identify merits and weaknesses of existing approaches
- Identify existing knowledge gaps that hinder the development of rational and scientifically-supportable water reuse criteria
- Develop a rationale for setting standards/guidelines based upon pathway/risk end point.

The following specific tasks were undertaken:

- Identify and compile existing water reuse standards and guidelines in the United States, Europe, Australia and elsewhere via a review of published literature, published regulations and guidelines, and other means
- Where available, summarise the rationale behind the existing criteria/guidelines
- Form an international committee of experts in areas including, but not limited to, microbiology, risk assessment, epidemiology, toxicology, regulations/permitting, engineering, environmental experts, public agencies
- Committee will critique approaches and rationale used to develop existing criteria to assess their relative strengths/weaknesses or identified approaches (output may be presented in matrix form)
- Develop a framework to guide the expert group's deliberations
- Develop a preferred approach based on the Committee's evaluation of existing rationale/approaches and determination of parameters that need to be considered during regulation development (e.g., use of risk assessment as a tool)
- Conduct a hypothetical case study as a proof of concept.

A committee of experts was assembled at the University of Warwick for a two-day workshop in April of 2004. A list of the delegates is provided in Appendix 3. Members of the committee included engineers, chemists, microbiologists and toxicologists from around the world. The committee spent two days reviewing the framework and providing suggestions and comments to improve the framework to make it applicable to developed and, if possible, developing countries. The purpose of this document is not to provide standards for water reuse but to lay down a framework, which will guide those intending to develop water reuse.

When proposing a scheme where use of reclaimed water is considered, this framework is intended as an aid to the decision making process and identifies the factors that need to be taken into account.

1.7 Approach to using this framework

This report provides a discussion of the key issues that require consideration when planning a project to augment or substitute resources that provide water for drinking water supplies. It also provides a basis for systematically working through the requirements for assuring the safety of consumers and the environment for such projects. The high level framework provides the overall approach to identifying the questions that need to be answered for a range of potential project scenarios and applications in which treated wastewater will provide a means of directly augmenting supplies or replacing drinking water for non-potable uses.

Justification and public perception are vital and require consideration from the outset, whatever the project. There are three aspects of the process that require assessment. The first is to determine the range of applications, the potential for exposure of crops, humans, stock or wildlife and the route to the end receptor, e.g., man through crops. The second is to determine the standards and or barriers required to achieve the necessary quality for the use or to protect the receptors. Such barriers can be associated with treatment of wastewater or application controls to prevent exposure of the receptor such as trickle irrigation compared to spray irrigation for edible crops and, in the case of drinking water supplies, additional barriers at the drinking water treatment works. The third is to ensure that the hazards and risks have been properly determined and that the treatment systems (barriers) in place are working at all times, including when circumstances may be unusual, unexpected or when conditions are at extremes such as low temperature or high rainfall.

Specific standards for both microbial and chemical parameters are discussed and guidance is given as to existing sources of standards if these are not available locally.

Detailed frameworks are given for a range of uses that do not involve reuse directly for potable water. A separate framework is provided for more direct reuse as drinking water supplies. Finally two case studies are presented that cover a wide range of issues for each study.

The framework is not intended to be a detailed instruction book and no attempt is made to present information in this light. However, it is intended to assist the user in identifying the issues that will need to be addressed for their particular project proposal. The framework is supported by a bibliography.

2 Issues

2.1 Introduction

Untreated wastewater contains a range of hazards in the form of pathogens and chemicals. While pathogens present a largely acute risk, although there may be long-term sequelae to acute infections, chemicals primarily present a chronic risk, since few chemicals could be present at concentrations that give rise to toxicity following short-term exposure. The exception is the case of an accidental spill of a large quantity of a substance and its subsequent presence in high concentrations in wastewater. The potential for both microbial and chemical contaminants to cause adverse effects will depend on the receptor and the level of exposure. The receptor could be man, through drinking water or recreation or from eating crops, meat and fish produced with reclaimed wastewater, or it could be an irrigated crop or livestock directly exposed to the water, intentionally or unintentionally. It may also be the workforce through exposure to reclaimed wastewater in the course of their work. However, exposure will be highly dependent on the means of deploying the reclaimed wastewater. Wastewater also contains material such as suspended solids that can cause significant practical problems (e.g. in spray irrigation) and the biochemical oxygen demand could result in the depletion of oxygen in some circumstances. The final pH of the water is also an important determinant of its impact on the behaviour of substances present in soils and their propensity for leaching to ground or surface water. In some cases, where there is a high salt content there is also the potential for salination of soil or corrosion of pipework. Wastewater treatment can easily deal with these potential hazards but in the event of a release to sewer of a sufficiently large quantity of a substance to interfere with wastewater treatment, levels in the treated wastewater stream can be sufficient to cause severe problems.

2.2 Microbial contaminants

Microbial contaminants can be divided into three groups namely bacteria, viruses and intestinal parasites. The last may also be divided into two groups, the protozoa and the helminths. All these groups have been reviewed extensively in Mara and Horan (2003). The numbers of microbial contaminants in wastewater will vary considerably depending principally on the range and extent of infections in the community. In general, with the exception of industries associated with animals, industrial input is small. The bacterial pathogens, for example, *Campylobacter,* may only survive in the environment for a few days but some of the viruses and the helminth eggs may survive for weeks or months, although their numbers will be reduced principally by sunlight, pH and temperature. Contact with contaminated water and the risk of infection is based on a large number of factors. These will include the infective dose of the pathogen, the numbers present in the wastewater and the susceptibility of the host to infection. In some circumstances, infection may result in a carrier state where disease is not recognised. Host susceptibility can be multi-factorial and include age and general health, immune competence, nutritional status, pregnancy, malignancy and metabolic disorders.

Secondary treatment of wastewater will provide some degree of removal, however complete removal cannot be guaranteed and therefore secondary treated wastewater has applications only where there is no public access and the products being irrigated will not be consumed without processing. Disinfection of secondary effluent with chlorine will reduce bacteria and virus numbers but will have little effect on many of the intestinal parasites. Tertiary treatment will effect further removal of pathogens. Tertiary treatment involving physical filtration, for example, ultrafiltration, microfiltration or membrane bioreactors, will effectively remove the cysts and ova of intestinal parasites and viruses. Optimisation of chemical coagulation and filtration can also achieve the removal of parasites. Tertiary treatment will further reduce turbidity.

Disinfection forms the final barrier against microorganisms in wastewater. Different disinfectants are effective against a range of types of organisms but none are completely effective against all organisms. Table 1 outlines the broad impact of wastewater treatment on the removal of pathogens. However, it must be remembered that the key value of importance is the residual concentration of pathogens in the final water, which will be dependent on the concentration of pathogens in the influent water. In addition, it must be remembered that the actual concentration of pathogens in the final effluent may not be reflected by the concentration of microbial indicators. This topic is considered in much more detail in Section 4.

Table 1 Microbial reductions achieved with different wastewater treatment strategies

Microbial category	Secondary treatment	Media filtration	Disinfection	Comment
Viral indicators	1 - 5 log reduction	0 - 2 log reduction	0 - 4 log reduction	No correlation between enterovirus and coliform removal
Bacterial indicators	1 - 3 log reduction	0 - 5 log reduction	0 - 4 log reduction	Improved removal with pre-chlorination
Protozoan pathogens	0 - 3 log reduction	0 - 3 log reduction	< 1 log reduction	Sensitive to backwashing practices

2.3 Chemical contaminants

There are potentially many chemicals that could be present in wastewater. Some are natural, some will be excreted by humans and some will be generated by man in the form of substances used in consumer products and industry. Most substances will be present in relatively low concentrations and the great majority will be reduced in concentration, removed or broken down in wastewater treatment. The extent of removal will depend on the types of treatment and the efficiency of the treatment processes, along with the degradability, and adsorbability of the substance and its breakdown product. Removal may vary according to the loading on the treatment process and the ambient conditions, such as temperature. Where disinfection is practised as part of tertiary treatment, disinfection by-products may be formed in the treatment process.

2.3.1 Inorganic constituents

The types of water discharges feeding into the wastewater stream will be an important influence on the types of inorganic substances present. Hard waters will contain greater quantities of calcium and often magnesium, along with greater quantities of carbonate and sulphate. A number of inorganic substances will be present in wastewater in significant concentrations, as a consequence of excretion by humans. These include sodium, potassium, chloride, phosphorus and nitrogen. Others will be present as a consequence of household activities, such as boron from some washing powders. Metals such as copper and, to a lesser extent, lead, nickel and chromium may also be present as a consequence of their use in plumbing in buildings. Smaller amounts of substances such as cadmium and zinc may be present from domestic uses and from industries discharging to sewer, however, the quantities of the more toxic metals, such as cadmium and mercury, are declining in most countries as efforts are made to reduce their diffuse loss to the environment.

The range of potential inorganic substances present will depend on the wastewater catchment and the range and types of industrial discharge. However, many of the substances will be present in very small concentrations. A number of the substances present are essential for plant growth and for animal nutrition. Many inorganic substances will vary in solubility depending on the chemical form and speciation and a few, such as boron, are poorly removed in wastewater treatment.

2.3.2 Organic constituents

A wide range of organic substances is present in wastewater. Some are naturally present as part of human metabolism and physiology, some are excreted by humans after they have been ingested and some will be present as a consequence of their use in personal care products and in the household. Others will be present as a consequence of industrial discharges. Some will be present as the parent compound while others will be present as metabolites. All will be reduced in concentration, broken down or removed in wastewater treatment. In particular, substances that are largely hydrophobic will adsorb to particles and will be removed in wastewater sludge.

Recent concerns have been expressed about the impact of a number of these substances on receiving waters, and potentially on drinking water. These concerns include substances with properties that may lead to the disruption of endocrine activity, particularly in fish, pharmaceutical residues and personal care products such as the synthetic musks. However, many of these substances are relatively hydrophobic and can be removed in wastewater treatment to a significant extent. Other organic substances, about which concern is frequently expressed, such as pesticides, are less likely to be present in municipal wastewater. In general, extended treatment times will result in a greater removal of chemical contaminants.

Where tertiary treatment is applied to wastewater this may lead to the reduction or removal of organic substances and, where chlorine or ozone disinfection is applied, the generation of organic by-products of disinfection. The latter will depend on the organic matter remaining in the water, the disinfectant dose, contact time and other factors such as temperature and pH.

It is increasingly difficult and unproductive to attempt to control contaminants by an ever-lengthening list of individual standards for the end product and so it is more practical to develop an approach similar to the risk based Water Safety Plans that are being proposed for assuring the quality and safety of drinking water (WHO 2004).

2.4 Risk assessment

The key issue for assessing the potential risks of microorganisms and chemicals is whether there will be exposure of receptors such as plants and humans, and whether that exposure will be sufficient to be of concern both in terms of concentration, or numbers, and period of exposure. The questions that need to be addressed are as follows:

- Will the chemical or pathogen reach a receptor such as an animal, including man, or plant, either directly or indirectly?
- Will a chemical or pathogen deposit on the leaves of plants? This may be of no direct concern for the plants, but if the plants are eaten by humans or livestock it could be of concern.
- Will the pathogen be taken up by humans through contact during recreation or similar circumstances?
- Will the chemical accumulate in an animal or plant and, if so, will it accumulate in the parts of that animal or plant that will be used in food or food production?
- Is the chemical present in sufficient concentration to damage that animal or plant?

- Will the chemical leach or percolate into groundwater, or surface water, giving rise to subsequent problems?
- Will the chemical accumulate in the soil and damage crops at a later stage?
- Will the pathogen accumulate in shellfish or fish?
- Is there a potential for disease transmission or uptake of chemicals through aerosols associated with the use of wastewater?

With regard to drinking water the position is relatively simple in terms of assessing human exposure but with other uses of wastewater, e.g. irrigation, aquaculture, stock watering, or industrial applications such as cooling water, assessing exposure may be more complex. Exposure may also be specific to particular circumstances. This is of great importance in crop irrigation where the types of soil, the depth of groundwater, the types of crop grown and the method of irrigation will all impact on the potential risks. There will, therefore, always be a requirement for consideration of local circumstances. Use on green spaces can lead to the potential presence of pathogens that could be taken up by hand to mouth transfer or through cuts. In other circumstances the use of reclaimed wastewater in fountains and in uses generating aerosols, such as toilet flushing, car washing or cooling towers, have the potential to expose consumers through inhalation if pathogens are present in the reclaimed water.

2.5 Health-based targets

Increasingly, the concept of water quality targets is being introduced by WHO, and some countries, as a means of developing a meaningful and consistent basis for determining the necessary level of treatment required to ensure the fitness for purpose of a water for a range of uses. This concept is discussed in more detail in the third edition of the Guidelines for Drinking-water Quality (WHO 2004) and in a number of other documents (Fewtrell and Bartram 2001). Such targets have been primarily developed for use with drinking water safety plans and drinking water guidelines and standards. However, it has been proposed that such targets could also be used in other applications in order to harmonise water-related guidelines and standards (Fewtrell and Bartram 2001).

Health-based targets form a key part of a harmonised framework and allow comparison between various water use guidelines in terms of the level of health protection provided. Health-based targets provide the overall objective for water safety and can be used to identify specific interventions and control measures required to achieve that objective. They also mark out milestones to guide and chart progress towards a predetermined health and/or water quality goal. Table 2 lists some of the benefits of health-based targets.

Table 2 Benefits deriving from the use of health-based targets (Bartram et al., 2001)

Target development stage	Benefit
Formulation	Gives insight into the health of the population Reveals gaps in knowledge Gives insight into consequences of alternative strategies Supports the priority-setting process Increases the transparency of health policy Ensures consistency among several health programmes Stimulates debate
Implementation	Inspires and motivates partners to take action Improves commitment Fosters accountability Guides the allocation of resources
Monitoring and evaluation	Supplies concrete milestones for evaluation and adjustments Provides opportunities to test feasibility of targets Provides opportunities to take actions to correct deviations Exposes data needs and discrepancies

Due to the range of constituents within water, their mode of action and the potential for fluctuations in concentration, WHO (2004) has outlined four principal types of health-based targets.

- Health outcome targets: In some circumstances, where water-related/waterborne disease contributes to a measurable burden of illness, it may be possible to establish a health-based target in terms of a quantifiable reduction in the overall level of disease. This is most applicable where adverse effects follow shortly after exposure, are readily and reliably monitored and where changes in exposure can also be monitored readily and reliably. This type of health outcome target is primarily applicable to some microbial hazards in developing countries. In other circumstances health outcome targets may be the basis for evaluation of results through quantitative risk assessment models. (See Section 2.6). In these cases, health outcomes are estimated based on information concerning exposure and dose-response relationships. For example this could include establishing a tolerable risk of less than one infection per 10,000 people per year.

- Water quality targets: Established for individual reclaimed water constituents that represent a health risk from long-term exposure and where fluctuations in concentration are small or occur over long periods. These would typically be expressed as concentrations of the chemicals of concern. Guideline values and standards represent water quality targets. Specifying a minimum log removal for viruses or protozoa represents a performance target.

- Performance targets: Performance targets could be employed as part of the reclaimed water system for constituents where short-term exposure represents a public health risk, or where a large fluctuation in numbers or concentration can occur over short periods of time with significant health implications. They are typically expressed in terms of required reductions of the substance of concern or effectiveness in preventing contamination.

- Specified technology targets: Such targets may identify specific permissible devices or processes for given situations. In the case of water reuse specifying tertiary treatment, as a minimum requirement for a particular use is a technology target.

It is important that health-based targets are realistic under local operating conditions and are set to protect public health.

2.6 Ways of developing health-based targets

There are a number of ways in which health-based targets can be developed for both microbial and chemical contaminants. In both cases the health-based targets are used to develop the barriers and controls that will achieve the level of exposure that will, in turn, ensure the acceptable level of risk is achieved. As indicated above, actual disease targets may be used in some developing countries in relation to drinking water. This approach has also been used by WHO in determining microbiological targets for some aspects of wastewater use in agriculture in developing countries. However, for developed countries such measures are not sufficiently sensitive and approaches have been developed using quantitative assessment of the risk of infections from different pathogens, such as estimating the number of a particular pathogen that will give rise to an annual risk of one infection per 10,000 population. The value of one per 10,000 is an example and different countries may use different levels of risk. This approach can also be used to derive the risk from multiple pathogens. Where the impact of infection varies in its significance, a modified approach has been used by WHO in which the risks from different hazards can be compared on a similar basis by determining the number of disability adjusted life years (DALYs) (WHO 2004). In some cases authorities have moved to a goal of no detectable pathogens and although this can be applied practically on a local basis, it does require a substantial amount of evaluation of a process, usually in a pilot plant to determine the level of protection required since continuous sampling may not be feasible. Once a process has been evaluated the no detectable pathogen aim can be translated into a performance target and monitored using a surrogate parameter such as turbidity for filtration processes designed to remove viruses and protozoa.

For chemicals, a somewhat different approach is used as chemicals may be present all of the time and it is the level that is the determinant of the potential for adverse health effects. With substances for which it is acknowledged that there is a demonstrable threshold below which no effects will occur, the health target is not risk-based but incorporates a margin of safety. The health target is then the standard or guideline value for that particular chemical. This is very straightforward for drinking water but can be more complex for reclaimed water applications where the pathway to humans is through the food chain. Health targets for those substances for which there is uncertainty about the dose response at the low levels usually encountered through environmental exposure may be assessed by determining risks, usually one additional case per lifetime of exposure in a population of 100,000 or 1 million using theoretical mathematical models. The level of exposure associated with this value, often the upper 95% confidence limit on the risk, then becomes the health target.

Such targets for both pathogens and for chemicals can then be used to determine the operational targets necessary to achieve that outcome.

The question for public perception and public trust includes the issue of who sets the targets and who determines what level of risk is acceptable. There are also issues of whether the risk is an aggregate risk for the community or whether the risk is an individual risk. In most cases the risk is an aggregate population risk and, particularly in the case of chemicals, the actual, as opposed to calculated, risk may be much lower and could approach, or even be, zero. It is important that it is recognised and made clear that achieving such risk levels does not equate to actual cases of disease or illness avoided.

3 High Level Framework

3.1 Introduction

Among the majority of professionals in the international water industry there is recognition of the need to conserve water resources and one way of doing this is to recycle wastewater. There is also confidence, and extensive international experience, that treatment techniques are available that enable any type of water to be treated to standards that are even higher than those presently required for drinking water. However, the benefit and role that reuse already plays in the water cycle, and could play in the future, is not well understood by many stakeholders. In addition, the requirement to conserve resources, and to consider wastewater recycling as part of that strategy is not so generally recognised by many of the communities in which such schemes would be of considerable value. This may be due to a tradition of managing drinking water and wastewater as if they were different and unconnected waters. There is, therefore, an important requirement for ensuring that the public and stakeholders have a clear understanding of the local water cycle and the alternative solutions, and accept the need for recycling as a pre-requisite to any scheme. Acceptance of need is a vital component in influencing public and stakeholder perception as discussed above.

The approach may also be somewhat different if the scheme is a new wastewater treatment facility compared to an existing facility. In this case there is the potential to design the facility with reclamation in mind. There are two circumstances in which there may be a driver for the use of reclaimed water. These are:

- Pressure on resources due to drought, population density, or river basin water management (groundwater and surface water protection reducing abstraction). There is, therefore, a requirement to find a means of reducing pressure on those resources, so the need is to find acceptable uses for reclaimed water.

- When a new water user cannot obtain access to traditional water sources and is seeking a source of reclaimed water.

However, in both cases there is an additional dimension relating to sustainability, since the wastewater will still require disposal irrespective of whether or not it is reclaimed for use. Reclamation of wastewater will therefore turn used water, which is currently considered to be a waste, into a valuable resource. It is, therefore, important to consider the whole water cycle when developing a water resource strategy.

It may not be appropriate to apply a simple set of standards in all areas since standards will need to be adapted to local conditions, which vary significantly in different parts of the world. The following is a framework built on a number of levels of increasing detail that can be used to establish criteria with a similar fundamental basis in any circumstances. In this way the framework will assist in developing novel applications for the use of reclaimed water where there are no existing criteria.

When proposing a scheme where use of reclaimed water is considered, this framework is intended as an aid to the decision making process and in identifying the factors that need to be taken into account.

The framework builds on existing guidance and standards to develop a structure that will allow a logical means of establishing the appropriate treatment process standards and safeguards and final water quality standards for a variety of applications for reclaimed wastewater. The key to the process, as indicated above, is the potential exposure of crops, livestock and humans, the standards required for their protection, the treatment or system that can deliver those standards, and the process controls on the treatment or system to ensure safety. It is an objective of the framework to provide a basis for developing criteria that ensure the water is suitable for the application for which it is intended.

It is important that the scientific basis of such standards and guidelines is clear and transparent. Where this is not the case, it is pointed out in the framework. Where there are no appropriate standards or guidelines available this need is identified. However, knowledge is increasing all the time and additional substances or pathogens will emerge as concerns in the future. The framework also provides a basis for water managers to respond to such concerns; to reassure themselves, stakeholders and their customers as to whether such emerging issues are a concern in their particular circumstances and whether additional actions are needed to deal with them.

Standards and guidelines do not just relate to numerical values for checking the treated water but also include treatment-based standards or controls that provide a means of ensuring that a range of biological or chemical contaminants are adequately reduced or removed. The development of the water safety plan concept for drinking water can be equally applied to wastewater recycling. This process provides a more comprehensive mechanism for ensuring that the processes are in place that will result in standards and guidelines being achieved. It will also demonstrate that the treatment processes are not only working efficiently but continue to do so at all times. In addition, the approach is proving to be of value in considering emerging hazards, without the need for increasing lists of numerical standards for the end use. Ultimately, they will also provide a guarantee of quality and safety to the end user.

In developing standards it is important to retain proportionality because the tighter the standard the higher the cost is likely to be. Precautionary standards may be superficially attractive but they may impose a cost that could undermine the viability of the project. It is for this reason, as much as any other, that a sound scientific basis is desirable.

In assessing the need for standards, the final use of the water is an essential consideration. In particular, identification of the receptor and the potential for exposure of the receptor, as indicated above, is a key part of the process. Risk is a combination of the hazard and the level of exposure. If there is no exposure to a contaminant then there is no risk. This will drive many of the standards. For example the irrigation of ornamental plants by trickle irrigation with no access by the public and therefore no exposure to man is a no risk circumstance compared with spray irrigation of a sports recreational area with open access, where there could be considerable exposure to man of pathogens, and some chemical contaminants, and so an identifiable risk.

The greater the potential for exposure, the greater is the need for treatment and other controls.

Although the technology is available to produce very high quality water from sources that would not have been considered suitable in the past, there is a cost to reclamation that generally increases according to the extent of treatment required. The cost of this treatment is in addition to the potential cost of delivering such water to the end user. In addition, the value of reclaimed wastewater is often relatively low and this is also a consideration. It is, therefore, important that the appropriate level of treatment for the anticipated use is applied. It is also important that the treatment can be shown to be both reliable and consistent. There are two approaches to achieve these latter goals, which are complementary:

- To apply management systems backed by operational monitoring, preferably continuous.

- To measure the treated water against accepted standards. The level of treatment applied should, therefore, be appropriate to the end use and appropriate to meet the accepted standards.

An important component of these approaches is to run extensive pilot studies to understand the processes involved, which will also build local experience and the confidence of stakeholders.

Achieving the standards and requirements for particular end uses may require additional stages of treatment, although that treatment may also consist of dilution and storage in rivers, surface water reservoirs or groundwater. Breaking the apparent direct train from wastewater to end use will have benefits in both providing a valuable treatment stage and in helping to achieve a greater degree of acceptance by end users and the community. End users may be the person or industry using the recycled water or the customer of that person or industry.

3.2 The framework

The framework is based on the identification of requirements for specific applications for reclaimed water and establishing treatment processes and application methods that will deliver the required level of quality and safety. There are two levels, an overarching high-level framework and more detailed frameworks for the different layers within the high-level framework. The more detailed frameworks are based around the appropriate uses associated with differing levels of treatment. Such an approach is clear and transparent while allowing the development of criteria that are generically applicable and can be used in the development of specific projects. The approach also allows for third party verification that the treatment and management structures in place will consistently deliver the required level of quality and safety for any particular project and that appropriate systems are in place to prevent untoward incidents based on risk assessment.

The general approach to water safety plans is to identify hazards and to determine the likelihood and risks of the hazards occurring. It identifies the barriers to these hazards and ensures that they are in place. This allows appropriate management tools to be put in place in order to manage the risks, with a means of determining that the system is working properly at all times. The process can be shown to be working properly at all times and is also verifiable by an independent third party. The position with recycled water is slightly different from drinking water and the authority to achieve the desired controls is also different. A simplified approach indicated in Figure 2, below, provides a useful basis for establishing a mechanism for the framework, given further below in Figure 3, to work effectively.

Figure 2. Simplified water safety plan approach

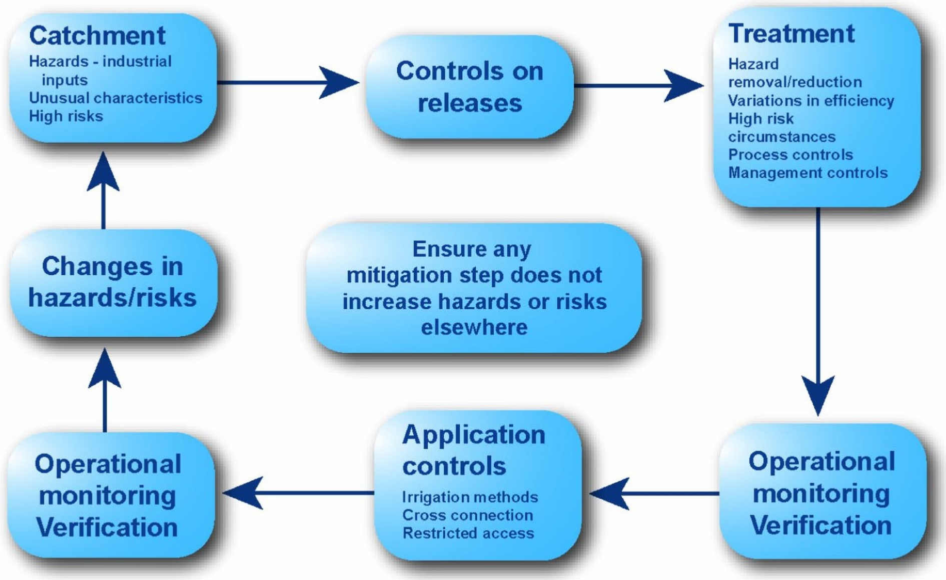


Figure 2 Simplified water safety plan approach.

The key issues for the wastewater catchment relate to the extent of industrial input and the hazards associated with that input along with any particular circumstances, e.g. the concentrations of heavy metals that could affect or restrict use in irrigation. It is also important to determine the particular circumstances that could lead to significant adverse impact on the wastewater treatment processes, such as an accidental (or deliberate) release of a toxic substance that will damage biological treatment or the potential for stormwater to impact the process. The potential to control hazards at this stage may well be limited, but the hazards need to be understood.

The key issues for wastewater treatment are the capacity for and extent of removal or reduction in hazards and the reliability and variability of the process under different circumstances such as seasonal variations in temperature and flow and variations in the quality of discharges to the wastewater collection system. It is also important to identify high-risk circumstances in which the treatment can fail or operate at a sub-optimal level leading to a reduction in the extent/efficiency of removal of hazards. Another example of a high-risk circumstance is when there is a disease outbreak in the community and the load of the pathogen of concern will be increased, resulting in a greater chance of pathogens breaking through in significant numbers. The size of the system and the potential for dilution will also be factors under such circumstances, which is an important consideration for the requirements for reliability in small systems. Frequently the point at which major problems occur is when two different high-risk circumstances overlap such as a very high pathogen load combined with sub-optimal treatment performance. Management and process controls provide the means of ensuring that the system does operate properly and that steps are in place to prevent problems or incidents becoming serious. Operational monitoring is a means of demonstrating, usually on a continuous basis, that the system is working correctly and to give early warning of problems. Should the process fail and the reclaimed water fail to meet the pre-determined criteria, there needs to be a means of either recycling back through treatment, diverting or storing the water in order to prevent the use of water that may be considered not fit for purpose. In wastewater recycling, the delivery may not need to be continuous and processes and procedures, such as storage, that can provide additional treatment, may smooth variations in quality. However, it is also important to ensure that such stages do not lead to new hazards. For example, excessive nutrients may give rise to algal or cyanobacterial blooms in still or in slow moving open storage or delivery systems.

Application controls relate to the manner in which the recycled water is to be used. This may apply to a method of irrigation that removes the risk of pathogens reaching the edible parts of crops, for example the specification of trickle irrigation as opposed to canopy level spray irrigation. It may also apply to the proper management of exclusion zones to keep people or pets out of an irrigated area, or adherence to exclusion periods for stock on pasture. In the case of dual systems for domestic or industrial use it may relate to preventing cross-connection with drinking water lines and inappropriate use.

An additional and vital step in the decision making process is to check and ensure that intervention steps to reduce a risk do not lead to an increase in other hazards or risks. An example of this is the generation of disinfection by-products by the disinfection step but other circumstances can arise through the whole process from the wastewater catchment to the final use of the recycled water.

The final stage in the process is verification that the system is working and delivering a suitable level of safety, not least to maintain the confidence of users, their customers and members of the community. However, this is a continuing process and it is necessary to be aware of changes in the hazards or risks at any stage and to take appropriate steps to ameliorate these risks if they are threats to the process or the public perception of recycling.

Expanded high level framework diagrams showing in more detail the inter-relation between wastewater quality and treatment, potential uses for recycled water, criteria for reuse and the key considerations of hazard identification, risk assessment, monitoring, controls and verification is shown in Figures 4 and 5.

The approach outlined in Figure 4 is in essence an extension of the first right hand box in Figure 3 and expands the questions that will need to be answered from the point of view of an application seeking to use reclaimed water.

Figure 3. High level framework for development of standards for recycling wastewater

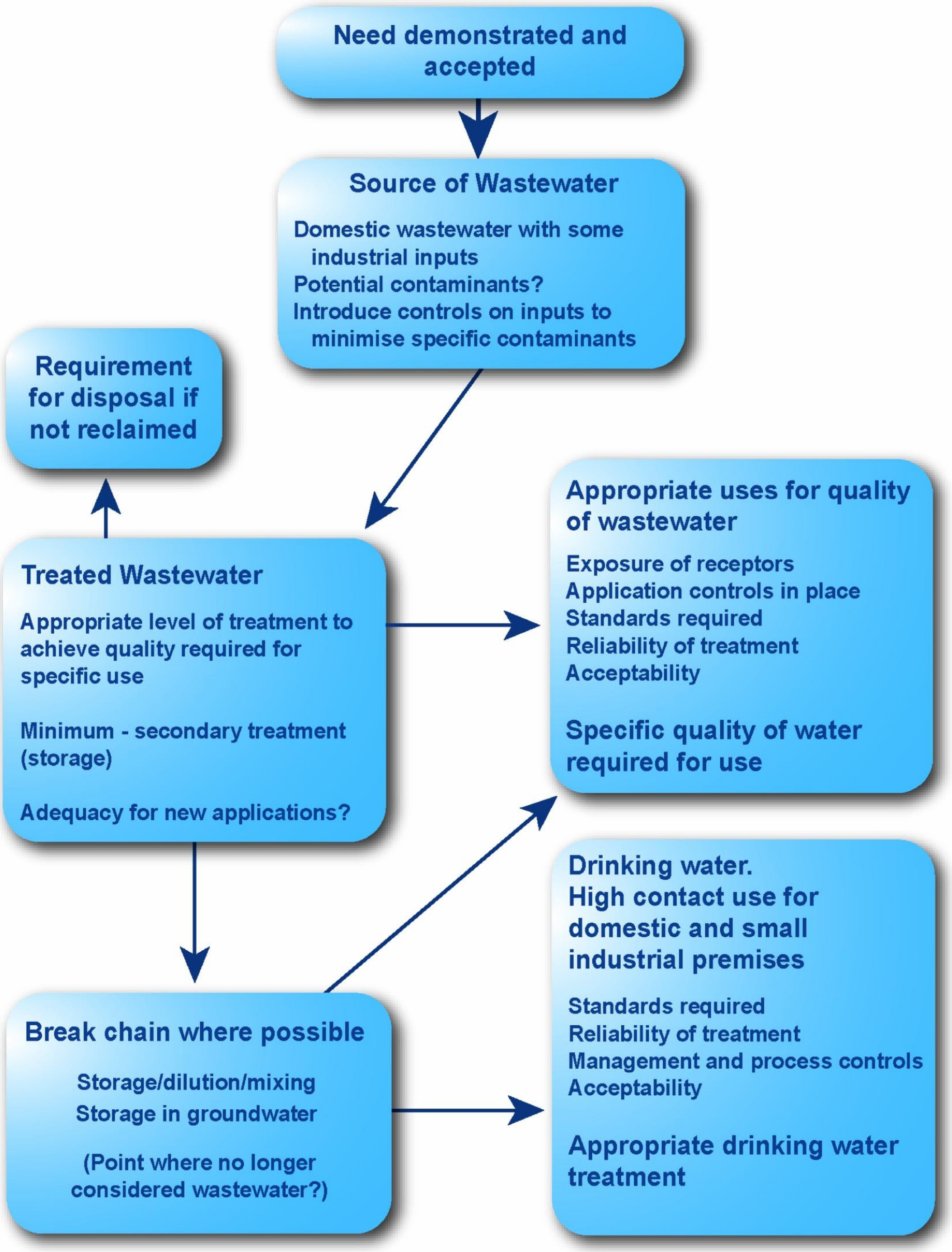


Figure 3 High level framework for development of standards for recycling wastewater.

Figure 4. High-level framework for application seeking a suitable supply of reclaimed water

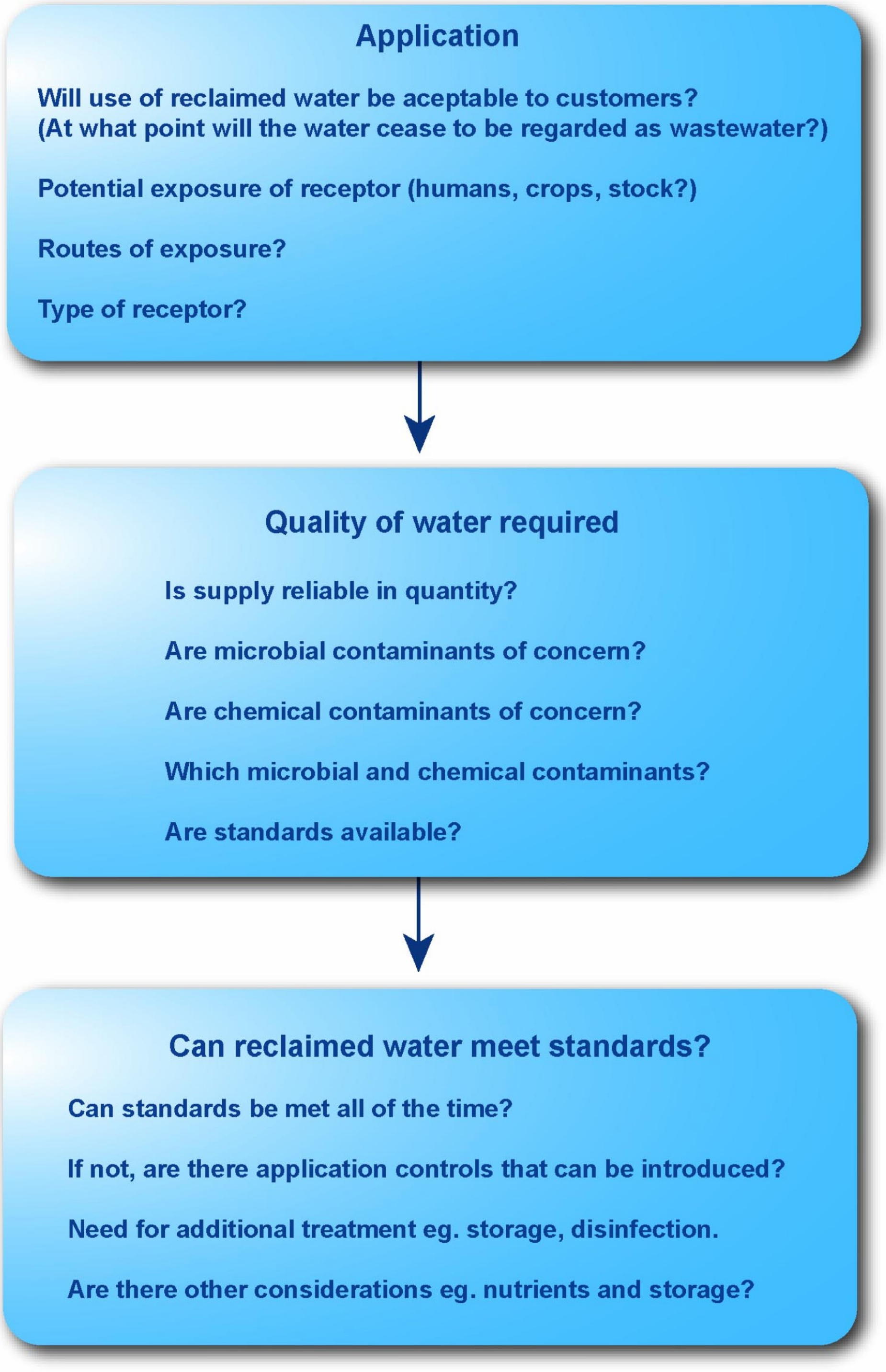


Figure 4 High level framework for application seeking a suitable supply of reclaimed water.

Figure 5. Framework for use of reclaimed water as drinking water supply or as a substitute where drinking water is currently used

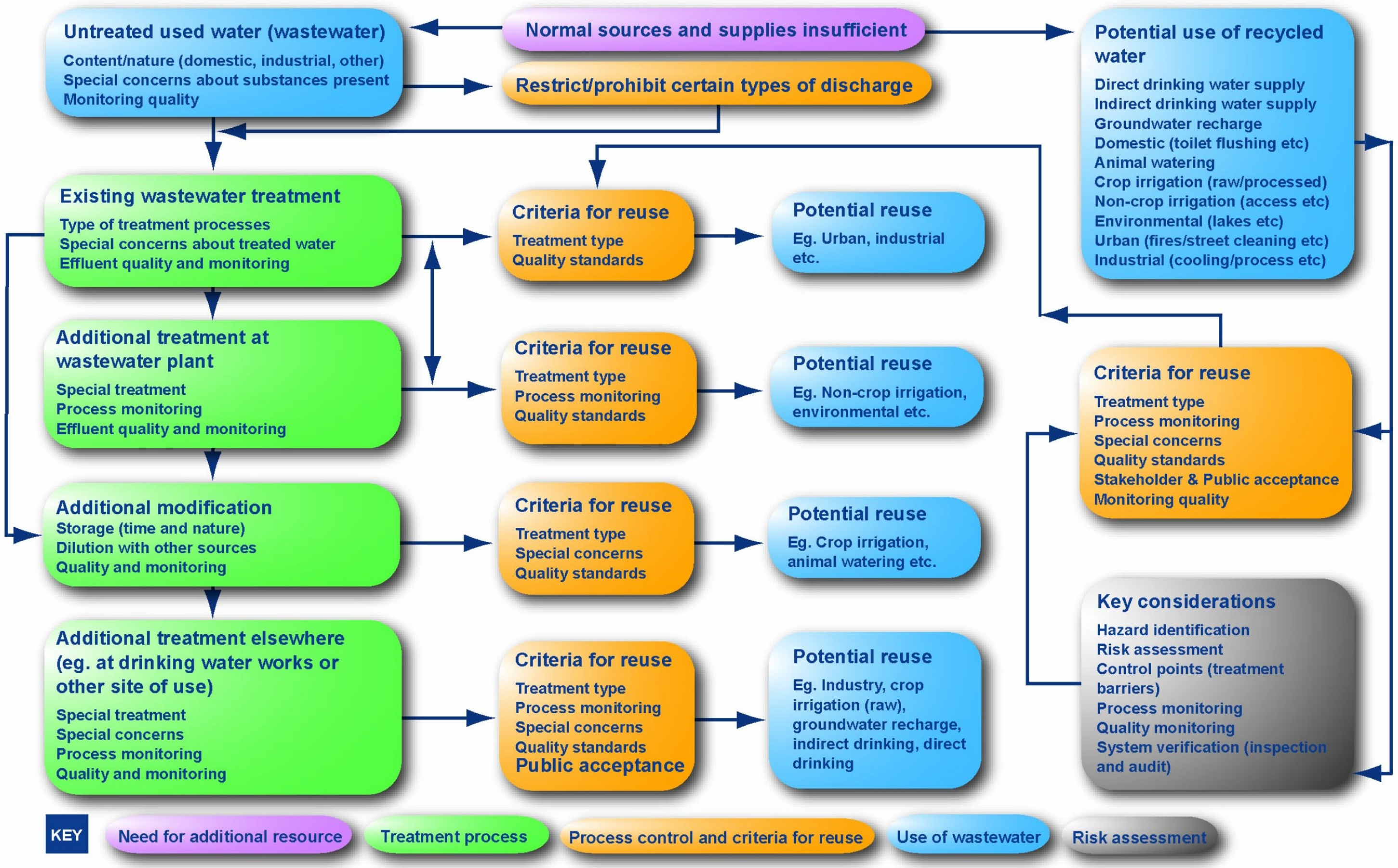


Figure 5 Framework for use of reclaimed water as drinking water supply or as a substitute where drinking water is currently used.

4 Wastewater Treatment

4.1 Conventional wastewater treatment

Municipal wastewater treatment can vary but broadly falls into three categories as indicated in Table 3. In order to achieve a quality of treated wastewater suitable for reclamation in developed countries, it is anticipated that the minimum level of treatment would be secondary, but for many applications the minimum requirement would be for tertiary treatment.

Table 3 Processes commonly used in wastewater treatment (modified from Drinan 2001)

Level of treatment	Steps or processes	Objective and achievability
Primary	Screening Shredding Grit removal Pre-aeration Chemical addition Primary settlement	Removal of solids, suspended solids and BOD. Should achieve 90 –95% removal of settleable solids, 40 – 60% removal of suspended solids and 25 – 35% BOD. Little effect on the removal of bacteria and viruses but some parasite cysts and ova will settle out.
Secondary	Biological treatment Activated sludge Membrane bioreactors Trickle filters Secondary clarification Oxidation ponds.	Effluent with < 20 mg/l BOD should achieve < 20 mg/l suspended solids. Excellent removal of microorganisms particularly cysts and ova of parasites Good removal of microorganisms Small works, restricted use, poor final microbiology without extra storage.
Tertiary	Disinfection (usually specified separately) Chemical coagulation Filtration Nutrient removal N, P Effluent polishing Other treatments including storage.	Kills pathogens. Disinfection method may vary, some methods result in by-products. Improves overall quality of effluent to protect receiving waters, important for recycling applications. May be used for providing a reservoir for users. Can still be a treatment stage.

4.2 Primary and secondary treatment

Conventional wastewater treatment (primary and secondary) consists of screening to remove larger particulate material, grit removal, primary sedimentation, biological treatment and secondary clarification. The treatment is designed to reduce particulate material, dissolved and suspended organic matter and to oxidise ammonia to nitrate. It will also reduce the levels of microorganisms in the wastewater although they will not be completely removed. Primary treatment may be defined as treatment up to and including primary sedimentation. Secondary treatment includes biological treatment and secondary clarification. Raw wastewater will have received no treatment.

The biological treatment may use a fixed film of microorganisms over which the wastewater is allowed to trickle or a suspension of microorganisms grown in a large tank, the activated sludge process. Microorganisms that grow in each process are removed from the treated wastewater during secondary clarification. The current standards required in the United Kingdom for wastewater treated in this way are a suspended solids level of 30 mg/l and a biochemical oxygen demand of 20 mg/l. There are no standards for microbiological parameters.

In countries where there is adequate sunlight, a low cost option for the treatment of wastewater is the use of waste stabilisation ponds (WSPs). Where large quantities of wastewater are to be treated, land availability and its related cost are considerations that must be taken into account. The energy for the treatment process is derived from sunlight and they therefore require a greater land area than conventional treatment processes. The technology consists of a series of ponds, the first of which is an anaerobic pond, the second a facultative pond and the third a maturation pond. The bulk of the organic material is removed in the anaerobic pond. Facultative ponds continue this process and here oxygen is provided by the growth of algae. The maturation pond is designed to reduce the levels of microorganisms, particularly through the action of sunlight.

In some circumstances membrane bioreactors (MBRs), described in section 4.2, are being introduced as a replacement for processes such as activated sludge and WSPs.

Wastewater treatment will vary in its capability under different circumstances; for example, biological treatment will depend on a number of factors including temperature and the presence/absence of substances that inhibit the biological process. The removal of BOD and organic chemical contaminants may, therefore, vary with external factors such as temperature. The extent of removal may also depend on the acclimatisation of the bacteria to a particular substance or group of substances. Steady concentrations of a substance are more likely to lead to efficient removal than a sudden shock loading. Biological treatment will also be vulnerable to substances that can poison the microbial flora responsible for the breakdown of the substances of interest. Accidental, or deliberate, discharge of high concentrations of substances toxic to biological treatment, such as cyanide, will have a major impact on treatment and so the potential for such occurrences needs to be taken into account.

4.3 Tertiary treatment

Where a higher quality of wastewater is required, additional treatments can be added to the above process. These treatments are designed to improve the chemical and microbiological quality of the wastewater still further and are termed tertiary treatments. Some tertiary treatments will remove microorganisms completely. Tertiary treatment is also used to remove nutrients such as nitrate and phosphorus. There are a number of tertiary treatments available and these are discussed below. In some cases, tertiary treatment can be used to replace secondary treatment. Treated wastewater may also be subjected to disinfection to remove additional microorganisms. The more common forms of tertiary treatment and disinfection are discussed below. Table 4 provides information on the efficacy of these processes in removing microorganisms.

4.3.1 Storage of wastewater in lagoons or ponds

Improvements in both chemical and microbiological quality of treated wastewater can be achieved by storage in lagoons and ponds. Such ponds, typically termed wastewater storage and treatment reservoirs (WSTR) are 5 – 15 metres deep and function like the facultative WSPs described above. They are used in Israel, Australia and other countries. A single pond can be used where the wastewater is intended for restricted irrigation or several ponds in series can be used for unrestricted irrigation. The retention time can be such that they can hold 6 – 8 months of treated wastewater to accommodate storage at times when there is no demand. This type of system can be used to remove the ova of intestinal parasites. Additional details on this type of tertiary treatment can be found in Mara, 2003.

4.3.2 Filtration

Drinking water treatment processes can be used as tertiary treatment processes for wastewater. Filtration is a common practice used to remove particulate material prior to disinfection. The process involves passing the wastewater through a bed of sand, anthracite or a combination of the two (dual media filtration). Most processes use downward flow filtration but a continuous backwash process uses upward flow. Cloth and compressed media filters are also available. These processes are reviewed by Castleberry *et al*, (2003). Filtration may be improved by the addition of a suitable polymer or coagulant. Optimisation of hydraulic load and filter operation is necessary to produce a high quality effluent with the maximum removal of particulate material and microorganisms.

4.3.3 Membrane Bioreactors (MBRs)

Membrane bioreactors incorporate membranes that are submerged in the screened sewage or the activated sludge. They provide micro- or ultra-filtration either by applying a vacuum behind the membranes to pull the treated wastewater through the membrane or by using hydrostatic pressure to push the treated wastewater through the membrane. To prevent membrane fouling, compressed air is used to scour continuously the membrane.

Membrane bioreactors can operate at considerably higher levels of microbial solids or mixed liquor suspended solids (MLSS) than those found in a conventional activated sludge plant. Typically, for a conventional plant, the MLSS would be in the range of 1,500 – 5,000 mg/l whereas the MBRs can operate at between 10,000 – 12,000 mg/l. This gives a much better removal of soluble and particulate material and generates considerable space saving by removing the need for secondary clarification, described by many writers as a compact footprint. In addition, the high level of microbial solids should ensure that there is full nitrification of the ammonia in the wastewater. Nutrient stripping can also be achieved in the same plant if this is required.

Membranes can be hollow fibre or flat sheet. The pore size of the membranes is typically 0.4 - 0.04 µm. This pore size ensures that the final effluent turbidity remains at < 0.1 NTU. The BOD is typically less than 2 mg/l and TSS less than 2 mg/l. In addition, most bacteria and all intestinal parasites will be removed. Enteric viruses will be removed partially through adsorption on the flocs in the activated sludge process. Many, however, are small enough to potentially pass through the membrane.

MBRs may have a lower capital cost to install as well as a lower operation and maintenance cost over conventional wastewater treatment. They can also be retro-fitted into existing facilities. The configuration of the plant will vary depending on the degree of nutrient removal required. Aerobic and anoxic basins may be used. Pre- treatment screens of no more than 3 mm are required to remove grit and hair.

Major facilities can be developed within existing wastewater treatment works. Alternatively, satellite treatment systems can be developed within local communities. Such systems can be designed to have minimal environmental impact, operate mostly on a remote status and can be very reliable. MBR can be used for pre-treatment of wastewater before reverse osmosis.

MBRs are widely used in Japan.

4.3.4 Submerged attached growth bioreactor (SAGB)

The process is similar to the MBR but has a small number of differences. Like the MBR it requires no secondary clarification and can operate at a high solids concentration. The general process consists of a deep bed of sand, which is intermittently aerated to obtain a combined removal of organic material and nitrogen. During the process, the wastewater is cycled backwards and forwards through the sand bed. The retention time in this process is short and therefore the footprint is small. Attached to this is a hollow fibre membrane micro-filtration system with a pore size of 0.1 µm. Treated wastewater is pumped through the filter under pressure.

4.3.5 Micro-filtration (MF) and reverse osmosis (RO)

Micro-filtration is designed to remove smaller particulate material prior to using reverse osmosis. The pore size for the micro-filters is nominally 0.1 – 0.2 µm. Micro-filtration prevents fouling of the reverse osmosis membrane and the two processes are usually run in series. Reverse osmosis is the separation of ions and organic molecules from water by forcing the water through a semi-permeable membrane using pressure. Removal of nitrogen can be achieved by the use of a SAGB (Submerged Attached Growth Bioreactor) stage after micro-filtration. Micro-filtration can also be used as a replacement for conventional media filtration following secondary treatment.

Table 4 Typical numbers of microorganisms found in raw wastewater and various treatment processes

Organism	Numbers of organisms per 100 mL* or per Litre							
	Crude	Primary	Secondary	Filtration	MBRs	RO[#]	WSPs	WSTRs
Faecal coliforms*	10^8	10^7	10^3 -10^6	10^2 - 10^3	<1	<1	<10^3	<1
Salmonella	10^4	10^3	10^2	<1	<1	<1	<1	<1
Shigella	10^4	10^3	10^2	<1	<1	<1	<1	<1
Listeria	10^4	10^3	10^2	<1	<1	<1	<1	<1
Campylobacter	10^5	10^4	10^3	10^1	<1	<1	<1	<1
Enteric viruses	5 x 10^4	1 x 10^4	10^3	10^1 - 10^2	5 x10^1	<1	10^1	<1
Helminth ova	8 x 10^3	10^1 - 10^2	<1 – 6 x 10^1	<1	<1	<1	<1[b]	<1
Giardia	10 - 10^5	5 x 10^4	10^2	<10^1 - 10^2[a]	<1	<1	<1 - 10^2	<1
Cryptosporidium	10^2 - 10^4	10^1 – 5 x 10^3	1 -10^2	<10^1 - 10^2[a]	<1	<1	<1 - 10^2	<1

These numbers, particularly the removal figures, assume optimal design and operation of the various treatment processes.
After RO the numbers of pathogens would normally be, in effect, zero assuming membrane integrity.

Sources:
Godfree 2003
Stott, 2003
Smith and Grimason, 2003

[a] Removal is improved by the addition of coagulant or polymer prior to filtration.
[b] Dependant on the retention time in each wastewater stabilisation pond system.

4.4 Disinfection

A number of disinfection processes are available to reduce the microbial load to acceptable levels and in some cases provide a disinfectant residual for the distributed reclaimed water. The following is an overview of the types of disinfection that can be considered.

4.4.1 Chlorine

Chlorine is an inexpensive and effective disinfectant. It is available as a gas but because of the public health implications of accidental release, sodium hypochlorite is more generally used. The efficacy of chlorine depends on a number of factors including water temperature, pH, adequate mixing time, contact time and the presence of interfering substances. The optimum pH for disinfection is between 6 and 8. The concentration that is used varies but depends, in part, on the level of disinfection that must be met. In addition, the required dosage will also depend on the turbidity and TOC of the water to be disinfected and is usually between 2 –10 mg/l but may even be as high as 20 mg/l. There should always be a residual chlorine value at the end of the disinfection process. In California, for example, tertiary treated reclaimed water for uses where there may be public contact, such as playfield irrigation, requires a chlorine residual of at least 5 mg/l after a minimum model contact time of 90 minutes. This residual can be maintained in the distribution system. Excess chlorine can be readily neutralised by the use of sulphur dioxide or other chemicals. A range of disinfection by-products such as trihalomethanes (THMs) may be generated from organic matter and this may need to be considered. In addition there may be formation of N-nitrosodimethylamine (NDMA) from ammonia.

Interfering substances include organic material that can create a chlorine demand, particulate material that can provide protection for microorganisms and ammonia, which combines with chlorine to form chloramine, a much less effective disinfectant.

4.4.2 Chlorine dioxide

Chlorine dioxide is available as a gas or liquid. Unlike chlorine, chlorine dioxide remains a true gas even when dissolved in water. It can be prepared through the reaction of sodium chlorite with chlorine or sodium hypochlorite with hydrochloric acid, and can be generated on site. It is an effective biocide (a 99.9999% kill of *E. coli* is achieved in a one minute), even when the pH is above 8.0. It does not combine with ammonia to form chloramines and does not produce THMs from organic material. In this respect it has a much lower demand than chlorine. It has proven effective at destroying biofilms and is used as a sanitising agent in a wide range of applications from the food industry and hospitals to drinking water disinfection. Chlorine dioxide produces fewer by-products but breaks down to chlorite and chlorate and some countries have standards for chlorite, particularly in drinking water supplies. WHO has also proposed guideline values for chlorite and chlorate in drinking water (WHO 2004).

4.4.3 Ozone

Ozone is a powerful oxidising agent. It is more efficient than free chlorine for inactivating viruses, bacterial spores and cysts. It is unstable and rapidly decomposes in water. It therefore has to be generated on-site where it will be used and will not provide a residual for the distribution system. It will remove colour and contribute oxygen. Ozone is however more expensive to use. The main by-product of concern is bromate, formed by the oxidation of bromide, but a range of other brominated by-products may also be formed, although usually at lower concentrations than with chlorine.

4.4.4 Ultra-violet (UV) light

UV light irradiation is a physical disinfection process and the optimum wavelength for disinfection is 254 nm. It is absorbed by nucleic acids, changing their structure and therefore preventing replication. Its effectiveness is dependent on the light penetrating the water and the turbidity of wastewater should be less than 2 NTU. It is cheaper than ozone to use but does not provide a disinfectant residual. Unlike chlorine, UV light is effective against *Cryptosporidium*. The normal intensity of radiation supplied by a system would be around 100 mJ/cm^2.

A variety of different systems are available including low-pressure low intensity lamps, low-pressure high intensity lamps and medium pressure lamps. Medium pressure lamps produce light of varying wavelengths and as a consequence are less effective.

The National Water Research Institute (2003) in collaboration with the State of California and AwwaRF has developed a guideline for the design, evaluation and approval of UV disinfection facilities for water reuse. The guideline recommends a UV dose of 100 mJ/cm^2 following granular media filtration, 80 mJ/cm^2 following microfiltration or ultrafiltration and 50 mJ/cm^2 following RO treatment. The guideline uses a standard method, based on bioassay, to assure that the facility is delivering the recommended dose.

The US EPA has devised technology fact sheets for the use of chlorine, ozone and UV light that provide more information. There is also a publication from the Water Environment Research Foundation (1995) comparing the use of chlorine and UV light for the disinfection of wastewater.

4.4.5 Ultra-sound

Ultrasound operating at low frequencies is an effective way of breaking up aggregated material. Increasing the frequency also causes cell destruction. The use of high frequencies to disinfect wastewater is currently impractical. However the use of frequencies at around 20 kHz can improve the effectiveness of disinfectants such as UV and chlorine by breaking up particulate material, reducing particle size and thereby improving the exposure of microorganisms to the disinfectant. Ultrasound and a disinfectant can be used in combination to achieve the best results.

4.4.6 Advanced oxidation

The purpose of all advanced oxidation technologies is to produce hydroxyl radicals. These are highly reactive oxidising agents that react with and destroy most organic pollutants in water. In the basic process, UV light or ozone is used to dissociate hydrogen peroxide injected into the wastewater to produce hydroxyl radicals. The resultant hydroxyl ions breakdown a range of organic molecules including hormones and other substances possessing oestrogenic activity and wastes such as those from dyeing. In addition, the hydroxyl ion is an efficient biocide. The process uses less ozone and can therefore be cost effective and can also reduce the production of bromate.

4.5 Storage of treated wastewater

It is important to determine the characteristics of the treated wastewater and to establish the variation in the final quality under different circumstances. Where storage of treated wastewater is sufficient and there is adequate mixing, this may be used to smooth out normal variations in quality. Storage may be part of the user's process since many users will not require water on a continuous basis and the costs of pumping and direct piping may be excessive.

4.6 Pilot studies

In developing a new wastewater treatment plant, or if considering additional treatments to be added to an existing plant, the selection of treatment processes will depend on a number of factors. These will include the intended use of the reclaimed water, the quality of reclaimed water that is required, the type and process of the use and financial considerations including the amount of land available for the treatment process. A risk assessment of the various uses will help to define the microbial and chemical criteria that are required and to determine whether existing standards are appropriate. It is then valuable to undertake pilot studies to determine the variability and quality of the feed wastewater (loading, temperature etc), whether the treatment options considered will actually provide a suitable treated water quality on a consistent basis and to optimise the process. For example, the quality and quantity of the effluent may vary diurnally and this must be taken into consideration.

4.7 Monitoring

Monitoring is required for a number of purposes. One is to characterise existing systems and another is to demonstrate that the system is operating at its optimum at all times. However, monitoring is also required to verify that the treatment processes are delivering the appropriate level of quality required. Monitoring in wastewater treatment works that do not provide reclaimed water is still required in order to show that they can meet the conditions of discharge to the environment, usually to surface waters.

4.7.1 Operational monitoring

The basis of operational monitoring is to establish a means of demonstrating that the treatment processes are operating within the boundaries necessary for optimum removal and breakdown of contaminants. In addition, it provides a warning when the treatment process, or parts of the treatment process, are in danger of moving out of specification or the process is under threat of catastrophic failure. It is, therefore, valuable to determine an operational parameter or group of operational parameters that can be measured easily, and preferably continuously, to be used as process control parameters and also to verify that the process is operating within the limits that will deliver the required final quality. These measurements and the records of actions taken to ensure that the process remains within operational limits, provide an important basis for verification (Section 4.6.3). A number of possibilities are available, including pH value, turbidity, suspended solids, ammonia and, for tertiary treatment, additional parameters such as phosphate, nitrate or chlorine residual as appropriate. Where membranes are part of the treatment process measures of membrane integrity will be important. Where storage is used for balancing the reclaimed water quality it may be possible to operate with a wider range of specifications but the requirements will vary according to specific circumstances.

4.7.2 Assessment of existing systems

When assessing the quality and capability of existing systems it is appropriate to carry out a data gathering exercise as indicated in the water safety plan approach and this can usefully be backed with analytical data on both microbial and chemical parameters that will help to characterise the 'normal' quality of influent and effluent and the quality under stressed operating conditions. The selection of parameters will depend on the specific circumstances but it might be helpful to examine the variation in quality over 24 hours for a seven day period. While typical microbial indicators are useful in this context, it would also be of value to consider more specific microbial indicators and pathogens.

4.7.3 Verification

Monitoring to verify that the system is delivering the quality expected and to support operational monitoring is usually a key part of the process, particularly in satisfying regulators and in maintaining public confidence. As well as the normal parameters such as BOD, SS etc, it is valuable to consider more specific parameters that may be of particular concern. In the case of microbial contaminants consideration should be given to monitoring a wider range of indicators, such as bacteriophage for viruses and, where appropriate, pathogens such as *Cryptosporidium*. In this event it may also be more appropriate to carry out monitoring on an irregular and more intensive manner. Such an approach in which sampling might be less frequent but more intensive would potentially provide more information from the data. For example, instead of sampling daily for a particular parameter, it would be possible to sample monthly but to carry out 24 hour sampling at 2 hourly intervals.

4.7.4 Final product monitoring

Where there is a potential for exposure of receptors through the final product, whether this be a crop or a recreational water or playing field, there may be a need for final product monitoring at intervals. This will frequently be carried out by the user of the reclaimed water but there may need to be such monitoring by the supplier of the water where users do not have adequate resources. Such monitoring will primarily relate to microbial contamination of crops to be eaten raw but there may be a requirement to examine some chemical parameters if they are present at significant concentrations in the reclaimed water, particularly those chemicals that impact on stock through fodder crops. However, chemical monitoring would only be necessary intermittently.

4.7.5 Chemical parameters

In addition to the normal range of chemical and physicochemical parameters that are used to assess treated wastewater there will be a number of parameters that may require further consideration, depending on the anticipated uses of the water. These would include salinity, hardness and a number of metals and metalloids as discussed below, depending on the results of the catchment risk assessment. In addition consideration may be needed for some of the persistent organic pollutants, which will rarely, if ever, be present in quantities measurable by routine analytical methods but which are of high public concern. Parameters such as these would only require very infrequent measurement. In addition, it may be appropriate to consider occasional monitoring for the 'newer' contaminants of concern such as oestrogens and some pharmaceuticals, depending on the end use. The individual chemical parameters and the basis for concern are discussed in more detail below in Section 5.

4.7.6 Microbial parameters

The standard microbiological parameters conventionally used for monitoring are total coliforms, faecal coliforms or *Escherichia coli*. Total coliforms as well as being faecal in origin, are common environmental organisms found in water, soil and on vegetation in the absence of faecal contamination. Faecal coliforms are those within the group that are able to grow at elevated temperatures. Unfortunately, not all faecal coliforms are faecal in origin. The true measure of faecal contamination is derived from assessing the concentration of *E. coli*. This subject has been reviewed by Gleeson and Gray (1997) and Kator and Rhodes, (2003). Microbial parameters are also discussed along with the basis for standards in section 5.

Under suitable circumstances, coliforms can grow in water, including drinking water and recycled water in distribution systems. In addition, coliforms may be more difficult to remove from wastewater by treatment and disinfection. Under these circumstances, total coliform monitoring may be viewed as a more severe challenge to wastewater treatment and disinfection processes, although there are different preferences in different countries. Whatever the treatment and disinfection process used to process wastewater, wherever there is public contact, or a reasonable risk of public contact, the final product should have none of the target organisms detectable in a volume of 100 ml by an approved method. The absence of the above microbial indicators, whilst demonstrating the efficacy of the treatment and disinfection process, is not an absolute guarantee that all pathogenic microorganisms have been removed. Alternative microbial indicators may need to be considered in addition to those listed above.

4.7.7 Alternative microbial indicators

A number of other microbial indicators are available to denote the presence of faecal contamination. Some of these are more resistant to treatment and disinfection processes and others can be used as indicators for the presence of pathogenic viruses. Some of the suggested alternatives are discussed briefly below.

- Enterococci

  Enterococci are normally present in slightly lower numbers in wastewater than total and faecal coliforms. They are more resistant to environmental stress and to chlorination. They may therefore be used as an additional indicator to demonstrate the efficacy of treatment and disinfection processes, both in pilot plant studies and full-scale monitoring.

- Sulphite reducing clostridia and *Clostridium perfringens*

  This group of organisms produces spores that are very resistant and can survive for long periods in the environment. They can survive disinfection with chlorine and have therefore been suggested as indicators for the presence of *Cryptosporidium* and *Giardia* in treated drinking water although the literature is divided as to their value. They may prove useful in assessing the efficacy of disinfection techniques other than chlorine.

- Bacteriophages

  Bacteriophages (phage) are viruses that infect and multiply in bacteria. Coliphages (bacteriophages specific for *E. coli*) are found in wastewater and their presence has been correlated with the presence of enteric viruses (Havelaar *et al*., 1993). They have been proposed as indicators of enteric viruses. Two groups of phage have been suggested, the somatic coliphages which attach to the bacterial cell wall and the F-specific coliphages which attach to the F or sex pili of *E. coli*. They are removed in sewage treatment processes in a similar manner to enteric viruses. Relatively simple methods are available for their detection.

- Other indicators

Amongst the other organisms that have been suggested as indicators are *Pseudomonas aeruginosa, Staphylococcus aureus, Rhodococcus* spp. and *Candida albicans*.

Effluent quality can also be categorised both in microbial and chemical terms which can then be used to define the applications for which they are suitable. Alternatively the application may be used to drive the category for which the recycled water can be used. Examples of these include the categories derived for the guidelines developed for some states in the United States and in Australia. The reason for the categories must be transparent to enable novel applications of water reuse to be fitted into the correct category.

5 Detailed Framework for Irrigation Using Reclaimed Wastewater

5.1 Introduction

Irrigation represents the largest potential replacement of fresh or treated drinking water. It has applications in both the agricultural and the urban environment. There appears to be widespread acceptance of such applications and standards or guidelines have been promulgated by a number of countries and by WHO. There are broad divisions in the quality of the reclaimed water and these relate to exposure of the appropriate receptor, plant, livestock or humans. While the greatest concern has been microbial contaminants, in all cases aesthetic considerations are also central in achieving acceptability.

A framework for using reclaimed water for irrigation purposes is presented in Figure 6. This describes the applications that are suitable for recycled water based on the degree of treatment that is applied and the process controls that are required. It is not possible to specify chemical and microbiological standards that are valid for the different applications, but guide values are given in Table 5.

5.2 Irrigation in agriculture

The use of reclaimed water for irrigation in agriculture is well established and has been used for many years with considerable success. There appears to be the potential for a significant increase in this application for treated wastewater since agriculture is the largest consumer of fresh water and the demand seems to be growing.

In planning for agricultural reuse, there are a number of requirements for controls and guidelines that need to be taken into account. These are:

- Type of crop, low contact/high contact: turf farm, ornamental nursery, biofuel or other industrial, forestry, seed crops, ornamental for cutting, fodder crop (can include pasture), food crop processed, food crop unprocessed.

- Means of irrigation: channel, trickle, spray (various levels of contact with the crop).

- Nutrient content: nutrients available for uptake, nutrients available for leaching (especially nitrate and phosphate).

- Toxicity to plants: salination (significant site influence), toxic substances such as boron (depends on crop tolerance).

- Uptake by plants: inorganic substances, organic substances (potential for accumulation).

- Accumulation in soil: metals.

- Deposition on plant surfaces: salts (phytotoxic, toxic to stock), organics (perception), pathogens.

- Run off and leaching: groundwater quality, effects on surface water and wildlife (largely site specific).

Two primary approaches are available, one is to base requirements on the level of treatment applied and the other is to base requirements on standards or guidelines. In practice a combination of the two is often the most practical and criteria in various countries are usually based on this approach, although some rely primarily on setting numerical standards. This is also the basis for the barrier approach proposed in Israel (Oron personal communication) that also includes the means of application and the treatment of the crop as barriers against exposure of humans to pathogens and minerals. In this approach various treatment options count as a series of barriers and some such as disinfection with a specified contact time of 30 minutes and a total residual chlorine concentration of 1 mg/l or equivalent for other disinfectants or combinations of disinfectants are required for use on vegetables that are eaten raw. For fruits, drip or trickle irrigation is used and a 50 cm height above ground between the drip feed and the crop is considered as two barriers, similarly sub-surface drip-irrigation is counted as two barriers since the reclaimed water does not reach the soil surface. However, puddles forming on the surface of the soil would disqualify the subsurface drip-irrigation technique as a barrier. In Israel there is a requirement for retention of the reclaimed water for at least 60 days or 30 days in a closed reservoir.

The greatest concerns relate to practical considerations that result from pH, suspended solids (including algae if storage ponds/lakes are used), biologically available dissolved organic matter, pathogens and toxicity to plants, including salination. Organic substances are of much lower concern unless there is the potential for pesticides to be present, particularly herbicides to which some crops can be extremely sensitive. Organic substances, in particular, can be significantly removed in wastewater treatment, for example those that are biodegradable and those that are hydrophobic. In addition some will be controlled through the method of application. The extent of treatment will also help to optimise the removal in treatment. This will be true of some metals that will bind significantly to solids. Pathogens, however, remain the greatest concern for human health.

The key parameters addressed by existing standards are discussed below with an indication of their scientific basis and are summarised in Tables 5 and 6.

5.2.1 Microbial contaminants and standards for microbial contaminants

As indicated above, a substantial number of microorganisms can be present in wastewater and, although significant removal can take place in treatment, many can also be present in treated wastewater streams at concentrations that depend on the level of treatment and the application of disinfection. The main concern lies with pathogens that could cause human or animal disease. In general, the practice is not to monitor treated wastewater for pathogens but to use *E. coli*, thermotolerant coliforms or total coliforms as an indicator of faecal contamination. Total coliforms may be misleading in these circumstances, depending on the point of sampling, because non-faecal coliforms that are not pathogens are likely to be present and can easily grow in such waters. Thermotolerant coliforms can be used, but because not all thermotolerant coliforms are *E. coli* or are of faecal origin, they are not as specific in demonstrating the efficacy of treatment and disinfection processes. In tropical or sub-tropical areas, these may grow and give misleading results. For the future, in establishing a new project it may be appropriate to consider some measurements of indicator/pathogen removal and correlating this with a suitable operational parameter that can be measured, preferably continuously, to demonstrate that the process is working efficiently and, equally important, when the process is not working efficiently.

The microbiological standard applied to drinking water is based on the absence of faecal indicator bacteria, as discussed above. Care is therefore required in applying this standard to treated wastewater, which will always by its nature be faecally contaminated and will contain human pathogens. It is recognised that coliforms, as an environmental organism, can grow in water and are therefore not always an accurate indicator of the presence of faecal contamination. *Escherichia coli* is therefore considered as the best indicator of direct faecal contamination. It is also seen as a direct measure of the efficiency of treatment and disinfection. However, its absence in drinking water, for example, does not prove the absence of pathogens and there have been outbreaks of waterborne disease when *E. coli* has been absent. Efficient treatment in respect of the removal of particulate material together with adequate disinfection has been shown over many years to correlate the absence of *E. coli* with the absence of pathogens. There is no convincing epidemiological evidence to suggest otherwise in developed countries. In considering both standards and monitoring for reclaimed water, it is important to give proper consideration to where monitoring will be carried out. Monitoring immediately after the final point of treatment will give the best information on the microbial quality of the product. Monitoring subsequently must take into account the potential for regrowth, which will often be substantial, and the potential for post treatment contamination with both indicators and pathogens. For example, open conduits or storage will be vulnerable to contamination by pathogens from animals and indicator organisms from animals and birds. Where control of microbial contamination, particularly regrowth, in the product water during storage and distribution is important, such as in urban dual systems for the use of reclaimed water, some monitoring through the system will probably be appropriate.

The microbiological standards applied to wastewater for recycling vary depending on the country and the application. The first standards to be used in wastewater were by the State of California in 1918. The first comprehensive criteria were adopted in California in 1968. The requirement was a total coliforms limit of 2.2 per 100 ml (in conjunction with treatment requirements that included biological oxidation, chemical coagulation, clarification, filtration and disinfection). The standard was adopted to assure the absence of all pathogens including viruses. The latter were considered difficult and expensive to monitor. Whilst it was recognised that the coliforms group was less resistant to disinfection than some pathogens, the test was easy to perform and 2.2 per 100 ml is a reportable value using a most probable number (MPN) test (Crook, 2002). Higher levels of coliforms were rejected as this was seen as an unacceptable risk in unrestricted uses. Protozoan parasites such as *Cryptosporidium* and *Giardia* were not well known and helminths were not considered to be a public health problem in America. The coliform standard has remained in California and, based on the results of the Pomona Virus Study (1977), direct filtration is now allowed in lieu of the extensive treatment train that required chemical coagulation and clarification. This standard was shown to be satisfactory for the reduction of five logs of poliovirus. New technologies are now required to demonstrate achievement of this reduction before they can be accepted for wastewater treatment and reuse.

Other States in the USA and other countries have adopted faecal coliforms and *E. coli* as their indicator. Levels are based on the final use of the reclaimed water and can vary from none detected per 100 ml, to give assurance that pathogens have been removed to between 5,000 - 10,000/100 ml based on restricted access and the nature of use, as is the specification in Cyprus. These standards are largely supported by epidemiological data such as that reviewed by Blumenthal and Peasey, (2000) and Blumenthal *et al*., (2000) for WHO. The recognition of *Cryptosporidium* and *Giardia* in wastewater and their greater resistance to chlorine has led to some monitoring for these parasites, and also viruses, in waters used for non-restricted recreational impoundments where clarification has not been used.

WHO (1989) has published guidelines for water for irrigation of crops in developing countries where these are eaten raw and for sports fields and public parks. The guideline of 1000 faecal coliforms/100 ml reflects the quality of water that can be achieved with oxidation pond technology without disinfection. There is recognition that helminths are a bigger problem in developing countries and this has led to the guideline value of less than one egg per litre of water. The guideline of 200/100 ml for faecal coliforms is required where there might be greater public access e.g. hotel lawns. Epidemiology provides evidence that these guidelines are satisfactory to protect public health.

Where the public are likely to come into contact with recycled water, to use it or to consume it indirectly through unprocessed food, it is essential that the standard or target that is adopted can assure that contact will not result in health problems. If therefore, there is evidence of residual faecal contamination through the presence of *E. coli*, the inference cannot be made that the water is free from pathogens. Under these circumstances, recycled water should contain no detectable *E. coli* per 100 ml, using an approved method, together with evidence of effective treatment for removal of non-bacterial pathogens. Where recycled water is to be used for purposes that do not include human contact, the level of treatment and the standard can be relaxed. How far the relaxation goes is for debate, because the standards are not based on direct scientific evidence of an effect on human health. The key consideration is the risk of exposure, so that where exposure of the public is probable it is preferable that the standard adopted should be the most stringent and arguably should be no detectable *E. coli* per 100 ml, using an approved method. Clearly this is a conservative approach and could be modified by using a quantitative risk assessment for the various pathogens but this in turn means that a better understanding of pathogen survival and exposure is needed. There is scope for developing methods for monitoring specific pathogens in such circumstances rather than relying on just *E. coli*.

There is a variety of commercially available chromogenic and fluorogenic media that can be used for the detection of *E. coli*. They can also be prepared easily in a microbiology laboratory. These provide a simple presence/absence test by the addition of a test sample to the medium followed by incubation. An obvious colour change indicates the presence of *E. coli*. The system will work equally well by the inoculation of the media with smaller volumes of the test sample.

The organisms for which monitoring for specific pathogens in treated wastewater may be required are intestinal parasites such as *Cryptosporidium* and the eggs of parasitic worms (helminths). These are pathogens that may resist treatment and be present in numbers that would be of concern for health, especially when treated wastewater is used for irrigation in circumstances where there can be human contact. Removal is primarily by filtration and sedimentation. Complete removal can be assured using MBRs.

Guidelines and standards for the eggs of parasitic worms are based primarily on epidemiological evidence of illness, or rather absence of illness, in populations exposed to wastewater contaminated with these organisms. Where treatment regimes can demonstrate complete removal it is suggested that monitoring is unnecessary.

A number of other indicators are used in water microbiology. These include enterococci, *Clostridium perfringens* and bacteriophages. The enterococci and clostridia are recognised as being more robust in relation to survival during water treatment and survival in the environment. They may have a role to play in assessing the efficacy of some treatment regimes. The somatic and F-specific coliphages have been used as surrogates for the viruses, being similar in size and survival to some groups of pathogenic viruses. They have been used (in addition to poliovirus) to assess the efficacy of wastewater treatment and disinfection processes. The requirement in the California regulations for some reclaimed water applications is the reduction of viruses by five logs.

The difficulty is that none of these indicators have been found suitable for the intestinal parasites. For this reason, some guidelines recommend testing for *Cryptosporidium, Giardia* and the helminths. Standards have been defined for the latter, usually less than one helminth ova per litre of water. The most appropriate approach to controlling intestinal parasites would be to select treatment technologies that can be demonstrated to remove parasite ova and to correlate the level of removal with treatment process controls that can be monitored continuously, for example turbidity. This would only be necessary where direct contact with the public, workers or animals might occur.

5.2.2 Chemical and physical parameters and standards for chemical and physical parameters

The aesthetic quality of the water is important. It should generally be free from visible turbidity and colour. However, colour may be added post-treatment to recycled water in a dual system to help differentiate the water from drinking water. It should always be free from unpleasant odour. Low turbidity is important where UV light is used as a disinfectant. The efficacy of UV light is directly dependent on the penetration of light and where there is significant turbidity, penetration may be less then one centimetre. Ideally, for UV light to be effective, a consistent turbidity of less than 2 NTU should be used. Under these conditions a UV light dose of 50 – 100 mw-s/cm^2 is effective in meeting US EPA guidelines (US EPA 1992, National Water Research Institute 2003).

Where chlorination is practised and treated wastewater is discharged to water bodies it may be necessary to protect aquatic life, which is highly sensitive to free and combined chlorine by a final free chlorine removal stage. A chlorine residual may be desirable to prevent re-growth of bacteria during distribution to users, particularly where a dual distribution system is used. Such growths may cause unsightly turbidity, create biofilms and induce corrosion in distribution systems. However, this requirement would need to be judged on a case by case basis at the local level.

- pH

The acidity of treated wastewater is important in two respects, the potential to corrode irrigation equipment and the impact on the solubility and availability of metals and minerals. There is some variation in the recommended pH ranges for treated wastewater for irrigation to deal with these issues, but they are quite small and most range from 6.0 to 8.5, although some authorities accept pH values as low as 5.0. As a general rule a pH range of 6.0 to 8.5 is within the normal range of treated municipal wastewaters.

- BOD

Biochemical oxygen demand (BOD) reflects the amount of organic matter available for microbial growth. High levels of BOD will give rise to excessive growth of microorganisms and the development of excessive slime growth. This can cause problems with reducing the efficiency of irrigation equipment and the clogging of the irrigated soils. Recommended levels for BOD vary but values between 10 and 30 mg/l are widely recommended as suitable, depending on the use, based on practical experience and experience of clogging of soils. However, many authorities do not specify values for BOD. The use of secondary treatment as a minimum should result in a BOD of no more than 20 mg/l. Tertiary treatment can reduce the BOD further.

- Suspended solids

Suspended solids and turbidity reflect the potential for light exclusion and will impact on disinfection where this is practised in tertiary treatment of wastewater. This is particularly important where UV light is the disinfectant of choice. Suspended solids are unsightly and can also result in deposition of sediment in irrigation systems. The use of secondary treatment as a minimum should result in suspended solids of no more than 20 mg/l.

Standards and guidelines, either in place or proposed, range from 5 to 30 mg/l of suspended solids or a turbidity of less than 10 NTU. For effective disinfection of treated wastewater it would be appropriate to have a much lower turbidity, less than 2 NTU. The basis of the figure of 10 NTU appears to be practical experience with problems arising from suspended solids rather than any specific scientifically derived values, since there will be significant variation in impact from different types of irrigation system. The lower figure associated with disinfection relates to laboratory and field data on turbidity levels needed to assure effective disinfection with chlorine and on the penetration of UV light. Where storage is practised increased turbidity may result from excessive growth of algae or cyanobacteria. These too can cause significant problems and cyanobacteria, which can produce potent toxins, will also be of concern where animals have access to the water.

- Salinity

Dissolved solids in the form of salts, particularly sodium chloride, can give rise to salination of soils with subsequent phytotoxicity. However, there is significant variation in the salt tolerance of different crops, for example some grasses are highly or moderately tolerant, flax and lettuce are moderately sensitive and much fruit is sensitive. In addition to damage to soils and crops through uptake, saline water supplied for spray irrigation can also cause damage to the leaves. The potential for salination is dependent on a range of factors, including soil type and the rate of leaching of sodium and chloride ions from the soil. This leaching may also give rise to salination of groundwater under extreme circumstances but this is unlikely to be encountered with municipal wastewater. There are well established methods for assessing the risk of salination and these can be found in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) and the USEPA Guidelines for Water Reuse (USEPA 2004) along with information on the salt tolerance of different crops. Salinity is one of the most important factors affecting the use of reclaimed water for irrigation in many countries. However, to prevent the impact of high salt loading on plants and soil the value considered to be protective of all circumstances is a total dissolved solids (TDS) value of 500 mg/l or a conductivity of less than 800 μS/cm.

- Nutrients

Nutrients in the form of nitrates and phosphates are essential for plant growth and their presence in treated wastewater can confer a positive benefit. However, excess nutrients are available for leaching and can give rise to significant problems for groundwater and surface water. Nitrate is primarily of concern for groundwater that may be used as a drinking water source and a number of regions now have specific regulations relating to controls on the application of nitrate in agriculture. Where reclaimed water is used for irrigation the nitrate content must be borne in mind in calculating total nitrate loading so the nitrate level is an essential piece of information for agricultural users. Phosphate is the limiting nutrient for the growth of algae and cyanobacteria in slow flowing or stagnant surface waters but both nitrate and phosphate contribute to enhanced eutrophication. This can and does result in significant problems with cyanobacteria in many parts of the world. Many species of cyanobacteria produce toxins that have been implicated in human health effects and in the death of livestock and pets drinking from water containing large blooms of these organisms. Where reclaimed water is stored in lakes and ponds the potential for cyanobacterial growth is an important consideration. Nitrate and phosphate removal may become an important requirement for a number of applications for reclaimed water.

The value proposed by the Australian and New Zealand Authorities (Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000) is 5 mg/l as nitrogen or 25 mg/l as nitrate. This document also provides a means of calculating short-term trigger values for nitrogen since external nitrogen sources may be an issue under circumstances where reclaimed water is used to supplement natural waters or where reclaimed water is used on pasture that receives significant nitrogen input from animal manure. The value proposed for phosphorus is 0.05 mg/l as phosphorus or 0.15 mg/l as phosphate, which is primarily to prevent excessive growth of algae/cyanobacteria and subsequent clogging of irrigation equipment.

- Metals and metalloids

A number of metals and metalloids may be present in wastewater, although some may be controlled through restricting discharges. Some are more likely than others to be present at concentrations that are significant and these are summarised in Table 6. One of the difficulties encountered with inorganic substances is the variation in uptake and tolerance by different plants. The standards/guidelines discussed below relate to the protection of primarily the most sensitive plants, where this is not the case the sensitive species are indicated. More detailed information on crop sensitivity is given in the USEPA Guidelines for Water Reuse (1992, 2004) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000). In addition there will be considerable variation in the potential for accumulation in soils and in mobility and availability in differing soils associated with the soil pH and the soil type. It is, therefore, essential to take local conditions into consideration in consultation with soil science experts.

In deriving guidelines and standards for the impact of metals and metalloids on soil through irrigation, a number of assumptions have been developed that are accepted and widely used internationally (USEPA 2004). These assumptions are conservative in order to include the most vulnerable soils for long-term use. The assumptions are as follows:

Annual application of irrigation is equivalent to 1000 mm rainfall.

Inorganic contaminants are retained in the top 150 mm soil.

Irrigation will continue annually for a maximum of 100 years.

The soil bulk density is 1300 kg/m^3.

Assumptions are also made for short-term use, allowing higher concentrations of contaminants. The assumptions are for periods of up to 20 years instead of 100 years; however, these are not discussed further in this framework. The details are available in USEPA (1992).

Modified values can be developed using specific data and determining the cumulative contaminant loading, which takes into account existing soil background loadings. The methodology is described in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000).

Such detailed consideration will only be required where it will be difficult to meet the long-term criteria discussed below and will require a cost-benefit calculation as to the potential costs of reducing contaminants in wastewater and the potential for loss of other applications.

- Specific contaminants

The detailed derivation of values is not entirely transparent and it is necessary to include some pragmatism since the range of circumstances to be covered is extensive.

Aluminium – Primarily an issue for acid soils, the ion is phytotoxic but it is not normally found in the ionic form at pH values above 5.5. The value generally accepted is 5.0 mg/l.

Arsenic – Toxicity to different species varies very widely but the value has been derived to protect against the direct phytotoxicity of arsenic in irrigation water. There may be little or no margin of safety for some crops such as rice. The value generally accepted is 0.1 mg/l.

Beryllium – This is generally not available in soil but data from studies using nutrient solutions have shown that beryllium is phytotoxic, although in common with many other metals and metalloids, the toxicity varies significantly between plant types. It is not likely to be present at significant concentrations in treated municipal wastewater unless there is an input from specialised metals industries such as armaments. The value generally accepted is 0.1 mg/l.

Boron – This is one of the most important contaminants in terms of reclaimed wastewater to be used for irrigation. It is both a plant nutrient and a phytotoxin with the margin between the two relatively small. The value is based on protecting the most sensitive plants, citrus, although the margins are small. Other species, including most grasses are much more tolerant. Boron is found widely in treated wastewater, from which it is not removed. The reduction in the use of borates in washing powders will lead to a reduction in levels in wastewater. Different authorities propose different values, from 0.4 mg/l to a high of 3 mg/l. The value proposed by Israel is 0.4 mg/l while the value proposed by USEPA is 0.75 mg/l.

Cadmium – This is toxic to beans and some root crops at low concentrations and may also accumulate in crops such as rice. Cadmium may also be introduced into soils by some phosphate fertilizers. However, the value is primarily intended to protect against excessive accumulation in food crops. It is not likely to be present in treated municipal wastewater at significant concentrations unless there is a very high industrial input. The value generally accepted is 0.01 mg/l.

Chromium – There is considerable uncertainty as to the impact of chromium on plants since it is usually present as Cr III, which is poorly absorbed. The value is based on nutrient solution studies in which phytotoxicity is observed. The value of 0.1 mg/l that is generally accepted is probably conservative but most municipal wastewaters are unlikely to give rise to concentrations of concern.

Cobalt – This is primarily of concern to tomato plants, which are particularly sensitive, and in acid soils. There appear to be few indications that it causes problems in practice. The generally accepted value is 0.05 mg/l but significant concentrations are unlikely to be found in treated municipal wastewater.

Copper – This is found in municipal wastewater as a consequence of inputs from a number of sources. However, concentrations in treated wastewater are usually low. Copper is toxic to aquatic life at relatively low concentrations and has been shown to be phytotoxic to a number of plants in nutrient solution studies, although it is also an essential nutrient. The values proposed vary from 0.2 to 0.5 mg/l and are to protect against direct phytotoxicity of copper in reclaimed wastewater for irrigation. Both the USEPA and Australian authorities have proposed a value of 0.2 mg/l. This value should easily be achieved in most treated municipal wastewater.

Fluoride – There are few data on the phytotoxicity of fluoride, although nutrient solution studies do indicate that it can be phytotoxic to some crops. It causes skeletal fluorosis in mammals, the risk of which increases with long-term regular consumption of drinking water containing greater than 2 mg/l. The values proposed vary between 1 and 3 mg/l. The lower value will protect against possible phytotoxicity and the impact on stock, particularly horses, of deposition of fluoride on pasture and fodder.

Iron – The greatest problem for plants is iron deficiency. However, in oxygenated waters iron is primarily present in the ferric form, which is of low solubility and can precipitate giving rise to problems of discolouration of water, deposition of spots on the foliage of plants irrigated by overhead spray and potentially blocking of equipment. The value set by different authorities varies significantly, between 0.2 mg/l (Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000) and 5.0 mg/l (USEPA 2004). The lower value is set to minimise problems of precipitation of iron in water and is the same as that usually adopted for drinking water. The higher value is based on minimising the potential contribution of iron to soil acidification and its impact on molybdenum and phosphate levels as a consequence. Since treated municipal wastewater will have gone through a significant level of oxidation it would appear unlikely that iron in solution will be present in concentrations in excess of 0.2 mg/l.

Lead – Lead is phytotoxic at high concentrations and is toxic to animals with horses being probably the most sensitive. The values set by different authorities vary from 2.0 mg/l (Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000) to 5.0 mg/l (USEPA 2004), the former being set to minimise risks to horses consuming fodder grown with irrigation as well as direct phytotoxicity of soluble lead.

Lithium – Lithium is phytotoxic and the value of 2.5 mg/l is set to avoid this problem. However, citrus crops are considered more sensitive and the recommended value for citrus is 0.075 mg/l.

Manganese – Under aerobic conditions manganese in water precipitates as manganese oxides. It is also mobilised under acid conditions and is toxic to a number of crops. The value of 0.2 mg/l is set to avoid toxicity in acid soils and excess deposition of black oxides.

Mercury – Mercury is phytotoxic but is not usually found in significant concentrations in municipal wastewater. The value of 0.001 mg/l is set on the basis of phytotoxicity, however, mercury is rarely found in municipal wastewater in developed countries following the increased efforts to control all environmental discharges.

Molybdenum – Molybdenum is an essential trace element for plants and is of low phytotoxicity. However, forage that is grown in the presence of high available molybdenum can be toxic to stock and can induce copper deficiency. The value of 0.01 mg/l is based on the protection of stock.

Nickel – Nickel can be present in municipal wastewater but its phytotoxicity is primarily a concern in acid waters and acid soils, usually at a pH of less than 6.0. The value of 0.2 mg/l is set on the basis of phytotoxicity.

Selenium – Selenium is an essential element for mammals but the margin between essentiality and toxicity is relatively small. It is phytotoxic and fodder containing high levels is potentially toxic to stock. The value of 0.02 mg/l is set on the basis of preventing toxicity to stock.

Vanadium – Vanadium is phytotoxic at relatively low concentrations and the value of 0.1 mg/l is set on this basis, although concentrations in municipal wastewater would be expected to be very small.

Zinc – Zinc is essential to plants but is phytotoxic, usually at low pH. The value of 2.0 mg/L is set to prevent direct phytotoxicity of irrigation waters, although it will be less toxic as the pH increases above 6.0.

- Organic substances

There are many organic substances found in municipal wastewater before and after treatment. Concern is often expressed about pesticides, PCBs, dioxins, chemicals that can impact on the endocrine system (EDCs) and pharmaceutical residues. Most of these substances are not likely to be discharged to municipal wastewater in significant quantities and highly lipophilic chemicals, such as PCBs and dioxins, will be strongly adsorbed to sludge. The only substances that would be of particular importance for irrigation would be pesticides. There are a number of herbicides that are highly toxic to plants but these are not likely to be found in municipal wastewater. If present they would only be expected to be intermittent and so catchment control would be more appropriate than post treatment monitoring.

EDCs will be present in municipal wastewater as a consequence of the excretion of hormones from humans. A proportion will be broken down in treatment, particularly biological treatment, but some is found in treated wastewater and has been implicated in the feminisation of male fish in receiving waters. However, projects in Europe have indicated that there is almost complete removal in a number of plants, which appears to be due to longer retention times in treatment. The compounds are relatively lipophilic and will be adsorbed on soil. They will be largely removed in storage. There may also be some man-made chemicals present, particularly alkylphenol ethoxylates from older type detergents. These break down to the parent alkylphenol in treatment and it is the parent compound that is the most active. They have been found in treated municipal wastewater with a high proportion of input from small and medium sized industries. They are readily adsorbed to particulate matter and are expected to be completely removed in tertiary treatment and storage. Catchment control has shown to be successful in the UK in a region in which a number of such industries discharged to municipal sewers, in this case the industries changed to more modern products. The pharmaceuticals are present as a consequence of excretion by humans. Although the database on such substances is relatively limited but there are numerous research projects on the topic. Currently pharmaceuticals appear not to be important for the use of reclaimed water for irrigation.

Where chlorination is practised there is also the potential for forming a range of chlorinated by-products. Most of these substances are primarily of concern for drinking water and are unlikely to be of significance for the other uses of reclaimed water. A more recently identified by-product of the chlorination of wastewater is N-nitrosodimethylamine (NDMA). The concern regarding this contaminant is potential carcinogenicity following long-term exposure. Although, this appears to be unlikely to be of significant concern with regard to irrigation, it could attract media attention and have a significant negative impact on public and user perception.

Table 5 Parameters and standards for the use of wastewater in agriculture

Crop Parameter	Industrial crops	Forestry	Ornamental Low access Turf farms	Ornamental Cutting High access	Fodder/ Pasture	Processed food crop	Unprocessed food crop	Basis
Wastewater treatment	Secondary	Secondary	Secondary	Tertiary	Tertiary	Tertiary	Tertiary	Removal capability
Application restriction			Exclusion for turf prior to public use, 7 days.	Avoid aerosols during access	Exclusion 5 days.	Exclusion 5 days	Trickle irrigation	Exposure control/ experience
Faecal coliforms cfu/100 ml		< 1000 if public access		< 10	< 10	< 10	<1	Epidemiology/ experience
Helminth eggs/l		< 1 if public access		< 1	< 1	< 1	<1	Epidemiology
PH	6-8	6-8	6-8	6-8	6-8	6-8	6-8	Metal speciation
Suspended solids mg/l/ turbidity NTU	<10 – 30 < 20	<10 – 30 < 20	<10 – 30 < 20	<10 < 2	<10 <2	<10 < 2	<10 < 2	Visible and exclusion of light. Clogging.
BOD mg/l	<20	<20	< 20	<10	<10	<10	<10	Practical experience
Salinity	Specific allowance determined for salt tolerant crops and high leaching soils, most sensitive see TDS							
TDS/ Conductivity	<500 mg/l 800 µS/cm	< 500 mg/l 800 µS/cm	<500 mg/l 800 µS/cm	<500 mg/l 800 µS/cm	<500 mg/l 800 µS/cm	<500 mg/l 800 µS/cm	<500 mg/l 800 µS/cm	No impact on salination

Table 6 Limits on metals and metalloids present in wastewater for long-term irrigation*

Metal	Standard Total mg/l	Basis	Metal	Standard Total mg/l	Basis
Aluminium	5.00	Phytoxic in acid soil	Lead	2.00	Accumulate in soils & secondary toxicity in animals
Arsenic	0.10	Directly toxic to plants	Lithium	2.50 (0.075 for citrus)	Direct toxic to plants
Beryllium	0.10	Toxic to most sensitive plants	Manganese	0.20	Toxic to plants in acid soils
Boron	0.5 – 0.75	Toxic, may be marginal for v. sensitive species	Mercury	0.001	Direct toxic to plants
Cadmium	0.01	Toxic to some crops. Uptake by some crops	Molybdenum	0.01	Toxicity of forage to stock
Chromium	0.10	Uncertain	Nickel	0.20	Toxic to some plants in acid soil
Cobalt	0.05	Toxic to some plants in acid soil	Selenium	0.02	Toxicity of forage to stock.
Copper	0.20	Phytotoxic	Vanadium	0.10	Toxicity to plants
Fluoride	1.0	Toxicity to stock of fodder and pasture	Zinc	2.00	Toxic to plants in acid soils.
Iron	5.0 0.2	Reduction in available P & Mo Clogging equipment			

*(USEPA 2004, Australia and New Zealand Guidelines for Fresh and Marine Water Quality 2000)

5.3 Urban irrigation

There is a wide range of urban irrigation applications that may be considered when planning the development of a reclaimed water project. The applications include:

- Irrigation of public parks, recreation centres and sports fields, school playing fields.
- Irrigation of landscaped areas surrounding commercial offices and buildings and industrial developments, highway borders and landscaped areas around public buildings.
- Irrigation of golf courses.
- Ornamental landscapes and decorative water features such as pools, waterfalls and fountains.

A number of issues arise in using reclaimed water for urban irrigation. The problems of chemical and physical parameters remain largely the same as for irrigation in agriculture, with phytotoxicity, salination and accumulation of heavy metals in soil and vegetation being important. The probable target of accumulated metals is urban wildlife.

In most of these applications, the public have direct access to the areas being irrigated. The most important considerations therefore are pathogens and aesthetic impacts of using reclaimed water. The former will depend on the type of access and the type of use of the green space. It will also depend on the frequency of irrigation and the potential for exclusion of the public. Where children have access, it is important to take into account the high degree of hand to mouth transfer of dirt and, in some cases, soil in those individuals exhibiting pica[1]. In terms of criteria for water quality, it is appropriate that in order to ensure public health protection and continuing public acceptance, these should be similar to those for crops that will be consumed without further processing. However, in some circumstances there will be a greater potential for die away of microorganisms as a consequence of UV exposure and desiccation and therefore there is a potential for lower exposure. Existing and proposed standards and guidelines depend on the treatment requirements, particularly disinfection by chlorine in which a residual can be demonstrated. Where there are microbiological standards, total coliforms (e.g. ≤ 2.2 total coliforms/100 ml), faecal indicators and parasite eggs are used. For faecal indicators they range from not detectable in 100 ml to a minimum requirement of less than 10/100 ml for faecal coliforms. For parasite eggs the standard is usually not detectable in a litre or less than 1/litre. The aesthetic impacts relate to appearance, including colour and turbidity, and, particularly odour which could affect storage and irrigated areas.

Planning for this type of application might include the need for a ‘dual distribution system’, which is considered in more detail below.

The issues that arise from such uses are related to microbial contaminants and the potential for aerosol exposure and aesthetic impact. The acceptable minimum level of wastewater treatment should be appropriate to remove any significant risks of problems with chemical contaminants, although pH and BOD will be important from a practical and aesthetic

[1] An eating disorder characterised by persistent and compulsive ingestion of non-food items, including soil

perspective. As in all urban uses in which the public will be involved the aesthetic issues, such as appearance and odour, are as important as the public health considerations. Where there is a potential for significant aerosol production, the standard needs to be higher than that adopted where aerosol production is minimal. Therefore it would be appropriate to set a standard of no detectable *E. coli*/100 ml for the former. However, the same considerations with regard to the use of quantitative risk assessment as discussed in section 5.2.1 apply here. In some circumstances, where there is an opportunity for the proliferation of *Legionella*, for example recirculating ornamental fountains, appropriate treatment at the point of use may be necessary.

5.4 Urban commercial uses

Urban commercial uses of treated wastewater include a range of applications:

- Vehicle washing and laundry.
- Nurseries and garden centres.
- Highway and hard standing dust control.
- Use in construction such as the preparation of concrete mixes.
- Fire protection through fire hydrants (requires a separate distribution system and considerations of demand unlikely to be used in the absence of other major uses requiring a dual system).

Many of the issues regarding urban commercial uses are simpler than for broader irrigation applications. For nurseries and garden centres the requirements with regard to phytotoxicity and soil quality are similar but in general the issues for chemical hazards are less. However, it is important that microbiological quality and issues regarding acceptability, particularly odour and potentially colour are adequately covered. The central driver is the potential for exposure of users and the public and the level of control over access for unauthorised use. In the case of vehicle washing and fire-fighting there is an increased likelihood of aerosol generation and inhalation exposure. Many of the same issues exist for some of these uses as for irrigation of recreational areas with uncontrolled access and, therefore, similar constraints apply for microbial criteria. There is the potential for the growth of *Legionella* in equipment but to an extent, this possibility exists with current drinking water applications.

5.5 Industrial uses

Industrial use of water is significant so increasing numbers of applications are being identified for industrial use of reclaimed water. These include:

- Cooling water and process/boiler feed water.
- Petroleum refineries, chemical plants and metal working industries.
- Industrial process water, pulp and paper industry.
- Geothermal groundwater recharge.

As with other uses, the means of delivery will depend on the requirements and the need for a continuous or intermittent supply.

The primary industrial use to be considered here is that of the use of treated wastewater in cooling towers. The major concerns in relation to reclaimed waters are deposits, corrosion and biological problems. Similar problems arise from potable water use but the concentration of some contaminants in recycled water may be higher. Reclaimed water of good quality may only require the addition of a biocide, corrosion inhibitors and pH correction to be satisfactory as cooling water. Microbiological concerns relate to organisms that can contribute to solids accumulation and cause microbial corrosion. These can be controlled by a number of means including maintaining an appropriate free chlorine residual. Organic carbon and ammonia may contribute nutrients to the system and can reduce the effects of commonly used biocides. A programme of biocide use would normally be required to control microbial and algal growth.

The main concern for the public would arise from any aerosols that might be generated during the operation of the cooling tower and consequently pose a threat to public health from *Legionella* and other microorganisms. In this respect, it is necessary to treat the water in the cooling tower system to minimise the growth of *Legionella* and this would be sufficient to deal with other microorganisms.

Other uses like boiler feed water will only require consideration of the chemical and physical characteristics. Reclaimed water may require further treatment, particularly to remove chemicals such as calcium, magnesium, silica and aluminium, which cause boiler scaling. Advanced treatment might include ion exchange and reverse osmosis depending on the circumstances and the quality of the water required. Recycled water has been used as a successful and economically viable alternative to fresh water and the more expensive drinking water as the cost of treatment for boiler feed is controlled by the dissolved solids content of the feed water.

Paper production requires considerable amounts of water and the industry in the USA has been recycling its water for many years. A good quality of water is required to prevent scaling and biofouling problems and tertiary treated water would be the minimum quality demanded. However, the primary constraint for the use of municipal wastewater is likely to be the location of the industry in relation to the wastewater source.

Figure 6. Framework for the use of recycled water for irrigation and industrial purposes

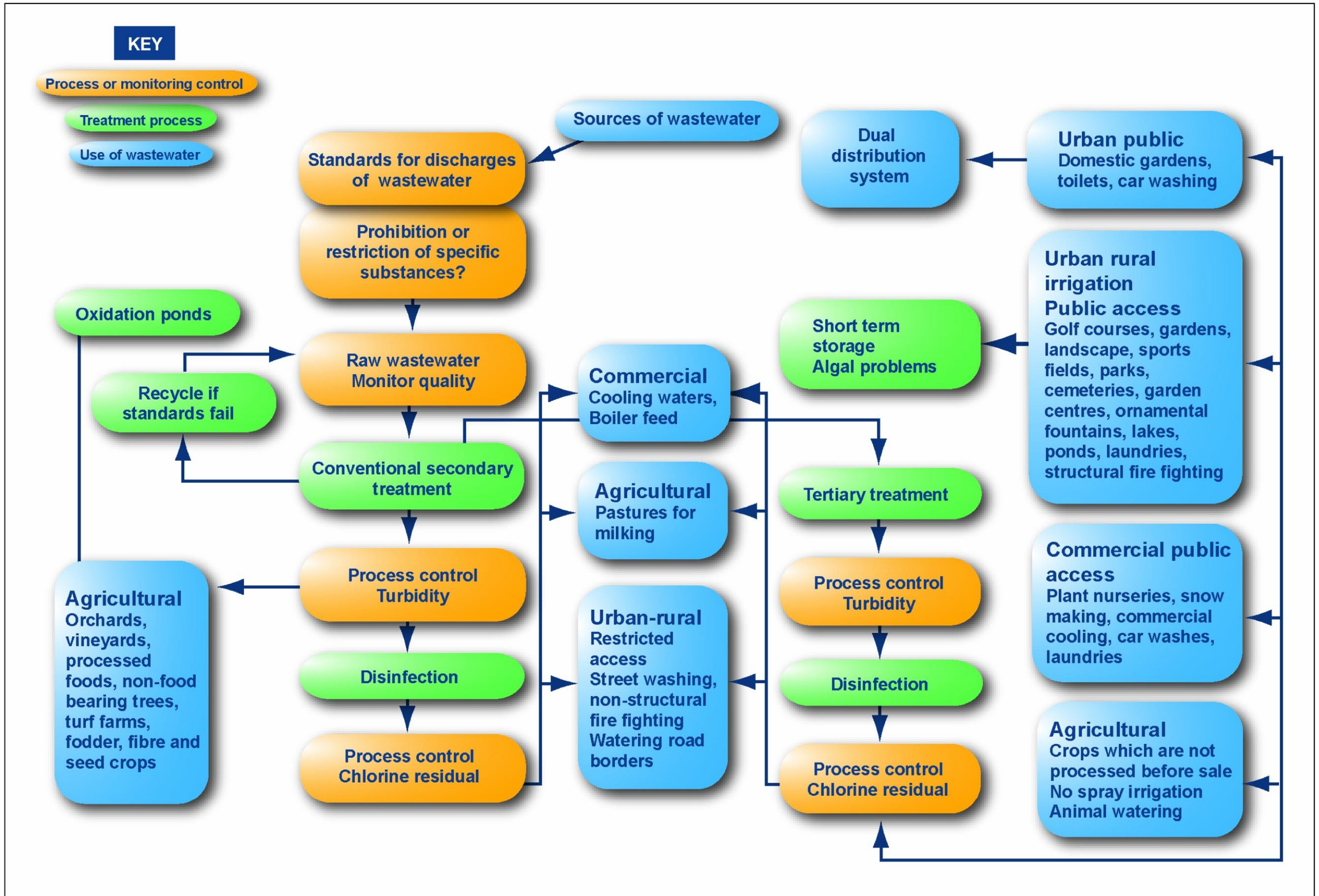


Figure 6 Framework for the use of recycled water for irrigation and industrial purposes.

6 Groundwater Recharge

6.1 Introduction

One means of utilising storage and at the same time reducing public perception of the link between treated wastewater and reclaimed water is to transfer reclaimed water into an aquifer. However, this can also be a means of treatment if the water is recharged by surface infiltration. Groundwater recharge using reclaimed water may also be a specific application. The various reasons for groundwater recharge are given below.

- To establish a barrier to prevent saline water intrusion in coastal areas.

  Over-exploitation of groundwater in coastal areas may result in seawater being drawn into an aquifer rendering it unsuitable for further extraction. Injection of reclaimed water into the aquifer can create a barrier, thereby preventing saline intrusion and protecting the groundwater resource. The reclaimed water could be abstracted for drinking purposes but is more likely to be available for other uses for which drinking water supplies are currently used.

- To provide additional treatment for subsequent extraction and use as a potable water.

  Groundwater usually undergoes purification by percolation through the soil and lower strata in the unsaturated zone before reaching the saturated zone. This purification process can also be used to provide additional treatment for reclaimed water. Depending on the circumstances and efficiency of this process in a specific case the water may not require extensive additional treatment before being supplied, even as drinking water. The reclaimed water can be discharged over the surface above the aquifer in the recharge zone, from whence it will percolate to the saturated zone. Such an approach is often referred to as managed aquifer recharge (MAR) with soil aquifer treatment (SAT) which is in many respects similar to bank infiltration from a river supplemented with reclaimed water. Both are considered to be forms of indirect reuse.

- To augment potable or non-potable aquifers or to act as a means of storage for subsequent reuse as a reclaimed water.

  Two approaches are available, one in which the water will be recovered from the injection well, known as aquifer storage and recovery (ASR), and the second is one in which the water is injected into the ground at one point to be extracted at a different point, known as aquifer storage, transfer and recovery (ASTR). The Australian Environment Agency (EPA 2004) has published a code of practice for ASR. Additional information can be obtained from CSIRO (1996).

  Aquifer storage can also be used to balance supply and demand with storage for reclaimed water at times when demand is low. The stored water can then be recovered at a later time. Recovered water is usually used for irrigation or similar purposes and not for drinking. It is important that the injected water does not affect the quality of groundwater, particularly if the water is also extracted for potable supplies.

6.2 Soil aquifer treatment (SAT)

Recharge of groundwater through discharge to the soil surface and subsequent percolation through the soil is common practice. During percolation, organic material and ammonia will be oxidised by bacteria and pathogens will be removed either by adsorption, predation, starvation or filtration processes. It is important that the soil is of a suitable nature such that it does not become clogged. In surface spreading the majority of the organic and microbial contaminants are removed in the top two metres of soil, although the majority of microbial contaminants are normally removed in the top few centimetres.

There are a number of ways in which percolation to groundwater can be accomplished. The reclaimed water may simply be spread onto the land at regular intervals and allowed to percolate before further spreading. Alternatively, the water can be discharged into furrows, which is particularly applicable to sloping land. Unfortunately, in this case only a small proportion of the land is utilised for percolation. Streams can be modified to restrict horizontal flow and thereby encourage greater downward percolation. River bank or dune filtration is another option that is practiced, particularly in Europe with an added dilution factor in the river as indicated above. The river water is allowed to percolate through the riverbank and is pumped from the saturated zone. Alternatively, treated wastewater is discharged to a river, which may then be pumped into canals, lakes and spreading basins from where it percolates into the groundwater.

The most widely practised means of groundwater recharge is through infiltration basins. These are flat-bottomed areas filled with water, allowed to drain and then allowed a further drying period. The drying period allows any clogging layers to dry out and the soil to re-aerate before the next cycle. Algal growth is controlled by the correct management of the discharge.

In order to operate any of these recharge systems, the minimum degree of treatment is usually secondary, often with disinfection. It may be necessary to remove nitrate if the infiltrate is to be used for potable supplies.

SAT systems are designed such that all the infiltrated water is recovered either by wells, drains or seepage into surface water. With this technique, greater BOD removal can be achieved than with secondary treatment. It is also possible to achieve nitrate removal. Soil treatment can also achieve removal of some micro-pollutants and other toxic chemicals.

6.3 Injection

Reclaimed water may be injected into the vadose zone above an aquifer or directly into an aquifer. Vadose zone injection is a cheaper option that allows for reclaimed water treatment by percolation, similar to soil aquifer treatment. Direct injection is usually into a well-confined aquifer and is used where conditions on the surface are not suitable for spreading, for example poor hydrogeology or lack of land. Because the vadose zone is by-passed injected water must be treated to a higher quality, usually by applying advanced treatment processes. A major problem with direct injection wells can be clogging caused by accumulation of microbial biomass and organic and inorganic solids. Clogging can be minimised by correct pre-treatment of the reclaimed water and, where appropriate a system of back flushing.

Storage in groundwater is increasingly used as an environmental buffer before treatment for a variety of uses, including for drinking water (Crook *et al.*, 1999). California has proposed draft guidelines for groundwater recharge for indirect potable reuse. The proposed regulations address both surface spreading and injection projects and include sections on treatment requirements, microbial, chemical and physical reclaimed water quality limits together with dilution and monitoring requirements. If the abstracted water is to be used without further treatment, it must meet all drinking water quality requirements. The guidelines define minimum separation distances between injection and recovery wells together with the minimum retention time underground before abstraction. Requirements for monitoring are also defined. A similar document has been produced by CSIRO (1996) for in Australia.

7 Wetlands and Impoundments

7.1 Wetlands

Wetlands are areas of land where saturation with water is the dominant feature determining the types of plants and animals which use them as a habitat. Many wetlands have been destroyed through the development of agriculture and industry and over-exploitation of ground water. They provide many useful functions including the development of specific plant types, waterfowl and aquatic life, flood alleviation, improvements in water quality, aquifer recharge and recreational facilities. Reclaimed water can be used to:

- Create new wetlands or restore and maintain existing wetland systems. New designs can be created to provide maximum habitat diversity.
- Provide additional treatment to wastewater through the removal of nutrients, particulate and organic material before discharge to surface water.
- Provide a wet weather and low demand disposal alternative for wastewater.
- Enable aquifer recharge through percolation into the ground.

Wetlands can be divided into four different categories. These are marshes, swamps, bogs and fens. Once established, wetlands have a low operational cost and considerable environmental benefit. Design and planting with appropriate species is important, as is knowledge about the salinity of the wastewater where saline tolerant species may have to be used. There are potential significant benefits from the development of wetlands in terms of public benefit and the impact on public perception of the sustainable use of reclaimed water.

The minimum treatment requirements for wetlands would normally be secondary treatment. The construction of the wetland should be such that nutrients and organic material are removed on a continual basis. Microorganisms will be removed naturally through predation, sedimentation and the effect of sunlight. There may also be a requirement to consider chemical contaminants such as hormones and other oestrogenic substances since these could impact on fish if they are exposed close to the point of discharge. However, the use of wetlands will normally provide extended treatment, which is beneficial for the removal of such substances.

The USEPA has collected together a significant amount of information on habitat functions of treatment wetlands. This documentation is available as a report (USEPA, 1999) in electronic format. In addition, the USEPA have a web site dedicated to wetlands (www.epa.gov/owow/wetlands). Additional information can be obtained from Girts and Knight (1989), Kadlec and Knight (1996) and Kadlec *et al* (2000). There are a number of commercial companies in the UK who offer reed bed technology for the treatment of domestic and industrial wastes and sludges. Systems can be small to treat individual properties or small hotels to large complexes treating industrial or domestic wastewater. There are also garden centres which produce reeds. The major water companies in the UK also use reeds beds as a tertiary treatment.

7.2 Impoundments, recreational waters.

An additional use for reclaimed water that can be perceived as a significant benefit to the community is the creation of water bodies and impoundments to be used for recreational purposes. Such systems can also include flowing systems that can be used to develop safe waters for canoeing. The impoundments can be of varying sizes and can also provide a means of storage for a range of other uses. They can include water parks, areas for fishing, water sports such as wind surfing, water skiing and yachting and swimming, if they meet appropriate microbiological standards. Indeed many existing water bodies used for recreation are natural waters with a high degree of treated wastewater content and many would not be useable without such input.

The level of treatment required for this purpose will vary according to the intended use and the potential for contact with the water. Where there is intimate contact, in particular water immersion sports, the level of treatment required is likely to be higher than where there is no contact; however, the quality of the water may well be higher than that encountered in many natural water bodies and rivers. In addition nutrient removal may be required to limit the growth of alga, particularly cyanobacteria, which can produce toxins and can pose a serious threat to health if large blooms form in a water body.

Most developed countries have standards for bathing waters that particularly relate to microbial contaminants. In Europe, water quality standards are currently defined by CEC (1976) and in the US by USEPA (1986). However, depending on circumstances it is possible that the loading of human pathogens, particularly viruses, will be higher if the proportion of reused water is much higher than normally encountered. Where there is the potential for a high degree of contact with the water and where risk assessment indicates, there may be a need for more stringent standards that would reflect the identified increase in risk in particular circumstances. This will depend on the extent of the treatment applied to the reused water, the means of incorporating the reused water, e.g. by infiltration through wetland for nutrient removal which will also increase microbial removal, and the anticipated recreational uses of the water body.

Where these are used for fish and other wildlife there will be a requirement for there to be no detectable toxicity, which would normally be achievable with secondary treatment. However, consideration would need to be given regarding endocrine disrupting compounds, such as natural oestrogens and ethinyl estradiol, which may impact on the reproductive capacity and stability of fish populations. There may also be issues for other chemical contaminants frequently found in wastewater with regard to aquatic life where there is limited or slow dilution.

8 Aquaculture

Aquaculture involves the production of food in the form of plants and animals for human consumption, fry for recreational fishing and natural fisheries, ornamental fish and plants for the aquarium trade, raw materials for energy and biochemicals and a number of products for the fashion industry. It is increasingly becoming a potential outlet for the use of treated wastewater since there is concern over both the quantities of water that can be consumed by aquaculture and the impact of wastewater from aquaculture on natural waters. Where there is a potential for the use of reclaimed wastewater, this is largely for the production of freshwater species. There are several issues that are associated with the use of recycled water in aquaculture but these are to an extent dependent on the aquaculture crop.

There is a strong relationship between water quality and the growth of aquaculture products. In addition, although a product may grow in inferior water quality, low levels of pollutants or microorganisms can cause products to become contaminated and may produce off tastes and odours. Uptake may be through the gut, the gills or the skin. Some aquatic plants may also accumulate toxic chemicals, particularly heavy metals. In the case of fish and non-filter feeding shellfish grown in water that is faecally contaminated, human pathogens can be accumulated on the on the skin surface, in the gastrointestinal tract and even in the muscle. Once there, they can survive for considerable periods and may be difficult to remove if the food is not properly processed.

There are a number of sources of information on the concentrations of potential chemical contaminants and their impact, many of which will act in an additive manner. Most countries will have standards or guidelines for the protection of aquatic life and some have developed guidelines specifically for aquaculture, for example the Australian and New Zealand Governments have developed guidelines for aquaculture (Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000). WHO is also developing guidelines for the use of wastewater in aquaculture, which relate primarily to developing countries and to the consideration of microbial contaminants (WHO 1989).

The issues for the use of wastewater in aquaculture relate to the following:

- Physico-chemical parameters such as dissolved oxygen and factors that can impact on dissolved oxygen, such as BOD.

- Chemical contaminants that are directly toxic to aquatic organisms. Sensitivity to toxicants may be much greater in respect of a number of chemicals, such as chlorine and ammonia, and some such as copper and zinc may depend on the hardness of the water. Excessive growth of cyanobacteria as a consequence of high nutrients, particularly phosphate, can both deoxygenate the water and give rise to toxins that may be directly toxic.

- Chemicals that could accumulate in aquatic organisms. In the case of fish or prawns this will largely relate to uptake through the gills, gut and skin but filter-feeding shellfish can also accumulate particles in their gastrointestinal tract. Specific standards exist in most developed countries that control the concentrations of such chemicals in the final product.

- Pathogens may contaminate the surface of aquatic organisms but the major concern is accumulation in the gut of fish and particularly shellfish that are often eaten raw or may be undercooked. Standards have been adopted by Australia and New Zealand, the European Union and the United States for water for the culture and harvesting of shellfish. Depuration is a process whereby shellfish can be cleaned of microbiological contamination but whilst this might be suitable for the removal of *E. coli*, viruses tend to remain in the flesh even when the indicator organisms have been removed. It is recommended that reclaimed wastewater should not be used for such purposes unless there are no human pathogens present.

In some cases aquatic plants, such as watercress, are grown as food crops, usually with little preparation or processing. These too could accumulate pathogens on the surface that would be difficult to remove with simple rinsing. Most of these plants require a very high water quality but may accumulate metals and are sometimes highly sensitive to metals such as zinc that may be present in reclaimed wastewater at higher concentrations than some natural waters.

In the case of breeding stocks there should be no significant impact of endocrine disrupting compounds. This remains an area of uncertainty but may be a consideration in some cases.

Hydroponic cultivation is also being introduced more widely, particularly for high value greenhouse crops. In this case the same requirements would apply although the microbial risks would be minimal. The issue of inorganic contaminants would be similar to those for irrigation in agriculture but there would be no attenuation of minerals by the soil and greater sensitivity to metals and other minerals might be expected.

9 Domestic and Industrial Dual Systems

Domestic and industrial dual systems appear to be gaining popularity. Significant investment is required to develop dual distribution systems where these are to be installed retrospectively. For new housing and industrial development, however, where the ground has to be excavated for drinking water mains, recycled water mains can be laid at the same time, ideally not next to or above the drinking water main. In such circumstances, particular care needs to be taken to ensure that such distribution systems are clearly labelled as recycled water to prevent cross-connections into drinking water and/or are constructed in pipe work that is coloured differently to the drinking water supply pipe work. It may also be possible to colour recycled water to prevent human consumption in the event of accidental cross-connection.

In the case of domestic systems, recycling provides water for non-potable uses such as toilet flushing, garden watering, and even laundry. It is also useful for toilet and urinal flushing facilities in public and commercial buildings and in public facilities. While chemical contaminants are of similar concern to those for irrigation there is a greater requirement for high aesthetic quality and for good microbial quality since the level of control over the users is significantly less. In addition there is a requirement to ensure that cross-connection with the drinking water system cannot occur and that users are educated in the way such water can be used. It would not seem to be practical to restrict watering to lawns and flowerbeds. Watering of vegetable plots, particularly for those vegetables eaten raw would require a high microbiological quality. Care also needs to be taken in the use of such water for car washing where an aerosol will be created. In addition, water may be stored for some time in water tanks used for flushing toilets, e.g. during holiday periods. Under such circumstances, water containing a higher dissolved organic carbon than would normally be encountered in municipal drinking water could give rise to slime growth, and potentially the growth of opportunist pathogens such as *Pseudomonas.*

In order to minimise the risk or adverse perception of health implications and to minimise the actual risk should cross-connections occur, water should be treated and disinfected to ensure the removal of pathogenic microorganisms. The appropriate standard could be no detectable *E. coli*/100 ml using an approved method, while a standard of no detectable total coliforms/100 ml would be even more stringent since after-growth can occur in distribution. The health potential of heterotrophic bacteria that regrow in water distribution systems has been considered by WHO (2003) with the conclusion that they are unlikely to be of risk to health, allowing that pathogens have been destroyed at an earlier stage of treatment. This can be demonstrated firstly by ensuring that treatment and disinfection technologies are capable of removing and inactivation all pathogens and then ensuring a quality assurance and on-line monitoring programme to demonstrate continuing quality.

An example of developing dual systems may be found in Australia. The Pimpama Coomera region has developed a master plan for water reclamation. This includes a dual system to supply reclaimed water for toilet flushing, watering gardens and fire fighting. Aquifer storage will be used for any excess reclaimed water which will then be recovered when demand is high, chlorinated and distributed through the system. This part of the master plan alone is targeted to save 45% of drinking water use. More information can be obtained from www.goldcoastwater.com.au.

10 Drinking Water

For many decades it has been common practice for treated wastewater to be used indirectly to augment the sources that are abstracted for treatment for drinking water supplies. It is in any case necessary that the treated wastewater is discharged to the environment. Frequently it is discharged to a river where it is diluted with the normal river flow and there is significant improvement in quality through natural processes, and sometimes further dilution, as the water moves downstream. Thus where there is abstraction for drinking water downstream, the water is no longer considered to be wastewater and there is wide public acceptance of this. The abstracted water is treated at a drinking water treatment plant using conventional multi-barrier treatment processes such as storage in reservoirs, coagulation, filtration and disinfection and often supplemented with additional processes such as oxidation and adsorption on granular activated carbon. However, sometimes the treated wastewater, often treated to drinking water standards, is being used to recharge groundwater with subsequent abstraction and appropriate treatment for drinking water supply and this practice is increasing. This common practice of indirect use of treated wastewater as a component of a surface or groundwater source for abstraction for treatment as drinking water supply has been generally accepted and regarded as safe by all stakeholders including the public, although some planned indirect potable reuse projects in the US have been rejected due to public and/or political opposition.
.
There is a need to consider more direct reuse of treated wastewater. An example is discharging treated wastewater to a new fresh water storage reservoir or to an existing surface water storage reservoir, thereby omitting the dilution and natural purification that occurs in rivers. Another example is using the treated wastewater to recharge groundwater either directly or following infiltration through the soil. The water in the storage reservoir or the

groundwater aquifer is then abstracted for treatment for drinking water supply. These represent a form of indirect reuse because there is physical separation of treated wastewater discharge from the drinking water treatment process. The ultimate is direct use of treated wastewater whereby the treated wastewater goes directly into the drinking water treatment plant or, where the combined treatment is such as to produce water of drinking water quality, directly into the drinking water distribution system.

When a scheme is proposed to reuse treated wastewater more directly, or directly as a source for treatment as drinking water supplies, it is essential that consumers are fully comfortable with the principle of wastewater recycling and fully confident in its safety in respect of their health. Therefore stakeholder and public acceptance is absolutely vital and this can only be achieved by demonstrating that the water is safe both in chemical and microbiological terms. There is, therefore, an important role for standards for drinking water quality, and monitoring against those standards to act as a benchmark against which safety can be demonstrated. However, standards alone cannot provide sufficient assurance of safety because of the many chemicals that could be present in treated wastewater and the limited proportion of the water that can be sampled for microbial contaminants, for which the concern is acute exposure.

There need to be additional safeguards based on risk assessment and risk minimisation. This risk assessment needs to consider what might happen in atypical conditions as well as in normal conditions. There needs to be two sets of barriers. The first should include controls on the sources of wastewater, demonstration of the adequacy and reliability of wastewater treatment and the consistent quality of the final treated wastewater by appropriate monitoring and controls. In general it is anticipated that the minimum would be tertiary treatment of wastewater. The second set of barriers and assurance steps relate to the treatment of the reclaimed water to produce drinking water. This would include demonstration of the adequacy and reliability of all the treatment processes, safety controls on the drinking water treatment processes, process monitoring against appropriate safety criteria and final treated water quality monitoring against safety indicator parameters as well as against established drinking water standards. To be acceptable it is considered that the treatment processes should as a minimum include an additional barrier such as reverse osmosis that removes or reduces in concentration nearly all of the substances that are present. Reliability is not just the ability of the process to remove substance of concern but also the mechanical and electrical reliability of the plant and involves adequate inspection and maintenance schedules.

Together these guidelines, controls and standards constitute a water safety plan for the operation of water reuse schemes for drinking water supplies. However, before a scheme is brought into use, it is essential that a reasonable sized pilot plant of the full process be operated to demonstrate that all the guidelines, controls and standards are met, and to identify possible circumstances when the risk of a breach of the barriers could occur. The water safety plan and therefore the pilot plant has to consider the normal variations in treated wastewater quality and the source that is abstracted for treatment **and** the variations that might occur when there is an **atypical** challenge such as might occur if there was a failure of wastewater treatment or an outbreak of illness in the community resulting in a higher than normal microbial challenge.

10.1 The framework for drinking water

The proposed framework is shown diagrammatically in Figure 7. The elements relating to public perception and public acceptance are shown within the circle in the centre of the diagram. This shows how the guidelines, controls and standards feed into the risk assessment and water safety plan leading to risk minimisation and public acceptance. Round the outside of the diagram are the treatment processes and the controls, standards and monitoring that need to be considered to produce safe drinking water from reuse of treated wastewater. These processes and controls are discussed below.

This proposed framework is considered appropriate for the more direct reuse of treated wastewater such as when the treated wastewater is added to a surface water reservoir containing other sources of water or used to recharge groundwater and the water is subsequently abstracted from the reservoir or groundwater for treatment as drinking water supplies. It is also considered appropriate for the direct use of treated wastewater as a source for treatment for drinking water supply but it is accepted that in many countries it may not be possible to gain public acceptance and other stakeholder acceptance of a direct reuse scheme. It is considered that most stakeholders will wish to have a physical separation of treated wastewater from the drinking water treatment plant by use of an adequate surface water or ground water storage.

10.2 Treatment of wastewater

10.2.1 Sources of wastewater

There are many potential sources of input into municipal wastewater including domestic sewage, industrial and commercial effluents and storm water run-off. There is a need to control the discharge of some of these inputs to the sewerage system, particularly some industrial effluents. These controls normally protect the wastewater treatment process and ensure that the treated wastewater can meet the standards for its discharge to the environment. As indicated above, it may be necessary to restrict or prohibit the discharge of certain substances in industrial and other relevant effluents in order to safeguard the wastewater treatment process to ensure that the quality of the treated wastewater is not compromised and remains consistent. It follows that there should be an inventory of all industrial and other relevant effluents and their contents. It may be necessary to require more stringent controls on particular industrial effluents that are discharged to the wastewater collection system when the treated wastewater is to be used more directly as a source for drinking water in order to safeguard the drinking water treatment process and to provide additional public reassurance. There may be a requirement for monitoring of particular industrial effluents or upstream monitoring of wastewater streams to warn of possible threats to the wastewater treatment process and any subsequent drinking water treatment processes.

10.2.2 Treatment processes for wastewater

The treatment provided for the raw wastewater will depend on the requirement for reuse. As a minimum for the application as a drinking water source, wastewater should receive at least conventional secondary treatment (primary sedimentation followed by trickling filters or activated sludge or equivalent) and tertiary treatment depending on the specific requirements, for example de-nitrification or phosphate removal.

10.2.3 Monitoring of treated wastewater quality

It is necessary to establish appropriate monitoring of the treated wastewater to check that it meets the final requirements for reuse as a drinking water source (and any requirements for its discharge to the environment when not all of it is used as a source). This monitoring can take the form of check monitoring for specific parameters and additional monitoring, if needed, for any specific substances that may be of concern to consumers in respect of drinking water. For example, where wastewater is being disinfected with chlorine, a potential concern is the formation of disinfection by-products such as N-nitrosodimethylamine (NDMA). However, check monitoring should be supported by operational monitoring to demonstrate that the wastewater treatment processes are operating at their optimum at all times.

10.2.4 Short-term storage

In some cases short-term storage of the treated wastewater may be beneficial to balance its quality. It is unlikely that this would result in any significant improvement in general quality. There is a possibility that short-term storage may result in deterioration of some aspects of quality, for example algal blooms that could cause problems for subsequent treatment for drinking water supply and so there could be a requirement for appropriate levels of nutrient removal in the wastewater treatment or for algal control in the stored water. This short-term storage could be in a purpose built lagoon or in an existing surface water storage reservoir (for example bank-side storage).

10.2.5 Long-term storage

In some cases there may be a long-term storage and balancing stage between the treated wastewater and the abstraction and further treatment for drinking water. An example of the practical use of this technique is the NEWater project in Singapore (www.pub.gov.sg/NEWater). There will usually be a requirement for nutrient stripping to prevent excessive growth of algae and particularly cyanobacteria. Long-term storage also requires that there is adequate mixing and no short-circuiting. The potential benefits of long-term storage are the further reducing microbial and chemical contamination by natural processes and there are benefits in public and other stakeholder perception by separating wastewater treatment and drinking water abstraction. This long-term storage could be in a purpose built lagoon or in an existing surface water storage reservoir.

10.2.6 Groundwater recharge

The treated wastewater could be used for groundwater recharge and provide an additional resource for subsequent abstraction for treatment as drinking water supply. It could be discharged directly to the groundwater through a borehole and recovered through the same borehole (Aquifer Storage and Recovery – ASR) or recovered through a down gradient borehole (Aquifer Storage Transfer and Recovery – ASTR). It could be spread on the land above the aquifer and allowed to infiltrate into the aquifer through the soil in which case there would be some improvement in microbiological and chemical quality (Soil Aquifer Treatment – SAT). The groundwater could also be recharged through bank infiltration as practised in Berlin. In all cases the level of initial treatment of the wastewater will need to be related to the type of aquifer for recharge and the additional treatment that can be achieved by the method of infiltration.

The treated wastewater could also be used in the aquifer to provide a barrier to prevent saline water intrusion into the aquifer thereby protecting the existing and future water in the aquifer and enabling it to be abstracted for treatment for drinking water supply.

The second set of barriers (see section 10.3) may be provided in advance of groundwater recharge where it is necessary to avoid degradation of high quality groundwater or it is impractical to provide advanced treatment at multiple abstractions points in the aquifer. In this case the treatment for supply as drinking water after abstraction from the recharged aquifer could be limited to disinfection.

10.3 Treatment for drinking water supply

10.3.1 Introduction

The treatment plant for drinking water supply could be sited next to an existing conventional treatment works (as IWVA Torrelle, www.IWVA.be) or it could be a purpose built treatment works at a new site. Ultimately the wastewater treatment and the drinking water treatment could be at one site but it is unlikely that this will be publicly acceptable in the foreseeable future. The treated wastewater could be stored in a purpose built lagoon or it could be mixed with other surface water in an existing surface water storage reservoir. Alternatively it could be mixed with groundwater as a consequence of its use as groundwater recharge before abstraction to the drinking water treatment plant (as IWVA Torrelle). Irrespective of whether the treated wastewater passes more directly, or even directly, to the drinking water treatment plant, for public acceptance and safety of the produced drinking water the treatment processes should include an additional barrier such as reverse osmosis that removes or reduces in concentration nearly all the substances present. The overall process is described below and illustrated in Figure 7.

10.3.2 Pre-treatment

In order to make the reverse osmosis plant as efficient and as effective as possible, it is essential that there is pre-treatment to remove suspended matter, colloidal substances and some of the dissolved substances (this may not be necessary when the treated wastewater is used to recharge groundwater and there is natural filtration and dilution). One method of achieving this could be conventional coagulation with an iron or aluminium compound, possibly assisted with a polymeric coagulant aid, and followed by filtration. An alternative technique could be microfiltration or ultrafiltration, particularly if the treated wastewater is of a high quality. There is a question about whether an oxidation step, such as ozonation or peroxide with UV, should be included to break down complex organic substances. However this creates much smaller organic substances that may not be as efficiently removed by reverse osmosis and could react with the final disinfection process, where this is chlorination, to produce undesirable concentrations of disinfection by-products. In this case an additional biological removal step may be required. However, in most situations, the oxidation step is applied after the reverse osmosis stage where it primarily acts as a final disinfectant. There is also a question about whether disinfection should be included at the start of the pre-treatment process for example to control slime formation in the treatment plants.

10.3.3 Monitoring/control of pre-treatment

There should be some process control on the coagulation/filtration or micro-filtration treatment process in order to continuously monitor that it is working efficiently. It is suggested that continuous monitoring of turbidity with an appropriate alarm setting, for example 0.2 NTU, is used. Exceeding the alarm setting should result in the automatic or manual shut down of the treatment works and immediate investigation of the high turbidity. The plant should not be restarted until the cause of the high turbidity is found and rectified.

10.3.4 Reverse osmosis

This is the key treatment process that provides a barrier to substances present in treated wastewater. Only very small molecules are not removed by reverse osmosis. Consideration will be needed as to which of these might be present in the abstracted water, e.g. boron and some organic constituents. The great majority of the major hazards and substances of concern likely to be present in treated wastewater, such as microorganisms, endocrine disrupters, pharmaceuticals, NDMA etc are usually completely removed, or significantly reduced, by reverse osmosis. This process is needed to gain public assurance and acceptance that the complete treatment system is safe. One challenge with reverse osmosis is that about 15-30% of the influent water is rejected thus reducing the amount of drinking water produced. Also this rejected water contains all the removed substances and requires treatment and/or disposal to the environment. Therefore consideration needs to be given to the means and costs of such disposal and whether a permit to discharge the reject water is necessary.

10.3.5 Monitoring/control of reverse osmosis

There should be two controls on the reverse osmosis plant. One control should monitor the integrity of the reverse osmosis membrane to make sure it remains intact. Different manufacturers of reverse osmosis systems use different methods. If the membrane integrity falls below a pre-set level, there should be automatic or manual shut down of the treatment works. The second control should monitor the quality of water produced by the reverse osmosis plant to make sure it is working efficiently. The integrity control and quality control may use the same parameter. A number of parameters have been suggested and they include continuous, or discrete but very frequent, monitoring of turbidity, conductivity, total organic carbon (TOC) and sulphate. Some doubts have been expressed about whether the methods for turbidity or conductivity are sufficiently sensitive for this purpose and TOC or sulphate appear to be gaining favour. It is suggested that in respect of a particular reuse project, there should be discussion with the reverse osmosis plant manufacturer to decide the most appropriate control or controls taking into account the quality of the water being supplied to the reverse osmosis plant. Whatever controls are decided, values for the parameters being monitored should be set, which if exceeded cause automatic or manual shut down of the treatment works. Any control failure should be immediately investigated to determine the cause and the works should not be restarted until the cause is rectified.

10.3.6 Re-mineralisation, pH adjustment and disinfection

Reverse osmosis removes much of the mineral content from the water so that the produced drinking water is less palatable and will be corrosive to materials in the distribution system and within premises. Therefore re-mineralisation and pH adjustment are needed. In addition to consideration of stabilisation to prevent corrosivity, it is suggested that both palatability and nutritional considerations be taken into account. WHO has begun the process of considering remineralisation of drinking water following processes such as desalination and reverse osmosis treatment but has so far not made any firm proposals. However, consideration should be given to the addition of appropriate salts of calcium and magnesium for remineralisation. In many countries there will be a requirement to disinfect the final water with an appropriate chlorine based chemical or other suitable disinfectant. This can provide an additional barrier to reassure consumers and will provide some hygienic protection in distribution.

10.3.7 Monitoring and control of final treated water

There need to be appropriate process controls, both continuous and intermittent but frequent, that will trigger manual or automatic shut down of the treatment plant when not met. The treatment plant should not be restarted until the cause has been investigated and any deficiencies in the treatment processes rectified. As a minimum the following triggers are suggested:

- An appropriate maximum turbidity, e.g. 0.1 NTU
- An appropriate pH range, 7.5 to 8.5
- An appropriate conductivity range – this will depend on primarily the re-mineralisation and pH adjustment process
- Where practised, an appropriate minimum disinfectant residual, say 0.3 to 0.6 mg Cl/l (depending on the complexity of the distribution system)

There will be appropriate standards that must be met in the final water as part of drinking water quality requirements. These will vary in different countries or regions. In the European Union for example these standards will be, as a minimum, those set in the EC Drinking Water Directive 98/83/EC and any subsequent revisions of the Directive. In the United States of America these standards will be, as a minimum, those promulgated by the Environment Protection Agency as part of the Safe Drinking Water Act. It is suggested that there is no need to tighten these existing standards because wastewater is being reused. However, in addition to these minimum standards, there may be a need for additional standards for other parameters that may be of specific concern in respect to the reuse of treated wastewater. These other parameters will depend on the sources and quality of the raw wastewater, the wastewater treatment provided, the quality of the treated wastewater and the treatment, including the various forms of storage, provided to convert the treated wastewater into drinking water. They will also depend on local public sensitivities and concerns.

There also needs to be appropriate monitoring to check compliance with those standards but this monitoring need not be particularly frequent. In addition to the triggers above there should be relatively frequent operational monitoring. It is suggested that for microbiology, there should be daily monitoring of *E. coli* against a value of 0/100 ml, somatic coliphage against a value of 0/1 ml and colony counts at 22 °C for which there should be no significant increase above the normally expected value. Any exceedence of the first two values and any significant increase in respect of colony counts should be immediately investigated and action taken to rectify any process deficiencies found. Continuous monitoring of turbidity and conductivity as suggested above provide a good indication of the effective removal of microorganisms and chemicals. It is suggested that in addition there should be occasional GC/MS scans to check that no significant concentrations of organic chemicals are present. Consideration has been given to including bioassays, with water that is not disinfected with chlorine, using organisms such as fish, as a sentinel and for reassurance. The value of such assays would need to be determined on a case by case basis.

10.4 Pilots studies of the drinking water treatment process

Before any treated wastewater is used to provide a more direct, or even a direct, source for drinking water supply, it is considered essential that there should be a pilot plant study of the effectiveness of the proposed processes to convert the treated wastewater into drinking water. The pilot plant needs to be of such a size that one can be confident that the results from it will be representative of the results from the full-scale plant. The pilot plant should be used to determine the conditions for operation of the pre-treatment process, the reverse osmosis process, the final re-mineralisation, pH adjustment and disinfection processes and the process controls for each of these processes. The pilot plant has to investigate the effectiveness of the treatment processes and the controls for the normal variations in treated wastewater quality and the source that is abstracted for treatment **and** the variations that might occur when there is an **atypical** challenge such as might occur if there was a failure of wastewater treatment or an outbreak of illness in the community.

10.5 Audit of the drinking water treatment process

So that the public can continue to have confidence in the safety of a scheme using treated wastewater, it is considered necessary for there to be periodic audit, at least annually, preferably carried out by an independent organisation, of the entire drinking water treatment process including the operating procedures and the process controls at each stage of the process.

Figure 7. Framework for the direct recycling of treated wastewater as drinking water supplies

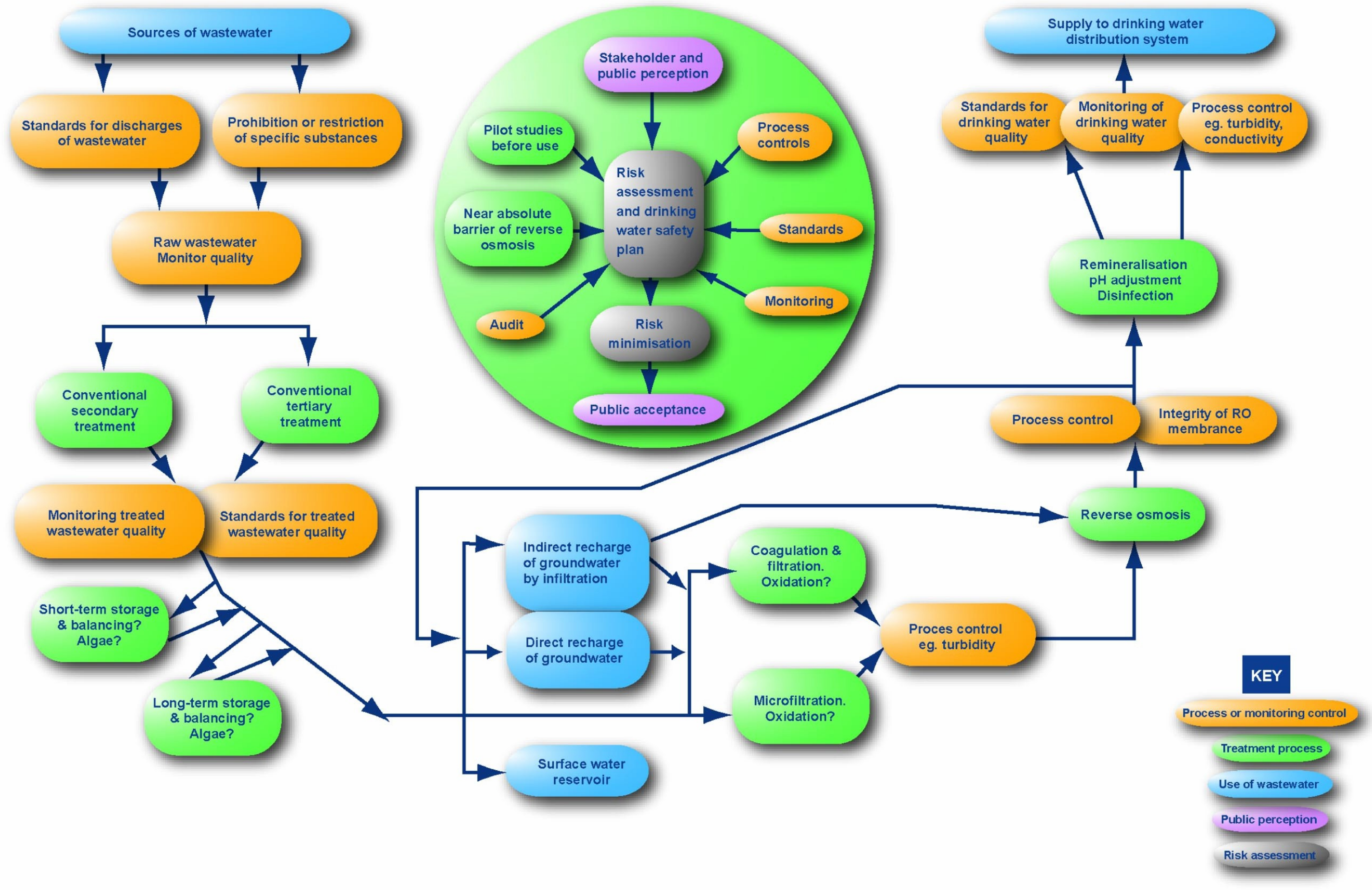


Figure 7 Framework for the direct recycling of treated wastewater as drinking water supplies.

11 Knowledge Gaps

A number of knowledge gaps exist that can potentially restrict the introduction and application of wastewater reclamation and recycling. The requirements for more knowledge are as follows:

- Additional approaches to wastewater treatment, including in sewer treatment, to optimise removal of both pathogens and chemical contaminants

- More extensive research on what can be achieved by both traditional and emerging wastewater treatment processes, alone and in combination, under differing conditions in the removal of both microbial and chemical contaminants, including more recently recognised contaminants such as endocrine disrupters and pharmaceuticals and personal care products, with a specific view to recycling. (Berlin multi-stakeholder R&D NASRI project www.kompetenz-wasser.de)

- Identification of a wider range of suitable operational criteria and how these can be used and monitored on a continuous basis for process control.

- Introduction of improved methods for monitoring pathogens.

- The development of bioassays that can provide additional reassurance to users and consumers.

- Better understanding of the total composition of wastewaters and reclaimed wastewater.

- Information on the variation in specific contaminants in raw wastewater streams, particularly pathogens and some specific chemicals.

- Better basis for understanding the routes of contaminants to man, including uptake of organic contaminants by plants and surface survival of pathogens.

- Better understanding of the economic externalities and their impact, e.g. taxation of disposal of concentrates from RO.

- Better understanding of institutional frameworks and the success or otherwise of various regulatory scenarios.

12 Discussion

Reuse or recycling of appropriately treated wastewater can take a number of forms. These range from the simple use of untreated sewage for agriculture and aquaculture on a small scale in order to take advantage of both nutrients and water, to the use of highly treated wastewater for watering green spaces and sports fields, including golf courses. In addition, there is an increasing move towards using treated wastewater to augment drinking water supplies and to even provide a direct source of drinking water. There are a number of sources of advice as to the quality of water needed for the various uses and on how to achieve such quality. In this document consideration is only given to developed countries and the use of municipal wastewater as a starting point.

The guidelines available show a high degree of overlap and concordance. Most consider reuse from the point of view of good practice and are designed to support a detailed permitting or authorisation system in which each scheme is considered in detail on its merits. The approaches take into account the end use and the potential for exposure to hazards present in the wastewater. There are also proposals with regard to the level of wastewater treatment that would be appropriate. The numerical guidelines regard microbial hazards as the most important for non-potable applications of reclaimed water, but there is some consideration of chemical hazards, especially where these might cause toxicity to crops or result in salination of agricultural land. The consideration of chemical hazards in non-potable applications therefore primarily focuses on inorganic contaminants.

However, in order to further promote recycling of wastewater as a means of replacing drinking water and drinking water resources, there is a clear need for a framework to assist users in developing criteria for wastewater recycling in a wide range of circumstances. In particular, public perception is potentially a major hurdle and an internationally recognised means of demonstrating that appropriate barriers are in place and that those barriers are optimised at all times will be a key factor. In this respect there is a need to provide an approach that is both practical and transparent.

In order to achieve this there are five elements that are necessary:

- A set of numerical and scientifically-based guidelines or standards that provide a target for wastewater and, where appropriate, drinking water, treatment and to provide a means of final verification that the quality of recycled water in use will not cause damage or adverse health effects.

- A set of operational and process controls, with appropriate fail-safe systems, that apply to the wastewater treatment system and any subsequent treatment for particular uses, particularly in respect of drinking water

- A set of wastewater treatment guidelines or standards that apply to a range of uses with increasing treatment levels as the potential risks of consumer exposure increase.

- A set of controls associated with the end uses of recycled water that will provide another layer of barriers to exposure of consumers/crops/livestock to both microbial and chemical hazards.

- An adaptation of the use of HACCP as used in the Water Safety Plans proposed by WHO and encompassed in the Bonn Principles in order to provide a management structure that will ensure the risks of the process breaking down are minimised and that this can be externally verified.

This combination of elements provides a transparent means of assuring the safe and acceptable use of recycled water. It also provides a practical framework that allows recycling to be considered by existing wastewater treatment plants and for the planning of new facilities.

The final high-level framework and the detailed frameworks require that the need for recycling be accepted by the community. It is also necessary that the community and the customers of producers using recycled water accept it to be demonstrably safe. Without these steps there is a significant danger that the generally adverse perception of wastewater recycling will prevent projects from going ahead. It is, therefore, essential that there is extensive consultation with stakeholders and the public throughout the process.

Consideration is also required of the catchment for wastewater and the sources that may impact on the quality and treatability. Controls over discharge to sewer are increasing and there is a need to make clear the consequences to the resource of some discharges and particularly accidental or deliberate release of chemicals or mixtures that can threaten the wastewater treatment process.

The framework is based on appropriate quality of recycled water for particular uses. Such a premise can also be considered in reverse in finding appropriate applications for a particular quality of wastewater. Matching quality against final use requires consideration of the receptor sensitivities, be it crop, livestock or human, and the food chain where food crops or livestock are potentially impacted. In the case of drinking water, additional barriers will necessarily be applied for both safety and acceptability.

The final consideration is that of the reliability of the barriers and controls and a means of demonstrating and verifying that reliability.

The detailed frameworks take these concepts and apply them in more detail. Drinking water is regarded separately from other applications of recycling because of the direct exposure of humans by ingestion and the need for significant additional treatment.

13 Conclusions

The recycling of wastewater provides an important and valuable resource that reduces the reliance on drinking water and high quality sources that might be used for drinking water.

The framework provides a means of identifying a way to set standards or criteria at a national or local level that builds on existing international practice but provides a more formal structure that is applicable to a wide range of circumstances.

The most flexible approach is to introduce effective process controls and further treatment, as required, supported by process monitoring and a limited number of numerical standards.

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WateReuse Association Annual Symposium September 7-9, 2003, San Antonio, Texas.

WateReuse Association Annual Symposium September 19-20,2004, Phoenix, Arizona.

Appendix 2 GLOSSARY

Aquaculture	The production of aquatic plants and animals for use of and consumption by humans.
ASR	Aquifer storage and recovery is the injection of reclaimed water into an aquifer for subsequent recovery from the same site for further use.
ASTR	Aquifer storage, transport and recovery is the injection of reclaimed water into an aquifer for subsequent recovery from a different site as a means of indirect potable reuse.
AwwaRF	American water works association Research Foundation.
BOD	Biochemical oxygen demand is a measure of the amount of oxygen consumed by microorganisms during the oxidation of organic material in a water sample over a 5 day incubation period.
Confined aquifer	A layer of water underground that is trapped below an upper impermeable layer of material, usually clay.
DALY	Disability adjusted life year.
Direct potable reuse	The conversion of wastewater directly into drinking water without any interim storage.
Disinfection	The use of physical or chemical processes to reduce or remove microorganisms from water.
DOC	Dissolved organic carbon.
Endocrine disruptors	Chemicals, both natural and man-made that interfere with endocrine glands and their hormones, or where the hormones act in animals and humans.
HACCP	Hazard analysis and critical control point.
Hydrophobic	Molecules or molecular groups that mix poorly with water.
Indirect potable reuse	The use of reclaimed water for potable supplies after a period of storage in surface or a groundwater.
MBR	Membrane bioreactor.
MLSS	Mixed liquor suspended solids.

Non-potable reuse	The use of reclaimed water for other than drinking water, for example, irrigation.
NTU	Nephelometric turbidity unit.
Nutrients	Inorganic compounds nitrate and phosphate in wastewater that can encourage the growth of algae.
pH Value	A measure of the acidity or alkalinity of liquids.
Primary treatment	The first stage of wastewater treatment which may consist of screening, grit removal and settlement.
Raw wastewater	Wastewater that has not received any treatment.
Reclaimed water	Treated wastewater suitable for purposes such as irrigation.
Salination	An increase in salts in wastewater and the subsequent accumulation of those salts in soil following irrigation. Some plant species are more resistant to salination than others.
Secondary treatment	The application of a biological treatment process, either activated sludge or trickling film (fixed film bioreactor) to primary treated wastewater.
SS	Suspended solids.
Tertiary treatment	Advanced wastewater treatment beyond secondary treatment to remove organic material, suspended solids, nutrients and microorganisms.
TOC	Total organic carbon.
TSS	Total suspended solids.
UKWIR	United Kingdom Water Industry Research.
Unconfined aquifers	A layer of water underground found below porous layers allowing water to percolate directly into the aquifer. This makes them more susceptible to contamination.
Vadose zone	The unsaturated soil layer above an aquifer through which water will flow.
Wastewater	Used water derived from communities and industry.
Water safety plans	A system designed to ensure safe drinking water by preventing contamination during collection, removal of

	contaminants during treatment and prevention of contamination during distribution and consumption of water.
Wetlands	Land where saturation with water is the dominant feature. The saturated soil defines the types of plants and animals living on and in the wetland.
WHO	World Health Organisation.
WRF	WateReuse Foundation.
WSP	Waste stabilisation ponds**.**

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Appendix 4 HYPOTHETICAL CASE STUDY OF THE REUSE OF TREATED WASTEWATER TO SUPPLEMENT DRINKING WATER SUPPLIES

Introduction

This hypothetical case study looks at the need for an additional resource, derived from reusing treated wastewater, to supplement existing water resources that are abstracted for treatment for drinking water supplies. It follows the framework for Drinking Water described in Section 8 of this report and is a worked example of the use of that framework.

The Need for Additional Water Resources

The Forward Thinking Water Supplier (FTWS) supplies about 300 Megalitres per day (Mld) on average, with a record output of 375 Mld, to a population of about 1.1 million people in a mixed urban and rural area with some arable agriculture. Average annual rainfall in the area is about 500 mm that, after allowing for losses through evapotranspiration, gives an effective annual rainfall of about 100 mm. Parts of the area receive less rainfall and are classed as semi-arid by the United Nations.

Currently the water supplies are drawn from two main rivers in the area and stored in two large surface water reservoirs before being treated at three water treatment works. There are no usable aquifers in the area to provide a ground water source. Water is abstracted from these rivers (they do contain some treated wastewater effluent) mainly in the winter months to fill the two reservoirs and these reservoirs are drawn down in the summer months when river flows are low. Existing resources within the FTWS area are fully utilised. Increasingly in recent years FTWS has had difficulty maintaining supplies in the summer months because of shortage of water resources and has had to resort to restrictions on use such as prohibiting use of hosepipes for garden watering.

The population in the area is rising steadily as is the per capita use of water and there is considerable uncertainty over the potential effect of climate change on future weather patterns and therefore on water resources. The FTWS has a long term plan to import a significant quantity of surface water from a neighbouring water supplier and to increase substantially the size of one of its reservoirs to store this water. With the need for consent from the Environment Agency and the Planning Authority including an Environmental Impact Assessment, the design of the scheme and the construction of a large fairly long pipeline and extension to the reservoir, it is likely to be 15 to 20 years before the scheme comes to fruition. Meanwhile in the short term there is an urgent need for an additional resource of about 30 Mld within at the most five years.

Because there are no other local resources, the FTWS needs to consider reusing treated wastewater. It has identified a potentially suitable treated wastewater belonging to the Newtown Wastewater Treatment Company (NWTC). It has considered how treated wastewater might be used instead of piped drinking water supplies for a variety of agriculture and golf course irrigation schemes and for some urban irrigation and recreational uses within Newtown. However it is not practical to use treated wastewater for these without building a substantial and costly dual pipeline system. So the only practical possibility is to use treated wastewater to supplement the existing sources that are currently treated for drinking water supplies.

The Potential Treated Wastewater Source

The potential treated wastewater source is shown in diagram 1 below with its relationship to the New River, the Newtown Reservoir and the existing Newtown Drinking Water Treatment Works. The Newtown Wastewater Treatment Works treats the domestic sewage from Newtown together with a number of consented industrial discharges to the sewers. The treatment consists of screening, primary sedimentation and trickling filters and the effluent is discharged to New River Estuary below the tidal limit with a consent of BOD_5 of 30 mg/l and suspended solids of 40 mg/l. Water is abstracted from the Newtown River some 5 km upstream of the tidal limit into Newtown Reservoir. This reservoir has an average retention time of over 100 days. The Newtown Drinking Water Treatment Works consists of coagulation with aluminium sulphate, settlement, rapid gravity sand filtration, granular activated carbon filtration to remove pesticides and final chlorination.

Diagram 1

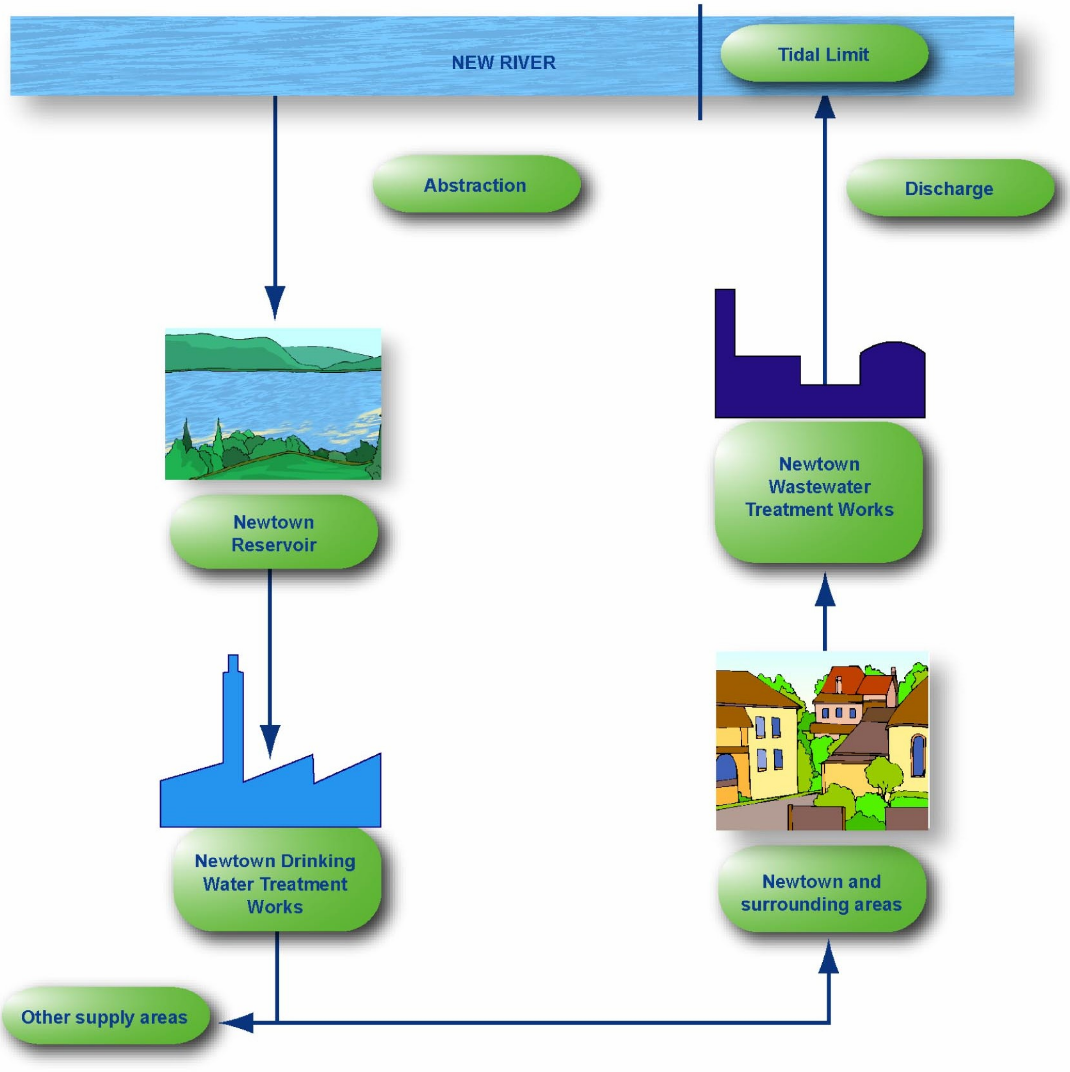

Diagram 1.

There a number of potential ways in which the treated wastewater could be reused following additional treatment either at the wastewater treatment works or the drinking water treatment works or at both. These ways are:

- **Option 1** – additional treatment of the wastewater at the Newtown Wastewater Treatment Works and discharge to the New River upstream of the Newtown Reservoir with or without additional treatment at the Newtown Drinking Water Treatment Works;

- **Option 2** - additional treatment of the wastewater at the Newtown Wastewater Treatment Works and discharge directly to the Newtown Reservoir with or without additional treatment at the Newtown Drinking Water Treatment Works; and

- **Option 3** - additional treatment of the wastewater at the Newtown Wastewater Treatment Works and discharge to the inlet of Newtown Drinking Water Treatment Works with or without additional treatment at that Works.

These options are shown in red on diagram 2.

Diagram 2

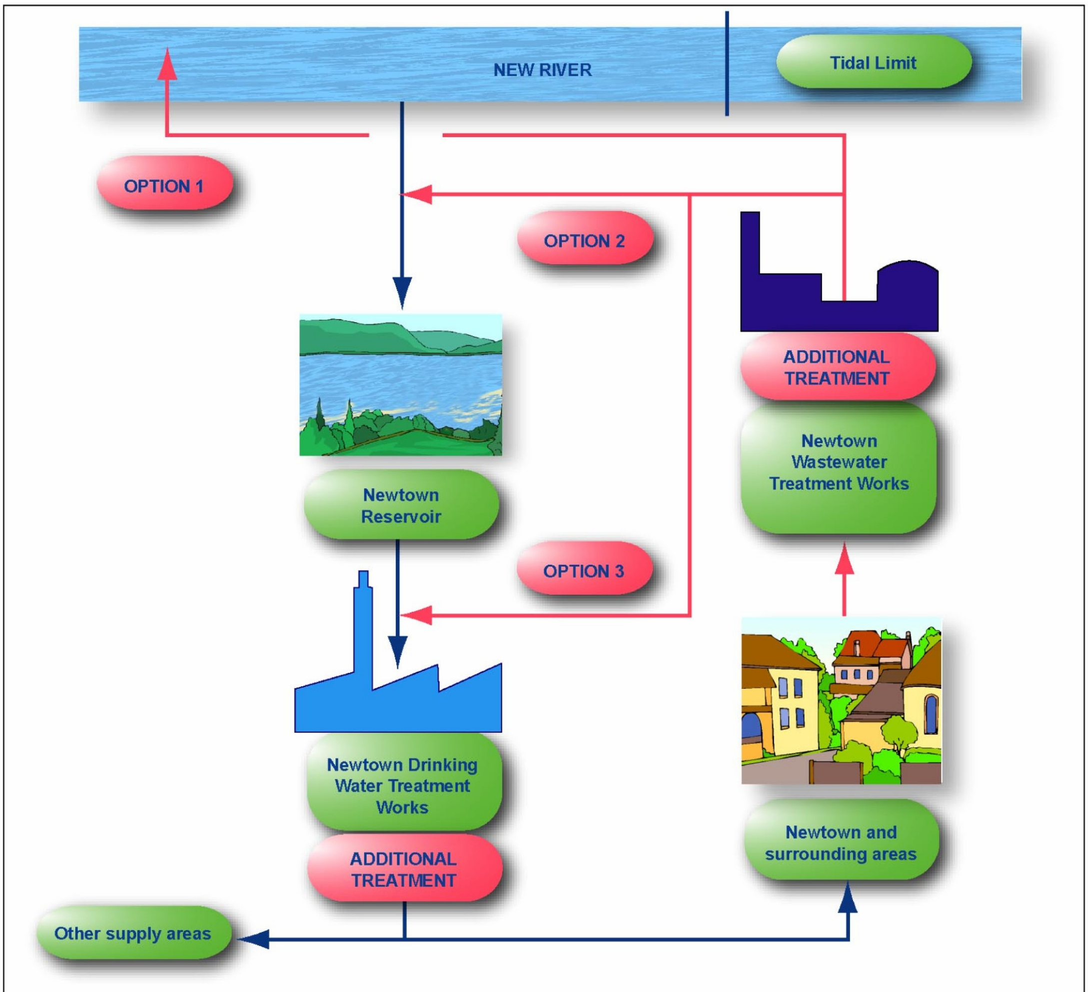

Diagram 2.

Public Perception and Public Acceptance

The FTWS held a series of initial public meetings at various locations in Newtown and surrounding areas. At these meetings the FTWS explained:

- the need for an additional resource in the short term in the next five years;
- that the only available resource was to reuse treated wastewater;
- the three options for reusing treated wastewater and the estimated costs of these options and the impact on users' bills;
- the pilot studies being planned to test these options, including the additional treatment processes proposed at the wastewater treatment works and at the drinking water treatment works;
- how a risk assessment of the entire process for each option would be carried out and a dinking water safety plan produced that would minimise any risk;
- how various process controls, including fail safe systems, would be put in place and how there would be operational monitoring against criteria derived from the drinking water safety plan and compliance monitoring against standards; and
- how audits of the entire process would be carried out at regular intervals to make sure that the selected option was operating fully satisfactorily.

The public at these meetings reluctantly but generally accepted that treated wastewater would need to be used as a drinking water resource. Their acceptance was influenced by the fact that some treated wastewater is already present in the New River as a result of discharges well upstream of the abstraction point for the Newtown Reservoir. The public showed a clear preference for option 1 because it provides the maximum separation of the treated wastewater from the drinking water treatment plant, with the discharge point of the treated wastewater being sited as far upstream of the abstraction point as reasonably practical. Option 1 is also probably the best way of dealing with fluctuating demand for drinking water supplies because any excess treated wastewater that is not needed to supplement the sources used simply flows down the New River to the estuary.

Sources of Wastewater

The FTWS asked the NWTC to carry out a full inventory of all the industrial discharges to the sewerage system that feeds the Newtown Wastewater Treatment Works. This inventory included the existing conditions for consent to discharge plus all the substances likely to be present and their estimated concentrations. The FTWS, NWTC and the Environment Agency (EA -responsible for discharges to rivers) considered the inventory in the context of the three options.

There were two industrial discharges that gave concern in relation to the treated wastewater being discharged to the New River upstream of the tidal limit or to the Newtown Reservoir and to the subsequent treatment for drinking water supply. One was a pharmaceuticals manufacturer and the other a manufacturer of a range of synthetic organic chemicals used in the rubber and plastics industry. The substances involved were not of concern when the treated wastewater was being discharged below the tidal limit because of the very large dilution in the estuary. It was decided that the discharge consents for these two industrial effluents should be tightened considerably in order to protect wildlife in the New River or Newtown Reservoir and to provide an additional margin of safety for drinking water supply. A limit on total organic carbon was set, together with limits on some individual substances of concern. This required the industrial organisations to make some changes to their manufacturing processes, to introduce a treatment stage before discharge to the sewer and to monitor and record daily the quality of the discharge. The NWTC would also monitor these industrial discharges to the sewer on a monthly basis to check that the discharge consents were being met.

Treatment of Wastewater

The EA decided that if the treated wastewater was going to be discharged to an inland water (New River or Newtown Reservoir), it would need to tighten the discharge consent to BOD_5 of 20 mg/l and suspended solids of 20 mg/l and additionally add consent conditions of 30 mg/l nitrate and 1 mg/l phosphate in order to prevent eutrophication and excessive growth of algae in the Newtown Reservoir. Consideration was given to disinfection of the treated wastewater before discharge but it was decided that this was not necessary as the microbiological quality of the effluent was likely to be at least as good as that in the New River or the Newtown Reservoir.

Pilot studies of the available wastewater treatment processes indicated that these new consent conditions could be met by the following additional processes:

- addition of ferric sulphate and polyelectrolyte to precipitate the phosphate followed by separation in a lamella clarifier;
- an anaerobic biological denitrifying column using methanol as the carbon source to convert nitrate to nitrogen gas and a further aerobic (aerated) denitrifying column to remove ammonia and reduce the BOD from the previous stages; and
- a sludge dewatering plant with the dewatered sludge being disposed to landfill.

The extended wastewater treatment process would be monitored daily by the NTWC to check that the discharge consent conditions set by the EA were being met. The EA would check the records of that monitoring monthly and it would also check monthly by its own monitoring that the discharge conditions were being met.

Storage

Following the public consultation, the FTWS decided that option 3 (discharging the additionally treated wastewater directly to the inlet to the Newtown Drinking Water Treatment Plant) would not be publicly acceptable even though it was confident that it could provide additional treatment to make the drinking water safe. A further factor was that any treated wastewater that was not required as a source would need to be discharged so it would be necessary to maintain the existing discharge to the New River downstream of the tidal limit. It also decided that it could discharge the treated wastewater into the New River about 2 km upstream of the abstraction point (option1) for a relatively small extra cost compared with discharging it directly to Newtown Reservoir (option 2). Option 1 is the preferred option publicly because of the greater separation of wastewater from drinking water. But it also has additional benefits because there is considerable dilution in the New River and the opportunity for limited further improvement in quality from natural processes as the water travels the 2 km to the abstraction point. Therefore FTWS decided only to pursue option 1.

Drinking Water Treatment

The existing treatment consists of coagulation with aluminium sulphate, settlement, rapid gravity sand filtration, granular activated carbon adsorption and disinfection. In order to secure public confidence FTWS decided that a reverse osmosis plant would be added to provide a barrier against practically every substance likely to be present in the treated wastewater and the pre-treated drinking water. The design output of the existing works is 120 Mld, although it has occasionally exceeded this throughput when demand has been very high. The average output is about 100 Mld. FTWS is aware that when the output rises above about 100 Mld there is a decline in quality as the coagulation, settlement and filtration process approaches its design output although the final water meets the current regulatory standards. The average output with the proposed new scheme would rise steadily to about 130 Mld and would occasionally exceed 150 Mld. The FTWS decided that it would add additional coagulation, settlement and filtration capacity to bring the design output up to 160 Mld. The granular activated carbon adsorption plant and the disinfection plant is already capable of treating 160 Mld. The additional coagulation, settlement and filtration plant together with the granular activated carbon adsorption plant should assure the quality of water going to the reverse osmosis plant in all foreseeable conditions.

The FTWS also considered whether an oxidation stage using ozone or UV irradiation with hydrogen peroxide should be added as a pre-treatment stage before reverse osmosis. There is uncertainty about whether this would benefit the overall process and improve water quality. FTWS decided to look at the whether oxidation benefited water quality in the pilot study.

The reverse osmosis plant would be designed for an output of 160 Mld. The pilot study would be used to determine the controls and monitoring needed for this plant. About 20% (up to 30 Mld) of the influent water is reject water and needs to be disposed. FTWS had discussions with the EA and the latter agreed to the discharge of the reject water at a point just downstream of the tidal limit on the New River. Because reverse osmosis removes most of the mineral content of the water, it is necessary to remineralise the water using appropriate salts of calcium and magnesium an to adjust the pH value of the water to ensure it is not corrosive to the materials of the distribution system. Following this process the water is disinfected using the breakpoint chlorination process with the final chlorine residual adjusted by addition of sulphur dioxide.

Pilot Studies of the Proposed Drinking Water Treatment Processes

A pilot plant, capable of treating 1 Mld, was constructed to test the proposed drinking water treatment process. The pilot plant utilised the effluent from the pilot wastewater treatment process that had been diluted with water from Newtown Reservoir to the degree estimated to exist when the scheme came into operation. The pilot plant was also run with only half the expected dilution to represent a worst-case scenario as identified in the risk assessment. Various stages of the drinking water treatment process were monitored for appropriate operational and control parameters.

Comparison of the results obtained with and without an oxidation pre-treatment stage showed no drinking water quality benefits from oxidation. Consequently FTWS decided that it would not install an oxidation stage. The pilot studies confirmed that the final drinking water quality met all the regulatory standards and was significantly better than the majority. The pilot studies allowed the FTWS to establish operational control criteria and operational monitoring criteria for each process that would ensure that the treatment processes were operating correctly. If any of these criteria were exceeded for a short, but defined period of time, the FTWS decided that on the full scale plant there would be either automatic or manual plant shut down as an additional safety feature.

Monitoring and Control of the Drinking Water Treatment Processes

The risk assessment and the pilot plant studies enabled the FTWS to set the following criteria for monitoring and control of the various stages of the treatment processes:

- coagulation, settlement and filtration stage:
    - optimum coagulant dose 20 to 25 mg/l aluminium sulphate;
    - optimum coagulation pH value 6.6 to 7.0; and
    - continuous monitoring of filtered water turbidity from each filter. If turbidity from any filter exceeds 0.2 NTU for more than 2 minutes that filter will automatically be taken out of service, and alarm status will require immediate investigation of the cause. If there appears to be any problems with other filters the treatment works would be shut down.
- Granular activated carbon adsorbers:
    - weekly monitoring of the water from the GAC adsorbers for the specific pesticides that the GAC is designed to remove (this is an existing control); and
    - continuous monitoring of the water from the GAC adsorbers for TOC to check that it is within the expected range of 2.0 ± 0.3 mgC/l. Values above this range mean that the organic content of the water is higher than expected and the operation of the reverse osmosis plant should be carefully checked to make sure it is removing the additional organic material.
- Reverse osmosis:
    - continuous monitoring of the product water for TOC. If the TOC exceeds 0.2 mgC/l for more than 1 minute it indicates that the integrity of the plant has been compromised (failure of part of the membrane) and the treatment works will automatically be taken out of service and the plant investigated immediately; and
    - continuous monitoring of the product water for turbidity. If the turbidity exceeds 0.1 NTU for more than 1 minute that indicates that something unexpected has passed through the reverse osmosis plant and the treatment works will automatically be taken out of service and the cause immediately investigated.

- Remineralisation, pH adjustment and disinfection:
    - addition of calcium chloride to give 15 mg Ca/l and magnesium chloride to give 10 mg Mg/l;
    - addition of sodium hypochlorite to achieve breakpoint and after an appropriate contact time, partial dechlorination with sulphur dioxide to give a final chlorine residual of 0.4 mg Cl/l; and

addition of sodium hydroxide and carbon dioxide to give a pH value of 8.3 ± 0.2.

Final Drinking Water Quality Monitoring

The FTWS set the following criteria for operational monitoring of final drinking water quality:

- continuous monitoring of chlorine residual with alarm when below 0.3 mg/l leading to immediate investigation;
- continuous monitoring of pH value with alarm when outside 8.3 ± 0.2 leading to immediate investigation;
- continuous monitoring of turbidity with alarm when above 0.1 NTU leading to immediate investigation;
- daily monitoring of *E. coli* against a value of 0/100 ml with investigation of any detection;
- daily monitoring of somatic coliphage against a value of 0/1 ml with investigation of any detection;
- daily monitoring of colony counts at 22 ^{o}C with investigation of any value outside the normally expected range; and
- weekly monitoring using GC/MS scan to check that no significant concentrations of organic substances are present.

FTWS will also carry out compliance monitoring at the prescribed regulatory frequencies for all the regulatory parameters either in the final water leaving the treatment works or at consumers' taps as appropriate. FTWS also discussed the risk assessment with the Drinking Water Inspectorate (DWI) to consider whether additional specific substances should be subject to monitoring. It was agreed that the above monitoring was sufficient and there was no need for monitoring for additional specific substances.

Audit of the Drinking Water Treatment Process

The FTWS decided that it would carry out its own internal audit of the drinking water treatment process every six months. This audit would include a review of the documented operating procedures, the controls and the monitoring for each part of the process, a check that these documented procedures were actually being used in practice and a review of the results of the operational and compliance monitoring. This audit, if necessary, would also lead to a review of the risk assessment. Similarly the Drinking Water Quality Regulator has informed the FTWS that it will be carrying out an unannounced annual audit of the whole drinking water treatment process as part of its routine inspection.

Public Perception and Public Acceptance

FTWS held a second series of public meetings at various locations in Newtown and surrounding areas. At these meetings the FTWS explained:

- how it had used the opinions expressed at the first series of public meetings;
- the risk assessments it had carried out;
- the decision to pursue option 1, the option most favoured by the public;
- the pilot plant to investigate option 1 and the results of those investigations;
- the additional treatment processes it proposed to construct;
- the operational controls, criteria, fail safe systems and monitoring it proposed to put in place to ensure that the treatment processes delivered drinking water that met all the standards and other requirements and was safe;
- the compliance monitoring it would be carrying out against the standards; and
- the audits of the whole process that it and the Drinking Water Quality Regulator would be carrying out once the additional plant was constructed.

The public were reassured by all the safeguards, controls and monitoring that FTWS proposed to put in place.

The final scheme is shown in diagram 3 below:

Diagram 3

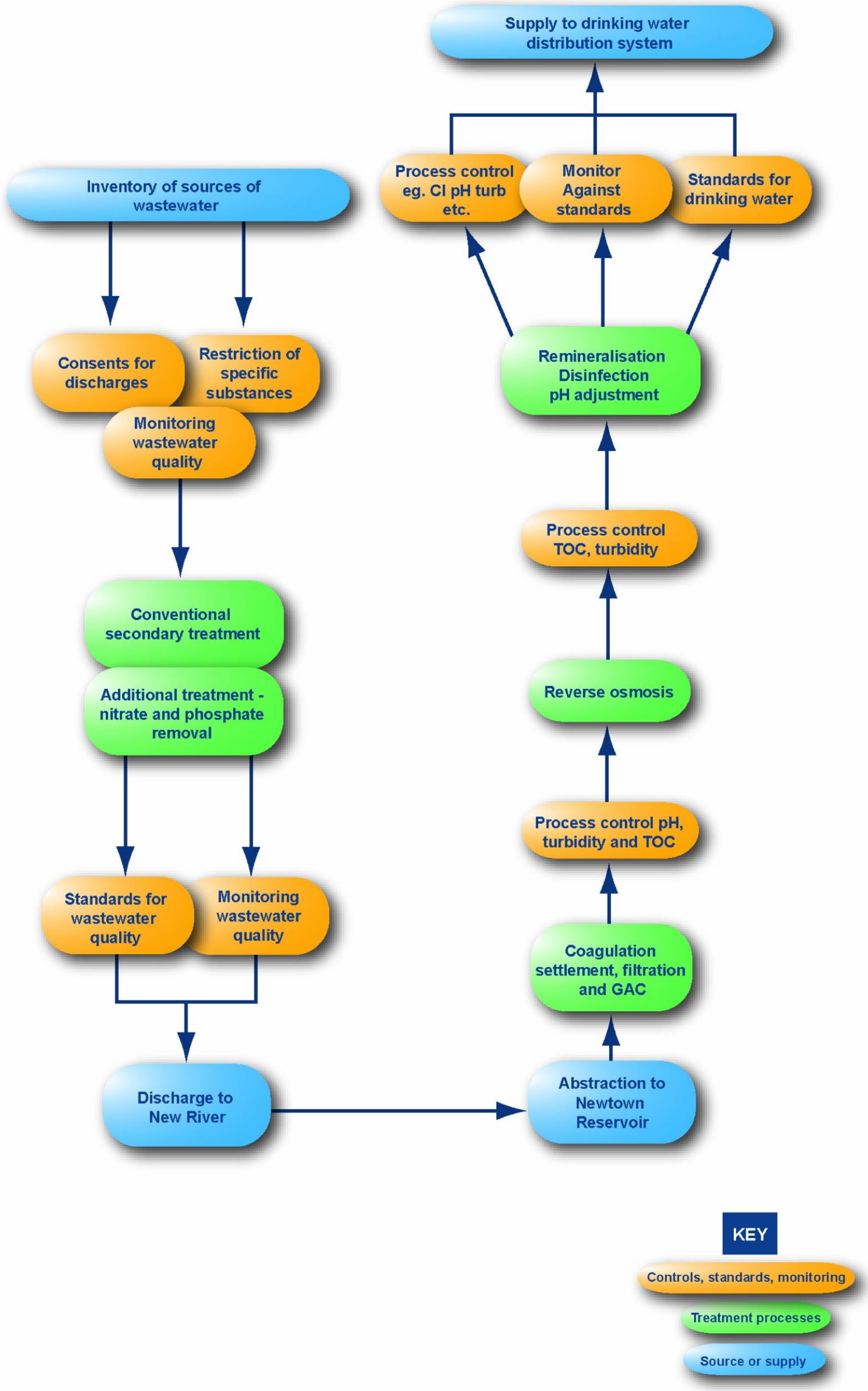

Diagram 3.

Appendix 5 HYPOTHETICAL CASE STUDY OF THE USE OF TREATED WASTEWATER TO REPLACE WATER TAKEN FROM A POTABLE WATER SOURCE

Introduction

The Forward Thinking Water Supply Company (FTWSC) supplies 300 Mld to a small town set in an area of limited and largely seasonal rainfall. The town is expanding but planners wish to make the area attractive by providing a number of green facilities. Local agriculture also uses a significant quantity of water, primarily groundwater, to supply crops for both the local market and for sale in other parts of the country, much of it through supermarkets.

The only reasonable source of water is groundwater and the capacity is rapidly being reached in summer. A period of low recharge of groundwater would cause severe difficulties within a period of 3 years. The sewage treatment provided by a sister company, the Forward Thinking Wastewater Treatment Company (FTWWTC) delivers an effluent that is discharged away from the town into a small river that provides some dilution in winter. The river is not available for use as a drinking water source due to environmental considerations although there is a small amount of abstraction for agriculture. It is probable that the environmental considerations will result in much tighter quality requirements on the discharge of treated effluent to the river and there is also likely to be further restriction on agricultural abstraction.

The FTWSC has shown that it can only meet the demands for expansion of the town by conserving the groundwater resources and/or by using the surface water from the river. While some members of the community are opposed to expansion of the town, there will be advantages in attracting alternative industries. The FTWSC has explained the strategy to local government, which is highly supportive.

The wastewater is treated by the FTWWTC using an activated sludge plant. However some form of tertiary treatment will be required in the future to improve nutrient removal and to improve the effluent quality for reuse.

The reclaimed water can be pumped into a series of depressions to form artificial lakes that provide a means of storage and can balance the demand. One of these areas would be suitable for the development of a reed bed of suitable size to achieve significant nutrient removal and would add to the wildlife habitat and amenity value of the area. The use of a series of lakes enables greater control over the flow and acts to dilute the perception of treated wastewater. The microbiological quality in the final lake is adequate to allow water sports such as sailing and sailboarding to provide a recreational centre. This will also provide a degree of ground water recharge and indirect supplementation of potable water sources.

The reclaimed water can be taken from the largest lake or the penultimate lake and is used to irrigate green areas for recreation and civic gardens in both the new areas of the town and in the older areas of the town. Irrigation is carried out using spray systems but the public are excluded during the spray phase as a precautionary measure.

As the quantity of wastewater increases, it will be used to provide water for agricultural irrigation. This will be achieved by a series of irrigation channels that are fed through an area of constructed wetland to increase the retention and improve the treatment. This also provides an opportunity for groundwater recharge with SAT. Additional agricultural areas can be served by the establishment of storage ponds and tankering recycled water that has been through the wetland treatment.

Not all of the residents are happy with the expansion of the town although most recognise that expansion is necessary if the facilities are to maintained and improved. There is also some friction between the farming community and some of the residents, particularly those who do not depend on agriculture and food production for their livelihood. There is, therefore, a small but potentially very vocal minority who are likely to oppose the scheme as a means of blocking expansion or to antagonise the farming community. The local council have established a stakeholder forum in advance of the process to examine possible options. Having done this and achieved a considerable level of acceptance, there is also the issue of safety because of an increasing number of children as young families move into the area.

The approach used by the FTWSC and the FTWWTC, in conjunction with the council, is to present a series of options that will provide a clear understanding of the barriers in place and the steps being taken to ensure safety and aesthetic quality. The use of the wetland treatment area and the series of lakes have helped to dilute the concept of wastewater and will be supported by a monitoring programme the results for which will be available to the public. The farming community were concerned about safety and demonstrating safety to their customers, particularly the major supermarket chains. This has been achieved by a combination of treatment options that include UV disinfection, and application controls, particularly the use of trickle irrigation for edible crops. Meetings have been held with representatives of the major supermarket chains and the scheme has been presented on the basis of sustainability since the supermarkets increasingly want to be seen as sustainable. A demonstration project has been established with a pilot plant and a small wetland area. The FTWSC has worked closely with the agency responsible for environmental protection, including ground and surface water protection to ensure that the selected approaches will receive the full support of the agency. The safety aspects are supported by bioassay using fish to demonstrate both short and long-term safety for the environment.

The scheme has been established with full recovery of additional costs over the existing costs for treatment and discharge of wastewater. Land costs were borne to a significant extent by the community by using the minimum of agricultural land; the wetland areas and lakes are owned by the community but with appropriate legal safeguards for the continuation of the scheme. There is also an offset of increasing future costs for license to discharge to the environment and the increased revenue for both drinking water supply and sewage disposal from the increased number of both domestic and commercial customers with the expansion of the town.

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