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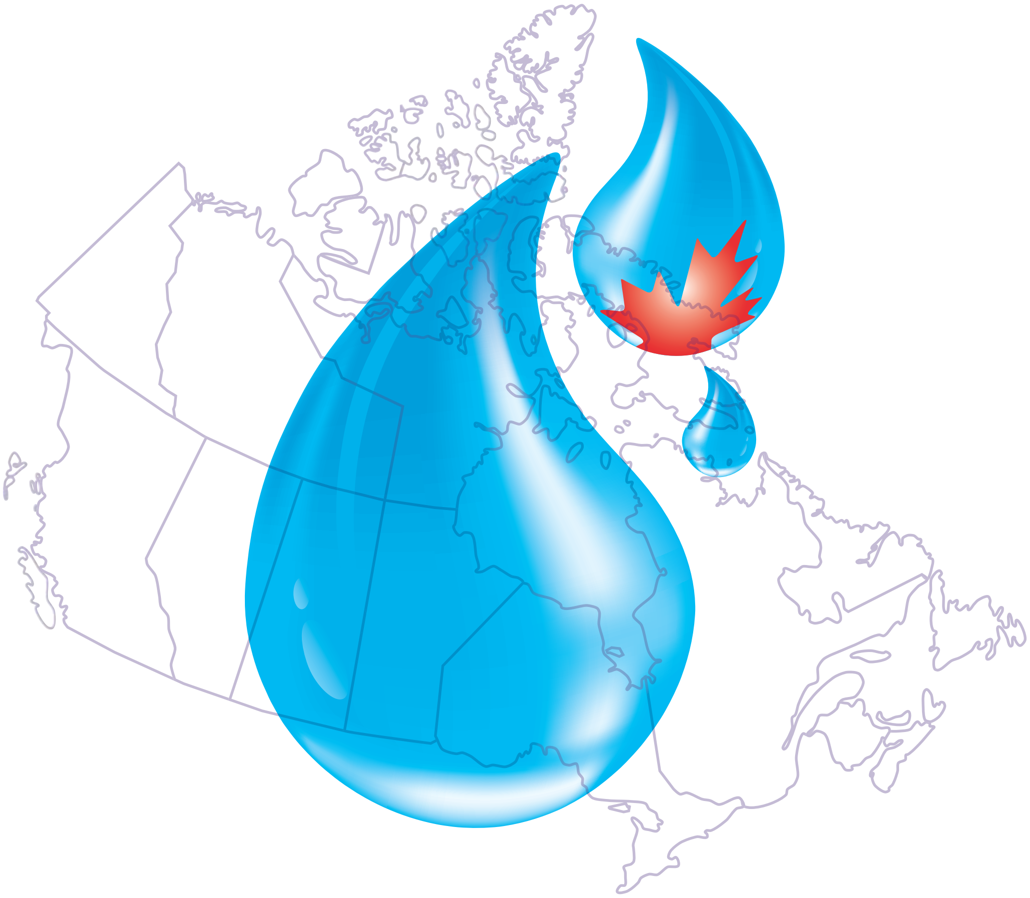
Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing



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Published by authority of the
Minister of Health

Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing is available on Internet at the following address: www.healthcanada.gc.ca

Également disponible en français sous le titre :
Recommandations canadiennes sur les eaux domestiques recyclées destinées à alimenter les chasses d'eau des toilettes et des urinoirs

This publication can be made available on request on
diskette, large print, audio-cassette and braille.

For further information or to obtain additional copies, please contact:
Publications
Health Canada
Ottawa, Ontario K1A 0K9
Tel.: 613-954-5995
Fax: 613-941-5366
Email: info@hc-sc.gc.ca

Cat.: H128-1/10-602E
ISBN: 978-1-100-15665-1

Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing

Prepared by the
Working Group on Domestic Reclaimed Water
of the
Federal-Provincial-Territorial Committee on
Health and the Environment

Ottawa, Ontario

January 2010

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Acknowledgements

The contributions of the following individuals to the development of these guidelines are acknowledged:

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This work benefited greatly from the published reports of the Australian Water Conservation and Research Program. It also relied heavily on the information and concepts introduced in the draft *National Guidelines for Water Recycling* (October 2005) prepared by the Environment Protection and Heritage Council of Australia and the Natural Resource Management Ministerial Council of Australia and published in 2006 as the *Australian Guidelines for Water Recycling* (NRMMC-EPHC, 2006).

Executive summary

The Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing have been developed as an option to reduce water consumption, in response to the growing interest in water conservation in Canada. The use of domestic reclaimed water can make significant contributions to reducing water use. However, domestic reclaimed water must be treated and managed effectively, as there is a potential health risk to users, particularly from pathogens that can be responsible for severe gastrointestinal illness. Although the long-term goal is to develop comprehensive guidelines to allow the safe use of reclaimed water for many beneficial purposes, the focus of this version of the guidelines is limited to the specific end use of toilet or urinal flushing.

This document provides guidelines for domestic reclaimed water quality, as well as guidance on potential elements of a management framework (Part I) and an overview of the scientific basis for the guidelines (Part II). It recommends possible elements of a management framework that are applicable to on-site or decentralized treatment of domestic water for reuse in residential or commercial toilet and urinal flushing. Plumbing requirements for non-potable water systems are addressed by CSA Standard B128.1-06/B128.2-06, Design and installation of non-potable water systems/Maintenance and field testing of non-potable water systems (CSA, 2006).

The objective of establishing guidelines for domestic reclaimed water is to ensure that the operation of water reclamation systems is protective of public health. Consequently, the guidelines include values for several water quality parameters that have been selected because they can demonstrate the effectiveness of treatment on an ongoing basis.

These guidelines are intended for use by regulatory authorities, public health professionals, engineering consultants and others with a technical understanding of the subject area.

Health effects

There are situations where the use of domestic reclaimed water to flush toilets (and urinals in commercial buildings) can make significant contributions to reducing water use. However, the presence of pathogenic microorganisms (bacteria, protozoa and viruses) and some chemicals in domestic wastewater may pose a health risk if the wastewater is improperly treated or if it is used for purposes other than toilet or urinal flushing.

Although effective treatment can produce domestic reclaimed water that is virtually free of disease-causing microorganisms, a small number of pathogenic organisms may still be present and pose some risk, such as in the case of accidental cross-connections between the reclaimed system and the drinking water system. This can lead to ingestion of water containing human enteric pathogens that can cause severe gastrointestinal illness. This is of particular concern for susceptible individuals, such as infants, the elderly and those who have compromised immune systems, for whom the effects may be more severe, chronic (e.g., kidney damage) or even fatal. Users of domestic reclaimed water for toilet and urinal flushing may also accidentally ingest very small volumes of water through aerosols or hand-to-mouth contact with droplets.

Exposure to chemicals from the domestic reclaimed water is expected to be minimal when compared with other domestic exposures. Consequently, the health impacts from exposure to chemicals in domestic reclaimed water used only for toilet and urinal flushing are also expected to be minimal.

Management framework

Management of on-site reclaimed water systems is of particular importance. Such systems could include collection and treatment of water from single domestic dwellings or from clusters, such as apartment buildings. Although they will affect fewer people than will large systems, small systems, from a process perspective, may have a complexity similar to that of larger systems. The potential health risks associated with decentralized domestic reclaimed water treatment systems mean that there is a need for a high level of treatment reliability and oversight.

It is recommended that authorities develop and implement a management program for domestic reclaimed water systems, giving due consideration to the protection of public health, local administrative and operational capacity, and economic considerations. A site-specific risk assessment should be conducted initially to determine the appropriate levels of microbiological reduction or inactivation needed for the specific system. Treatment technologies used should consistently achieve the guideline levels established in this document. Operational oversight, inspections and ongoing monitoring should form key components of a management program to ensure that treatment of reclaimed water is effective on a long-term basis.

1.0 Introduction

Canadians are some of the highest per capita users of water in the world. According to Environment Canada's "Freshwater Website" (www.ec.gc.ca/water), simple changes to water use habits and domestic equipment can reduce water consumption in the home by up to 40%. There are many measures and strategies that can make a significant contribution to reducing water use. Some are quite common, simple and inexpensive, whereas others are relatively new or ground-breaking. One that fits into this latter category is using reclaimed water. There is a growing interest in using reclaimed water within the context of sustainable water management. Other factors that contribute to the interest in reclaimed water use include:

- the opportunity to provide reliable water services in remote or environmentally sensitive locations;
- overburdened traditional water sources;
- the rising costs of meeting drinking water treatment and wastewater discharge standards;
- the potential to reduce domestic wastewater discharges to water bodies;
- seasonal water shortages and droughts (potentially exacerbated by climate change); and
- population movement to large centres, resulting in changes to the spatial patterns of water demand (Anderson et al., 2001).

Despite the advantages of using reclaimed water, pathogens or chemicals in reclaimed water may pose a risk to human health or the environment. Owing to these risks and the low cost of water in Canada, pursuit of water reclamation has been slow. At present, British Columbia is the only Canadian province to have enacted a reclaimed water standard (Municipal Sewage Regulation) for a variety of applications, including for toilet flushing and irrigation (Government of British Columbia, 1999). Alberta legislation (Government of Alberta, 1993) allows the use of treated municipal wastewater for irrigation; in support of the legislation, Alberta Environment (2000) has produced guidelines to aid in evaluating projects. The *Atlantic Canada Wastewater Guidelines Manual for Collection, Treatment, and Disposal* includes a chapter on reclaimed water use, with a focus on irrigation (Environment Canada, 2006). Other provinces use a case-by-case approach to proposed water reclamation projects. In the absence of guidelines, some jurisdictions are using demonstration or test sites to explore water reclamation (CMHC, 1997; Ho et al., 2001).

Several reports have concluded that guidance and leadership from senior government on reclaimed water are needed to ensure that it is incorporated into future water management strategies (Marsalek et al., 2002; Brandes and Ferguson, 2004). It has been noted that two major barriers to the adoption of water reclamation as a strategy are 1) the lack of standards for plumbing requirements for non-potable water systems and 2) the lack of national guidelines for reclaimed water quality (CMHC, 1997). CSA (2006) has developed CSA Standard B128.01-06/B128.2-06, Design and installation of non-potable water systems/Maintenance and field testing of non-potable water systems, which addresses plumbing requirements. This current document addresses the second barrier and will contribute to the development of a consistent, national approach for the safe and sustainable use of domestic reclaimed water.

1.1 Scope of the document

This document provides guidelines for domestic reclaimed water quality as well as guidance on potential elements of a management framework. Part I of the document provides guidance on management frameworks and models, and Part II outlines the scientific basis of the water quality guidelines. The guidelines and management guidance presented in this document are applicable only to water reclamation where the water source is domestic wastewater or grey-water and the end use is toilet or urinal flushing, either on site or at a nearby residential or commercial location. Commercial applications are intended to be light commercial uses, such as retail. This document does not cover rainwater harvesting, nor does it cover recycling of storm-water and wastewater that includes industrial sources of contamination.

The limited scope of these guidelines is considered a first step towards broader uses of reclaimed water. The long-term objective is to provide the tools and guidance needed to allow the safe use of reclaimed water for many beneficial purposes, while minimizing the associated human health and environmental risks. The design, installation and maintenance requirements for the plumbing components of non-potable water systems are addressed in CSA Standard B128.1-06/B128.2-06 (CSA, 2006).

These guidelines are intended for use by regulatory authorities, public health professionals, engineering consultants and others with a level of technical understanding of the subject area. The guidelines take a conservative approach to establishing water quality parameters for domestic reclaimed water. Even though exposure to reclaimed water used for toilet or urinal flushing is expected to be low, the potential health effects associated with coming into contact with microbiologically contaminated water are serious enough to warrant a precautionary approach.

1.2 A risk-based approach

This document adopts a risk-based approach in order to ensure that the quality and management of domestic reclaimed water are protective of public health over the long term. The aim of a risk-based approach is to identify all of the potential hazards in a reclaimed water treatment system, assess their potential impact on water quality and on public health, and find ways to mitigate those risks, rather than to simply react when problems occur. Risk management considerations, including elements of a management framework and potential management models, are outlined in Part I. The guidelines are based on risk assessment, including the identification of hazards, assessment of exposure and characterization of risks, as outlined in Part II.

2.0 Guidelines for reclaimed water quality

Table 1 recommends levels for several reclaimed water quality parameters. Within an overall management framework, the guideline values in Table 1 are intended to enhance treatment reliability and disinfection effectiveness, thus protecting public health. These guideline values could be used to ensure water quality conditions upon start-up of a reclaimed water system, for periodic verification of the system and as a safety precaution if operational parameters are not met.

Table 1: Guideline values for domestic reclaimed water used in toilet and urinal flushing[a]

		Water quality parameters	
Parameter	Units	Median	Maximum
BOD_5	mg/L	≤ 10	≤ 20
TSS[b]	mg/L	≤ 10	≤ 20
Turbidity[b]	NTU	≤ 2	≤ 5
Escherichia coli[c]	CFU/100 mL	Not detected	≤ 200
Thermotolerant coliforms[c]	CFU/100 mL	Not detected	≤ 200
Total chlorine residual[d]	mg/L	≥ 0.5	

[a] Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility or treatment unit. BOD_5 = five-day biochemical oxygen demand; TSS = total suspended solids; NTU = nephelometric turbidity unit; CFU = colony-forming unit.

[b] Measured prior to disinfection point. Only one of TSS and turbidity needs to be monitored in a given system.

[c] Only one of *Escherichia coli* and thermotolerant coliforms needs to be monitored in a given system. Further information is provided in Box 1.

[d] Measured at the point where the treated effluent enters the distribution/plumbing system.

All domestic reclaimed water used for toilet and urinal flushing should be disinfected. Primary disinfection may be accomplished by any chemical, physical or biological means that results in the destruction, inactivation or removal of microorganisms. Chlorination should be used at least as a secondary means of disinfection to maintain chlorine residual within the storage system (if applicable) and the distribution/plumbing system. Box 1 provides the rationale for selecting these parameters. A management program, including treatment technologies in place, should consistently achieve the reclaimed water quality criteria shown in Table 1.

Box 1: Domestic reclaimed water quality parameters

Parameter	**Rationale for selection**
Biochemical oxygen demand (five-day) (BOD_5)	Excessive five-day biochemical oxygen demand (BOD_5) can lead to aesthetic and nuisance problems (odour and colour problems). Organics can be broken down by micro-organisms, causing a decrease in oxygen content of the water, and can adversely affect disinfection processes. Maintaining BOD_5 at the levels recommended in Table 1 will help ensure that aerobic conditions are maintained in the system.
Total suspended solids (TSS)	Total suspended solids (TSS) are monitored for both health and aesthetic reasons. Organic contaminants and heavy metals are adsorbed on particulates, and this suspended matter can shield microorganisms from disinfectants and can lead to odour problems. Maintaining levels at or below those noted in Table 1 will help disinfection efficiency; it is recommended that **either** TSS **or** turbidity be monitored.
Turbidity	Turbidity is monitored for both health and aesthetic reasons. Turbidity can be organic in nature and may contain toxins or harbour pathogens. Excessive turbidity can lead to odour problems and will interfere with disinfection. It is a useful parameter for monitoring the performance of the treatment unit or facility. Maintaining levels at or below those noted in Table 1 will help disinfection efficiency; it is recommended that **either** TSS **or** turbidity be monitored.
Escherichia coli	In systems reclaiming domestic wastewater, the presence of *E. coli* in water leaving the treatment unit can be used to assess disinfection adequacy. A well-designed and well-operated treatment system should be capable of consistently reducing *E. coli* to undetectable levels. Therefore, the guideline for *E. coli* in domestic reclaimed water systems is none detectable per 100 mL. However, as even the most sophisticated treatment system cannot provide water that is absolutely free of disease-causing micro-organisms all the time, a maximum concentration of 200 CFU/100 mL is acceptable under the conditions outlined in Section 2.1. For systems reclaiming only greywater, it is recommended that thermotolerant coliform values be utilized instead of *E. coli*.
Thermotolerant coliforms	The presence of thermotolerant coliforms in domestic reclaimed water leaving the treatment unit can be used to assess disinfection adequacy in systems reclaiming wastewater or greywater. Some greywater systems have been shown to have high levels of thermotolerant coliforms in the absence of *E. coli*. A well-designed and well-operated treatment system should be capable of consistently reducing thermotolerant coliforms to undetectable levels. Therefore, the guideline for thermotolerant coliforms in domestic reclaimed water systems is none detectable per 100 mL. However, as even the most sophisticated treatment system cannot provide water that is absolutely free of disease-causing microorganisms all the time, a maximum concentration of 200 CFU/100 mL is acceptable under the conditions outlined in Section 2.1.
Total chlorine residual	Disinfection is essential to this process, and a chlorine residual must be present in the domestic reclaimed water storage system and distribution system piping. The total chlorine residual is a measure of all chemical species containing chlorine in an oxidized state. It is usually the sum of the free and combined chlorine concentrations present in water. A minimum measurable total chlorine residual of 0.5 mg/L is an indication that the level of disinfection is adequate (e.g., exceeds the chlorine demand) and may control bacterial regrowth in the reservoir or storage tank. Monitoring chlorine residual is also a simple, quick and inexpensive measure for providing information on microbiological water quality.

2.1 Application of the guideline

Reclaimed water treatment systems have different monitoring requirements for systems during the start-up period and for ongoing verification monitoring of established systems. Systems at start-up require a more intensive sampling regime to verify that the treatment system is performing adequately. During the first 30-day period of operation (i.e., start-up), a minimum of five samples should be collected and tested for all of the guideline water quality parameters listed in Table 1. Some parameters, such as chlorine residual, may be tested more frequently. The samples should be collected at regular intervals during the 30-day period. The median of five samples should meet the values outlined in Table 1. The maximum limit for any parameter should not be exceeded. This monitoring frequency needs to be continued until the system is shown to meet all of the guideline values in Table 1.

When a 30-day sampling period shows that the treated domestic reclaimed water meets the guideline values for all the parameters, the monitoring frequency can be reduced for some parameters. Monitoring frequencies for residual chlorine and for turbidity or TSS (where possible) should be maintained, whereas frequencies for *E. coli* or thermotolerant coliforms and BOD_5 can be reduced to semi-annual or annual monitoring (depending on the jurisdiction) to verify that the system is still working effectively. During semi-annual or annual monitoring, a minimum of two samples should be taken for each parameter being analysed. These samples should be collected at least an hour apart to provide a better estimate of the water quality being produced. The results from these samples should meet the median values outlined in Table 1, without exceeding the maximum value. If only two samples have been collected (and therefore a median cannot be determined), as long as one sample is less than or equal to the median value and all samples are less than the maximum value, the water quality is still considered to meet the guideline for that parameter. If both samples exceed the median or any sample exceeds the maximum, follow-up samples should be collected to confirm the exceedance.

Confirmation of an exceedance of any guideline parameter should result in the system returning to monitoring as outlined for systems during the 30-day start-up monitoring period and an investigation into the cause of the exceedance. If the guideline median values are exceeded, but all samples are less than the maximum values, the system can continue to be used during the investigation of the water quality. If the maximum values have been exceeded for any parameter, the system should be bypassed until the problem has been shown to be corrected and the water quality returns to meeting the guideline values.

2.2 Calculating microbiological treatment goals for reclaimed water

To complement the guideline values, jurisdictions can calculate health-based treatment goals to achieve a health target (see Section 4.5). Potential sources of domestic reclaimed water considered in these guidelines include domestic wastewater and greywater. The source of the water to be reclaimed may have an impact on the treatment goals required to achieve the guideline values in Table 1. The risk assessment (outlined in Section 4.0 and Appendix B) provides an example of treatment goals as log removal requirements for treating domestic reclaimed water derived from wastewater. An important variable for calculating removal/inactivation requirements is the initial pathogen concentrations. Appendix B uses default values for pathogen concentrations in wastewater. System-specific data on pathogen concentrations can be gathered and used as an alternative to the default values.

There are limited published data currently available on pathogen concentrations in greywater sources; therefore, default values for greywater have not been included. In the absence of default values for greywater, the wastewater default values can be used. However, site-specific data may be particularly useful for greywater systems, as they would be expected to have lower inputs of faecal matter than wastewater, and thus lower concentrations of enteric pathogens. Although the faecal inputs are expected to be lower, the concentrations of microbiological and chemical hazards in greywater can vary over a wide range (see Tables 3 and 5 in Part II). It is hoped that over the longer term, sufficient data on pathogen concentrations in greywater will become available, making it possible to calculate removal/inactivation requirements specific to greywater.

Part I: Potential Elements of a Management Framework for Domestic Reclaimed Water

3.0 Managing health risks in on-site and clustered domestic reclaimed water systems

Management of on-site domestic reclaimed water systems is of particular importance. Local and provincial governments will need a comprehensive strategy, such as a multi-barrier approach, to effectively manage domestic reclaimed water systems. The ultimate goal of a multi-barrier approach should be to protect public health. The risk management principles outlined in *From Source to Tap: The Multi-Barrier Approach to Safe Drinking Water* (FPTCDW/CCME, 2004) can be applied to reclaimed water. Reclaimed water systems include the source water to be reclaimed, the treatment system and the distribution/plumbing system. All aspects of the reclaimed water system should be managed in an integrated manner using the principles outlined in Box 2. These have been adapted from the *From Source to Tap* document (FPTCDW/CCME, 2004) to address the safe management of reclaimed water systems. Management strategies for reclaimed water have also been developed and published by other nations (U.S. EPA, 2005; NRMMC-EPHC, 2006).

Successful implementation of a reclaimed water system includes numerous additional considerations, including plumbing and system management, economics, management models, technology validation and certification, installation and commissioning of new systems, and operational oversight, inspections and monitoring. Plumbing and system management aspects are published as part of CSA Standard B128.01-06/B128.2-06 (CSA, 2006). This standard includes information on minimum plumbing requirements for non-potable water systems, including marking of pipes, backflow prevention, pressure testing, cross-connection testing and proposed maintenance schedules. As such, these details will not be included as part of this document.

3.1 Economic considerations

It is important to consider the costs and benefits of any water reclamation project. However, it is often difficult to get a true accounting of these costs (Law, 1996; Ni et al., 2003; Radcliffe, 2004). It is recommended that any domestic water reclamation project be evaluated on a case-by-case basis to determine if it is economically feasible. The first step in this process should be to establish a water budget for all of the water uses in the building in question. Water efficiency measures, such as low-flow fixtures, should be adopted as a first step. If reclaiming water is still an attractive or necessary option after this analysis, proponents should consider the following costs: 1) capital costs of treatment system, storage and plumbing; 2) operation and maintenance costs, including electrical, repair, consumables and monitoring; and 3) fees that may be applied for permits and inspections. Other costs may also come to bear, whereas benefits will accrue from reduced water use and reduced need for wastewater treatment capacity. The Canada Mortgage and Housing Corporation website (www.cmhc-schl.gc.ca) includes several case studies of successful and economically feasible reclaimed water projects.

Box 2: Risk management principles for on-site and clustered domestic reclaimed water systems

Legislative and policy frameworks
To ensure that human health is adequately protected, legislative and/or policy frameworks should support a clear commitment to the responsible use of reclaimed water (including responsible by-product disposal) and to the application of a preventive risk management approach. Policy frameworks should include the responsibilities for the various aspects of domestic reclaimed water systems, including the responsibilities of authorities, owners and operators. These responsibilities will vary between jurisdictions.

Public involvement and awareness
It is essential to establish and maintain partnerships and communication among the various stakeholders and with members of the public interested in domestic reclaimed water use. Strategies to accomplish this goal may include:

- informing the public about health risks and providing educational materials on issues such as water disinfection, guidelines, conservation issues and costs of providing service;
- providing information on programs or services in place for managing domestic reclaimed water systems; and
- for cluster systems, making monitoring results or summaries available and issuing regular reports about the system, its operation and planned improvements or changes.

Guidelines, standards and objectives
Guidelines, standards and objectives provide responsible authorities, owners and operators with water quality targets that can be used, in conjunction with monitoring, to maintain an acceptable quality of reclaimed water for the intended end use. This may include water quality targets for protecting human health or the environment.

Treatment and distribution
Treatment of reclaimed water is an important part of the multi-barrier approach for protecting public health. Therefore, treatment systems need to be appropriately designed and constructed. There is also a need for a high level of treatment reliability and oversight. Owners and operators should know what to do and whom to contact in case of treatment failure in their reclaimed systems, as well as how to maintain and operate systems effectively. Design and construction of distribution/plumbing systems for reclaimed water systems need to follow guidelines and standards and need to include cross-connection control programs.

Management
Effective management of water reclamation systems is essential to ensure the protection of public health; therefore, management programs need to be in place. There may be opportunities to integrate domestic reclaimed water treatment considerations into existing wastewater treatment programs to manage systems more effectively. Management programs should include basic elements of good practice, such as owner and/or operator training, community involvement, research and development, validation of process efficacy and systems for documentation and reporting. In addition, preventive risk management strategies or plans should be developed for all reclaimed water systems. Owners and operators of reclaimed water treatment systems need to understand, at a basic level, the entire reclaimed water system, the hazards and events that can compromise reclaimed water quality and the preventive measures and operational control necessary for ensuring safe and reliable use of reclaimed water. Regulatory authorities should provide information and support to owners and operators in an ongoing manner so that they understand their responsibilities.

Monitoring
Water quality monitoring for reclaimed water systems can aid in the selection of the type of treatment needed, determine if the treatment system is working properly and ensure that the water is of an acceptable quality for its intended end use.

3.2 Management programs

Experience with private wastewater treatment (e.g., conventional septic systems) has shown that most management programs rely on homeowners to assume full responsibility for the operation and maintenance of their individual systems. However, many of these programs experience problems for a variety of reasons, including:

- a lack of trained service providers;
- no legal authority to hold homeowners accountable for properly maintaining their systems;
- little to no training for homeowners; and
- lack of inspections and monitoring once systems are in place.

To overcome some of these issues, there are several management models and approaches that can be adapted for decentralized reclaimed water quality systems. While decentralized systems will affect fewer people than will large systems, small systems, from a process perspective, have a complexity similar to that of larger systems. Therefore, these systems can be considered moderate to high risk and should have the appropriate management approach and program in place to respond to this level of risk. Table 2 provides some management models, adapted from U.S. EPA (2005), that are applicable to decentralized reclaimed water systems and can be used as part of a management program.

Table 2: Management models for decentralized reclaimed water systems[a]

Typical application	Program description	Benefits	Limitations
1. Maintenance contract model			
• Systems serving a single-family home	• System performance requirements • Systems properly designed • Installed according to CSA Standard B128.01-06/B128.2-06 • Inspection prior to start-up • Service contracts in place and maintained • Inventory of all systems • Contract tracking system	• Lower risk of treatment malfunctions • Homeowner's investment protected • Less resource-intensive than other program options • System properly installed and maintained	• Difficulty tracking and enforcing compliance due to reliance on the owner or contractor to report lapses in service • No mechanism currently in place to assess the effectiveness of the maintenance program • Requires contract tracking system

Table 2 (continued)

Typical application	Program description	Benefits	Limitations
2. Operating permit model			
• Systems serving a single-family home • Systems in a multi-unit residential or commercial building	• System performance and monitoring requirements • Engineered designs allowed, but may provide prescriptive designs for specific sites • Installed according to CSA Standard B128.01-06/B128.2-06 • Regulatory oversight by issuing renewable permits that may be revoked for non-compliance • Inventory of all systems • Tracking of operating permit and compliance monitoring • Minimum for larger-capacity systems	• Regular compliance monitoring reports • Non-compliant systems identified, and corrective actions required	• Higher level of expertise and resources for regulatory authority to implement • Requires permit tracking system • Requires enforcement powers for authorities
3. Responsible management entity (RME) operation model			
• Multi-unit residential or commercial buildings • Cluster systems	• System performance and monitoring requirements • Installed according to CSA Standard B128.01-06/B128.2-06 • Professional operation and maintenance (O&M) services through RME • Regulatory oversight by issuing operating permits to RME (system ownership remains with property owner) • Inventory of all systems • Tracking system for operating permit and compliance monitoring	• O&M responsibility transferred to professional RME that holds the operating permit • Problems identified before malfunctions occur	• May require enabling legislation to allow RME to hold the permit for an individual system owner • RME must have owner’s approval for repairs • Need for easement/right of entry • Need for oversight of RME by the regulatory authority

Table 2 (continued)

Typical application	Program description	Benefits	Limitations
4. Responsible management entity (RME) ownership model			
• Cluster systems serving multiple properties under different ownership	• System performance and monitoring requirements • Installed according to CSA Standard B128.01-06/B128.2-06 • Professional management of all aspects of decentralized systems • Trained and licensed owners/operators • Regulatory oversight through permits • Inventory of all systems • Tracking system for operating permit and compliance monitoring	• High level of oversight • Reduces risk of non-compliance • Removes potential conflicts between owners and RME	• May require enabling legislation or establishing of a management district • May require significant financial investment from RME • May limit competition/ innovation

[a] Adapted from U.S. EPA (2005).

Across the country, the different institutions, arrangements and procedures involved in a management program will depend on many factors, including enabling legislation, available resources and the needs or desire of the individual or community to pursue water recycling. Because of this diversity, management programs and outcomes are also likely to be different from jurisdiction to jurisdiction. Management structures can range from an informal network of partners working under a coordinated framework to a highly structured responsible management entity (RME) that owns or maintains a set of treatment systems. Authorities in each jurisdiction will have to determine what type of management program will best suit the needs of their communities. Preventive risk management strategies or plans should be developed for all reclaimed water systems. The aim is to provide a measurable and ongoing assurance that performance requirements are met and that, as far as possible, faults are detected and corrective actions are taken before there is a negative health impact. While all risk management plans should be consistent with the principles described in the multi-barrier approach, the level of detail and demands of an individual plan should reflect the complexity and potential level of risk associated with the reclaimed water system in question, as well as the capabilities of the system owner/operator.

3.3 Technology validation and certification

The design requirements for decentralized treatment systems focus on the protection of public health and water resources. Yet systems must also be affordable. Prescriptive codes simplify design reviews, but limit development options and innovation. Experience has shown that equipment failures are at the root of many waterborne disease outbreaks. In the case of reclaimed water treatment systems, the potential health risks and the need for treatment reliability underscore the need to have system performance validated. Ideally, a technology verification program should be available to provide a reliable, third-party assessment and certification of treatment devices (see Appendix C). Protocols for testing processes or technologies should determine their performance under a variety of upset conditions. There is currently no technology verification program in Canada that targets reclaimed water treatment systems. The NSF International/American National Standards Institute (NSF/ANSI) Standard 40 and Bureau de Normalisation du Québec (BNQ) Standards NQ 3680-910/NQ 3680-915 are examples of standard and testing protocols intended for the certification of on-site wastewater treatment systems; these protocols could conceivably be adapted to meet the requirements for reclaimed water systems, particularly with regard to disinfection. They offer good starting points towards an appropriate reclaimed water technology verification protocol. A limited overview of applicable treatment technologies is provided in Appendix D.

3.4 Installation and commissioning of new systems

Authorities will need to ensure the proper installation and functioning of a system prior to commissioning and should adhere to the requirements of CSA Standard B128.01-06/B128.2-06, Design and installation of non-potable water systems/Maintenance and field testing of non-potable water systems, for field-testing of a new system (CSA, 2006). Of particular importance is preventing cross-connections with potable water plumbing lines and the use of air gaps wherever possible (air gaps that are properly designed are preferred over backflow prevention devices) (NOWRA, 2004). In addition to the CSA Standard B128.01-06/B128.2-06 requirements, authorities should verify that sensors and monitoring instrumentation are functioning properly and that the treatment system is meeting the effluent water quality requirements (see Section 2.0). Note that it may take up to three weeks for biological systems to reach equilibrium or steady-state operation following start-up or a significant process change. Additional specific requirements may be imposed to fit local conditions and capabilities.

As part of a management program, authorities should consider certification or licensing of installers, as well as appropriate training. These recommendations are not meant as a substitute for applicable legal requirements. Interested parties should ensure that they are aware of, and adhere to, any applicable legal requirements where a system is under consideration.

3.5 Operational oversight, inspections and monitoring

As previously noted, any management program should be developed with due consideration given to protection of public health, water quality guidelines, regulatory authority capacity, administrative and operational capacity, and the local political, social and economic climate. Once effluent water quality parameters are verified upon start-up, as described in Section 2.0, frequent sampling of decentralized and small-scale/on-site wastewater treatment systems may be too resource intensive and expensive to be practical. In addition, statistics such as median and average values have very little meaning when assessing small-system water quality, where samples may be collected on only an annual or biannual basis (NOWRA, 2004). For such systems, it is recommended that monitoring be based on robust secondary parameters, such as motor performance, fluid pressure, temperature and flow, in addition to monitoring chlorine residuals or turbidity with simple tests or sensors that do not require frequent calibration. Verification of effluent water quality could be conducted on a periodic basis (e.g., biannually) and whenever the operational parameters show change in the system.

Once a treatment system has been shown to be capable of achieving the required water quality under specific operating conditions, verification of those operating conditions should be sufficient to verify continued performance. For example, once a specific chlorine dosage and residual concentration have been demonstrated to achieve the bacteriological water quality criteria, then verifying dosage and chlorine residual levels should be sufficient for routine monitoring. Periodic water quality sampling/analyses can be used to support this routine monitoring. Dosage can be verified by monitoring chlorine tank liquid levels, and chlorine residuals can be monitored using oxidation–reduction potential or other sensors on a real-time basis (as opposed to daily bacteriological verification sampling and testing). Chlorine residuals can also be monitored using simple chlorine test strips.

Those parameters that can be measured with automated equipment are most reliable when the equipment is used on a continuous basis and is equipped with an alarm. They may represent critical control points. Disinfection and power supply are two such critical control points. A disinfection system should be tested anywhere from daily to weekly, depending on the magnitude of the potential risk. For example, cases of gastrointestinal illness occurring in a household with a reclaimed water system may result in a higher level of pathogens in the wastewater entering the reclaimed system. It may therefore be advisable to monitor the operation of the disinfection system more closely to ensure that it is working properly. Levels of chlorine residual can be used to monitor a chlorine disinfection system. A backup power supply (e.g., battery or small generator) should be considered for short-term power loss. Consideration should be given to the use of telemetry where appropriate to allow better operational oversight.

Management programs should focus on proper operation and preventive maintenance (including by-product disposal) to ensure long-term system performance. All systems should have written operating and maintenance instructions. CSA Standard B128.01-06/B128.2-06 provides a maintenance schedule for various components of non-potable water systems, such as pumps, filter systems, storage and pressure tanks. This is in contrast to the more traditional “end-point” evaluation of water quality that focuses on system failure or malfunction. The elements described in this section are intended to provide a starting point for developing and implementing an effective management program.

Part II: Science and Technical Considerations

4.0 Risk assessment

The process of risk assessment includes four components:

1. *Hazard identification*—Hazard identification is generally a qualitative process of identifying microorganisms or chemicals of concern in the water.
2. *Exposure assessment*—The exposure assessment should provide an estimate (with associated uncertainty) of the occurrence and level of a contaminant in a specified volume of water at the time of the exposure event (ingestion, inhalation or dermal absorption).
3. *Hazard characterization*—A hazard characterization will describe the adverse health effects that may result from ingestion, inhalation or dermal absorption of a microorganism or chemical. When data are available, the characterization should present quantitative information (dose–response relationship, probability of adverse outcomes).
4. *Risk characterization*—The risk characterization is an integration of the three previous steps to derive a risk estimate—that is, an estimate of the likelihood and severity of the adverse health effects that would occur in a given population, with associated uncertainties.

In the first step of the risk assessment process for domestic reclaimed water, hazard identification, it is necessary to establish, at least approximately, the quality and quantity of water that is produced from domestic activities (the domestic effluent) and that is available for treatment and beneficial reuse.

The terminology used in discussions of water reclamation often makes a distinction between “greywater” and “wastewater.” Sources of greywater can include bath, shower, sink and laundry water, but not toilet water (Asano, 1998). Greywater does not generally include kitchen sink or dishwasher waste, as these are highly contaminated with fats and food waste. Domestic wastewater includes the discharge from all domestic sources, including toilet and kitchen waste. Although greywater will contain less faecal matter than wastewater, both sources of water can contain a wide range of agents that pose risks to human health, including chemicals and pathogenic microorganisms.

Regardless of whether greywater or wastewater is being reclaimed, the finished water quality must meet the guideline values set out in Table 1. The treatment processes required to meet these guideline values may differ for wastewater and greywater; in most cases, there will be more than one treatment option available that is capable of producing reclaimed water of an acceptable quality. When selecting a reclaimed water treatment system, the disposal requirements for any by-products produced by the system need to be considered (e.g., biosolids, membrane concentrate). The type and use of household appliances, the number and age distribution of occupants, their personal habits and the total quantity of water used can all have a marked effect on the final composition of the untreated effluent. Constituents of untreated effluent may include:

- microorganisms, some of which may be pathogenic;
- chemical contaminants, such as dissolved salts (sodium, nitrogen, phosphates and chloride), soaps and detergents;
- a high organic content from fats and oils;

- particles from food, lint, grit, hair, etc.; and a variety of household, vehicle and garden chemicals.[1]

4.1 Hazard identification—microbiological characteristics

Microbiological hazards have been identified as the greatest source of risk to human health from the use of domestic reclaimed water (Yates and Gerba, 1998; Toze, 2004; U.S. EPA, 2004; NRMMC-EPHC, 2006). Several factors contribute to the critical nature of microbiological contamination. These include the potentially high numbers of pathogens in effluent, particularly in wastewater, and the highly infectious nature of some organisms. The acute nature of disease in the exposed individual or community combined with the potential for person-to-person infection make microbiological threats of paramount importance (Devaux et al., 2001; FAO/WHO, 2003).

Human enteric pathogens can be found in water contaminated by human waste and may be washed into greywater during hand washing, bathing, showering and clothes laundering. In conditions of high levels of biodegradable carbon and warm temperatures, such as might be found in recycled water storage, opportunistic pathogens such as *Pseudomonas aeruginosa* and *Aeromonas* spp. could conceivably grow, whereas biofilms in water pipes have been shown to allow the growth of *Legionella* spp. and *Mycobacterium avium.* The growth and survival of total coliforms (indicator organisms) in household storage containers for potable water have also been reported (Trevett et al., 2005). Tables 3 and 4 demonstrate the wide range in the concentration of indicator bacteria that may be found in greywater and wastewater (Table 3) as well as faeces and raw sewage (Table 4).

Table 3: Concentration ranges of indicator bacteria reported in untreated grey- and wastewater[a]

	Concentrations (CFU/100 mL)			
Source of greywater	Total coliforms	Thermotolerant coliforms	*Escherichia coli*	Faecal enterococci
Hand basins	$2.4 \times 10^2 - > 2.4 \times 10^6$	n.a.[b]	$0–2.4 \times 10^6$	$0–2 \times 10^4$
Bath/shower and hand basins	$2.5 \times 10^2 - 1.8 \times 10^8$	$0–5.0 \times 10^3$	$10–10^5$	$10–10^5$
Laundry, kitchen sink	7×10^5	7.3×10^2	n.a.	n.a.
Greywater[c]	$10^2–10^6$	$10^2–10^6$	$10–10^5$	n.a.
Wastewater	$10^6–10^8$	$10^6–10^8$	$10^6–10^8$	$10^4–10^6$

[a] From Gardner (2003), Koivunen et al. (2003), Lazarova et al. (2003), Ottoson and Stenstrom (2003), Birks et al. (2004), FBR (2005) and NRMMC-EPHC (2006).
[b] n.a. = not available.
[c] Wastewater from all domestic sources, excluding the toilet and kitchen sink.

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[1] Some examples include turpentine, brake fluid, pool chemicals, insecticides, stains, wood preservatives, oven cleaners, disinfectants, herbicides, fungicides, furniture stripper, gasoline and window cleaner.

Table 4: Enteric pathogens and indicators reported in faeces and raw sewage[a]

Organism	Numbers in faeces (per gram)	Numbers in sewage (per litre)
Bacteria		
Coliforms (indicator)	10^7–10^9	
Escherichia coli (indicator)		10^5–10^{10}
Pathogenic *E. coli*		Low
Enterococci (indicator)		10^5–10^7
Shigella	10^5–10^9	10 –10^4
Salmonella spp.	10^4–10^{11}	10^3–10^5
Clostridium perfringens (pathogen and indicator)		10^4–10^6
Viruses		
Enteroviruses	10^3–10^7 [b]	10^2–10^6
Adenoviruses	10^{10} [c]	10–10^4
Noroviruses	10^{12} [c]	10–10^4
Rotaviruses		10^2–10^5
Somatic coliphages (indicators)		10^6–10^9
F-RNA coliphages (indicators)		10^5–10^7
Protozoa		
Cryptosporidium	10^6–10^7	0–10^4
Giardia	10^5–10^7	
Helminths		
Helminth ova		0–10^4

[a] From Chappell et al. (1996), Chauret et al. (1999), Haas et al. (1999) and NRMMC-EPHC (2006).
[b] Cell culture assays.
[c] Electron microscopic observation of viral particles.

Although several studies have shown that domestic greywater can contain high levels of indicator organisms (i.e., total coliforms or *E. coli*), it has been suggested that bacterial indicator densities overestimate the faecal load of greywater significantly when compared with chemical biomarkers of human faecal pollution (Ottoson, 2002; Ottoson and Stenstrom, 2003). Based on measured levels of the chemical biomarker coprostanol, Ottoson and Stenstrom (2003) estimated the faecal load in domestic greywater to be 0.04 g/day per person. Using counts of *E. coli* resulted in an estimated faecal load of 65 g for the same greywater. This illustrates that estimating the faecal load of greywater at a domestic level is challenging.

Estimating the faecal load of wastewater is also a challenge. There is great variability in colonic function, not only between individuals, but also within the same individual. Wyman et al. (1978) studied bowel movements in healthy subjects and found the mean frequency of bowel movements to be approximately one in 24 hours, with a mean size of individual stools ranging from 111.3 g (female, standard deviation [SD] 32.5) to 142.4 g (male, SD 55.5). As seen in Table 4, a single gram of faeces can contain a very high number of pathogens if the individual has a gastrointestinal illness. The implication for reclaimed water is that a minor outbreak of disease in a household served by a cluster or on-site system could increase the level of pathogens in the untreated water (Charles, 2004). If the treatment system cannot effectively deal with the increased pathogen loading, this could increase the risk of disease in the households receiving the reclaimed water.

4.1.1 Significance of microorganisms in reclaimed water

The diversity of microbiological pathogens that may be found in wastewater and grey-water makes it impractical to monitor all of the pathogens that could be present. In drinking water treatment, authorities rely on the detection of indicator organisms to provide information about either treatment performance or the potential presence or absence of pathogens. Traditionally, these indicators have been a bacterium (e.g., *E. coli*) or a group of bacteria (e.g., total coliforms or thermotolerant coliforms). However, it is now known that these bacterial indicators do not correlate with the presence of protozoan or viral pathogens. It is more difficult to remove or inactivate protozoa and enteric viruses than to remove or inactivate bacteria by standard drinking water and wastewater treatment processes. Ingestion of low numbers of these organisms (compared with most enteric bacteria) can lead to illness. For these reasons, protozoa and enteric viruses are likely to be of greater concern than bacteria (Blumenthal et al., 2000; Dufour et al., 2003; Gerba and Rose, 2003).

As these groups of pathogens vary in their characteristics, behaviours and susceptibility to water treatment processes, leading health authorities[1] have recommended that reference pathogens be used to represent each of the major groups of pathogens (i.e., bacteria, protozoa and viruses) in a risk assessment. The reference pathogens described in this document have been well characterized in the literature. For this reason, only a brief description of these pathogens is provided, together with references for further reading.

Ideally, a reference pathogen will represent a worst-case combination of:

- high occurrence;
- high concentration in water to be reclaimed;
- high pathogenicity;
- low removal in treatment; and
- long survival in the environment.

4.1.2 Viral reference pathogens

There are numerous enteric viruses known to infect humans. Enteric viruses associated with human waterborne illness include noroviruses, hepatitis A virus, hepatitis E virus, rotaviruses and enteroviruses (polioviruses, coxsackieviruses A and B, echoviruses and four ungrouped enteroviruses). Enteric viruses are obligate parasites, depending entirely on other living cells for reproduction (Health Canada, 2004a; Krewski et al., 2004). Although they cannot

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[1] See, for example, World Health Organization (WHO) guidelines (WHO, 2004), Australian guidelines (NRMCC-EPHC, 2006) and the European Union's Microrisk project (Loret et al., 2005).

multiply in the environment, viruses can survive longer in water and are more resistant to disinfection compared with most intestinal bacteria. They are also highly infectious. It has been well demonstrated that human enteric viruses can be recovered from domestic wastewater and other sewage-contaminated waters, as well as recycled water distribution biofilms (Storey and Ashbolt, 2003). Infected individuals shed viruses through faeces, often for several weeks (Krikelis et al., 1984; Hovi et al., 1996; Cloete et al., 2004).

Rotaviruses have been used in several risk assessments that examine water quality (Havelaar and Melse, 2003; Westrell et al., 2003, 2004a; Howard et al., 2006). Rotaviruses have been identified as a significant cause of viral gastroenteritis worldwide and have a relatively high infectivity compared with other waterborne viruses (Havelaar and Melse, 2003; Cloete et al., 2004). Adenoviruses have also been suggested as a candidate reference virus because they cause a range of infections (including enteric and respiratory infections) that may be associated with use of reclaimed water (WHO, 2004). A recent study has confirmed that adenoviruses, in particular adenovirus 40, are the enteric viruses most resistant to inactivation by ultraviolet (UV) light (Gerba et al., 2002; Nwachuku et al., 2005). Noroviruses, although causing less severe disease than rotaviruses, have been shown to be a prevalent cause of gastrointestinal illness in developed regions (Lopman et al., 2003; Maunula et al., 2005). There is no published dose–response model for noroviruses at this time, but one study found that as few as 10 organisms may be sufficient to cause infection (Schaub and Oshiro, 2000). Humans are the only natural reservoir for noroviruses, enteroviruses and rotaviruses.

Owing to the prevalence of infection in children, the possibility of severe outcomes and the availability of a dose–response model, rotavirus has been selected as the reference pathogen for the viral risk assessment in these guidelines.

4.1.3 Protozoan reference pathogens

Protozoa are relatively large pathogenic microorganisms that multiply only in the gastrointestinal tract of their hosts. The enteric protozoa that are most often associated with waterborne disease include *Cryptosporidium parvum* and *Giardia lamblia*. Emerging protozoan pathogens include *Cyclospora cayetanensis* and many microsporidian species (Cloete et al., 2004). *Cryptosporidium parvum* has been identified as a good candidate for a protozoan reference organism. It is reasonably infective, although different genotypes appear to have unique virulence and infectious dose properties (Gale, 2001; Teunis et al., 2002; Health Canada, 2004b). This protozoan is resistant to chlorination (at the dosage and contact times used for drinking water and wastewater treatment) and has emerged as one of the most important waterborne human pathogens in developed countries (NHMRC/NRMMC, 2004). *Giardia lamblia* is another protozoan pathogen that is highly resistant to environmental stresses. It is typically present at some 10–100 times the concentration of *C. parvum* (Yates and Gerba, 1998), and it may be marginally more infective than the latter (Rose et al., 1991). *Giardia* infections are believed to be endemic in both humans and animals. However, compared with *Cryptosporidium* spp., *Giardia lamblia* is more readily removed by water treatment processes and is more sensitive to most types of disinfection (Health Canada, 2004b; NHMRC/NRMMC, 2004; WHO, 2004).

As with rotavirus, the prevalence of *C. parvum*, the potential for widespread disease, the organism's resistance to treatment and the availability of a dose–response model make *C. parvum* a useful choice as the reference pathogen for protozoan hazards.

4.1.4 Bacterial reference pathogens

There are a number of candidates for bacterial reference organisms, including pathogenic *E. coli*, *Campylobacter jejuni*, *Shigella* spp. and *Salmonella* spp. Although *E. coli* is a normal component of the human faecal flora and a useful marker of faecal pollution, some strains are human pathogens. There are six main virulence types of pathogenic *E. coli*, which may be divided into non-enterohaemorrhagic and enterohaemorrhagic groups. The first group includes enteropathogenic, enteroinvasive and enterotoxigenic strains; approximately 2–8% of the *E. coli* found in water have been found to be pathogenic *E. coli* (Haas et al., 1999; Hunter, 2003). The enterohaemorrhagic strain *E. coli* O157:H7 has a higher disease burden per case than any of the other organisms noted above, owing in part to the potential for approximately 10% of children less than 10 years of age to develop haemolytic uraemic syndrome following exposure to this pathogen (Havelaar and Melse, 2003; Hunter, 2003). This organism has been of increasing concern in Canada since a devastating waterborne disease outbreak occurred in 2001 in Walkerton, Ontario. Together with *Campylobacter jejuni*, *E. coli* O157:H7 was identified as the aetiological agent in this outbreak, which resulted in 2300 illnesses and 7 deaths (O'Connor, 2002). This organism is prevalent in foods and appears to have a low median infectious dose (Haas et al., 1999). The severe illness caused by the O157:H7 strain of *E. coli* is a result of a pathogenic mechanism that produces shiga-like toxins. The dose–response relationship for *Shigella dysenteriae* and *S. flexneri* has been suggested as a reasonable approximation for *E. coli* O157:H7 (Cassin et al., 1998; IOM, 2002). This is supported by dose–response modelling work that incorporates data from *E. coli* O157:H7 outbreaks, which demonstrates a good fit to the *Shigella* model (Teunis et al., 2004; Strachan et al., 2005).

The availability of an acceptable dose–response model, data on levels of generic *E. coli* spp. in water and wastewater, the relatively low infectious dose and the severity of disease from *E. coli* O157:H7 make it an appropriate reference for bacterial pathogens.

4.1.5 Helminthic reference pathogens

Helminths are multi-organ worms that are more complex in structure than bacteria or protozoa. In general, helminth transmission by water is not a concern in developed nations such as Canada (Krewski et al., 2004). Addressing the health risk from the protozoan reference pathogen is expected to adequately address risks from helminths.

4.2 Hazard identification—chemical characteristics

These guidelines focus on toilet and urinal flushing as an end use for domestic reclaimed water. As such, exposure to chemicals from the reclaimed water is expected to be minimal when compared with other domestic exposures. These guidelines also recommend that all domestic reclaimed water used for toilet and urinal flushing be disinfected. This may result in the formation of disinfection by-products (DBPs). However, the health impacts from exposure to chemicals, including DBPs, in the reclaimed water are expected to be minimal. Information on general physical and chemical characteristics is presented here, as these parameters may affect treatment requirements and system performance. The physical and chemical parameters most often measured in reclaimed water systems are shown in Table 5.

Table 5: Physical and chemical parameters measured in raw greywater and raw wastewater[a]

Parameter	Unit	Raw greywater (range)	Raw greywater (mean)	Raw wastewater
Suspended solids	mg/L	45–330	115	100–500
Turbidity	NTU	22–> 200	100	n.a.[b]
BOD_5	mg/L	90–290	160	100–500
Nitrite	mg/L	< 0.1–0.8	0.3	1–10
Ammonia	mg/L	< 1.0–25.4	5.3	10–30
Total Kjeldahl nitrogen	mg/L	2.1–31.5	12	20–80
Total phosphorus	mg/L	0.6–27.3	8	5–30
Sulphate	mg/L	7.9–110	35	20–100
pH		6.6–8.7	7.5	6.5–8.5
Conductivity	mS/cm	325–1140	600	300–800
Hardness (calcium and magnesium)	mg/L	15–55	45	200–700
Sodium	mg/L	29–230	70	70–300

[a] From WC/DHWA/DEWA (2005).
[b] n.a. = not available.

It is not yet possible to identify the complete mix of compounds present in wastewater (Crook, 1998; Eriksson et al, 2002), although these may include:

- endocrine disrupting chemicals;
- pharmaceuticals (drug residuals) and personal care products (PPCPs); and
- complex mixtures.

As the long-term goal is to develop guidelines that will address many beneficial end uses of reclaimed water, it is useful to be aware of chemical compounds that may be found in domestic effluent, including DBPs that may be produced as the result of treatment. These are discussed in the following sections.

4.2.1 Disinfection by-products

Reclaimed domestic wastewater for use in toilet and urinal flushing should be disinfected prior to use to ensure that it does not pose an unacceptable risk to human health. DBPs are usually dissolved organohalogenated compounds formed from the oxidative breakdown of organic substances in water, as a result of the application of a disinfectant (Bellar et al., 1974; Rook, 1974; Rebhun et al., 1997). Chlorine is the most commonly used disinfectant for reclaimed water. Since high concentrations of DBP precursors can be found in reclaimed wastewater, chlorination of such water requires high chlorine dosage and long contact time—conditions especially conducive to the formation of DBPs (Cooper et al., 1983; Bauman and Stenstrom, 1990). In general, human exposure to DBPs is possible through multiple routes, including ingestion, dermal absorption and inhalation (Health Canada, 2006). In the case of domestic reclaimed water used for toilet and urinal flushing, ingestion or inhalation of or dermal contact with reclaimed water should be minimal, resulting in minimal overall exposure to DBPs.

4.2.2 Endocrine disrupting chemicals

Broad ranges of chemicals have been identified as having the potential to alter normal endocrine function in humans and wildlife; these chemicals are referred to as endocrine disrupting chemicals. Candidate endocrine disrupting chemicals include both synthetic and naturally occurring chemicals, such as surfactants, plasticizers, pesticides, polychlorinated biphenyls (PCBs), synthetic steroids, human and animal steroid hormones and phytoestrogens. WHO and others have recently published reviews of endocrine disrupting chemicals in the context of both drinking water and reclaimed water (Damstra et al., 2002; CRCWQT, 2003; Ying et al., 2003; Snyder et al., 2007).

Endocrine disrupting chemicals have been detected in reclaimed waters and in water bodies that receive reclaimed water discharges (Kolpin et al., 2002) and have been shown to affect aquatic biota. At this stage, there is no evidence that environmental exposure to low levels of potential endocrine disrupting chemicals affects human health. However, more research is needed on potential human health impacts of endocrine disrupting chemicals, their distribution in reclaimed waters and their removal by treatment processes (Asano and Cotruvo, 2004). There is very little information available on the presence of these chemicals in domestic wastewater.

Although comprehensive data are lacking, analyses of recycled water have generally found that levels of pesticides, PCBs and other organic chemicals identified as candidate endocrine disrupting chemicals are below limits of detection (NRMMC-EPHC, 2006).

4.2.3 Pharmaceuticals and personal care products (PPCPs)

Pharmaceuticals are predominantly organic compounds formulated for therapeutic uses in humans and animals. Personal care products (PCPs) include the active ingredients found in cosmetics, fragrances, insect repellents, sunscreens and many other consumer products. Hundreds of compounds are used in significant quantities. The fate of these compounds after wastewater treatment processes is still largely unknown. Some PPCPs are potential endocrine disrupters. The limited data available suggest that many of these chemicals survive treatment and that some others are returned to a biologically active form by deconjugation of metabolites (Wells et al., 2004; NRMCC-EPHC, 2006; Snyder et al., 2007). Human use and excretion of these compounds are the primary sources of PPCP residuals in sewage. The limits of detection for many compounds range from micrograms per litre to nanograms per litre.

The significance of trace organic compounds in wastewater is the subject of considerable debate (Fujita et al., 1996). Work by Ongerth and Khan (2004) demonstrates that residuals of pharmaceutical compounds will be present in wastewater effluents at concentrations that relate to use, excretion, degradability and other chemical characteristics. Residual concentrations reported to date are two or more orders of magnitude below those at which an effective therapeutic dose would result from ingesting water.

4.2.4 Complex mixtures

Complex mixtures of chemicals in drinking water and recycled water could have additive, synergistic or even antagonistic effects, even when the concentrations of the individual chemicals are very low or comply with water quality guideline values. Further research is required on the health effects of complex mixtures of chemicals.

4.2.5 Significance of chemicals in reclaimed water

It has been found that in centralized wastewater treatment systems, community-wide pretreatment and sewer use requirements effectively reduce the concentration of potential pollutants in the effluent (Chang et al., 2002). Analyses of the quality of reclaimed water produced in U.S. centralized treatment plants indicate that these facilities can consistently produce water that is of a chemical quality comparable to that of drinking water for most parameters, including heavy metals, organic chemicals, pesticides and DBPs (Crook, 1998; U.S. EPA, 2004). A study of an advanced water recycling system in San Diego, California, characterized 138 organic compounds and 28 metals and inorganic compounds over a 1.5-year period. The study found no significant health risks from the non-carcinogenic health risk assessment. The carcinogenic risk associated with direct consumption of water from the advanced treatment facility was predicted to be approximately 1000 times less than that associated with consumption of the city’s raw water supply (Olivieri et al., 1998). Smaller and on-site systems may have more difficulty in consistently achieving reductions in contaminant levels, and fewer data are available for these types of systems. In properly designed and managed recycled water systems where domestic reclaimed water use is limited to toilet and urinal flushing, health impacts from these chemicals are not expected, because of the relatively low exposure (see Table 6 in the next section).

4.3 Exposure assessment

The main focus of the exposure assessment is the consumer—for example, a person who occupies a dwelling that is supplied with domestic reclaimed water or where water is reclaimed on site. In the case of centralized systems, occupational exposure can be managed by health and safety procedures in the workplace. A complete exposure assessment must consider both planned and unintended uses—that is, intentional and accidental exposures. Unintended uses can be reduced by educating stakeholders (users, plumbers, etc.) and by management processes. These guidelines take into consideration accidental misuse of reclaimed water, such as a cross-connection with the potable water supply. The exposure assessment is based upon the available information, but further research is required to provide more accurate estimates of volumes and frequencies of exposure.

Usually, the main route of exposure to microbiological and chemical hazards from various end uses of reclaimed water is ingestion. While this route is expected to be minimal in the particular case of reclaimed water used for toilet flushing, a cross-connection could lead to accidental ingestion.

Some uses of reclaimed water, including toilet flushing, can produce aerosols. There is a risk that, for example, microorganisms that cause respiratory illness (e.g., certain types of adenoviruses) may be present in aerosols and pose a hazard (Gerba et al., 1975). Aerosols and droplets may also deposit on surfaces that may in turn be touched by occupants and subsequently ingested through hand-to-mouth contact. It is reasonable to assume that children will take less care to avoid hand-to-mouth contact after touching contaminated surfaces, but there is little information available to quantify this potential route of exposure (Trevett et al., 2005). The *Australian Guidelines for Water Recycling* (NRMMC-EPHC, 2006) suggests an average exposure from toilet flushing of 11 mL per person per year from aerosols. Ottoson (2002) estimated water intake from inhalation of aerosols as a log-normal distribution (dependent on time and droplet size). York and Walker-Coleman (2000) suggested that for a residential irrigation scenario, "average" consumption can be based on accidental ingestion of 1 mL of reclaimed water per person per day on each of 365 days, whereas maximum limits can be based on accidental ingestion of 100 mL on one occasion per year.

The estimated exposure volumes and frequencies presented in Table 6 are the default values presented in the *Australian Guidelines for Water Recycling* (NRMMC-EPHC, 2006). These guidelines note that the values are considered to be conservative.

Table 6: Exposures for recycled water

Source of exposure	Route of exposure	Exposure volume (mL)	Exposure frequency per person per year	Comments
Toilet flushing	Aerosol	0.01	1100	Frequency based on three uses of home toilet per day. Aerosol volumes are less than those produced by garden irrigation.
Cross-connection with drinking water supply	Ingestion	1000	365 for 1/1000 houses	Total consumption is estimated to be 1.5 L/day, of which 1 L is expected to be consumed cold (unboiled).[a] Affected individuals may consume water 365 days/year; however, only about 1/1000 houses is affected. This is likely to be a conservative estimate.

[a] Two recent reviews of drinking water consumption (Westrell et al., 2004b; Mons et al., 2005) calculated volumes of cold (e.g., unboiled) tap water consumption to be about 870 mL per person per day; therefore, 1 L is considered to be conservative.

4.4 Hazard characterization

As previously noted, pathogens are likely to be the most significant health hazard in reclaimed domestic water used for toilet or urinal flushing, whereas chemical risks are expected to be minimal. For this reason, the hazard characterization focuses on the adverse health effects that may result from the ingestion of pathogenic microorganisms. The health outcomes associated with microbial infections are varied, ranging from asymptomatic illness to different levels of acute and chronic disease and potentially death. The relationships between doses of organisms and responses, in the form of incidence or likelihood of infection or illness, are obtained either from epidemiological investigations of outbreaks or from experimental human feeding studies (Rose et al., 1991; Haas et al., 1999; Haas, 2000; Teunis et al., 2004; WHO, 2004).

In general, the doses associated with illness are much lower for viruses and protozoa than for bacteria. Ingestion of 1–10 virus particles or protozoan cysts can result in illness. In contrast, ingestion of 10^3 to more than 10^6 bacteria (depending on the type of bacterial pathogen) might be required to cause illness. *Shigella* spp., typhoid salmonellae and enterohaemorrhagic *E. coli* are notable exceptions to these, requiring fewer organisms to cause disease (Haas et al., 1999; Hunter, 2003; Teunis et al., 2004; WHO, 2004). An investigation of one outbreak found that average doses of *E. coli* O157:H7 in affected people were 30–35 organisms (Teunis et al., 2004). Other investigations have estimated a dose of 75 organisms ingested in a swimming-related outbreak in the United States and an average of 23 organisms consumed in a foodborne outbreak in the United States (Strachan et al., 2005). Dose–response can be influenced by host factors, such as immune status, pre-existing health conditions and nutrition. The approach adopted in these guidelines is to conduct risk assessments for the general population, through the normal course of life. The dose–response models and calculations are presented in Appendix B. Separate risk assessments can be undertaken for specific subgroups with increased vulnerability, such as people with severe immunodeficiency. However, it may be challenging to identify appropriate dose–response relationships for these vulnerable subpopulations.

4.5 Risk characterization

Using a burden of disease approach, the risk characterization in these guidelines uses the information from the hazard identification, dose–response and exposure assessments to estimate the magnitude of risk. A sample risk characterization is shown in Appendix B, Table 3B, and summarized in Table 7. The example in Appendix B demonstrates that even with very conservative assumptions, effective water treatment should reduce the annual risk of illness and the associated disease burden to a very low level.

Table 7: Risk of illness and disease burden calculated for reference pathogens

	Cryptosporidium	Rotavirus	*E. coli* O157:H7
Risk of illness (per year, i.e., 1100 events)	2.8×10^{-6}	4.4×10^{-5}	3.5×10^{-6}
DALY per year[a]	4.2×10^{-9}	3.5×10^{-8}	1.7×10^{-8}

[a] The disability-adjusted life year (DALY) is a common unit of risk to compare different health effects that vary in severity (e.g., from mild diarrhoea to death). All of the health outcomes from a particular agent are summed to provide an estimate of the burden of disease attributable to the agent; see Appendix B for a more detailed explanation.

Another approach is to calculate treatment goals to achieve a health target of 10^{-6} DALY[1] for the specified uses of reclaimed water, based on the initial concentration of a reference pathogen in the untreated source water. The disease burden, in DALYs, is calculated from the estimated exposures to pathogens in the recycled water. Because the reductions depend on the initial concentrations and the associated exposure, higher concentrations of pathogens in the wastewater or higher levels of exposure will require greater reductions of pathogens from treatment.

It can be seen from Table 8 that relying on treatment technology to minimize the health risk from an accidental cross-connection with a domestic reclaimed water system imposes higher treatment requirements. This illustrates the need to implement a strong management program, with a particular focus on cross-connection control; the optimal choice of measures or combination of measures to be used will depend on an analysis of important factors in a particular situation (Blumenthal et al., 1989). With a strong management program in place, treatment systems can be designed to meet the required log reductions based only on aerosols from toilet flushing.

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[1] Note that the health target of 10^{-6} DALY/person per year is used based on the current recommendations of the WHO (2004) and the decision of the Federal-Provincial-Territorial Committee on Drinking Water to use this target as an acceptable level of risk. Individual jurisdictions may want to set a different health target based on their needs and situation.

Table 8: Required log reductions

Organism	Dose equivalent[a]	Required log reductions Based on aerosols from toilet flushing	 Based on cross-connection[b]
C. parvum	5.3×10^{-2}	2.6	4.1
Rotavirus	5.5×10^{-3}	4.2	5.7
E. coli O157:H7	7.1×10^{-3}	5.3	6.8

[a] Doses equivalent to 10^{-6} DALY.

[b] Based on worst-case assumption of 1 person per 1000 (10^{-3}) consuming 1 L/day for 365 days.

Given the scope of these guidelines and the associated low exposure, no health-based guidelines have been derived for chemicals in domestic reclaimed water. However, the performance of small treatment plants and on-site recycled water treatment plants will be more susceptible than that of large plants to the impacts of unauthorized chemical discharges. Vigilance will be required to prevent or minimize any unauthorized discharges for on-site systems in particular. Preventive measures should include providing owners of systems with educational material about the need to avoid inappropriate dumping of household chemicals. The responsibilities of the owner in this regard will be similar to the need to protect, for example, a conventional septic system.

5.0 Rationale

The use of domestic reclaimed water in residential or commercial locations can help reduce water consumption in Canada. However, the presence of pathogenic microorganisms (bacteria, protozoa and viruses) and some chemicals in domestic wastewater may pose a health risk if the wastewater is improperly treated or if it is used for purposes other than toilet or urinal flushing. Although effective treatment can produce domestic reclaimed water that is virtually free of disease-causing microorganisms, a small number of pathogenic organisms may still be present and pose some risk, such as in the case of accidental cross-connections between the reclaimed system and the drinking water system.

Consequently, it is necessary to ensure that the use of reclaimed water does not pose a risk to the health of Canadians. These guidelines provide guidance to ensure that the risks associated with domestic reclaimed water are addressed through adequate treatment and management processes.

The guideline values for domestic reclaimed water quality have been established to protect public health from microbiological contaminants. There are minimal health impacts expected from chemicals in domestic reclaimed water used only for toilet and urinal flushing. Effective operation of the treatment system is essential for minimizing health impacts from microbiological pathogens. The guidelines include values for several water quality parameters that have been selected because they can demonstrate the effective operation of the treatment system, including disinfection.

On-site reclaimed water systems could include collection and treatment of water from single domestic dwellings or from clusters, such as apartment buildings. Although they will impact fewer people than large systems, their processes may have a complexity similar to that of larger systems. The potential health risks associated with decentralized domestic reclaimed water treatment systems mean that there is a need for a high level of treatment reliability and oversight. The guidance provided in this document also includes information concerning management programs for domestic reclaimed water systems.

It is recommended that authorities develop and implement management programs, giving due consideration to the protection of public health, water quality guidelines, regulatory authority capacity, administrative and operational capacity, and the local political, social and economic climate. The management program would include an initial risk assessment to determine the appropriate levels of microbiological inactivation needed for the system and identify treatment technologies that can consistently achieve the guideline levels established in this document. Operational oversight, inspections and ongoing monitoring should form key components of a management program to ensure that treatment of reclaimed water is effective on a long-term basis. Once effluent water quality parameters are verified upon start-up, it may be appropriate for ongoing monitoring to be based on robust secondary parameters, such as motor performance, fluid pressure, temperature and flow, in addition to real-time monitoring of chlorine residuals or turbidity with sensors that do not require frequent calibration. Verification of effluent water quality could be conducted on a periodic basis (e.g., biannually) and whenever the operational parameters show change in the system.

It is recommended that provinces and territories use this document as a basis for establishing their own requirements or options for the use of reclaimed water in their area of jurisdiction.

Appendix A: Abbreviations, acronyms and glossary

Abbreviations and acronyms

ANSI	American National Standards Institute
BNQ	Bureau de Normalisation du Québec
BOD	biochemical oxygen demand
BOD_5	five-day biochemical oxygen demand
CFU	colony-forming unit
CSA	Canadian Standards Association
DALY	disability-adjusted life year
DBP	disinfection by-product
NSF	NSF International
NTU	nephelometric turbidity unit
O&M	operation and maintenance
PCB	polychlorinated biphenyl
PCP	personal care product
PPCPs	pharmaceuticals and personal care products
RME	responsible management entity
SD	standard deviation
TSS	total suspended solids
UV	ultraviolet
WHO	World Health Organization

Glossary

Decentralized system—System that collects, treats and disposes of or reclaims wastewater from individual homes, clusters of homes or commercial/institutional facilities.

Domestic wastewater—Wastewater from all domestic sources, including the kitchen sink and toilet. Domestic wastewater does not include any sources that contain industrial wastes.

Greywater—Water from the bath, shower, sink and laundry. Greywater does not include water from the toilet, water from the kitchen sink or dishwasher waste.

Appendix B: Additional risk assessment information and calculations

Health-based targets

Health-based targets are the "goal-posts" or "benchmarks" that have to be met to ensure the safe use of recycled water. In Canada, common forms of health-based targets are numerical guideline values and/or performance targets for chemical and microbiological hazards. In relation to chemicals, a guideline value is generally the concentration or measure of a water quality characteristic that, based on present knowledge, does not pose any significant risk to the health of the consumer over a lifetime of consumption. Guideline values for microbiological hazards focus on reducing acute risks and generally rely on monitoring for indicator organisms. Performance targets describe the reduction in risk to be provided by measures such as treatment processes (aimed at reducing hazards) and on-site controls (aimed at reducing both hazards and exposure). The wide array of microbiological pathogens makes it impractical to measure for all of the potential hazards; thus, performance targets are generally framed in terms of categories of organisms (e.g., bacteria, viruses and protozoa) rather than individual pathogens.

Disability-adjusted life years (DALYs)

The most recent edition of the World Health Organization's (WHO) *Guidelines for Drinking-water Quality* (WHO, 2004) adopts 10^{-6} disability-adjusted life year (DALY) as a reference level of risk. In Canada, the Federal-Provincial-Territorial Committee on Drinking Water has also chosen to use this target as an acceptable level of risk from microbiological contaminants in drinking water. The *Australian Guidelines for Water Recycling* (NRMMC-EPHC, 2006) also cites this level of risk. Havelaar and Melse (2003) note that the concept of the DALY has been introduced as a common unit of risk to compare different health effects that vary in severity—for example, from mild diarrhoea to the most severe outcome, death. The basic principle of the DALY is to weigh each health effect for its severity, using standardized severity weights provided within the Global Burden of Disease project (Murray and Lopez, 1996). This weight is multiplied by the duration of the health effect and the number of people affected by the particular outcome. When all of the health outcomes caused by a particular agent are summed, the result is an estimate of the burden of disease attributable to this agent. The key advantage of the DALY as a measure of public health is cited as its aggregate nature, combining years of life lost (quantity) with years lived with disability (quality).

Other authorities use measures such as risk of infection or risk of illness. The U.S. Environmental Protection Agency target is a risk of infection of 10^{-4} from pathogens in drinking water (one additional infection per 10 000 people) (U.S. EPA, 2004). The reference level of 10^{-6} DALY is approximately equivalent to a lifetime additional risk of cancer of 10^{-5} (i.e., 1 case per 100 000 people) or, for a diarrhoea-causing pathogen with a low fatality rate, an annual risk of illness of 10^{-3} for an individual. To place this level of risk in a Canadian context, there are approximately 1.3 cases of enteric disease annually per person in this country. The reported rate of diarrhoeal illness for specific pathogens (from all routes of exposure) in Canada (for the year 2004, rate per 100 000 population) is shown in Table B1.

Table B1: Rates of selected notifiable diseases in Canada, 2004[a]

	Rate per 100 000 population	
Notifiable disease	Age group: all ages	Age group: 1–4 years
Campylobacteriosis	30.22	60.90
Cryptosporidiosis	1.85	11.56
Giardiasis	13.08	47.29
Shigellosis	2.35	5.55
Verotoxigenic *E. coli* (O157:H7)	3.36	13.15

[a] From PHAC (2005).

Dose–response models

Risk assessments are commonly based on data and dose–response models developed from human feeding studies. Log-normal, beta-Poisson and exponential distributions (Table B2) can be used to determine probabilities of infection following exposure to different doses of the pathogen (Haas et al., 1999). The dose from reclaimed water used for flushing toilets is expected to be low, as the water is not intended for ingestion. The dose is derived from the potential for accidental ingestion and exposure, as described in Section 4.3.

Table B2: Dose–response relationships for reference organisms

Organism	Distribution	Model	Parameters[a]
Enteric virus (rotavirus)	Beta-Poisson	$P = 1 - [1 + d/N_{50}(2^{1/\alpha} - 1)]^{-\alpha}$	$\alpha = 0.27$ $N_{50} = 5.60$
Bacterium (*E. coli* O157:H7)	Beta-Poisson	$P = 1 - [1 + d/N_{50}(2^{1/\alpha} - 1)]^{-\alpha}$	$\alpha = 0.2099$ $N_{50} = 1120$
Protozoan (*Cryptosporidium parvum*)	Exponential	$P = 1 - \exp(-rd)$	$r = 0.018$

[a] α and r are parameters describing probability of infection; d = dose; N_{50} = median infective dose; P = probability of infection. Model parameters are as described in Haas et al. (1999), except for *C. parvum*, where the value calculated in from Messner et al. (2001) is used.

Risk characterization

Using a burden of disease approach, the risk characterization in these guidelines uses the information from the hazard identification, dose–response and exposure assessments to estimate the magnitude of risk. A deterministic approach is used here to calculate a health-based target for the reference pathogens in the reclaimed water. This approach uses single estimates for exposure volumes and number of exposure events (e.g., point estimates), which has the disadvantage of neglecting to address variability and uncertainty and also tends to rely on conservative and even worst-case values. A stochastic analysis would help address these disadvantages, but would require more information than is currently available. A sample risk characterization is shown in Table B3. Single estimates are used for exposure volumes and number of exposure events. The estimates used are believed to be conservative. Formulae used in the calculations are shown in Box B1.

Table B3: Potential disease burdens for aerosols from toilet flushing

	Cryptosporidium	Rotavirus	*E. coli* O157:H7
Organisms per litre in source water[a,b]	2000	8000	1.2×10^{5}
Log reduction provided by treatment[c]	5	6	6
Exposure per event (L)	1×10^{-5}	1×10^{-5}	1×10^{-5}
Dose per event (organisms)	2×10^{-7}	8.0×10^{-8}	1.2×10^{-6}
Number of events per year	1100	1100	1100
Dose–response constants[d]	1.8×10^{-2}	$\alpha = 2.7 \times 10^{-1}$	$\alpha = 2.1 \times 10^{-1}$ $N_{50} = 1120$
Probability of infection per organism	1.8×10^{-2}	2.7×10^{-1}	4.8×10^{-3}
Risk of infection (P_{inf}) (probability of infection per event)	3.6×10^{-9}	4.6×10^{-8}	6.0×10^{-9}
Ratio of illness/infection[e]	0.70	0.88	0.53
Risk of illness (P_{ill}) per event	2.5×10^{-9}	4.0×10^{-8}	3.2×10^{-9}
Risk of illness (per year, i.e., 1100 events)	2.8×10^{-6}	4.4×10^{-5}	3.5×10^{-6}
Disease burden[f] (DALY per case)	1.5×10^{-3}	1.3×10^{-2}	5.5×10^{-2}
Susceptibility fraction (%)[g]	100	6	100
DALY per year	4.2×10^{-9}	3.5×10^{-8}	1.7×10^{-8}

[a] Concentrations of *Cryptosporidium* and rotavirus in raw sewage are taken from NRMMC-EPHC (2006); numbers of adenovirus are used as an indication of rotaviruses because of the lack of enumeration methods for rotavirus.

[b] Concentration of *E. coli* O157:H7 is calculated assuming that 2% of the maximum number of generic *E. coli* enumerated in raw wastewater samples from Canadian cities are pathogenic (6.2×10^{6}; Payment et al., 2001). More information is needed to refine this estimate.

[c] Based on log reductions shown in Tables D1and D2 (see Appendix D); hazard concentrations reduced by secondary treatment, coagulation, filtration and disinfection.

[d] Constants and models used to calculate risk of infection are shown in Table B2.

[e] Havelaar and Melse (2003).

[f] DALY per case based on Havelaar and Melse (2003).

[g] The proportion of the population susceptible to developing disease following infection. The figure of 6% for rotavirus is based on the fact that infection is common in very young children. The 6% equates to the percentage of population aged less than five years.

Box B1: Formulae used in Table B3

1. Dose per event = Source water concentration × log reduction × exposure

2. P_{inf} = Dose–response models and parameters as shown in Table B2

3. $P_{inf\ per\ year} = 1 - (1 - P_{inf})^{N}$

   where N = number of exposures per year

   For lower levels of risk, this can be approximated to:

   $P_{inf\ per\ year} = P_{inf} \times N$

4. $P_{ill\ per\ year} = P_{inf\ per\ year} \times$ ratio of illness to infection

5. DALY per year = $P_{ill\ per\ year} \times$ DALY per case × susceptibility fraction

Another approach is to calculate treatment goals to achieve a health target of 10^{-6} DALY[1] for the specified uses of reclaimed water, based on the initial concentration of a reference pathogen in the untreated source water. The disease burden, in DALYs, is calculated from the estimated exposures to pathogens in the recycled water. Because the reductions depend on the initial concentrations and the associated exposure, uses involving higher exposures will require greater reductions of pathogens from treatment.

The log reductions required to reach a target of 10^{-6} DALY per year in treated reclaimed water can be calculated. Dose equivalents to 10^{-6} DALY (dalyd) can be determined using the formulae given below:

$$\text{DALY per year} = P_{\text{inf per year}} \times N \times \text{ratio of illness to infection} \times \text{DALY per case} \times \text{susceptibility fraction}$$

Since the target DALY per year is 10^{-6} in this example, this equation can be written to solve for the dose equivalent:

$$\text{Dose equivalent} = \frac{\text{target DALY per year}}{\text{DALY per case} \times P_{\text{inf per organism}} \times \text{ratio of illness to infection} \times \text{susceptibility fraction}}$$

Where concentrations of organisms in source water are known, required log reductions (Table B4) can be calculated with the following formula:

$$\text{Log reduction} = \log(\text{concentration in source water} \times \text{exposure (L)} \times N \div \text{dalyd})$$

Where: L = volume, in litres
N = number of times the exposure occurs in one year
dalyd = Doses equivalent to 10^{-6} DALY

Table B4: Required log reductions

		Required log reductions	
Organism	Dose equivalent[a]	Based on aerosols from toilet flushing	Based on cross-connection[b]
C. parvum	5.3×10^{-2}	2.6	4.1
Rotavirus	5.5×10^{-3}	4.2	5.7
E. coli O157:H7	7.1×10^{-3}	5.3	6.8

[a] Doses equivalent to 10^{-6} DALY (dalyd).
[b] Based on worst-case assumption of 1 person per 1000 consuming 1 L/day for 365 days.

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[1] Note that the health target of 10^{-6} DALY per person per year is used based on the current recommendations of the WHO (2004) and the decision of the Federal-Provincial-Territorial Committee on Drinking Water to use this target as an acceptable level of risk. Individual jurisdictions may want to set a different health target based on their needs and situation.

Appendix C: Technology verification and certification

Technology verification and certification are used to help verify reclaimed water effluent quality and equipment reliability. Verification and certification processes may include the following:

- general design and construction requirements and testing procedures to confirm system integrity and robustness;
- efficacy of treatment (based on applicable effluent water quality guidelines/standards);
- evaluation methodology to verify treatment system compliance;
- plumbing requirements to meet applicable codes/standards;
- additional considerations for specific treatment processes;
- installation requirements as per design specifications and regulatory authority approval conditions;
- documentation requirements; and
- monitoring requirements.

To date, there are very few technology performance certification standards specific to reclaimed water systems. Some work has recently been published on greywater treatment systems (NSW, 2005; Diaper et al., 2008). In the absence of evaluation protocols for reclaimed wastewater systems, on-site wastewater treatment performance protocols offer a rigorous methodology that can be applied to reclaimed wastewater technology. These protocols include the Canadian BNQ 3680-600-8 (Onsite Residential Wastewater Treatment Technologies) and the NSF/ANSI Standard 40 (Residential Wastewater Treatment Systems). In addition to the technology evaluation standards that have been developed, complementary documents, such as the *Interim NSW Guidelines for the Management of Private Recycled Water Schemes* (NSW, 2008), can provide useful information.

Appendix D: Treatment processes

Water reclamation typically makes use of conventional wastewater treatment technologies that are widely used and readily available. The discussion of treatment for reclaimed water focuses largely on whether the treatment system is capable of consistently achieving an appropriate water quality. Most international examples of guidelines for the use of recycled water specify both general treatment processes and water quality limits for a particular group of applications (Bahri and Brissaud, 2003).

Overview of wastewater treatment for reclaimed water

The treatment of wastewater is usually performed by a combination of biological, physical and chemical processes. Biological treatment uses microorganisms in suspension in the wastewater or attached onto a support media, to assist in the removal of matter from the wastewater. Physical treatment removes the waste by filtration through a granular media or through a solid media, such as membrane filtration. Chemical treatment involves adding specific chemicals to precipitate targeted components or adsorbing them onto a media. All of these processes can provide different degrees of treatment. The terms widely used to describe these degrees of treatment, in order of increasing treatment level, are primary, secondary, advanced secondary and tertiary treatment. The definitions of these treatment levels vary. The definitions and descriptions provided in this appendix are for the purposes of this document only. Wastewater treatment levels considered suitable for the purposes of producing reclaimed water for toilet flushing use in residential and commercial buildings include secondary, advanced secondary and tertiary treatment systems. These are typically characterized by the water quality produced in terms of biochemical oxygen demand (BOD) and total suspended solids (TSS) concentrations and the degree of nitrification achieved in converting ammonium to nitrate. Table D1 provides an overview of indicative removals of microbial hazards that can be achieved using various treatment processes and treatment levels.

Table D1: Indicative log removals of enteric pathogens and indicator organisms[a]

	Indicative log reductions[b]				
Treatment	*E. coli*	Bacterial pathogens	Viruses	*Giardia*	*Cryptosporidium*
Primary treatment	0–0.5	0–0.5	0–0.1	0.5–1.0	0–0.5
Secondary treatment	1.0–3.0	1.0–3.0	0.5–2.0	0.5–1.5	0.5–1.0
Dual-media filtration	0–1.0	0–1.0	0.5–3.0	1.0–3.0	1.5–2.5
Membrane filtration	3.5–> 6.0	3.5–> 6.0	2.5–> 6.0	> 6.0	> 6.0

[a] Adapted from NRMMC-EPHC (2006).

[b] Reductions are dependent on specific features of the process;

Primary treatment

Primary treatment removes coarse organic and inorganic solids and grit by sedimentation and/or flotation. The organic contaminants removed can represent a significant portion of the overall BOD, TSS and fats, oils and grease in the raw wastewater. Some of the nitrogen and phosphorus may also be removed, but this is typically not an objective of primary treatment.

Primary treatment alone is not sufficient to generate reclaimed water of an acceptable quality. It is, however, an important step to conduct before most secondary and advanced secondary treatment processes.

Secondary treatment

The principal purpose of secondary treatment is to remove the soluble organic components of the wastewater, in addition to colloidal or suspended forms, following primary treatment in a septic tank for smaller decentralized or on-site treatment systems. Treatment benefits include the removal of residual particulate material, inorganic contaminants and pathogens that are adsorbed (attached) to the biosolids within the system.

Secondary treatment includes an array of biological processes and requires an environment within the treatment system that is suitable for rapid microbial growth. Since aerobic (oxygen-consuming) bacteria treat wastewater more quickly and efficiently than do anaerobic (no oxygen) bacteria, secondary treatment typically involves aerobic bacteria. This means that oxygen must be provided to the system either passively, through the diffusion of air through the system (as is the case with sand filters), or mechanically, introduced using blowers.

After secondary treatment, the effluent typically has BOD_5 and TSS concentrations less than 30 mg/L and can be effectively disinfected. Organic contaminants that are resistant to microbial breakdown, nutrients and residual solids may remain in the wastewater effluent after secondary treatment.

Advanced secondary treatment (an alternative to secondary treatment)

In advanced secondary treatment, the same treatment processes and technologies described for secondary treatment are followed by filtration to remove residual and colloidal solids and some additional BOD.

Advanced secondary treatment refers to systems that can reliably achieve effluent quality approaching the detection limits for BOD_5, TSS and (with disinfection) thermotolerant coliforms. The effluent from advanced secondary treatment systems is expected to have BOD_5 and TSS concentrations less than 10 mg/L. Filtration is included in the treatment process when efficient disinfection is required. This level of treatment is often used internationally in standards or guidelines for “unrestricted public access” reclaimed water use. “Unrestricted public access” applications typically include recreational water uses, playing field irrigation, landscape impoundments, direct discharge to streams, vehicle washing, etc.

Tertiary treatment

Tertiary treatment refers to further removal of colloidal and suspended solids, as well as nutrient (phosphorus and nitrogen) removal from the wastewater by either biological or chemical means. Nitrogen released to surface water can be a factor in nuisance algal growth and, if released in the form of ammonia, can be toxic to aquatic organisms.

Nutrient removal can be achieved in a number of ways, including biological and chemical treatment. Biological treatment is generally carried out using an activated sludge (suspended growth) treatment process, which has been compartmentalized into “environmental” zones, and in which bacteria can be conditioned to remove nitrogen or phosphorus. Treatment systems capable of removing nutrients biologically are more complex and require greater operator skill and attention as well as considerable engineering design input.

In chemical treatment, phosphorus can be precipitated by adding specific chemicals to the wastewater or by adsorption through a special filter. Ammonia can be removed with ion exchange resins or with zeolite. However, chemical addition is not generally considered practical for small wastewater treatment applications. The simple conversion of ammonia to nitrate using dissolved oxygen (i.e., nitrogen conversion but not removal) is also sometimes referred to as tertiary treatment. Although nitrogen is not effectively removed, the ammonia concentration in the effluent (and thus the potential aquatic toxicity) is reduced.

Disinfection

Disinfection is an essential treatment component of almost all wastewater reclamation applications. Disinfection destroys or inactivates the majority of microorganisms within the treated wastewater effluent, including those that are pathogenic to humans. There are three commonly applied methods of disinfection. These are 1) chlorine and alternatives (chlorine dioxide, chloramines); 2) ozonation; and 3) ultraviolet (UV) irradiation. Many disinfection technologies are available and can be designed for treatment applications ranging in size from small on-site to large-scale treatment applications. Although there are exceptions, treated effluents intended for use as reclaimed water will generally require filtration in order to enhance the impact of disinfection processes. Table D2 provides ranges of indicative log removals for enteric pathogens and indicator organisms. Tables D3 and D4 provide a comparison of the concentration (mg/L) and time (minutes) (CT) values for various degrees of virus and *Giardia* inactivation in water, for the methods of disinfection described in this section (chlorine, chlorine dioxide, ozone). Table D5 provides information on UV light dose for these same organisms as well as for *Cryptosporidium*. Note that the CT values and UV doses were developed for water of specific characteristics and not for domestic wastewater. Also, the CT values shown for chlorine are based on having a free chlorine residual.

Table D2: Indicative log removals of enteric pathogens and indicator organisms[a]

	Indicative log reductions[b]				
Treatment	*E. coli*	Bacterial pathogens	Viruses	*Giardia*	*Cryptosporidium*
Chlorination	2.0–6.0	2.0–6.0	1.0–3.0	0.5–1.5	0–0.5
Ozonation	2.0–6.0	2.0–6.0	3.0–6.0	0.5–3.0[c]	0.25–3.0[d]
UV light	2.0–> 4.0	2.0–> 4.0	> 1.0 adenovirus > 3.0 enterovirus hepatitis A	> 3.0	> 3.0

[a] Adapted from NRMMC-EPHC (2006).
[b] Reductions are dependent on specific features of the process.
[c] Value range based on published CT tables from U.S. EPA (1999).
[d] Value range based on published CT tables from U.S. EPA (2006a).

Table D3: CT values for inactivation of viruses[a]

	Inactivation (mg·min/L)		
Disinfectant	2 log	3 log	4 log
Chlorine[b]	3	4	6
Chlorine dioxide[c]	4.2	12.8	25.1
Ozone	0.5	0.8	1.0

[a] From U.S. EPA (1999). CT values were obtained from AWWA (1991).
[b] Values are based on a temperature of 10°C, pH range of 6–9 and a free chlorine residual of 0.2–0.5 mg/L.
[c] Values are based on a temperature of 10°C and a pH range of 6–9.

Table D4: CT values for inactivation of *Giardia* cysts[a]

	Inactivation (mg·min/L)					
Disinfectant	0.5 log	1 log	1.5 log	2 log	2.5 log	3 log
Chlorine[b]	17	35	52	69	87	104
Chlorine dioxide[c]	4	7.7	12	15	19	23
Ozone[c]	0.23	0.48	0.72	0.95	1.2	1.43

[a] From U.S. EPA (1999). CT values were obtained from AWWA (1991).
[b] Values are based on a free chlorine residual less than or equal to 0.4 mg/L, temperature of 10°C and a pH of 7.
[c] Values are based on a temperature of 10°C and a pH range of 6–9.

Table D5: UV dose (mJ/cm^2) required for up to 4 log (99.99%) inactivation of various microorganisms[a]

	Log inactivation							
Microorganism	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

[a] From U.S. EPA (2006b).

Biosolids and residuals treatment

Biosolids treatment involves the treatment of solids that settle out during either or both of he primary and secondary wastewater treatment processes. The requirements for treatment or disposal of biosolids may vary between jurisdictions. Depending on the size of the treatment facility, the primary solids may be stored and hauled away (e.g., septic tank) or transferred to a digestion facility to be stabilized prior to disposal. Digestion may be carried out by bacteria aerobically (with oxygen) or anaerobically (without oxygen), the former being a faster stabilization process but requiring more power, and the latter being a slower process that can be used to generate methane gas (biogas) for power generation if at an appropriately large enough scale. Alternative means of organic solids stabilization include composting and incineration.

Selection of appropriate treatment levels or scale

Wastewater can be treated on site, at the home or building where it is generated, or it can be transported via a sewer to a common wastewater treatment or reclaimed water treatment plant. Studies of centralized facilities have shown that wastewater treatment processes are capable of significantly reducing the numbers of pathogens or indicator organisms present in wastewater, although removal efficiencies will vary with the treatment process type, retention time, oxygen concentration, temperature and the efficiency in removing suspended solids (Garcia et al., 2002; Koivunen et al., 2003; Scott et al., 2003; Rose et al., 2004). In one study, a full-scale municipal treatment plant using biological treatment, filtration and chlorination was shown to reduce total and faecal coliforms by > 7 log and coliphages and enteric viruses by > 5 log. Protozoan pathogens (*Giardia* and *Cryptosporidium* species) were reduced by more than 3 log (Rose et al., 1996). While filtration has been found to be the most effective treatment process (in a conventional treatment train) for removing protozoan cysts and oocysts, infectious *Cryptosporidium* oocysts are detected even in the final effluent from facilities that use filtration processes (Gennaccaro et al., 2003; Scott et al., 2003; Rose et al., 2004). Monitoring data from Florida facilities indicate that, in general, the facilities that have reported pathogen data have been well operated (based on TSS, turbidity and total chlorine residual measurements). Some of the Florida facilities reporting the highest concentrations of pathogens in treated water appeared to provide effective filtration and disinfection. The range of *Giardia* cysts reported as potentially viable was 10–90% (average 61%), whereas the viable fraction of *Cryptosporidium* ranged from 70% to 90% (average 77%) (York et al., 2003). These findings suggest that although effective treatment of wastewater will produce a high quality of effluent, it is likely that some risks from viable pathogens will remain.

Over the last 20 years, many of the processes found in centralized treatment systems have been incorporated into on-site systems. The result has been improved system performance and wider-scale acceptance of the on-site wastewater treatment concept. New technologies that are capable of advanced secondary treatment are becoming available for on-site applications suitable for water reuse consideration (Chu et al., 2003; Diaper, 2004). Ranges in treatment performance are shown, as even an optimized system will show some variability in treatment performance. The information in Table D1 and D2 can be used to characterize risk in a simple, deterministic process such as that described in Section 4.5 and Appendix B. However, to characterize risk more accurately, it is preferable to use information that is specific to a given system designed to address the local or unique conditions of the installation. As an example, membranes come with a relatively wide range of pore size, which will have different performance expectations.

There are relative advantages and disadvantages to every type of treatment technology, regardless of the scale of application. Some processes are better suited to on-site needs, whereas others are better suited to more centralized applications. Those technologies that are mechanically complex or require greater operator attention are better suited to centralized facilities where skilled personnel are available. Processes of this kind can be broadly referred to as intensive systems that offer high performance but require a high degree of inputs, such as power, process control and operator skill level. Alternatively, processes that have fewer operating controls or variables, or where few skills are required to operate and maintain the system, are generally better suited to on-site applications.

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