

# Environment Canada

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## Environnement Canada

A review of water reuse and recycling with reference to

Canadaian practice and potential

1. Incentives and implementation

By:

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**A review of water reuse and recycling, with reference to Canadian practice and potential:  
1. Incentives and implementation**

**K. Exall, J. Marsalek and K. Schaefer**

**Abstract**

As a country on the whole, Canada enjoys abundant freshwater resources, yet there remain regions with severe discrepancies between supply and demand. One solution to insufficient water supplies that has been gaining in popularity in other areas of the world is that of water reuse. Reuse or recycling of treated wastewater reduces effluent discharges into receiving waters and offers a reliable alternative supply of water for applications that do not require high quality water, freeing up limited potable water resources. As compared to other countries worldwide, water reuse is currently practised infrequently in Canada. Use of reclaimed water requires a clear definition of the quality of water required, and while water quality criteria typically focus on pathogen risk to human health, chemical contaminants may also limit suitability for some reuse applications. Both health and environmental risk assessments are important steps in designing criteria for reuse projects. Alberta and British Columbia have recently produced guidance documents for water reuse projects; the permitted applications are discussed and the water quality criteria are compared with other standards and guidelines. Various treatment technologies for on-site and central wastewater reclamation facilities are described. Additional considerations for implementation of water reuse projects include project feasibility and planning, infrastructure needs, economics, and public acceptance.

## **Aperçu de la réutilisation et du recyclage de l'eau en fonction des pratiques et des possibilités au Canada :**

### **1. Mesures incitatives et mise en œuvre de projets**

K. Exall, J. Marsalek et K. Schaefer

#### **Résumé**

Dans l'ensemble, le Canada jouit d'abondantes ressources d'eau douce, bien que certaines régions présentent de grands écarts entre la demande et l'approvisionnement. La réutilisation de l'eau est l'une des solutions au problème d'insuffisance d'eau qui bénéficie d'une popularité croissante dans les autres régions du globe. La réutilisation ou le recyclage des eaux usées traitées permet de réduire les rejets d'effluents dans les eaux réceptrices et d'offrir une source fiable d'approvisionnement en eau pour des utilisations qui ne nécessitent pas une eau de grande qualité, libérant ainsi une partie des ressources limitées en eau potable. La réutilisation de l'eau est une pratique peu courante au Canada comparativement à d'autres pays. Pour utiliser une eau récupérée, il faut que la définition de la qualité d'eau requise soit claire. Toutefois, bien que les critères définissant la qualité de l'eau portent habituellement sur son risque de pathogénicité pour la santé humaine, les contaminants chimiques peuvent également en restreindre l'utilisation dans certains cas. L'évaluation du risque pour la santé et pour l'environnement sont des étapes importantes dans la conception de critères pour les projets de réutilisation de l'eau. L'Alberta et la Colombie-Britannique ont récemment produit des guides d'orientation pour de tels projets, qui traitent des applications permises et comparent les critères de qualité de l'eau à d'autres normes et lignes directrices. Diverses techniques utilisées pour traiter les eaux usées sur les lieux et dans des installations d'épuration y sont décrites. D'autres points à considérer dans la mise en œuvre de projets de réutilisation de l'eau comprennent la planification et l'étude de la faisabilité du projet, les besoins en infrastructure, l'aspect économique et l'acceptation du public.

## **NWRI RESEARCH SUMMARY**

### **Plain language title**

A review of water reuse and recycling, with reference to Canadian practice and potential: 1. Incentives and implementation

### **What is the problem and what do scientists already know about it?**

In water reuse, treated municipal effluents are utilized to provide a new source for non-potable water supply, while at the same time reducing the discharge of polluted effluents into receiving waters, thus reducing their pollution. Applications of water reuse are increasing throughout the world, and are beginning to gain popularity in Canada, particularly in B.C. and the Prairie provinces. This paper served to review aspects of water reuse, with reference to past and potential work in Canada.

### **Why did NWRI do this study?**

While applications of water reuse are becoming more frequent around the world, the knowledge in Canada has not been compiled and reviewed. A literature review was done in preparation for the CCME Linking Science to Policy Workshop on Water Reuse and Recycling; this work arose from that review.

### **What were the results?**

Some of the incentives for water reuse, relating to water availability and demands in Canada, are presented. Considerations for implementation of water reuse projects, including water quality criteria, existing guidelines and regulations, wastewater treatment technologies, and issues related to project implementation (project planning, infrastructure needs, economics and public acceptance), are discussed. Canadian experience is reviewed in the context of work going on in other areas of the world.

### **How will these results be used?**

This review is intended to inform Canadian environmental professionals about the current and potential practices of water reuse; this information can be used as a starting point in planning and implementation of new water reuse projects or guidelines.

### **Who were our main partners in the study?**

N/A, although this work arose from the CCME Linking Science to Policy Workshop on Water Reuse and Recycling.

## **Sommaire des recherches de l'INRE**

### **Titre en langage clair**

Aperçu de la réutilisation et du recyclage de l'eau en fonction des pratiques et des possibilités au Canada : 1. Mesures incitatives et mise en œuvre de projets

### **Quel est le problème et que savent les chercheurs à ce sujet?**

Dans les projets de réutilisation de l'eau, les effluents municipaux traités sont utilisés comme nouvelle source d'eau non potable, ce qui permet de réduire les rejets d'effluents pollués dans les eaux réceptrices et, par conséquent, d'en réduire la pollution. Le recours à la réutilisation de l'eau augmente de par le monde et cette stratégie gagne en popularité au Canada, surtout en Colombie-Britannique et dans les Prairies. Le présent article a permis d'examiner certains aspects de la réutilisation de l'eau, notamment en ce qui a trait aux travaux antérieurs et aux possibilités de recourir à cette technologie au Canada.

### **Pourquoi l'INRE a-t-il effectué cette étude?**

Malgré la popularité croissante de projets de réutilisation de l'eau dans le monde, au Canada, les données à cet effet n'ont pas été compilées ni examinées. Une revue de littérature a été faite lors de la préparation de l'atelier du CCME sur les liens entre les sciences de l'eau et les politiques de réutilisation et de recyclage de l'eau; le présent article est né de cette revue de littérature.

### **Quels sont les résultats?**

Certaines mesures incitatives pour la réutilisation de l'eau y sont présentées, par rapport à la disponibilité de l'eau et à la demande au Canada. Les points à considérer dans la mise en œuvre des projets de réutilisation de l'eau comprennent les critères de qualité de l'eau, les lignes directrices et la réglementation existantes, les technologies de traitement des eaux usées et les questions liées à la mise en œuvre du projet (planification, besoins en infrastructure, aspect économique et acceptation du public). L'expérience canadienne est examinée dans le contexte des pratiques employées dans d'autres régions du monde.

### **Comment ces résultats seront-ils utilisés?**

Le présent aperçu vise à informer les professionnels canadiens de l'environnement des possibilités et des pratiques actuelles en matière de réutilisation de l'eau; ces renseignements peuvent servir de point de départ à la planification et à la mise en œuvre de nouveaux projets de réutilisation de l'eau, ou à l'élaboration de lignes directrices.

### **Quels étaient nos principaux partenaires dans cette étude?**

Sans objet, bien que le présent travail provienne de la préparation de l'atelier du CCME sur les liens entre les sciences de l'eau et les politiques de réutilisation et de recyclage de l'eau.

## REVIEW ARTICLE

# A Review of Water Reuse and Recycling, with Reference to Canadian Practice and Potential: 1. Incentives and Implementation

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As a country on the whole, Canada enjoys abundant freshwater resources, yet there remain regions with severe discrepancies between supply and demand. One solution to insufficient water supplies that has been gaining in popularity in other areas of the world is that of water reuse. Reuse or recycling of treated wastewater reduces effluent discharges into receiving waters and offers a reliable alternative supply of water for applications that do not require high-quality water, freeing up limited potable water resources. As compared to other countries worldwide, water reuse is currently practised infrequently in Canada. Use of reclaimed water requires a clear definition of the quality of water required, and while water quality criteria typically focus on pathogen risk to human health, chemical contaminants may also limit suitability for some reuse applications. Both health and environmental risk assessments are important steps in designing criteria for reuse projects. Alberta and British Columbia have recently produced guidance documents for water reuse projects; the permitted applications are discussed and the water quality criteria are compared with other standards and guidelines. Various treatment technologies for on-site and central wastewater reclamation facilities are described. Additional considerations for implementation of water reuse projects include project feasibility and planning, infrastructure needs, economics, and public acceptance.

**Key words:** water reuse, water recycling, wastewater treatment, reclaimed water quality, guidelines

## Introduction

The growing water management challenge to provide a balance between water demand, water use and the protection of water resources quality occurs at various spatial scales, ranging from local, or regional, to national. This situation is particularly serious in developing countries of arid and semi-arid regions of the world, which are experiencing water shortages and rapidly growing populations. In Canada, on the whole, the situation is quite different, with relatively abundant water supplies in most regions. Annual precipitation in Canada averages 600 millimetres, although it ranges from 100 millimetres in the high Arctic to over 3500 millimetres along the Pacific Coast, with many agricultural lands in the Prairies and B.C. interior receiving an average of 300 to 500 millimetres of precipitation annually (Coote and Gregorich 2000; Statistics Canada 2000). There are therefore regions with limited water supplies, particularly in periods of droughts and high water demands, and high consumptive use in agriculture.

On a national basis, Canada has abundant sources of water and has been ranked second best in the world (after Finland) in a recent international survey of the

Water Poverty Index (Sullivan, 2002). This index takes into consideration water resources (internal flows, external inflows, population), access (percentage of population served by water supply and sanitation, access to irrigation water), use (domestic, industrial and agricultural uses), capacity (the level of human and financial capacity to manage the water system), and environment (indicator of ecological integrity, or adequacy of water resources for environmental needs). In spite of this favourable assessment of Canadian water resources, some communities in Canada have been experiencing water supply shortages, which may be caused by water quantity and/or water quality problems. In fact, about 26% of municipalities with water supply systems reported water shortages during the 1994 to 1999 period, for such reasons as seasonal shortages due to droughts, infrastructure problems, and increased consumption (Environment Canada 2001).

Adequate supply of good-quality water is essential for continuing development of Canadian society and its economy. The most recent data on gross water use indicate a steadily growing total intake, rising from  $36.7 \times 10^9 \text{ m}^3/\text{year}$  in 1981 to  $45.0 \times 10^9 \text{ m}^3/\text{year}$  in 1991 (Statistics Canada 2000). At the most recently reported level of 343 L/capita/day (Environment Canada 2001), nominal per capita water use in Canada remains well above that in advanced west European countries. Of the

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gross intake, in the personal and government sectors, only about 11% is consumed and the rest (89%) is returned, mostly as discharges of wastewater. Thus, many municipalities are faced with the challenge of providing water supply to their growing population, in competition with other sectors of the economy and relying on finite supplies, and controlling wastewater discharge into receiving waters. This challenge is further exacerbated by uncertainties with respect to future water availability, because of extreme weather patterns and climatic changes, increased competition across provincial and national boundaries for limited water supplies, and increasing demands on improved wastewater pollution control in support of beneficial uses of receiving water. In a modern integrated approach to solving this problem, the concept of total water cycle based management has been promoted, as "the integrated use and management of surface waters (including treated wastewater and stormwater discharges) and groundwater across the urban landscape to secure a range of social, economic and environmental benefits" (Lawrence et al. 1999). Within this holistic concept, one solution to the challenge is water reuse, which facilitates the use of treated municipal effluents as a new source for non-potable water supply, and at the same time reduces the discharge of polluted effluents into receiving waters, thus reducing their pollution. Under certain circumstances, economic benefits may be derived from water reuse, partly from savings on expansion of the water supply and wastewater treatment infrastructures.

Thus, the concept of total water cycle management provides a well-defined context for water reuse. The extent to which water reuse is practised then depends on water availability, economic incentives, regulatory feasibility, and public acceptance. Among these factors, water availability is probably the most important one; where water is scarce, water reuse is accepted by the general public, is economically feasible and a supportive regulatory environment is created.

### Brief History of Water Reuse

In recent years, the terminology used in water reuse has been somewhat standardized and the following common terms were paraphrased after Asano (1998):

- *Wastewater reclamation* involves treatment to a predetermined water quality, which facilitates reuse. In this context, the term wastewater includes municipal wastewater (representing a mixture of wastewater from residential, commercial, institutional and industrial sources), plus permitted inflows of rainwater or stormwater.
- *Reclaimed water* is treated effluent of a quality suitable for a specific reuse application.
- *Water reuse* is the use of treated wastewater for beneficial purposes. Direct reuse refers to a sys-

tem in which reclaimed water is transported to the points of reuse. Indirect reuse implies discharge of an effluent into receiving waters (surface or ground water) for assimilation and withdrawals downstream.

- *Water recycling or recirculation* typically refers to industrial systems, in which the effluent is recovered, usually treated and returned back into the industrial process.

The interest in water reuse in Canada emerged at least 25 years ago, when the Canada Mortgage and Housing Corporation (CMHC) sponsored one of the first large-scale Canadian projects on this subject (Canviro Consultants Ltd. and MacLaren Engineers Inc. 1984) and concluded that water reuse for practically all purposes (including potable water supply) was technologically feasible. Since that time, new chemicals of concern have been identified (endocrine disruptors, pharmaceuticals and personal care products) and there is a need to revisit the related water reuse issues. While worldwide water reuse has been rapidly rising and some experts consider water reuse to be the greatest challenge of the 21<sup>st</sup> century (Asano 2002), its spread in Canada is much more limited. The greatest water reuse occurs in world regions suffering water scarcity, such as in the Middle East, Australia or the U.S. southwest. The field is also growing rapidly in regions with severe restrictions on disposal of treated wastewater effluents, such as Florida, coastal and island areas of France, Spain and Italy, and densely populated European countries such as England and Germany (Lazarova et al. 2001). Countries with regional water resource disparities, such as Japan, also practise extensive water recycling and reuse (Ogoshi et al. 2001).

At present, water reuse is practised in Canada on a relatively small scale, and mostly in isolated cases. Globally, the most common applications of reclaimed water are in agricultural and landscape irrigation (including golf courses), although in Japan, reclaimed water is more commonly applied to non-potable urban reuse applications (Ogoshi et al. 2001). Other water reuse applications include on-site residential/greywater reuse, industrial reuse, rainwater and stormwater collection and reuse, surface water augmentation and groundwater recharge, and potable reuse. These applications will be described in further detail in the accompanying article (Exall 2004). As water demands increase and the readily available supplies dwindle, the interest in water reuse will increase.

### Water Quality Criteria, Guidelines and Regulations

#### Criteria

Numerous countries, states and organizations have developed standards or guidelines dealing with water

reuse. Criteria address public health and environmental protection, generally containing reference to reclaimed water quality, wastewater treatment processes, treatment reliability, distribution systems, and use area controls.

The removal of pathogens is typically the prime objective in treating wastewater for reuse. The main pathogens of concern in raw municipal wastewater can be classified in four main groups: bacteria, viruses, helminths, and protozoa (Alberta Environment 2000). The foremost bacteria of concern include *Salmonella* species, *Shigella* species, *Campylobacter jejuni* and *Escherichia coli*. There are also over 100 strains of enteric viruses that can be endemic in a community, and would therefore be present in raw wastewater. Some of the most common are Poliovirus, Norwalk agent and rotavirus. Intestinal parasites commonly found in wastewater include helminthic species such as *Taenia* species (tape worm) and *Ascaris lumbricoides* (round worm), and protozoan species such as *Giardia lamblia* and *Cryptosporidium parvum*. The ova of helminths and the cysts and oocysts of protozoa are of most concern in wastewater, as they can remain viable for an extended period of time outside of their hosts (Cooper and Olivieri 1998). In general, the occurrence and concentration of pathogens depends on such factors as the sources contributing to the wastewater, the existence of disease in the contributing population, and the ability of the infectious agents to survive outside of the host under various environmental conditions (Crook 1998).

Routine monitoring for every known pathogen is unrealistic; for this reason, surrogate or indicator organisms are commonly used. Total or fecal coliform bacteria (which are broadly equivalent to thermotolerant coliforms) may be used as indicator organisms for pathogens in general and provide a reasonably reliable indication of bacterial pathogens; however, they can be quite poor indicators of viral, protozoan and helminthic pathogens (WHO 1989). Although not yet standard, the use of coliphages as possible surrogates for animal viruses has been suggested. There are currently no suitable surrogates for helminth ova or protozoan parasites; *Cryptosporidium* oocysts are commonly used to represent protozoa, although an accurate and precise method of determination is still lacking, and viability of the oocysts can be difficult to determine (Cooper and Olivieri 1998). Salgot et al. (2001) reviewed biological control tools commonly used in wastewater reclamation and water reuse. They determined that the analytical controls usually recommended for reuse facilities (typically based only on bacterial indicators) are insufficient to guarantee a lack of risks or even an acceptable level of risk, but that increasing the control measures required would impact the price of reclaimed water.

Chemical constituents are generally not a health concern for urban uses of reclaimed water, although they may be the main health concerns for potable reuse. The suitability of reclaimed water for uses such as food crop irrigation,

industrial applications, and indirect potable reuse may also be affected by chemical constituents. The chemicals regularly monitored in water reuse projects can be classified into about half a dozen groups, including biodegradable organics, recalcitrant organics, nutrients, heavy metals, residual chlorine, and suspended solids. Biodegradable organics are usually characterized by biochemical oxygen demand (BOD). In general, organics provide food for microorganisms, impact adversely on disinfection, and consume oxygen. Recalcitrant organics resist conventional wastewater treatment and may be toxic in the environment; their presence may limit the suitability of reclaimed water for some reuse applications. Typically they are characterized by total organic carbon (TOC). Nitrogen, phosphorus and potassium are nutrients required for plant growth and thereby enhance the value of reclaimed water for agricultural irrigation. However, when reaching receiving waters, they may contribute to eutrophication or enhanced productivity. In on-land disposal, nitrogen may leach into groundwater and cause exceedance of drinking water standards. Heavy metals may accumulate in the environment and are toxic to plants and animals. Their presence limits the acceptability of reclaimed water for irrigation. Residual chlorine is toxic to many aquatic organisms and has to be removed prior to discharge to receiving waters (by dechlorination). Chlorine may react with organics in receiving waters and form chlorinated organics, which may be harmful to health. Suspended solids provide transport for trace organic constituents and heavy metals, react with disinfectants and thereby reduce disinfection effectiveness. They also reduce the effectiveness of UV disinfection. Finally, high levels of dissolved solids may reduce the suitability of reclaimed water for irrigation purposes and, if applied over extended time periods, reduce soil productivity (Crook 1998).

Additionally, chemical constituents become of major concern where reclaimed water may enter groundwater aquifers, and concerns about entry into water supplies increased in recent years with respect to such new chemicals of concern as endocrine disruptors, pharmaceuticals and therapeutic products (e.g., Servos et al. 2001). Some recent studies focus specifically on new chemicals of concern in reclaimed water (Drewes et al. 2002; Heberer et al. 2002; Sedlak et al. 2000).

For industrial water reuse and recycling, water quality requirements tend to be industry-specific, as changes to water chemistry may impact process performance. Typical water quality concerns for industrial reuse or recycling include scaling, corrosion, biological growth, fouling and foaming, as well as impacts on worker health, such as by inhalation of aerosols containing volatile organic compounds or microbiological pathogens (Ng et al. 2001; Hermanowicz et al. 2001; Asano and Levine 1998).

The criteria chosen for inclusion in guidelines and regulations depend on the assessed risk, which should be determined for both human health and environmental



factors. The method of health risk assessment that is applied is therefore also of great importance and has been considered by many researchers (Anderson et al. 2001; Tanaka et al. 1998; Sakaji and Funamizu 1998; Shuval et al. 1997; Ganoulis and Papalopoulou 1996). Two main approaches have been quantitative risk assessment (QRA), described as the "high technology/high cost/low risk" approach, and the "low technology/low cost/controlled risk" technique of real or attributable risk (AR). The QRA technique entails four steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization. The AR technique is based on epidemiological studies, and practices or guidelines are then based on incurring no incremental risk to the population (Anderson et al. 2001).

Environmental risk assessment is becoming increasingly recognized as an important tool to ensure that the effects of reclaimed water applications on soil and groundwater are sustainable in the long term. Factors often taken into account in environmental risk assessments include salt and chemical content, as well as hydraulic and nutrient loading rates (Anderson et al. 2001). Kontos and Asano (1996) have described the preparation of environmental impact assessment documents, particularly in reference to water reuse applications in California. Specific effects associated with water reuse projects, such as soil impacts and growth-inducing impacts, were also discussed.

Chang et al. (1996) compared two approaches to developing pollutant loading guidelines for irrigation with reclaimed water, one based on preventing pollutant accumulation in waste-receiving soil, and the other on maximizing the soil's capacity to assimilate, attenuate and detoxify chemicals. While the former aims to maintain ecological balances in the soil, it was suggested that meeting the stringent limits required might be difficult for some communities. A method of developing human health-related guidelines using the latter approach was derived by considering the food chain transfer of pollutants through intake of crops grown on wastewater-affected soils.

### Guidelines and Regulations

The water reuse guidelines or regulations most commonly cited are those of the World Health Organisation (WHO 1989), the U.S. EPA (1992) and the State of California Title 22 regulations (State of California 2001). Australia, many Middle Eastern and Mediterranean European countries, and many U.S. states also have water reuse guidelines or regulations in various conditions of development or implementation; ways in which the different national approaches to water recycling regulations could be linked to form international guidelines have also been discussed (Anderson et al. 2001).

**World Health Organisation.** In the WHO report "Health guidelines for the use of wastewater in agriculture and

aquaculture" (WHO 1989), guideline values of  $\leq 1000$  total coliform units per 100 mL and  $\leq 1$  intestinal nematode egg per L for irrigation of crops likely to be eaten raw were established, largely to improve attainability for developing countries. The coliform guideline is much less stringent than those given by some other standards, although the helminth egg restrictions are included. These standards were based on epidemiological studies and on the fact that in many developing countries, the main health risks are associated with helminthic diseases. The WHO guidelines are currently undergoing review and will likely be revised in the near future (Blumenthal et al. 2000).

**United States.** In the U.S., there are no federal regulations; legislation of water reuse applications is the responsibility of individual states. Arizona, Florida, California and Texas are the more active states pursuing water reuse. Technical guidelines and in some cases state regulations have been established that cover a wide range of water reuse practices, and the use of land treatment/reuse systems, on-site treatment and reuse, and dual water systems are growing in popularity. In 1992, the U.S. EPA published the manual "Guidelines for Water Reuse" (U.S. EPA 1992) to aid those areas without criteria or standards of their own. Included in the manual are suggested guidelines for various applications of water reuse, including urban reuse, restricted access area irrigation, agricultural irrigation for food and non-food crops, recreational and landscape impoundments, industrial reuse, groundwater recharge, and indirect potable reuse. As well as specifying reclaimed water quality guidelines, the manual suggests guidelines for wastewater treatment processes, monitoring, and setback distances from potable water supply wells and areas accessible to the public.

**California.** The State of California adopted the first reclamation and reuse standards in 1918 to address the use of reclaimed water for agricultural irrigation; these have been regularly updated and are used as a basis in the development of standards worldwide (Crook 1998). The California Code of Regulations Title 22 (State of California 2001) defines wastewater quality in terms of both treatment technique and microbiological content. Quality levels include "disinfected secondary-2.2 recycled water," meaning recycled water in which the median concentration of total coliform bacteria in the disinfected effluent does not exceed a most probable number (MPN) of 2.2 per 100 millilitres, and "disinfected secondary-23 recycled water," which requires that the median concentration of total coliform bacteria in the disinfected effluent does not exceed a MPN of 23 per 100 millilitres. The quality of the water required is determined by the type of application.

**Canada.** At this time, there exist no national guidelines on wastewater reclamation and water reuse. Interest in reuse applications has grown in regions experiencing

water quantity or quality concerns, however, and both Alberta and British Columbia have produced guidelines relating to water reuse.

**Alberta.** In April 2000, Alberta Environment published the Guidelines for Municipal Wastewater Irrigation (Alberta Environment 2000). Wastewater irrigation as a municipal wastewater disposal option requires authorization as defined in the Alberta *Environmental Protection and Enhancement Act*; the objective of the guidelines is to help wastewater systems owners and consultants with the approval process. The guidelines are meant to ensure that reclaimed municipal wastewater is used for irrigation only when environmentally acceptable and agriculturally beneficial. Potential hazards and benefits are discussed, as well as factors to be considered when planning reuse programs, including wastewater quality characterization, land suitability factors, soil and vegetation loading limitations, and various irrigation system design considerations.

Only certain crops are considered to be suitable for production on lands to be irrigated with treated municipal wastewater in Alberta. The current authorized crops include only forages, coarse grains, turf, and oil seeds. Other crops to be considered need to be supported by scientific studies that ensure there are no associated human health risks, and applied moisture and nutrient loading rates can be properly utilized by the crop.

Reclaimed water suitability for irrigation is based on water quality parameters. General health-related aspects such as bacteriological quality (potential human pathogens) and general chemical parameters (BOD, TSS, COD, pH, electrical conductivity [EC], sodium adsorption ratio [SAR], nutrients, major cations and anions, and metals) are considered. Treated effluent quality standards exist for both restricted and unrestricted use of reclaimed water for irrigation. The minimum treatment requirement is primary treatment followed by seven-month storage. As well, where warranted by public health concerns, e.g., golf courses, parks, etc., disinfection of wastewater prior to land application is required.

Wastewater irrigation may only be used in regions where additional moisture applied can be used for improved crop production. Site acceptability for irrigation is based on geologic and soil properties, topography, hydrology (with reference to surface water bodies or domestic wells nearby), climate (mean precipitation, evapotranspiration and seasonal crop moisture demands), zoning, and cropping intentions. System design considerations include required reclaimed water storage and sprinkler layout to optimize crop moisture and nutrient use while avoiding potential drawbacks (uneven distribution, drift, excessive leaching or runoff from site). Application loading rates depend on individual crop moisture and nutrient uptake needs. The amount of nutrients applied may not exceed the annual crop nutrient removal rates, although only nitrogen is likely to be restricting in terms of amount

of reclaimed water that may be applied in an irrigation season. Other major nutrients generally do not exceed annual crop uptake requirements.

**British Columbia.** In British Columbia, water reuse is considered for a much broader range of applications in the May 2001 document, "Code of Practice for the Use of Reclaimed Water: A Companion Document to the Municipal Sewage Regulation" (BC MELP 2001). The Code of Practice (CoP) serves as a guidance document for the use of reclaimed water in the province and to support the regulatory requirements prescribed in the Municipal Sewage Regulation (MSR) (BC MELP 1999). Compliance with the CoP and MSR enables use of reclaimed water in B.C., which supports water conservation practices, community planning goals and integration of water supply and wastewater infrastructure needs. The CoP gives quality and treatment requirements for two categories of water quality: unrestricted public access (Category 1) and restricted public access (Category 2, which requires that public access to the water be restricted by space, time or commercial processing of agricultural products). Schedule 2 of the MSR gives the treatment, water quality and monitoring requirements for categories 1 and 2, and specifies the uses for which each is approved.

Descriptions of reclaimed water use applications are given, along with considerations for use and specific design suggestions. The uses include: irrigation (with sub-headings of crop irrigation, frost protection, crop cooling, silviculture, greenhouses, and landscape irrigation); chemical spraying; fire fighting; toilet and urinal flushing; ponds and decorative uses; stream augmentation; habitat restoration/enhancement; commercial vehicle, driveway and street washing; snow and ice making; dust suppression and soil compaction; and industrial uses. Requirements and considerations for urban dual distribution systems (non-potable) are also discussed, as well as guidance on contingency options for surplus reclaimed water, storage, monitoring, labelling, storage and fencing, records and reporting, communications and emergency response plans.

Guidelines and regulations tend to be specific to the reuse application and the area in which reuse is to occur and because of this, straightforward comparison between standards is difficult. The general characteristics of various water reuse guidelines and regulations around the world are compared in Table 1. The number of water quality categories or classes varies, from two quality levels allowed by Alberta, B.C., Texas, and the WHO, to five separate categories in Arizona. While all documents contain coliform level limits for the use of reclaimed water in unrestricted irrigation applications, the details of the requirements differ. Many include restrictions on median or mean coliform levels, as well as specifying levels that are not to be exceeded in any single sample. Accordingly, the number and type of approved water reuse applications differs for each region covered by the

TABLE 1. Comparison of general characteristics of water reuse guidelines and regulations

Agency, state or province	Number of reclaimed water quality classes	Coliform limit for unrestricted irrigation (per 100 mL)	Reference
WHO guidelines	2	<200 FC	World Health Organisation (1989)
U.S. EPA guidelines	~3 (specific to application)	No detectable FC <sup>a</sup> (median), ≤ 14 FC (single sample)	U.S. EPA (1992)
California regulations	4	≤ 2.2 TC <sup>b</sup> (MPN <sup>c</sup> ), ≤ 23 TC (single sample)	State of California (2001)
Florida regulations	Application specific	≤ 25 FC (in 70% of samples per month)	Crook (1998)
Arizona regulations	5	≤ 2.2 FC (median), ≤ 25 FC (single sample)	State of Arizona (2001)
Washington guidelines	4	≤ 2.2 TC (mean), ≤ 23 TC (single sample)	State of Washington (1997)
Texas regulations	2	≤ 20 FC (geometric mean), ≤ 75 FC (single sample)	State of Texas (1997)
South Australia guidelines	4	≤ 10 thermotolerant coliform organisms (median)	South Australia EPA (1999)
Alberta guidelines	2	≤ 200 FC (geometric mean), ≤ 1000 TC (geometric mean); golf courses and parks only	Alberta Environment (2000)
British Columbia guidelines	2	≤ 2.2 FC (median), ≤ 14 FC (single sample)	B.C. MELP (1999)

<sup>a</sup>FC; Fecal coliforms.<sup>b</sup>TC; Total coliforms.<sup>c</sup>MPN; Most probable number.

regulations and guidelines. Most of the documents also contain treatment process requirements or suggestions, and many include requirements for such aspects of the project as monitoring frequency, setback distances from potable water sources, signage and labelling, and storage.

### Wastewater Treatment Technologies for Reclamation and Reuse

There is a vast array of treatment technologies that can be applied in water reclamation and reuse and in industrial water recycling. Full reviews of such technologies can be found in Asano (1998), chapters 3 to 8, and reviews on advanced treatment processes (State of California 2003a; Visvanathan et al. 2000; Mujeriego and Asano 1999) and disinfection (Lazarova et al. 1999) for wastewater reclamation are common in the literature. Different approaches may be required depending on the overall reuse strategy and the type of treatment under consideration. With respect to the treatment plant location, two situations are considered—on-site, decentralized treatment, or treatment at the central plant.

#### On-site Wastewater Reclamation and Water Reuse

Decentralized wastewater reclamation and water reuse is practised for individual homes and clusters of homes, or

isolated industries, service operations and institutional facilities. Under such circumstances, the most common types of reuse are agricultural and landscape irrigation, and toilet flushing. The most frequently used type of treatment is a septic tank serving for partial treatment of the wastewater, and a subsurface disposal field for final treatment of tank effluent. Other systems used include biological treatment units, membrane systems and shallow disposal trenches (Jefferson et al. 2001; Visvanathan et al. 2000; Roeleveld and Maaskant 1999; Tchobanoglous et al. 1998; Jowett and McMaster 1994).

Waller et al. (1998) and Townshend (1993) have described numerous treatment techniques applicable to on-site reuse and recycling, many of which are proprietary processes designed or sold by Canadian companies. In the former report, information is included for each method on treatment principles, operation and maintenance, suitability to small flows, capital costs, effluent quality, conditions for success, and suppliers, contractors and consultants specializing in the technique. A number of the technologies described are not well suited to treatment of combined wastewater (i.e., containing blackwater), but are primarily intended as greywater treatment techniques.

Jefferson et al. (1999) evaluated various technologies available for domestic water reuse. Basic two-stage systems consisting of coarse filtration with chemical disinfection represented the most common technology used for domestic water reuse in the U.K. The moderate cost

of such systems offers a minimum payback period of approximately eight years for a four-person household, and the periodic failure of the disinfection process results in occasional exceedance of proposed water quality standards (the U.K. does not currently have water reuse standards). Physical and physicochemical systems, such as depth filtration, membranes, coagulation or advanced oxidation are not affected by the problems of chemical shock loads that may adversely affect biological systems. However, fouling of membrane systems can affect the economic viability of such systems and result in poor-quality water. Biological treatment of greywater is required to remove biodegradable material and prevent biological regrowth in distribution systems. Two processes described are membrane bioreactors (MBRs) and biologically aerated filters (BAF). These have been used to effectively remove organics and other contaminants, but can be expensive and are subject to shock by bactericidal agents used in households.

### Central Facilities for Wastewater Reclamation

The processes applied at central facilities can be divided into relatively low technology systems and advanced treatment systems. Low technology systems, usually in the form of waste stabilization ponds (WSPs), are used widely in rural areas with land availability. WSPs are simple and low-cost systems, and are effective in removing pathogens and provide effluents of the quality suitable for unrestricted irrigation under the WHO rules (Asano 1998).

Many other treatment processes have been used in wastewater reclamation and water reuse, including primary treatment, activated sludge (A/S), nitrification, denitrification, trickling filters, rotating biological contactors, coagulation/flocculation/sedimentation, filtration after A/S, carbon adsorption, ammonia stripping, selective ion exchange, chlorination, ozonation, and UV disinfection. The selection of these processes and of their combination facilitates removals of specific constituents to meet the water reuse criteria. General performance of these processes is relatively well known (Table 2, Metcalf and Eddy, Inc. 2003). Many advanced wastewater treatment process combinations have been applied in wastewater reclamation, including membrane processes, lime clarification, nutrient removal, recarbonation, filtration, activated carbon adsorption, demineralization by reverse osmosis; and disinfection with UV, chlorine, or ozone (Metcalf and Eddy, Inc. 2003; Sakamoto et al. 2001; Liberti et al. 2000; Lazarova et al. 1999; Mujeriego and Asano 1999). There is no indication of the extent of use of various treatment technologies in Canada, but a number of Canadian companies specialize in such water reclamation technologies as UV, membranes and biofiltration.

Additional considerations include the reliability of the treatment plant in consistently producing reclaimed

water of acceptable quality, and dealing with influent composition variability affecting effluent quality. The former problem is generally handled by good maintenance; to address the latter one, remedial steps may have to be implemented. Eisenberg et al. (2001) described a methodology for evaluating water and wastewater treatment plant reliability, involving both mechanical reliability and plant performance. Such methods allow quantitative reliability analyses of treatment facilities employing or considering conventional and alternative treatment processes, and may be useful tools in decision making for reclaimed water projects.

### Project Implementation

Critical evaluation of past projects and experiences in other areas of the world can provide needed insight for planning future applications of water reuse in Canada. Some southern U.S. states (California and Florida, for example) are particularly experienced in water reuse. Mills and Asano (1996) completed a retrospective assessment of water reclamation projects in California to identify the successes and failures in implementation of the projects. Two-thirds of the projects were seen to provide 75 percent or less of the expected amounts of water, and the problems leading to these deficiencies were discussed. Hermanowicz et al. (2001) discussed the history and implementation of a successful water reclamation and reuse project in California. Planning and demand analysis, as well as early connection of large customers, were all seen as important aspects of project development. Problems were experienced when projected water demands did not arise. California's Recycled Water Task Force recently produced a report identifying twenty-six issues relating to obstacles, impediments and opportunities for increased recycled water usage in that state (State of California 2003b). Thirteen key recommendations were identified in the areas of funding for water recycling, public education and outreach, plumbing code/cross-connection control, regulations and permitting, economics, and science and health.

### Project Planning

Wastewater reclamation and water reuse projects are generally multipurpose, complex projects, which require the use of commensurate multi-objective planning methods and involvement of all stakeholders. The primary objective is cost effectiveness, which is determined by identifying the system that will result in the minimum total resources costs over time to meet project objectives. Non-monetary factors (intangibles) are documented descriptively by determining their significance and impacts. Mills and Asano (1998) described a planning analysis used to determine the project feasibility by focusing on seven major feasibility criteria:

TABLE 2. Unit processes for wastewater reclamation (after Metcalf and Eddy, Inc. 2003)

Constituent	Unit process											
	Activated sludge (A/S)	Nitrification	Denitrification	Trickling filter	Rotating biol. contactor	Coag./floc./ sedimentation	Filtration after A/S	Carbon adsorption	Reverse osmosis	Ozonation	Chlorination	UV
TSS	+++ <sup>a</sup>	+++	+ <sup>c</sup>	+++	+++	+++	+++	+++	+++			
TDS								+++				
Turbidity	+++	+++	+	++		+++	+++	+++	+++			
Colour	++ <sup>b</sup>	++		+		+++	++	+++	+++	+++		
BOD	+++	+++	+	+++	+++	+++	++	+++	+++	+		
COD	+++	+++	+	+++		+++	++	++	+++	+++		
TOC	+++	+++	+	++		+++	++	+++	+++	+++		
Phosphorus	++	+++	+++			+++	+++	+++	+++			
NH <sub>3</sub> -N	+++	+++	+		+++	+	++	++	+++			
NO <sub>3</sub> -N			+++				++	+				
Cadmium	+++	+++		+	++	+++	++	+				
Copper	+++	+++		+++	+++	+++	+	++				
Iron	+++	+++		++	+++	+++	+++	+++				
Lead	+++	+++		++	+++	+++	+	++				
Zinc	++	+++		+++	+++	+++		+++				
Foaming agents	+++	+++		+++		++		+++		+		
Total coliform	+++	+++		+		+++		+++		+++	+++	+++

<sup>a</sup>+++; Good removals >50%.<sup>b</sup>++; Intermediate 25–50%.<sup>c</sup>+; Low <25%.

- **Engineering feasibility**—water quality, public health protection, wastewater treatment alternatives, storage and treatment system siting and design, and matching of supply and demand for reclaimed water must be evaluated.
- **Economic feasibility**—reclaimed water may not always be cheaper than potable water, but added treatment, distribution and storage costs may be acceptable in urban, pollution-sensitive or water-scarce areas.
- **Financial feasibility**—two types of issues need to be addressed: financing construction/project implementation, and generating revenue. Construction financing addresses sources of capital funds and associated interests, and the availability of subsidies. In revenue generation, reclaimed water rates need to be established.
- **Institutional feasibility**—water reuse projects involve interaction of various institutions exerting influence at levels ranging from local to national; these need to be considered when assessing the project feasibility.
- **Environmental impact**—water reuse projects change flows of water, wastewater and associated pollutants, and thereby exert environmental impacts, which have to be evaluated at the project planning stage. Measured locally, these impacts can be either beneficial or adverse.
- **Social impact and public acceptance**—winning public support has become a key requirement for most water management projects, and it is of extreme importance in the case of water reclamation and reuse. These issues are particularly important in Canada, where most areas have abundant water resources and the need to reuse water will be seriously questioned by the public.
- **Market feasibility**—a key step in planning a water reuse project is to identify users or customers who are both able and willing to use reclaimed water. A market assessment provides data needed to formulate project alternatives, including facility location and capacities, design criteria, and reclaimed water pricing policy.

Typically, a municipality would be involved in collection and treatment of wastewater and the distribution of reclaimed water. Provincial guidelines or criteria would govern the quality of such water, and the operation of the project may impact on receiving waters and some of the federal responsibilities. Specific aspects of reclaimed water distribution (plumbing, marking of pipes, etc.) would be affected by the plumbing code, which is established at the national level. Further changes in these arrangements may be introduced by private water agencies, which may have locally specific modes of operation. Finally, the reclaimed water users may also represent commercial or industrial

entities with their own guidelines and regulations. Obviously the interactions among all these institutions need to be considered when assessing the project feasibility. The Canadian Water and Wastewater Association (1997) investigated the existence of regulatory barriers to the implementation of on-site water reuse in Canada. This review included both health and environmental regulations, as well as plumbing/building codes and municipal bylaws, and concluded that there were no absolute regulatory barriers to on-site reuse in Canada. In fact, the report noted that the main barriers to implementation were the lack of regulations and guidance, including plumbing codes, across the country.

### Infrastructure Needs

Urban water reuse requires a dual distribution system, in which one system is used for potable water and a second for reclaimed water. The first dual distribution system in the U.S. was built in the 1920s to supply reclaimed water for landscape irrigation and toilet flushing in Grand Canyon Village in Arizona (Okun 1997). The need for adequate labelling and signage of dual distribution systems often results in the use of coloured pipe or tape. In California, purple pipe has become the standard, while the City of St. Petersburg, Florida, uses brown piping to distribute reclaimed water. Cross-connection controls and inspections are also essential in protecting public health (Holliman 1998).

In order to plan adequate system size, storage needs must also be considered. Although reclaimed water supply is fairly constant, demand for reclaimed water varies through the day and year (particularly in irrigation applications); adequate daily and seasonal storage must therefore be provided. Additionally, emergency storage or potable water back-up must be provided to meet demand in case of a plant upset or other main supply interruption (Holliman 1998). Storage system design requires consideration of evaporation and degradation of water quality by growth of microorganisms or pests such as mosquito populations, and odour problems, both of which may be controlled with appropriate management techniques or use of underground storage aquifers (Okun 1997; Mujeriego et al. 1996).

### Economics

With respect to on-site residential water reuse in Canada, Waller (2000) and Waller and Salah (1999) compared the costs and benefits, and cost-effectiveness, of several innovative reuse technologies with that of more traditional wastewater servicing. Richard (1998) described a detailed methodology for estimating costs of wastewater reclamation using various treatment trains, taking into consideration facility construction, equipment purchases, and operation and maintenance costs needed to achieve

water quality requirements for a number of end-use options. Lazarova et al. (2001) discussed key economic, financial, regulatory, social and technical factors that contribute to the success of water reuse projects. It was noted that most water reuse projects have been helped by subsidies and grants, and that few projects recover costs in full. However, water reuse projects are often undervalued in comparison to other projects, since they generate both monetary and non-monetary benefits. Some of the benefits of reuse projects include improved environmental quality and public health, reduced discharge of nutrients into receiving waters, lower drinking water treatment costs, and conservation of recreational land.

Cuthbert and Hajnosz (1999) discussed the difficulties involved in setting prices for reclaimed water, which may cost more to provide than potable water, as well as generally being of lower quality. A survey of pricing strategies utilized by 23 U.S. utilities operating reclaimed water systems was summarized, and a case study developed for the city of Tucson, Arizona, was discussed. Okun (1997) noted that some large users have paid higher prices for reclaimed water to ensure continuation of service where critical water shortages could cause restrictions of potable supply.

### Social Impact and Public Acceptance

Consumer acceptance of water reuse largely depends on the perceived need for alternative water sources; when water is scarce, reuse applications are generally better accepted by the general public. Wegner-Gwidt (1998) reviewed principles of sound and proactive communication and education programs, which are required for the success of reuse projects. The main reasons for establishing a communication process are to (a) inform and educate the public, (b) add public input to the development of the final approach, (c) raise issues early and avoid surprises, and (d) identify the project opponents and their issues. The communication process is best implemented by soliciting public input, developing a series of educational/information activities, sharing the decision-making and problem-solving responsibilities, and focusing on winning and maintaining the community support. A citizens' advisory committee, with a broad representation, serves to make a vital connection between the government and citizens. One of the best ways to illustrate the benefits of water reuse is to organize presentations and/or visits of successful projects.

Higgins et al. (2002) surveyed users and providers of recycled water in Queensland, Australia, to determine concerns about recycled water quality and directions for applied research. Respondents represented sports clubs, industries, agriculture, environmental groups, and householders. Approximately 79% of respondents had concerns about water quality, ranging from microbiological components to salinity-related characteristics, nutrients and organics. However, only 33% of respondents

recommended that further research on aspects of recycled water quality was warranted, indicating that methods such as monitoring programs, education programs, and provision of information could help allay many concerns. Approximately 52% of providers and 19% of current users planned to expand their usage, and 30% of non-users planned to commence doing so within 5 years. Areas identified for further research included quality issues such as microbiological and organic constituents, nutrients and salinity, health and safety issues, treatment processes, usage options and economic factors.

### Conclusions

Despite abundant freshwater resources in Canada on the whole, there are regions where demand exceeds supply. Within the holistic concept of total water cycle management, one solution to the challenge is water reuse, which facilitates the use of treated municipal effluents as a new source for non-potable water supply. Reuse or recycling of treated wastewater reduces effluent discharges into receiving waters and offers a reliable alternative supply of water for applications that do not require high-quality water, freeing up limited potable water resources. As compared to other countries worldwide, water reuse is currently practised infrequently in Canada, but a great deal can be learned from the experiences of other countries. The microbiological health risks and chemical contaminants of reclaimed water have been well described, and emerging issues, such as endocrine-disrupting chemicals and pharmaceuticals in reclaimed water, are beginning to be examined. Health and environmental risk assessments are important steps in designing criteria for reuse projects; various methods have been applied. Guidelines and regulations dealing with water reuse projects exist around the world, and Alberta and British Columbia have recently produced guidance documents for water reuse applications in those provinces. Various treatment technologies for on-site and central wastewater reclamation facilities are available and have been well described in the literature. Additional considerations for implementation of water reuse projects include project feasibility and planning, infrastructure needs, economics, and public acceptance.

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