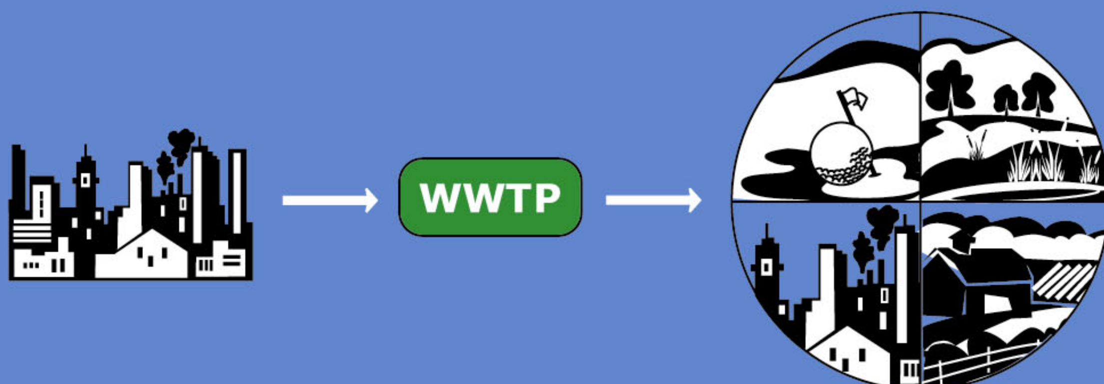
# Linking Water Science to Policy: Water Reuse and Recycling

A CCME sponsored workshop

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May 30 and 31, 2002

Calgary, Alberta

# CCME LINKING WATER SCIENCE TO POLICY WORKSHOP SERIES

# WATER REUSE AND RECYCLING

**A workshop sponsored by
the Canadian Council
of Ministers of the Environment**

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## WORKSHOP CONTEXT AND OVERVIEW

The Canadian Council of Ministers of the Environment (CCME) provides a forum for federal, provincial and territorial governments to cooperate on priority environmental issues. Because of concerns about water quality and the value placed on water by Canadians, CCME has made water quality one of its top priorities.

One active CCME initiative is directed at ensuring that CCME members, and policy and decision makers in particular, are up-to-date on the latest science with respect to various water quality issues. CCME also wanted to provide an opportunity for its members to give input to the scientific community on water quality-related research priorities.

CCME identified an initial list of three priority areas for information exchange:

1. water quality impacts of agricultural practices;
2. groundwater quality; and
3. water quality issues related to water reuse and recycling.

It was agreed that Environment Canada's National Water Research Institute (NWRI), on behalf of CCME, would organize a series of workshops where leading scientists would be invited to present the latest science related to the above issues. The targeted audience would include CCME members' representatives, and other federal, provincial and territorial departments, as well as stakeholders. The meetings would be designed to maximize the exchange of information and to provide CCME members and stakeholders an opportunity to comment on future research directions and priorities.

This is the report from the third workshop, held May 30 and 31, 2002 in Calgary, and co-chaired by NWRI and the Province of Alberta. The workshop brought together 50 participants from federal, provincial and municipal government departments, Canadian universities and industry, as well as representatives from the U.S. EPA, the Water Environment Research Foundation and the International Water Association. This report compiles the workshop's presentations and discussions on municipal wastewater reclamation and reuse, industrial water recycling, reuse technology, policy issues, and international perspectives.

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Sincerely,

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## EXECUTIVE SUMMARY

The Canadian Council of Ministers of the Environment (CCME) is the major inter-governmental forum in Canada for discussion and joint action on environmental issues of national and international concern. In the Fall of 2001, in response to concerns about water quality in Canada, CCME initiated a workshop series, *Linking Water Science to Policy*, on priority water quality issues. Organized by Environment Canada's National Water Research Institute with provincial co-chairs, the series communicates the results of new research and management practices to senior decision makers and policy makers, and provides a mechanism for scientists and water managers to contribute expert input to Canadian water programs.

The third workshop in this series - *Water Reuse and Recycling* - was held in Calgary on May 30 and 31, 2002, bringing together 50 participants from federal, provincial and municipal government departments, Canadian universities and industry, as well as representatives from the U.S. EPA, the Water Environment Research Foundation and the International Water Association. This report compiles the workshop's presentations and discussions on municipal wastewater reclamation and reuse, industrial water recycling, reuse technology, policy issues, and international perspectives.

At present time, water reuse is practiced in Canada on a relatively small scale, and mostly in isolated cases; however, interest in wastewater reclamation and reuse in Canada is growing, driven by:

- steadily increasing water demands exerted against finite supplies, endangered by climate change;
- opportunities to save on future expansion of the water supply infrastructure;
- needs to reduce or eliminate wastewater effluent discharge to sensitive receiving waters;
- opportunities for inexpensive provision of water services in isolated places, or single residential sites.

It is opportune, therefore, to address water reuse science and policy to provide some guidance for future developments in this emerging field.

### Water Reuse Regulations, Quality Criteria and Guidelines

In general, the provinces of British Columbia and Alberta have the most experience, both having developed regulatory guidance documents. Other provinces may allow individual wastewater reuse projects on an experimental basis, but do not yet have written regulatory guidance for routine applications of reuse. Municipalities in these provinces are typically reusing treated wastewater to irrigate urban parkland, landscaping, golf courses and agricultural non-food crops. There is also some limited experience with using stormwater to irrigate golf courses and parkland, and for wetland preservation. At the scale of individual buildings, there has been some experience with the reuse of wastewater in experimental housing and at isolated facilities (e.g., isolated resorts, truck stops) in several provinces.

Regions where wastewater reuse is commonly practiced, such as Australia and parts of the United States, have well-established standards and criteria governing such applications, and there is much to be learned from their experience. At the workshop, the following needs in the area of water reuse regulations, quality criteria and guidelines were identified:

- *National water reuse guidelines* - federal leadership is needed through development of national water reuse guidelines that would link proposed uses with water quality requirements; national guidelines developed in other countries should serve as a starting point.
- *Provincial standards* - or criteria that govern the quality of wastewater reuse should be established in all provinces in which reuse projects are being considered. British Columbia and Alberta have already developed regulatory guidance documents for water reuse.
- *Emerging contaminants of concern* - human health issues related to safety of reclaimed water containing endocrine disruptors, pharmaceutical chemicals, therapeutics and organic industrial chemicals are beginning to emerge. The impact of these chemicals - present in very low quantities - is not well understood with respect to long-term health effects, and research on these issues is in its infancy.
- *Environmental monitoring and impacts of reclaimed water* - the expected increased use of reclaimed water for wetland preservation, stream flow augmentation and groundwater recharge illustrates the need for research in this area.

## Wastewater Treatment Technologies for Reclamation and Reuse

An array of treatment technologies that can be applied in wastewater reclamation and reuse is already available. Many of these technologies, such as biofilters, membrane technologies and UV disinfection, have been developed and applied in Canada. These technologies are increasingly targeted at decentralized (satellite), small-scale, treatment facilities with direct application to the municipal, industrial and agricultural sectors. Information needs identified at the workshop included:

- *Performance criteria and validation protocols* - technology performance criteria in producing relevant water qualities (physical, chemical, biological [including biological content and biological impact), and validation protocols that allow innovative technologies/processes to be validated against those criteria and accepted for various applications;
- *Technology demonstration* –enhanced pilot testing and technology demonstration, and showcasing of economically sound and environmentally responsible examples of water reuse/recycling to garner public and political visibility and interest;
- *Technology for small-scale applications* - continued effort in developing simple, low-cost, versatile and low maintenance technologies for smaller (local) applications;
- *Knowledge sharing* - improved information sharing on best available technologies.

## Industrial Wastewater Recycling

Industry probably engages in more water reuse and recycling than other major water-using sectors in Canada; however, there is considerable variation within this sector. Given the large total water intake by industry in Canada, the greatest benefits, with the least ramifications for human and ecosystem health, would be derived by encouraging water recycling in industry, and wastewater reclamation and reuse for industrial purposes. Workshop participants indicated there was still enormous opportunity for improved water reuse here. Issues identified in industrial wastewater recycling included the following:

- *Need for policies supporting water recycling in industry* – increased water reuse and recycling in industry would be best achieved by supportive policies (with respect to disposal of industrial effluents) and economic incentives.
- *Non-process element build-up* – industrial water recycling (e.g. through a pulp mill) can lead to build-up of materials that may disrupt operation or produce air quality hazardous to mill staff. Methods to identify and eliminate such materials prior to recirculation must be established.
- *Lack of demonstrated technologies* – industries are reluctant to implement costly technologies that are seen as inadequately field-tested and demonstrated.

## Planning and Implementation of Wastewater Reclamation and Reuse

Wastewater reclamation and reuse projects are generally complex projects, requiring multi-objective planning methods and involvement of all stakeholders. Workshop participants identified a number of conditions needed to encourage wastewater reuse project planning and implementation in Canada.

- *Policies that encourage full-cost pricing for water resources* - the low price of water in Canada serves as a disincentive to implement water reuse and recycling programs and acts as a barrier to technological innovation and advancement.
- *National and provincial water reuse programs* – are needed to establish design standards, promote research in technology information, and educate the public on health risks and benefits.
- *Applied economic analysis and management systems* - to help assess the financial, engineering and institutional feasibility of projects, and evaluate environmental impact and public acceptance.
- *Public consultation* - advocate public consultation in implementing reuse programs, particularly in light of emerging human health issues related to pharmaceuticals and endocrine disrupting substances.
- *Communication programs* - highlight successes and continually educate and inform public.

## Research Needs

In spite of water reuse's growing popularity, the most significant concerns are those related to health risks. Until very recently, such considerations were based almost entirely on exposure to enteric viruses in reclaimed water. Workshop delegates identified the following research needs:

- *Emerging health issues* - identification of emerging human health issues regarding the safety of reclaimed water containing endocrine disruptors, pharmaceutical chemicals, organic industrial chemicals, and salts and heavy metals.
- *Long-term impacts* - improved environmental modelling, monitoring and assessment of long-term impacts of reclaimed water.
- *Contaminants and surrogate parameters* - evaluation of the fate of microbiological and chemical contaminants in reclaimed water, and determination of surrogate parameters that are both rigorous and cost-effective for water quality monitoring.
- *Storage* - assessment of the effect of storage on reclaimed water quality.
- *Effects on crops and soils* - evaluation of the impact of reclaimed water irrigation practices on crops, turfgrass, and soil.
- *Risk assessment* - development of risk assessment and management methods in designing reuse applications.
- *Multiple barriers* – developing well-defined multiple barrier strategies as tools for increasing the spectrum of pathogens and contaminants being controlled and reducing the formation of by-products.
- *Economic analysis* - applied economic analysis to quantify economic benefits and assess alternatives more effectively.
- *Collaboration* - improved collaboration and communication among researchers in the water reuse/ recycling field.

### Maintaining the Dialogue

Participants were passionate about the need to maintain and improve communication between researchers and water policy/program managers. They defined a number of opportunities for continued information exchange and dialogue between the science community and policy/program managers in the emerging area of water reuse and recycling, including:

- *Standing national committee/task force on water reuse -* create a committee or task force of academic, industry and government experts to develop a Canadian context for reuse/recycling, identify short- and long-term implementation opportunities, refine research needs, facilitate ongoing dialogue, help develop a national guidebook and foster technological innovation.
- *Follow-up workshops* - convene periodic follow-up workshops, or perhaps dedicated sessions at selected conferences, for both the science and policy communities.
- *Electronic networking* - various electronic media, such as dedicated web sites, electronic bulletin boards, moderated chat rooms, and subject-specific, subscription-based email lists could be considered as a means of ensuring continued information flow.

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## INTRODUCTION

An adequate supply of good quality water is essential for continuing development of Canadian society and the Canadian economy. The most recent data on gross water use indicate a steadily growing total intake, rising from 36.7 x $10^9$ $m^3$/yr in 1981 to 45.0 x $10^9$ $m^3$/yr in 1991 (Statistics Canada, 2000). During the same period, gross intake in the personal and government sectors remained almost constant, with a total intake of 3.76 x $10^9$ $m^3$/yr in 1981 and 3.80 x $10^9$ $m^3$/yr in 1991. Recognizing that during the same period the total population increased from 24.8 million to 28.0 million, the nominal per capita use somewhat declined, but even at the most recently reported level of 343 L/capita/day (Environment Canada, 2001) remained well above that in advanced west European countries. Of the gross intake, in the personal and government sectors, only about 11% is consumed and the rest is (89%) is returned, mostly as discharges of wastewaters. Thus, many municipalities are faced with the challenge of providing water supply to their growing population, in competition with other sectors of the economy, relying on finite supplies, and controlling wastewater discharge into receiving waters. This challenge is intensified by uncertainties with respect to the 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. One solution to this 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. Under certain circumstances, economic benefits may be derived from water reuse, partly from savings on expansion of the water supply and wastewater treatment infrastructures.

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 is construed rather broadly and includes municipal wastewater (representing a mixture of wastewater from residential, commercial, institutional and industrial sources), plus permitted inflows of rainwater or stormwater.
- **Water reuse** is the use of treated water for beneficial purposes, including agricultural irrigation and industrial cooling. Reclaimed water is treated effluent of a quality suitable for specific reuse. Direct reuse refers to a reuse system in which reclaimed water is transported to the points of reuse. Indirect reuse implies discharge of an effluent into receiving waters (surface water or groundwater) for assimilation and withdrawals downstream, which do not represent planned direct water reuse.
- **Water recycling** typically refers to industrial systems, in which the effluent is recovered, usually treated and returned back into the industrial process.

Typical examples of water reuse applications include:

- Toilet flushing;
- Irrigation of lawns, parks, landscape, gardens, golf courses, sport fields, school yards, residential lawns, cemeteries, freeways;
- Agricultural irrigation of food and non-food crops;
- Industrial reuse (cooling water, boiler feed water, steel processing, pulp and paper processing);
- Direct wastewater reclamation to augment potable water;
- Groundwater recharge, arresting saltwater intrusion;
- Recreational waters, waterscape (ornamental ponds).

The growing water management challenge to provide a balance among water demand, water use, and protection of water 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 that are short of water and have 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, as can be seen in Figure 1 (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 (70% of the total consumption in some areas). This creates local or regional interest in water reuse.

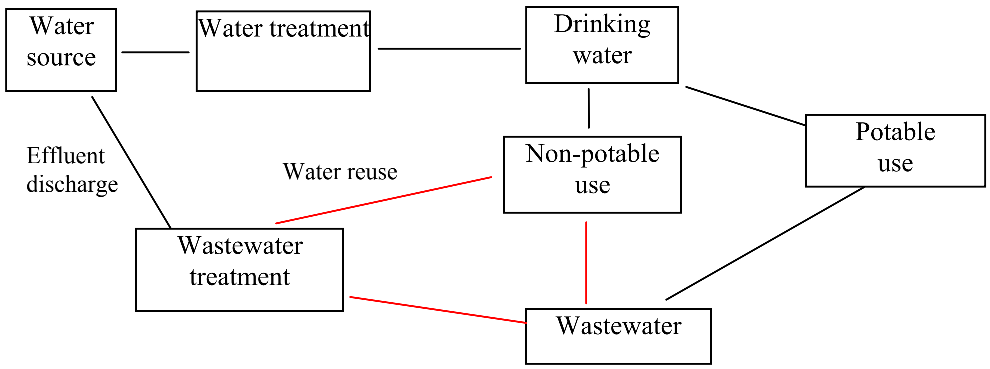
**Figure 1:** *map of Canada's annual precipitation by region (see Stats Can 2000 report, Chapter 3)*

The interest in water reuse in Canada emerged at least 30 years ago, when CMHC sponsored one of the first Canadian studies on this subject and concluded that wastewater 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 there is a need to revisit 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$^{st}$ 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, or in regions with severe restrictions on disposal of treated wastewater effluents, such as in Florida (Walker-Coleman, 2002), coastal or island areas of France and Italy, and densely populated European countries such as England and Germany (Lazarova *et al*., 2001). Countries with regional water resource disparities also practice extensive water recycling and reuse. Even though Japan has a mean annual precipitation of 1714 mm and numerous dams and reservoirs, regions of the country suffer from frequent droughts and in many areas, urban wastewater reuse has become a common practice (Ogoshi *et al*., 2001).

At the present time, water reuse is practiced in Canada on a relatively small scale, and mostly in isolated cases. Typical examples of such reuse include agricultural cropland irrigation in British Columbia, Alberta, Saskatchewan and Manitoba, golf course and landscape irrigation (B.C., Alberta, the feasibility was studied in PEI), experimental housing (Ontario, Nova Scotia, B.C.), and reuse of wastewater at isolated facilities such as isolated resorts, truck stops (B.C., Ontario). As water demands increase and readily available supplies dwindle, the interest in water reuse will increase. It is important, therefore, to address water reuse science and policy to provide some guidance for future developments in this field. At the same time it should be recognized that water reuse should be considered in a broad context, as an element of sustainable development. Such considerations are well supported by an emerging urban water management concept, total urban water cycle management.

Growing urban populations continue to exert profound impacts on water resources in affected areas, as urban developments pose water supply demand, alter runoff and streamflow due to catchment changes, contribute to pollution of receiving waters through discharges of urban effluents, and affect aquatic ecosystems. 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, several specific urban water management categories can be identified, including re-use of treated wastewater as a basis of disposing of potential pollutants, or as a substitute for other sub-potable water supply; integrated stormwater, groundwater, water supply and wastewater based management, as a basis for economic and reliable water supply, environmental flow management (deferment of new construction/infrastructure expansion, return of water to streams), urban waterscape, landscape provision, substitute non-potable sources of water (wastewater and stormwater reuse), and protection of downstream waters from pollution; and water conservation (demand management) based approaches, including more efficient use of water (water saving devices, irrigation practices), substitute landscape form (reduced water demand), and substitute industrial processes (reduced demand, recycling).

**Figure 2:** *A schematic depicting water reuse as a part of the (simplified) urban water cycle.*




Thus, the concept of total water cycle management provides a well-defined context for water reuse. The extent to which water reuse is practiced 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 general public, is economically feasible, and is supported by a regulatory environment.

## WATER REUSE CATEGORIES

The quality of reclaimed wastewater must match the needs of a particular reuse application; thus, it is useful to start examination of this subject by defining the water reuse categories and their corresponding water quality goals. The information below is based mostly on the U.S. EPA 1992 report expanded where applicable for the Canadian data or experience. Reuse practices can be classified into four categories, ranging from the highest water quality requirements, requiring the highest level of treatment, to the lowest.

### Potable reuse

Direct potable reuse, or the introduction of reclaimed water directly to a potable water distribution system, is rather rare and not applied in Canada or the U.S., although it has been studied in feasibility studies and implemented in at least one location (Windhoek, Namibia). There are serious concerns about this type of reuse from the points of view of public health, , public perception, and new knowledge about chemicals of concern, which may not be fully removed by traditional treatment processes (e.g., endocrine disruptors, pharmaceuticals, etc.). The water quality requirements and treatment goals are those which apply to drinking water. Treatment facilities would have to be designed specifically for this purpose.

Indirect potable reuse refers to the augmentation of potable water supply sources with highly treated reclaimed water. In a 1998 report, the American National Research Council concluded that indirect potable reuse of reclaimed water is viable, but that direct potable reuse is not, largely due to uncertainty regarding health effects. The potential human health risk of indirect potable reuse necessitates a thorough, project-specific assessment (including contaminant monitoring, health and safety testing and system reliability evaluation), and it should only be considered as a last resort in communities in which all other water conservation and non-potable reuse efforts have been examined. Although no adverse health effects have been uncovered in health-related research to date, the health data are sparse and the methods for research are limited. Planned indirect potable reuse has been studied in demonstration and pilot projects in a variety of locations in the U.S. (Crook et al., 1999). Additionally, many communities use water sources that include a significant wastewater component from upstream users, essentially practicing unplanned indirect potable reuse.

### Unrestricted urban and recreational uses, and agricultural irrigation of food crops

This reuse category requires a fairly high water quality, and at present, represents the highest level of reuse practiced routinely in many locations, including Canada (B.C., Alberta). Typical examples of unrestricted urban, recreational and agricultural use include:

- Urban use - landscape irrigation of parks, playgrounds, schoolyards; fire protection; ornamental fountains, impoundments; in-building uses including toilet flushing and air conditioning.
- Unrestricted recreational use – no limitations on body contact, including feed water for lakes and ponds used for swimming; snowmaking.
- Agricultural irrigation of food crops grown for human consumption and consumed uncooked. In most cases, environmental enhancement and groundwater recharge would fit into this category, but would be further controlled by local site-specific conditions. In these cases, reclaimed wastewater may be used to create constructed wetlands, enhance natural wetlands and sustain stream flows, and recharge groundwater aquifers. These uses are fairly common in the case of stormwater management, in which impacts of urban runoff are mitigated by ponds, wetlands and infiltration basins providing control of runoff flows and enhancement of runoff quality.

Treatment processes typically required include a minimum of secondary treatment, followed by filtration and disinfection, with strict limits placed on effluent biochemical oxygen demand (BOD), turbidity, total and/or fecal coliforms, disinfectant residuals and pH levels (US EPA, 1992).

### Restricted-access urban use, restricted recreational use, and agricultural irrigation of non-food crops or food crops processed before consumption

These are relatively frequent examples of water reuse in which either access to the affected areas is restricted, or activities themselves are restricted. These restrictions imply exposure of limited populations to reclaimed water and/or limited exposures of urban populations in the case of restricted activities. Typical examples of restricted access uses include:

- Landscape irrigation - golf courses, cemeteries, greenbelts and highway medians.
  Restricted recreational use – fishing, boating, and other non-contact recreational activities.
- Agricultural irrigation - such crops or operations as fodder, fiber, seed crops, pastures, commercial nurseries, sod farms, and commercial aquaculture.

The requirements on water quality in this category are the same for all the uses listed in this category. Typical reclamation treatment includes secondary treatment followed by disinfection, with slightly more lenient BOD and turbidity (or suspended solids) requirements than the unrestricted urban reuse category (US EPA, 1992).

**Reuse applications (in order of decreasing water quality requirements)**

- Potable reuse - direct<br>- indirect
- Unrestricted urban and recreational uses, irrigation of food crops
- Restricted-access urban use, restricted recreational use, agricultural irrigation of non-food crops or food crops processed before consumption
- Industrial reuse and recycling

### Industrial reuse and recycling

The industrial sector represents a large water user in Canada. Of the total intake in Canada in 1991, mining, other primary resource industries, and manufacturing industries accounted for more than 80%. However, less than 20% of this intake is consumed and there are many opportunities for recycling. To satisfy the needs of industry, reuse of municipal wastewater for industrial water supply started as early as in the 1940s (Baltimore, MD water reused by Bethlehem Steel) (Asano, 2002). In the Municipal Sewage Regulation, British Columbia has included guidance for the use of reclaimed municipal wastewater in construction and industrial uses, including aggregate washing, concrete making, equipment washing, cooling towers (excluding evaporative cooling), stack scrubbing, boiler feed, and process water (excluding food processing) (British Columbia Ministry of Environment, Lands and Parks, 2001). Even though no Canadian examples of such a reuse were presented at the workshop, this type of reuse is feasible, can be economically attractive, and is currently contemplated in Calgary.

Typical reclamation treatment for municipal wastewater in this category includes secondary treatment and disinfection, with effluent quality criteria for BOD, total suspended solids and fecal coliforms (US EPA, 1992). However, 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 (Asano and Levine, 1998). Although the bacteria *Legionella pneumophila* thrive in air conditioning cooling water systems, there is no indication that reclaimed water is more likely to contain *Legionella* than other water sources (Crook, 1998).

## WATER REUSE REGULATIONS, QUALITY CRITERIA AND GUIDELINES

### The regulatory environment at a glance

**Australia**

Approximately 11% of urban wastewater in Australia is reclaimed, with projected increases over the next few years, particularly in dry regions such as South Australia and Queensland. National guidelines for sewerage systems on the use of reclaimed water, recently updated by the Australian and New Zealand Environment and Conservation Council, specify five grades of water quality ranging from open access to restricted access quality. The appropriate grades are designated for each reuse application. Water reuse projects generally require individual approval or licensing from the relevant state environment protection agency or water regulation board prior to implementation; states such as New South Wales and South Australia have also developed guidelines to aid users in obtaining such approval.

**New South Wales (NSW)**.

The NSW effluent re-use guidelines, “Water Conservation by Re-Use - Guidelines for the Use of Recycled Water in New South Wales,” set out requirements for reuse of secondary treated effluent with supplementary disinfection for various purposes including: industrial uses; pasture, crop and forest irrigation; municipal landscape irrigation; and groundwater recharge. Under existing guidelines, each individual user must seek approval from the EPA. Guidelines have also been developed for urban and residential uses of reclaimed water (NSW, 1993). The urban reuse guidelines introduce a new class of reclaimed water, which has received additional treatment and quality control to render it suitable for most non-potable uses in urban residential areas with open public access and for general distribution through a dual reticulation system. Any supply authority that operates a dual distribution urban reuse system is expected to equal or better the requirements specified in the guidelines, and requires statutory approval from the EPA.

**South Australia**.

The South Australian Reclaimed Water Guidelines (Treated Effluent) (Environment Protection Agency, South Australia, 1999) describe methods for sustainable use of reclaimed water without imposing unnecessary risks to public health or the environment. It considers the use of reclaimed water for agricultural, municipal, residential (non-potable), environmental, and industrial purposes. Information is provided on the reclaimed water quality required for each use, treatment processes, system design, operation and reliability, site suitability, and monitoring and reporting. The guidelines do not contain mandatory provisions but compliance is recommended to those proposing to use reclaimed water. Provisions of the guidelines could be incorporated in a license issued under the Environment Protection Act or an approval issued pursuant to the Waste Control Regulations of the Public and Environmental Health Act.

**United States**

Increasing demands for water in the face of limited supplies, more restrictive discharge requirements, and a growing investment in wastewater infrastructure have all added to an increasing interest in water reuse. In the U.S., regulation of water reuse applications is left to individual states; Arizona, Florida, California and Texas are the more aggressive states pursuing water reuse. Technical guidelines and in some cases state regulations have been established that cover a wide range of water reuse practices such as the irrigation of golf courses, parkland, highway medians and agricultural cropland, use as industrial cooling and process water, toilet flushing, wetland habitat creation/enhancement, groundwater recharge, and augmenting potable water supplies. The use of land treatment / reuse systems, onsite treatment / reuse, and dual water systems is growing in popularity.

The main national definitive document remains the EPA's Guidelines for Water Reuse, which addresses an exhaustive list of water reuse practices, and includes case examples. The current document provides considerable information related to water reuse requirements and water reclamation processes, including a summary of state regulatory requirements and EPA recommendations. It is a guidance document that allows individual states to set their own standards. The EPA is currently updating the 1992 *Guidelines* to address improvements in technology, update and expand the number of case studies and coverage of international practices, expand coverage of institutional and public acceptance issues, and revise the state requirements matrix. Additional research effort in the U.S. is being directed at assessing the possible implications of trace amounts of pharmaceuticals, disinfection by-products, brominated fire retardants and other organic compounds being detected in reclaimed water.

**California**.

The first U.S. standards for water reuse were developed by the State of California in 1918, and have been continually revised ever since. Approximately 10% of urban wastewater in California is reclaimed, which translated to about 434 x $10^6$ $m^3$ in 1999. The Department of Health Services (DHS) establishes health-related standards for water reclamation and reuse, and under the California Water Code, nine Regional Water Quality Control Boards (RWQCBs) can establish water quality standards, prescribe and enforce waste discharge requirements and, in consultation with DHS, prescribe and enforce reclamation requirements. Each water reclamation project must obtain a permit from the appropriate RWQCB, which conforms to DHS criteria. Additionally, local health agencies may impose requirements that are more stringent than those specified by DHS or the RWQCBs. The California Water Code mandates that no person or public agency shall use water from any source or quality suitable for potable domestic use for non-potable uses if suitable reclaimed water is available and meets certain conditions regarding water quality, cost and downstream water rights and effects (Crook, 1999).

**Florida**.

The State of Florida is recognized as having one of the most exhaustive water reuse programs in the U.S. The need for water reuse in Florida stems from a population base that is 80% coastal, yielding limited amounts of freshwater, saltwater intrusion problems, and warm, slow moving streams with limited assimilative capacity for receiving wastewater discharge. Propelled by a population growth that is the fourth highest in the nation, Florida now has over two decades worth of intensive water reuse experience. In 2000, Florida reused 575 mgd of treated wastewater, just over 50% of the state's total wastewater treatment capacity. Landscape irrigation is the dominant use, followed by agricultural, industrial, groundwater recharge and wetland uses. Total reuse in the state has almost tripled since 1986.

Some of the key components of Florida's Water Reuse Program include: a mandatory reuse program, comprehensive rules, participating agency coordination, DEP district office permitting activities, the Antidegradation Policy, reuse feasibility studies, water resource caution areas, pathogen monitoring, educational materials/public notification, and the *Code of Good Practices for Water Reuse in Florida*.

The key statutory authority and language in Florida come from sections 373.250 and 403.064 of the Florida Statutes (dealing with environmental and wastewater control, and water resources and water supply), which establish the promotion of reuse of reclaimed water as a state objective. Florida's Reuse Rules, created in 1989 from earlier rules in 1980, are consistent with the EPA's Water Reuse Guidelines. The Florida Reuse Rules include details on: agricultural reuse (non-edible crops); urban reuse (e.g., irrigation, toilet flushing), and edible crops; rapid infiltration basins; groundwater recharge and indirect potable uses; overland flow; industrial uses; and permitting. Specific treatment requirements are specified for all use types.

A state Mandatory Reuse Program requires water management districts to designate "water resource caution areas." These are areas with critical water supply problems (either existing or anticipated during the next 20 years), and require the reuse of reclaimed water from domestic wastewater treatment facilities, unless such reuse is not economically, environmentally, or technically feasible.

Florida also has an Antidegradation Policy for Reuse Projects thatprohibits new or expanded surface water discharges from domestic wastewater treatment facilities unless the facility can demonstrate that the new or expanded surface water discharge is "clearly in the public interest." Since reuse is preferred over additional surface water discharges, the policy has proven to be an effective means to encourage reuse of reclaimed water, while discouraging the discharge and disposal of effluent.

**Other states.**

Many other states have established guidelines or standards regarding reuse of treated wastewater, while others are in the process of changing or clarifying their legislative codes to include such applications. The former category includes Arizona, Texas, and Washington, while the latter group includes Wisconsin and Maryland.

**Canada**

Currently, there are no national guidelines for wastewater reuse applications in Canada. However, British Columbia and Alberta have developed regulatory guidance documents for water reuse in those provinces.

**British Columbia.**

Despite the perception that British Columbia has vast quantities of fresh water resources, it has had considerable experience with water reuse (including range land irrigation, silviculture applications, stream augmentation and toilet flushing), and is one of only two Canadian provinces with some form of regulatory guidance for water reuse. Roughly 3% of wastewater in B.C. is reused. Water reuse is a key component of British Columbia's water conservation strategy and its promotion and support helps meet conservation goals by:

- shifting thinking away from single-use disposal, to multiple-reuse opportunities;
- matching water quality with the appropriate use;
- helping local communities address potential future water shortages; and
- creating incentives for innovation and continual improvement.

Beyond this, water reuse has helped raise awareness of the economic value of water, provided opportunities to better integrate water supply and wastewater infrastructure, thereby reducing costs, and helped protect the environment by avoiding disposal of wastewater effluent.

To help fully realize these benefits, the Ministry of Water, Land and Air Protection has developed a regulatory framework governing water reuse in British Columbia. The Municipal Sewage Regulation, enacted in 1999, is essentially a performance-based approach (replacing the previous time-consuming permit system) that sets standards for the treatment of municipal wastewater, water reuse, and disposal of treated effluent. Compliance with the province's Municipal Sewage Regulation - or for local governments, the option to implement area specific, liquid waste management plans - provides authorization for water reuse projects.

Authorized uses under the Municipal Sewage Regulation are grouped into two categories: unrestricted public access and restricted public access, the former of which necessitates significantly higher water quality standards. Examples of unrestricted public access use include: urban (park irrigation, toilet flushing); agriculture (orchards, aquaculture); and recreation (snowmaking). Examples of restricted public access use include: agriculture (sod farms); construction (concrete making); and industrial (cooling towers). The Regulation stipulates design, operation and monitoring requirements. Measures to prevent cross-connection are also documented such as separate plumbing for indoor uses, and a second water main and associated valves and pumps for outdoor uses.

In May 2001, the Province published a Code of Practice for the Use of Reclaimed Water. The Code serves as a key reference and guidance document for the use of reclaimed water in British Columbia and is designed to support the regulatory requirements prescribed in the Municipal Sewage Regulation.

**Alberta.**

Irrigation for agricultural purposes is extremely high throughout a large part of Alberta. Currently 71% of Alberta's surface fresh water supply is used for irrigation and more than 505,000 hectares of land in Alberta is presently being irrigated to help improve crop production. Consequently, Alberta Environment has supported the reuse of treated municipal wastewater for irrigation purposes on applicable lands as a sound management practice, but with the caveat that it requires adherence to strict management conditions in order to avoid any potential adverse risk to human health and safety. As a result, municipal wastewater reuse for irrigation is a regulated activity governed under Alberta's Current Environmental Protection and Enhancement Act (EPEA), and all applications for this purpose within Alberta require a formal approval before authorization. Issue of such approvals is administered by the Alberta Department of Environment and is subject to certain requirements as set out by the Department in its waste management and wastewater irrigation management guidelines.

Under the Province's EPEA, uses for municipal wastewater irrigation include: golf courses; municipal parkland and boulevards; forested woodlots under special approval consideration; and agriculture lands where used for pasture, forage, coarse grains, turf, and oil seeds. Any other crops to be considered must be first supported by scientific based studies that ensure no risk to human health or the environment. The authorization process for wastewater irrigation reuse in Alberta involves four main steps:

- wastewater quality evaluation;
- land suitability assessment;
- system design considerations; and
- the issuance of approval or registration.

## Quality criteria

The quality of water suitable for reuse in various applications is defined by existing water quality criteria and regulations. A key concern in developing such regulations has been human health and risks associated with exposure to pathogenic organisms. Water quality criteria are normally stipulated for specific water reuse applications and in conjunction with the treatment process (and its reliability), distribution system, and presence or absence of storage. The main goal of such criteria is protection of public health, focussing on microbiological and chemical constituents, although environmental protection is playing an increasingly important role in developing reclaimed water criteria.

The risk of transmission of infectious disease by pathogens is the most common concern associated with non-potable reuse of reclaimed municipal water. Although no disease outbreaks have been reported in the U.S. in recent times, a number of were reported elsewhere and generally these were connected with the use of poorly treated reclaimed water, which was contaminated by bacteria or parasites (Crook, 1998). Consequently, most attention is paid to removing pathogens from reclaimed water, and even though a limited presence of pathogens can be tolerated for some water reuse, the general practice is to provide all reclaimed water of a quality appropriate for the highest level of use of reclaimed water in the community. Typically, this highest-level reuse represents residential landscape irrigation, toilet flushing, and irrigation of parks, and for that purpose water should be essentially pathogen free. This water, if inadvertently ingested, would not present excessive risk of infectious disease.

The microorganisms of interest can be classified as bacteria, protozoa, helminths and viruses. Among the most common pathogens found in wastewater is *Salmonella*; other bacteria include *Shigella*, *Vibrio*, *Mycobacterium*, *Clostridium*, *Leptospira,* and *Yersinia* species. Waterborne gastroenteritis may be caused by *Escherichia coli* and certain strains of *Pseudomonas*. Protozoan parasite cysts and oocysts are found in wastewater, particularly *Giardia* cysts and *Cryptosporidium* oocysts. They are more difficult to inactivate by chlorination than bacteria and viruses. The most important helminthic parasites in wastewater are intestinal worms, including the stomach worm, tapeworms, the whipworm, the hookworms, and the threadworm. There are more than 100 different types of enteric viruses found in wastewater and capable of producing infection or diseases, that are excreted by humans. The major waterborne viruses causing diarrheal disease are the Norwalk virus and rotavirus (Crook, 1998). Analyzing each sample for every possible pathogen is impractical; for this reason, indicator organisms such as total or fecal coliforms are typically used. Some controversy exists over the suitability of various indicator organisms; for example, fecal coliforms provide a reasonably reliable indication of bacterial pathogens, but can be poorer indicators of viral, protozoan and helminthic pathogens (WHO, 1989).

Chemical constituents in municipal wastewater are not considered a major health concern for urban uses of reclaimed water, but may affect the acceptability of such water for food crop irrigation, indirect potable reuse, and some industrial applications. However, chemical constituents become of major concern where reclaimed water may enter groundwater aquifers. In recent years, for example, concerns have increased about the entry into water supplies of such chemicals as endocrine disruptors (see e.g., a recent review in Servos, M. et al., 2001), pharmaceuticals and therapeutic products (Servos et al. 2002). These chemicals are currently studied both in Canada and the U.S. with respect to their occurrence, environmental effects and risks, including long-term health effects; and risk mitigation by various control measures, including wastewater treatment. Some of these and other recent studies focus specifically on new chemicals of concern in reused water (Sedlak et al., 2000).

The chemicals monitored in water reuse projects can be classified into about half a dozen groups, including biodegradable organics, stable organics, nutrients, heavy metals, residual chlorine and suspended solids. A brief discussion of these groups follows.

Biodegradable organics are usually characterized by BOD (biochemical oxygen demand), which provides a measure of presence of biodegradable constituents. In general, organics provide food for microorganisms, have adverse impacts on disinfection, and consume oxygen. Stable 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 exceed 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 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.

| Main contaminants of concern in reclaimed water | |
|---|---|
| **Microbiological** | **Chemical** |
| - bacteria | - biodegradable and stable organics |
| - viruses | - nutrients |
| - protozoa | - heavy metals |
| - helminths | - residual chlorine |
| | - suspended and dissolved solids |
| | - emerging concerns (e.g., endocrine disruptors, pharmaceuticals) |

## Quality guidelines

Guidance for the quality of reclaimed water is well established in countries or their regions where reuse is practiced extensively. Areas with many years of experience in the area have revised their regulations over the years to account for development in reuse applications, treatment processes and analytical capabilities; Florida, California and New South Wales (Australia) are good examples of such areas.

Most regulations or guidelines include information on reclaimed water quality requirements, as well as wastewater treatment processes, monitoring, and setback distances from potable water supply wells and areas accessible to the public. Commonly, grades or classes of water quality are defined by treatment processes, quality criteria, or both, and these are matched to potential applications according to the potential for human contact or environmental risk. Instructions on monitoring frequency and setback distances are intended to provide additional public health protection.

The current California Code of Regulations Title 22 defines wastewater quality in terms of both treatment technique and microbiological quality. The quality of the reclaimed water required is determined by the type of application, which is described explicitly. For example, food crops where the edible portion is produced above ground and not contacted by the recycled water require at least disinfected secondary recycled water with strict total coliform requirements; while irrigation of orchards and vineyards where the recycled water does not come into contact with the edible portion of the crop, or food crops that undergo commercial pathogen-destroying processing before being consumed by humans require only undisinfected secondary recycled water (Crook, 1999). The State of California's regulations, which place a high importance on elimination of pathogen risk by requiring extremely low total coliform levels (depending on the application), have been criticized as overly conservative (WHO, 1989). In 1989, the World Health Organisation (WHO) published the report "Health guidelines for the use of wastewater in agriculture and aquaculture" to provide public health-based guidelines for those areas (in particular developing countries) in which planned wastewater reuse is routinely practiced. In contrast to California's regulations, the WHO guidelines are significantly less restrictive in terms of coliform requirements, in an effort to improve attainability for developing countries. However, the WHO guidelines do include guidance for helminth egg reduction, as these are considered the main pathogens of concern in many developing countries (WHO, 1989).

In 1992, the U.S. EPA published the manual "Guidelines for Water Reuse" to aid those regions in the U.S. 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, environmental reuse, groundwater recharge, and indirect potable reuse. For each reuse application, the manual specifies reclaimed water quality guidelines, as well as suggesting guidelines for wastewater treatment processes, monitoring, and setback distances from potable water supply wells and areas accessible to the public.

An international panel recently suggested the formation of an international framework for water recycling, using a quality/risk ladder progressing from low quality/high risk to high quality/low risk (Anderson et al., 2001). The resulting risks then depend on exposure, dose and response, which are governed by application method and local conditions. Determination of acceptable risk for a given area would then depend on local circumstances and affordability, and could be defined nationally or regionally.

Recognizing the provincial responsibility for drinking water and wastewater treatment, Canada has no specific federal regulations governing wastewater reclamation and reuse. Water reuse regulations are developed at the provincial level, and two examples of such documents were discussed at the workshop – for the provinces of Alberta (Forster, 2002) and British Columbia (Jenkins, 2002). These documents were referenced extensively in this section and further supplemented by comments reflecting other practices in Canada and elsewhere. It is believed that the available provincial documents could serve well as models for other provinces, which may need to develop their own regulations.

**British Columbia**. Table 1 and the accompanying notes summarize the permitted uses and standards for reclaimed water as described in British Columbia's Municipal Sewage Regulation.

**Additional Explanations**

Permitted uses are limited to those listed (others require further assessment) and include those with unrestricted public access. Urban uses include irrigation of parks (with some exceptions), playgrounds, cemeteries, golf courses (with some exceptions), road right-of-ways, school grounds (with some exceptions), residential lawns, greenbelts, and landscaping around buildings; vehicle and driveway washing; toilet flushing; outside landscape fountains; outside fire protection; and, street cleaning. Agricultural uses include aquaculture, food crops eaten raw, orchards and vineyards, pasture (no lag time for animal grazing), frost protection (requires further consultation), crop cooling, chemical spraying on crops eaten raw, and seed crops. Recreational uses include stream augmentation, impoundments for boating and fishing, and snowmaking for skiing and snowboarding (all subject to further regulations).

**Table 1.** *Permitted Uses and Standards for Reclaimed Water (after the British Columbia Ministry of Environment, Lands and Parks, 1999)*

| Permitted Uses | Treatment Requirements | Effluent Quality Requirements | Monitoring Requirements |
|---|---|---|---|
| Unrestricted Public Access – agricultural, recreational and urban uses | Secondary, with chemical addition, filtration, disinfection and emergency storage | - $BOD_5 \leq 10$ mg/L<br>- Turbidity ≤ 2 NTU<br>- Fecal coliform ≤ 2.2/100 mL<br>- pH = 6-9<br>- plus general considerations | Weekly<br>Continuously<br>Daily<br><br>Weekly |
| Restricted Public Access – agricultural, urban/recreational, construction, industrial and environmental uses | Secondary, with disinfection | - $BOD_5 \leq 45$ mg/L<br>- Total suspended solids ≤ 45 mg/L<br>- Fecal coliform ≤ 200/100 mL<br>- pH = 6-9<br>- plus general considerations | Weekly<br>Daily<br><br>Weekly<br><br>Weekly |

Restricted public access – agricultural irrigation includes commercially processed food crops (prior to sale subject to processing which destroys pathogens), fodder and fibre, pasture (grazing may be prohibited for 3-6 days after irrigation), silviculture, nurseries, sod farms, spring frost protection (pending further consultation), chemical spray, and trickle/drip irrigation of orchards. Urban/recreational uses (subject to additional regulations) include landscape impoundments and waterfalls, and snowmaking not intended for skiing and snowboarding. Construction uses include those related to soil compaction, dust control, aggregate washing, concrete production, and equipment washdown. Industrial uses include cooling towers, process water, stack scrubbing and boiler feed. Finally, environmental uses (subject to further regulations) include feed of wetlands, with additional limitations on fecal coliform counts.

Treatment processes are subject to the scrutiny of reliability, and for unrestricted public access, emergency storage is also required. Secondary treatment is defined as any form of treatment, excluding dilution, that produces an effluent quality characterized by $BOD_5 \leq 45$ mg/L and TSS ≤ 45 mg/L, except for lagoon systems, in which somewhat elevated TSS are permitted (60 mg/L). Chemical addition includes addition of non-toxic coagulants or polymers prior to filtration. Storage for 60 days may be substituted in lieu of filtration, provided that additional conditions are met. In distribution of reclaimed water, a total chlorine residual of 0.5 mg/L at the point of use must be maintained, unless the conditions for waiving this requirement are met.

With respect to effluent quality requirements, the effluent quality limits are calculated as running means at the treatment outflow, or in systems with storage, at the point of use. The turbidity limits must be met prior to disinfection; the mean is a 24-hour average, and discrete readings must be ≤ 5 NTU. When substituting TSS for turbidity, the average TSS must be ≤ 5 mg/L. Fecal coliform counts are "running" median values based on the last seven readings, and for unrestricted public access, no single sample count may exceed 14/100 mL. Under general requirements, additional conditions are imposed with respect to pathogens and parasites, odour, skin and eye irritation, toxicity, metals and nutrients. Compliance must be monitored and ascertained prior to reclaimed water distribution. Coliform testing is performed daily during an initial 60-day period and, if compliance is maintained, then it may be relaxed to weekly presence/absence testing.

**Alberta**. The pertinent Alberta guidelines provide complete guidance to municipalities considering irrigation for disposal of wastewater (Alberta Environment, 2000). With reference to the terminology introduced in Table 1, this application represents urban and agricultural uses in areas with unrestricted public access, and agricultural use in areas with restricted access. Such guidance comprises assessment of effluent quality, land suitability, and system design needs for wastewater irrigation to ensure that both human health and environmental protection are considered. For comparison to the data in Table 1 and elsewhere in the literature, the treated effluent quality standards for wastewater irrigation are summarized in Table 2.

**Table 2.** *Treated Effluent Quality Standards for Wastewater Irrigation (Alberta Environment, 2000)*

| Permitted Uses | Treatment Requirements | Effluent Quality Requirements | Monitoring Requirements |
|---|---|---|---|
| Conventional wastewater irrigation, both unrestricted and restricted | A best practicable treatment approach, providing the required effluent quality (essentially secondary treatment with disinfection) | - CBOD < 100 mg/L<br>- COD < 150 mg/L<br>- TSS < 100 mg/L<br>- EC < 1.0 dS/m for unrestricted use<br>1.0-2.5 dS/m for restricted use<br>> 2.5 unacceptable<br>- SAR < 4 for unrestricted use<br>4-9 for restricted use when EC > 1.0 dS/m<br>> 9 unacceptable<br>- pH = 6.5-8.5<br>- Total coliform < 1000 /100 mL<br>- Fecal coliform < 200 /100 mL | Twice annually<br>Twice annually<br>Twice annually<br>Twice annually<br><br>Twice annually<br><br>Twice annually<br>Geometric mean of weekly or daily samples in a calendar month, depending on whether or not storage is provided |

**Additional Explanations**
Parameters: CBOD - carbonaceous biochemical oxygen demand, COD – chemical oxygen demand, EC – electrical conductivity, and SAR – sodium adsorption ratio. Total and fecal coliforms are sampled only for irrigation of golf courses and parks using grab samples. For all other parameters, grab samples are used in systems with storage, composite samples in systems without storage.

Monitoring samples are collected before and after completion of a major irrigation event for all parameters, except bacteria (daily or weekly grab samples).

Reuse water quality regulations usually apply at two levels – firstly, when submitting applications for approval of wastewater reclamation and reuse projects (referred to as comprehensive wastewater characterization, Alberta Environment, 2000), and secondly in routine monitoring after implementing the project. The first protocol is much more comprehensive and may contain a large number of constituents of interest (Forster, 2002). Constituents of interest include human pathogens of concern (specific bacteria, protozoan parasites, helminth parasites, and viruses), general chemical parameters (BOD, TSS, COD, pH, EC, sodium adsorption ratios, nutrients (several forms of N, TP and dissolved phosphorus, potassium), major cations and anions (Ca, carbonate, F, Mg, bicarbonate, sulphate, Na, total alkalinity, and chloride), and metals (Al, As, B, Cd, Cr trivalent and hexavalent, Co, Cu, F, Fe, Pb, Li, Mn, Mo, Ni, Se, U, V and Zn). Routine monitoring is usually limited to a small number of parameters measured with various frequencies as specified in the project approval.

**Criteria development**. The criteria in Tables 1 and 2 agree fairly well with the U.S. EPA values for agricultural, recreational and urban uses with unrestricted public access. Both sources of data (British Columbia and Alberta) were presented and briefly discussed at the workshop. Other sources discussed were those developed at the 1999 CMHC workshop on water reuse and were referred to as the Ottawa 99 Protocol. In this protocol, it was recommended to provide full characterization of reclaimed water with respect to physical, chemical and microbiological constituents. It was further recommended to advance wastewater reclamation and reuse in Canada by establishing a classification system for the types of water reuse and developing guidelines for them, which should also specify appropriate monitoring systems. One of the highest levels of reuse considered in the Ottawa 99 Protocol was toilet flushing; recommended water quality criteria for this application are listed in Table 3 (Stidwill and Dunn 2000).

Furthermore, a criteria development process was proposed, in the form of a flow chart to:

- Develop a clear understanding of the end use of treated reclaimed water
- Conduct risk assessment
- Develop a list of potential parameters for water quality guidelines
- Review existing water quality criteria used in other jurisdictions
- Consult with health and environmental agencies
- Conduct research, test the proposed water quality criteria guidelines, and
- Develop suggested criteria as a first step towards formal approval.

**Table 3**. *Water Quality Criteria for Residential Water Reuse – Toilet Flushing (Ottawa 99 Protocol)*

| Parameter | U.S. EPA | CMHC Pilot Project | Updated Recommendations |
|---|---|---|---|
| Turbidity | 2 to 5 NTU | 20 NTU | 5 NTU |
| Colour | Clear | 30 TCU | 20 TCU |
| Odour | Odourless | | Odourless |
| Iron | | 1.0 mg/L | 0.5 mg/L |
| Manganese | | 0.5 mg/L | 0.5 mg/L |
| Temperature | | | < 45 C |
| BOD | 5 – 30 mg/L | | 10 mg/L |
| TSS | 5 – 30 mg/L | 10 mg/L | Use criteria for turbidity |
| pH | 6 – 9 | | 6 – 9 |
| Microorganisms | Fecal coliform non-detectable | Ontario Drinking Water Objectives | 10 *E. coli*/100 mL |

Some debate exists on the criteria needed for a relatively low potential contact application, such as toilet flushing. Setting the criteria too strictly greatly increases the cost of an application and reduces the feasibility of implementation. In some cases, this may even lead to unregulated reuse of water of lower quality than the treated, reclaimed water. However, any in-building reuse of sub-potable water necessitates dual plumbing and causes public health risks arising from accidental cross-connections or leakage. Under such circumstances, a precautionary approach to public health protection is appropriate and consistent with due diligence required from engineers and other professionals involved in designing and approving these projects.

One of the most serious public concerns about wastewater reclamation and reuse is the health risk involved, which is related to safety and acceptable health risks. The most common approach to health risk assessment is quantitative risk assessment (QRA). The QRA technique involves four steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization. The best-known example of a regulatory approach developed through this method is California's water recycling regulations which, as mentioned above, are relatively strict. Another method used in risk analysis is the "low technology/low cost/controlled risk" technique of real or attributable risk (AR). The AR technique is based on epidemiological studies, and practices or guidelines are then based on incurring no incremental risk to the population. The AR method is not as sensitive as QRA in the estimation of risks (Anderson et al., 2001).

Asano et al. (2002) and Tanaka et al. (1998) quantified health risks associated with exposure to enteric viruses in reclaimed water. In their studies, they used $10^{-4}$ annual risk of infection as acceptable, and calculated the reliability as the probability that the risk of infection does not exceed the annual acceptable risk. Such assessments were carried out by means of numerical simulations, for four different reuse applications and four wastewater treatment plants (in California), and different treatment processes. The results are summarized in Table 4.

Thus, the reuse applications meet the U.S. EPA Surface Water Treatment Rule of one pathogen-derived infection per population of 10,000 per year with respect to crop irrigation and groundwater recharge, for all the treatment processes tested. However, much lower reliabilities were noted for various exposures in recreational impoundments, where body contact and swimming may take place.

**Table 4.** *Reliability of various treatment and reuse applications meeting the risk of one enteric virus infection of $10^{-4}$ per year (after Asano 2002, and Tanaka et al., 1998).*

| Treatment process | Reliability % | | | |
|---|---|---|---|---|
| | Golf course irrigation | Crop Irrigation | Recreational impoundment | Groundwater recharge |
| Full treatment or contact filtration, 10 mg/L chlorine dose, virus removal 5.2 log | 99-100 | 100 | 62-99 | 100 |
| Chlorination of secondary effluent, dose = 5 mg/L, virus removal = 3.9 log | 84-100 | 100 | 10-93 | 100 |
| Contact filtration, chlorine dose = 5 mg/L, virus removal 4.7 log | 97-100 | 100 | 39-97 | 100 |

## WASTEWATER TREATMENT TECHNOLOGIES FOR RECLAMATION AND REUSE

There is a vast array of treatment technologies that can be applied in wastewater reclamation and reuse and in industrial water recycling. Full reviews of such technologies can be found in Asano (1998), Chapters 3-8. 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. At central advanced plants, various types of secondary and tertiary treatment are considered, including relatively low-technology waste stabilization ponds, with some modifications designed to accommodate special requirements of reuse projects. A brief discussion follows.

### On-site wastewater reclamation and reuse

Decentralized wastewater reclamation and reuse is practiced 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. The most important recent developments in this field include watertight septic tanks, which prevent entry of extraneous waters and facilitate downstream treatment units, such as effluent filters. These treatment units include intermittent sand filters (suitable for lower flow rates) and recirculating granular medium filters (suitable for higher flow rates). Other systems used include biological treatment units, membrane systems, and shallow disposal trenches (Tchobanoglous et al., 1998).

Several small system treatment technologies were discussed at the CCME workshop in more detail – a biofilter, membrane bioreactor, and UV disinfection system.

Independent testing of the Waterloo Biofilter® trickle filter indicated a fairly high rate of treatment, with cBOD and TSS < 10 mg/L, and an average E. coli removal of 99%. Such effluents can be safely disposed of below the surface. In several Canadian applications, the biofilter effluent was further polished and disinfected with ozone, and the effluent was of almost potable water quality, except for nitrate. In Ontario, five golf courses are reusing Waterloo® effluent for irrigation after UV disinfection, and one truck stop uses the technology after ozone and chlorine treatment for toilet flushing. While reuse in individual houses is known, communal systems are recommended because the larger systems can be better managed and more affordably monitored, and are less susceptible to the negative influences of antiseptic and cleaning chemicals used by some individuals.

Membrane technology is well suited for water reuse because it can provide very good treated water quality, a positive barrier for certain pollutants (including bacteria), non-specific removal of pathogens, and fairly reliable treatment without addition of chemicals. Direct membrane filtration of wastewater is impractical because of high rates of fouling, so the membrane is used in conjunction with bioreactors. The bioreactor converts foulants from their soluble form to easily filtered biomass. The process is highly stable, requires small footprints and produces high effluent quality. Another possibility is to add tertiary membrane filtration to a conventional activated sludge process. Again, a high quality effluent suitable for many reuse purposes is produced. Membrane systems with UV disinfection are also well suited for on-site water reuse with more than 200 existing applications in the U.S. and Canada.

The main benefits of UV disinfection include a lack of disinfection by-products; high efficacy against bacteria, viruses, and protozoan pathogens; a lack of sensitivity to pH and temperature; and easy maintenance, operation and handling. It is also an economical alternative to ozonation, and leaves no residual disinfectant, allowing flexibility in selection of residual and building a multiple disinfectant strategy. Cryptosporidium has been shown to be relatively insensitive to chlorine disinfection, but is very sensitive to inactivation by UV. As well, the temperature dependence of chlorination may lead to the use of higher chlorine doses at low temperatures, increasing the risk of chlorinated by-product formation. Note, however, that residual chlorine needs to be added to prevent microorganism re-growth in the storage and distribution systems. The use of multiple disinfectants can therefore improve pathogen control, while reducing the risk of disinfection by-product formation.

**Benefits and limitations of some on-site wastewater reclamation technologies**

**Biological treatment systems**
- consistent, high quality effluent
- low technology
- can achieve high hydrocarbons and VOC removal, good heavy metals removal
- depending on application, effluent may require further polishing and disinfection
- sensitive to excessive cleaning agents used on site

**Membranes**
- high quality effluent with compact footprint
- non-specific removal of pathogens
- tolerant to variations in suspended solids concentrations
- depending on application, membranes are used as pretreatment for reverse osmosis, or in combination with biological treatment as membrane bioreactors, or in tertiary filtration
- subject to fouling, which needs to be controlled by pretreatment, and physical and chemical cleaning methods

**UV disinfection**
- reduced footprint compared to conventional disinfectants
- avoids by-products formed during the use of conventional disinfectants (e.g. chlorine)
- broad range of effectiveness against biological and chemical contaminants
- sensitive to suspended particulates over 10 microns
- fouling waters require use of cleaning mechanism

## 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. The main advantages of WSPs include simplicity (simple structures - earthwork is required to construct a pond, additional structures include inlets, outlets); low cost operation (no energy requirements), high efficiency with BOD removals > 90% and lower removals of TSS, TN (70-90%), and TP (30-50%). WSPs are effective in removing pathogens, with a 5-log removal (99.999%), and provide effluents of the quality suitable for unrestricted irrigation under WHO rules (Asano 1998).

Many other treatment processes have been used in wastewater reclamation and reuse, including primary treatment, activated sludge, nitrification, denitrification, trickling filters, rotating biological contactors, coagulation/flocculation/sedimentation, filtration after A/S, carbon adsorption, ammonia stripping, selective ion exchange, breakpoint chlorination, reverse osmosis, 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 (Metcalf and Eddy, 1991). Additional considerations include the reliability of the treatment plant in consistently producing reclaimed wastewater of acceptable quality, and dealing with influent composition variability affecting effluent quality. The former problem is generally handled by good maintenance; for addressing the latter one, remedial steps may have to be implemented.

Many advanced wastewater treatment process combinations have been applied in wastewater reclamation, including lime clarification, nutrient removal, recarbonation, filtration, activated carbon adsorption, demineralization by reverse osmosis; and disinfection with UV, chlorine, or ozone. Effluents from such operations can be injected directly into potable water aquifers (Metcalf and Eddy, 1991). With respect to treatment and removal of conventional chemicals and pathogens, there are no technology gaps.

While the performance of advanced treatment processes is well understood for conventional chemicals and some priority pollutants, new chemicals of concern, including endocrine disruptors, pharmaceuticals and therapeutic products, present new challenges. The research on the occurrence and effects of these chemicals more or less started during the past few years, and very little is known about the fate of these chemicals in wastewater treatment plants. While hydrophobic chemicals in these groups may be retained with sludge, many pharmaceuticals are highly soluble and may pass through treatment plants unabated. At present, the concerns about these new chemicals pose a great challenge in wastewater treatment, and public concerns about their fate may impact on both wastewater reclamation/reuse and disposal of biosolids.

**Table 5.** *Unit process for wastewater reclamation (after Metcalf and Eddy, 1991)*

| Constituent | Activated sludge | Nitrification | Denitrification | Trickling filter | Rotating biol. contactor | Coag/ floc/ sedimentation | Filtration after A/S | Carbon adsorption | Reverse osmosis | Ozonation | Chlorination | UV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TSS | G | G | L | G | G | G | G | G | G | | | |
| TDS | | | | | | | | G | | | | |
| Turbidity | G | G | L | I | | G | G | G | G | | | |
| Colour | I | I | | L | | G | I | G | G | G | | |
| BOD | G | G | L | G | G | G | I | G | G | L | | |
| COD | G | G | L | G | | G | I | I | G | G | | |
| TOC | G | G | L | I | | G | I | G | G | G | | |
| Phosphorus | I | G | G | | | G | G | G | G | | | |
| $NH_3$-N | G | G | L | | G | L | I | I | G | | | |
| $NO_3$-N | | | G | | | | I | L | | | | |
| Cadmium | G | G | | L | I | G | I | L | | | | |
| Copper | G | G | | G | G | G | L | I | | | | |
| Iron | G | G | | I | G | G | G | G | | | | |
| Lead | G | G | | I | G | G | L | I | | | | |
| Zinc | I | G | | G | G | G | | G | | | | |
| Foaming agents | G | G | | G | | I | | G | | L | | |
| Total coliform | G | G | | L | | G | | G | | G | G | G |

G = good removals > 50%
I = intermediate 25-50%
L = low 25%.

## INDUSTRIAL WASTEWATER RECYCLING

As discussed in the introduction, Canadian industry accounts for about 74% of the total water intake (Statistics Canada, 2000), and of this total intake, about 36% is recycled. Recognizing the large industrial water intake and relatively low consumption, industrial water recycling is obviously very important, not just for conserving water resources for other uses, but also for reducing discharge of industrial effluents and associated pollution. General advantages of industrial water recycling are broadly recognized and it is practiced where deemed economically feasible. Table 6 illustrates the total water intake, discharge, consumption rate and recycling rate statistics for 1996 (Scharf et al., 2002). Within the manufacturing sector, recycling rates range from a low of 22% in the wood products group (up from 9% in 1991), to a high of 292% in plastic products (down from 641% in 1991).

Public policy role in this process is limited because essential elements of this process are internal business decisions, except for the conservation aspects. In recognition of the importance of this aspect, water recycling was briefly addressed at the workshop for three important Canadian industrial sectors – the oil recovery, pulp and paper, and metal finishing industries. A brief summary of such presentations follows.

**Table 6.** *Industrial water use and recycling (after Scharf et al., 2002).*

| Industry sector | Total water intake (MCM / year) | Discharge (MCM / year) | Consumption rate (as a % of intake) | Recycling rate (as a % of intake) |
|---|---|---|---|---|
| Manufacturing | 6 037.4 | 5 486.7 | 9 | 115 |
| Mineral extraction | 518.2 | 671.9 | - | 231 |
| Thermal power generation | 28 749.7 | 28 241.8 | 2 | 41 |

Note: MCM = million cubic metres

## Oil recovery industry

Substantial quantities of water (5.5 billion barrels in Canada, annually) are co-produced with oil during the recovery of both conventional and heavy oils. This water is referred to in the industry as produced water, which must be properly managed to minimize environmental impacts and support socio-economic development. The main pollutant in this water is oil, with concentrations ranging from 50 to 5000 mg/L. Other pollutants of great significance include silica, total suspended solids (TSS), and total dissolved solids (TDS), which can be as high as 35000 mg/L. Management options for produced water depend on its characteristics, regulatory requirements for its disposal, and economics of reuse of the produced water for such purposes as steam generation, irrigation and enhanced oil recovery. Innovative reclamation technologies include oil and TSS removal by granular media filtration, liquid-liquid hydrocyclone and membrane filtration; silica removal by hot-lime softening and activated alumina; and TDS removal by vapour compression evaporation, electrodialysis, freeze desalination and membrane distillation. While numerous technologies have been proposed for the treatment of oilfield brines to recover residual oil and the water, many of these technologies have not been field tested and demonstrated. It was suggested that the price of fresh water and the penalty for discharging wastewater was too low in Canada and did not reflect the true total costs to the society. Thus, there are hardly any incentives, which would encourage more water recovery through recycling and reuse.

## Pulp and paper industry

The pulp and paper industry is another large producer of wastewater, with discharge of about 50 $m^3$ of process water per tonne of pulp produced. As an alternative to traditional end-of-pipe wastewater treatment, an increasing number of pulp and paper mills are considering reuse of some process waters as process feedwater. This form of recycling would allow users to increase mill capacity without expanding existing wastewater treatment systems, improve the efficiency of such systems, reduce chemical and energy costs, and reduce water intake. The recycling process may lead to build up of non-process elements (NPE) throughout the mill and disrupt its operation, and cause build-up of volatile and odourous compounds that can generate air of quality hazardous to the mill staff. To address these problems, a number of innovative "kidney" technologies have been developed to purge these NPEs from the process water; several examples were presented. There is some reluctance of the industry to adopt these technologies because of sizeable investments required, highly variable revenue earned by the industry, lack of confidence in new technology, and lack of specific financial or regulatory incentives. It was felt that such incentives would encourage Canadian pulp and paper mills to adopt more broadly these new technologies and increase recycling of their wastewaters.

## Metal finishing industry

The last sector addressed was water use and reuse in the metal finishing industry, which includes about 1400 facilities in Canada. Even though most such facilities are small, their water consumption can range from 50 to 5000 L/min. A recent survey revealed that a very small percentage of the industry uses some means of water recycling. Recycling could be increased with innovative approaches including an increased use of resource recovery technologies. There is some reluctance to this in the industry because of concerns over the impacts on product quality and company profits, restrictions of space and resources in the facility, and a lack of understanding of the actual implications of future water limitations. There is a need to make the industry aware of economic and social benefits of conserving and recycling water in this sector.

Overall, all three sectors presented a similar picture with respect to industrial water recycling. Larger users are aware of potential benefits, but higher uptake of recycling is impaired by certain technological inertia, reluctance to commit to large investments in recycling technology, and lack of regulatory/monetary incentives to recycle. Policies instituting such incentives would increase industrial water recycling.

Other regions, such as South Africa and California, have used various techniques as incentives to encourage industrial water recycling and reuse. Increased emphasis on cleaner production techniques in South African industries has been driven by water scarcity, but has been reinforced by external issues, including a new National Water Act, which gives priority to sustainability and waste minimization; an increasing number of multinational companies, which apply European, American or Japanese criteria; the use of environmental standards such as ISO 14001; and local regulatory authorities, which are removing concentration-based limits if a waste minimization program is in place (Buckley *et al*., 2000). In the South Bay Water Recycling project in California, both pricing incentives and retrofit incentives were used to facilitate the connection of industrial customers with a reclaimed municipal water distribution system (Rosenblum, 1999). The cost of non-potable reclaimed water was reduced to 20-50% lower than the potable water cost, and a grant program offered customers up to 150 $US/m$^3$/day to construct retrofits required to connect to the reclaimed water system.

## RECLAIMED WATER STORAGE AND DISTRIBUTION

Following treatment, reclaimed water is distributed to individual users. Variations in demand for reclaimed water, as well as safety considerations during periods of non-compliance with water quality standards (the so-called emergency storage), require incorporation of storage into the water reuse system. During storage and transport in the distribution network, reclaimed water undergoes further changes with respect to its characteristics and this needs to be accounted for in storage and distribution design.

Reclaimed water storage design is similar to that applied in potable water supply. After establishing reclaimed water demand and its variation in time, and considering reclaimed water production, any shortfalls must be provided by storage to maintain reclaimed water supply reliability. These considerations are made over various time periods, ranging from daily to seasonal storage. For example, wastewater irrigation applications in Alberta are restricted to the period between May 1$^{st}$ and September 30$^{th}$, and adequate storage for the remaining seven months of the year is required (Alberta Environment, 2000). Emergency storage must also be provided so that if the reclaimed water does not meet the prescribed standard, it can be diverted into emergency storage until compliance with water quality standards is ensured and reuse can continue. In the B.C. reuse practice, a minimum of 20 days of emergency storage must be provided in systems without seasonal storage (British Columbia Ministry of Environment, Lands and Parks, 1999). For enhanced reliability of supply, supplemental supplies may have to be incorporated into the reuse system. Actual storage facilities are designed in various ways, including open reservoirs, or covered tanks. Reservoirs require larger footprints, with the associated land costs. Open reservoirs are susceptible to water quality degradation from biological growth, and maintenance of chlorine residual is particularly important under such circumstances (Holliman, 1998).

Transport systems for distribution of reclaimed water are designed similarly as potable water supply systems. The design methodology is well developed and fully computerized. With respect to hydraulics operation, there are no special requirements for reclaimed water. However, the most important consideration is clear identification of reclaimed water pipes and taps, to avoid accidental cross-connections to the potable system, or use for higher-level (including potable) purposes. This is usually achieved by using different material pipes, with clear identification of reclaimed water pipe, e.g., by colour, tapes or polyethylene wrapping. A shade of purple, Pantone 522, has been identified as the universal colour for reclaimed water, and use of materials painted this colour ("purple pipe") is required in many jurisdictions regulating reclaimed water use. Similarly, all outlets and areas in which reclaimed water is used should be marked by signs and tags. In the B.C. Waste Management Act, the provider of reclaimed water is required to incorporate design, construction, maintenance and inspection safeguards to prevent cross connection (British Columbia Ministry of Environment, Lands and Parks, 2001). It was noted at the workshop that the Canadian Plumbing Code does not make allowances for reclaimed water.

## PLANNING AND IMPLEMENTATION OF WASTEWATER RECLAMATION AND REUSE

Wastewater reclamation and 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. The planning analysis is used to determine the project feasibility by focusing on seven major feasibility criteria (Mills and Asano, 1998):

- Engineering feasibility
- Economic feasibility
- Financial feasibility
- Institutional feasibility
- Environmental impact
- Social impact and public acceptance
- Market feasibility.

The project development proceeds through three phases, conceptual, feasibility and facilities planning.

**Engineering feasibility**

Engineering feasibility of reuse projects is more complex than that employed in potable water supply design. Major issues addressed include water quality, public health protection, wastewater treatment alternatives, storage and distribution system siting and design, on-site conversions at water use sites (such as potable and reclaimed water plumbing separation), and matching of supply and demand for reclaimed water, including provision of supplemental and backup supplies.

**Economic feasibility**

Economic feasibility is of paramount importance to water reuse projects. In this field, many common misconceptions exist, including a false belief that reclaimed water represents a new source of cheap water. This may be true only in exceptional cases when considering water reclamation facilities near large agricultural or industrial users of reclaimed water without requirements for additional treatment beyond the existing standard in the locality (usually secondary treatment). In California, the cost of reclaimed water (Asano 2002) is about $\$0.50/m^3$ (without operation and maintenance costs), which may be too expensive for agricultural irrigation. Besides treatment costs, additional costs are incurred for storage, distribution and provision of supplemental/back up facilities. However, such costs may be acceptable for reuse in urban areas. Japanese experience shows that the price of reclaimed water is comparable to that of drinking water; however, reclamation brings about additional benefits that are often neglected in conventional analyses – reduced pollution of receiving waters and disturbance of the environment by increasing water withdrawals. In general, it appears that the costs of reclaimed water can be acceptable in water scarce regions, and for new projects in urban areas. Great economic benefits can be obtained in facilities with maximum utilization – generally meeting seasonal peak demands, which may be the most expensive to satisfy (high capacities and low utilization).

With respect to on-site residential wastewater recycling, Waller has compared the costs and benefits, and cost-effectiveness, of several innovative reuse technologies with that of more traditional wastewater servicing (Waller, 2000 and Waller and Salah, 1999).

**Financial analysis**

The financial analysis answers questions about the reuse project's financial feasibility. Two types of issues must be addressed – financing construction/project implementation, and generating revenue. Construction financing addresses sources of capital funds and associated interests, and availability of subsidies. In revenue generation, reclaimed water rates need to be established and should reflect the on-going costs of facilities existing prior to the project under investigation. Note also that the rates for reclaimed water are closely connected with those for freshwater. Where reclaimed water reduces demand for freshwater, the freshwater rates may increase. On the other hand, reclaimed water may reduce the need to purchase high-priced peak demand water. Thus, revenues from both sources may have to be shared in some way.

**Institutional feasibility**

Water reuse projects involve interaction of various institutions, exerting influence at levels from local to national. All these institutions may become involved in the project, or their activities may affect it. Typically, a municipality would be involved in collection and treatment of wastewater, and distribution of reclaimed water. Provincial guidelines or criteria would govern the quality of such water, and the operation of the project may have impacts on receiving waters and involve some federal responsibility. 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 interactions among all these institutions need to be considered when assessing project feasibility.

The Canadian Water and Wastewater Association (1997) investigated regulatory barriers to 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.

**Environmental impacts**

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. Examples of the former include reduced water intake, avoiding new construction for bringing new water supplies on line and transporting water to the point of demand, and prevention of treated wastewater plant effluent discharge into local receiving waters. For example, wastewater from golf courses can be reclaimed and used for irrigation on-site, allowing beneficial use of nitrogen and phosphorus in the wastewater for turfgrass fertilization, while avoiding potential groundwater contamination from subsurface disposal of the effluent. Adverse impacts arise from lack of dilution at the point where the wastewater effluent was diverted from receiving waters, disposal of new effluents from reclamation plants, possible impacts on the quality of soils irrigated with reclaimed water, and leaching of chemicals from such soils into surface waters and groundwater.

**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. There is agreement that while the success of reuse projects cannot be guaranteed, sound and proactive communication and education programs are essential (Wegner-Gwidt, 1998). To win support for water reuse, good communication with the public is needed, using creative, proactive outreach programs that inform citizens about water services. The first step is to identify the audience, and then gain the support of opinion leaders, media contacts and third-party experts. All this is planned well in advance. A citizens' advisory committee, with a broad representation, serves to make a vital connection between the government and citizens. This committee will help prepare for dealing with other groups. In this process, an information vacuum must be avoided. One of the best ways in which to convince the public about the benefits of water reuse is to organize visits to successful projects, or organize presentations.

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 project opponents and their issues. The communication process is best implemented by soliciting public input, developing a series of educational/information activities, sharing decision-making and problem solving responsibilities, and focusing on winning and maintaining community support.

These activities need to be supported by an educational program, which requires the knowledge of the education system, a good quality curriculum, planning what to say, deciding how to say it, training teachers, participating in educational events, and developing public relations programs with the schools. One of the key ingredients is to create a good media relations program (Wegner-Gwidt, 1998).

**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. Whether a user is able to use reclaimed water depends on the effluent quality available and its suitability for the type of use. As well, a market assessment provides data needed to formulate project alternatives, including facility location and capacities, design criteria, and reclaimed water pricing policy (Mills and Asano, 1998).

## MAIN WORKSHOP OBSERVATIONS AND RECOMMENDATIONS

At the present time, water reuse in Canada is practiced on a relatively small scale, and varies regionally depending on availability of water supplies and suitability of receiving waters for purification and transport of wastewater effluents. In general, the provinces of British Columbia and Alberta have the most experience, with both having some form of regulatory oversight. Municipalities in these provinces are typically reusing treated wastewater to irrigate urban parkland, landscaping, golf courses and agricultural non-food crops. There is also some limited experience using stormwater to irrigate golf courses and parkland, and for wetland preservation. Although statistics are lacking, experience with water recycling and reuse in Canadian industrial, commercial and institutional users is becoming more common, but varies depending on the specific sector. At the scale of individual buildings, there has been some experimentation with greywater treatment and re-use for toilet flushing, irrigation or other non-potable uses. Reports and pilot-scale installations over the past decade, most of which have been commissioned by CMHC, have documented applications of these measures in Canada and internationally (e.g., Canadian Water and Wastewater Association, 1997; Stidwill and Dunn, 2000; Totten Sims Hubicki, 1997; Waller and Totten Sims Hubicki, 1998; Waller and Salah, 1999; Waller, 2000).

On the whole though, there is a growing interest in wastewater reclamation and reuse in Canada, which is driven by:

- steadily increasing water demands exerted against finite supplies, endangered by climate change;
- opportunities to save on future expansion of the water supply infrastructure;
- reducing or eliminating wastewater effluent discharge to sensitive receiving waters; and
- opportunities for inexpensive provision of water services in isolated places, or single residential sites.

In the course of the two-day workshop a number of recurring themes emerged in the areas of technology, policy and regulation, research needs and public/political perceptions. In each case, the main observations from workshop participants are highlighted, followed by a listing of recommendations for further effort.

## Technologies

There is a growing array of innovative treatment technologies that have application for wastewater reuse (e.g., biological treatment systems, membrane technologies, UV disinfection). Many of these technologies have been developed in Canada and are internationally competitive. Export of these systems to other areas benefits the Canadian economy and increases Canada's presence in the international field. These technologies are increasingly targeted at decentralized (satellite), small-scale, treatment facilities with direct application to the municipal, industrial and agricultural sectors.

*Needs*

- continued effort in developing simple, low-cost, versatile and low maintenance technologies for smaller (local) applications.
- technology performance criteria in producing relevant water qualities (physical, chemical, biological [including biological content and biological impact]) and validation protocols that would allow innovative technologies/processes to be validated against those criteria and accepted for the various applications. This helps eliminate the need for policy makers and regulators to become proficient with every new technology or process that comes along.
- improved information sharing on best available technologies.
- enhanced pilot testing and technology demonstration, and the showcasing of economically sound and environmentally responsible examples of water reuse/recycling to garner public and political visibility and interest.

## Policy and regulation

Unlike the U.S. and Australia, there are no national guidelines or supporting documentation for water reuse and recycling in Canada. At the provincial level, only the provinces of British Columbia and Alberta have regulations and standards dealing specifically with reuse and recycling.

*Needs*

- federal leadership through development of national water reuse guidelines that link proposed uses with water quality requirements that take economic considerations into account, while recognizing that public health and environmental protection are of paramount concern; some regulatory flexibility may be important in the early stages of establishing the wastewater reclamation and reuse industry. National guidelines developed in other countries should serve as a starting point.

- national and provincial water reuse programs that will establish design standards, promote research in technology information and educate the public on health risks and beneficial impacts.
- provincial standards or criteria governing the quality of wastewater reuse.
- management systems to help identify the engineering, financial and institutional feasibility of projects, and help assess environmental impact and public acceptance.
- policies that encourage full-cost pricing for water resources; the low price of water in Canada serves as a disincentive to implement water reuse and recycling programs and serves as a major barrier to technological innovation and advancement. Manufacturers in Canada generally consider water a minimal expense and use it generously to solve or prevent a potential problem; higher water prices will help "internalize" water costs in the production of goods, thereby fostering reuse and recycling.

## Research

In spite of water reuse's growing popularity, the most significant concerns are those related to health risks. Until very recently, such considerations were based almost entirely on exposure to enteric viruses in reclaimed water. More recently, attention has been drawn to such protozoa as Cryptosporidium, which has been shown to be insensitive to inactivation by chlorine, but extremely sensitive to UV. As well, simulation studies have been recently employed to indicate the reliability (i.e., health risk) of water reuse for various applications. This risk must also be considered for downstream communities using the surface water as a drinking water source.

A great deal of international expertise on water reuse applications is available, particularly in Australia, Japan, some southern U.S. states (most notably California and Florida), and many areas in Southern Europe (particularly along the Mediterranean coast). The International Water Association (IWA) operates a specialist group on water reclamation, recycling and reuse, which functions as an international knowledge network focused on increasing awareness and understanding of water reuse through such methods as newsletters, publications and conferences. The U.S. organization, Water Environment Research Foundation (WERF), also supports numerous water reclamation and reuse research projects. Current research projects can be found on the WERF website: <http://www.werf.org/research/research.cfm>.

The Canada Mortgage and Housing Corporation (CMHC) has commissioned a number of on-site, residential wastewater reuse studies. The result has been targeted publications for engineers and technical audiences on the analysis, design and operation of water reuse systems (Totten Sims Hubicki Associates, 1997); water planning and management personnel to make them aware of available technologies and experiences with residential on-site wastewater recycling and reuse (Waller and Totten Sims Hubicki, 1998); and individuals interested in the requirements for monitoring and control protocols for small residential water reuse systems (Stidwill and Dunn, 2000). Additional research needs were identified at the workshop.

*Needs*

- emerging human health issues with respect to safety of reclaimed water containing endocrine disruptors, pharmaceutical chemicals, organic industrial chemicals, and salts and heavy metals. The ramifications of these chemicals - present in very low quantities - are not well understood with respect to long-term health effects, and the research on these issues is its infancy. These concerns are not specific just to water reuse, but apply also to biosolids disposal on land, and will slow down further expansion of water reuse.
- environmental modelling and monitoring of long-term impacts of reclaimed water; the

expected increased use of reclaimed water for wetland preservation, stream flow augmentation and groundwater recharge illustrates the need for research in this area.
- evaluation of the fate of microbiological and chemical contaminants in reclaimed water and determination of surrogate parameters that are both rigorous and cost-effective for water quality monitoring.
- assessment of the effect of storage on reclaimed water quality.
- evaluation of the impact of reclaimed water irrigation practices on crops and soil (e.g., on nutrient, salt and heavy metal management, and pathogen survival).
- risk assessment and management methods in the design of reuse applications.
- development of well-defined multiple barrier strategies, including multiple disinfectant use, as tools increasing the spectrum of pathogens being treated and reducing the level of by-products formed.
- applied economic analysis; enhanced research to better quantify the economic benefits of water reuse projects, life cycle cost comparisons, and cost-effectiveness analyses to compare options and help advocate the benefits of water reuse and recycling, particularly in areas with limited water availability.
- improved collaboration and communication among researchers in the water reuse/ recycling field.

## Public and political acceptability

Workshop participants argued that among all potential barriers, the barrier of public perception may be the greatest, particularly as it relates to exposure to treated wastewater. Although there is relatively little documented information on this in Canada, there is considerably more to be learned from the U.S. experience where this area is getting some additional research effort, in addition to municipalities doing their own polling and developing rather exhaustive public consultation programs. Research has typically shown that residents are most opposed to reused water for drinking, bathing and swimming, and less opposed to irrigation and limited-contact uses (such as toilet flushing). Delegates noted that even though the perception of the public to water reuse can often be hostile, there are many municipalities in Canada that have for years been consuming water from sources that are at the receiving end of previously treated wastewater. At the same time, the experience from Walkerton indicates that the public expects high levels of human health protection, involving government regulations and their enforcement. In this process, the principles of precaution and due diligence must be applied.

*Needs*
- encourage environmental groups to engage in the water reuse/recycling dialogue sooner than later.
- advocate public consultation in implementing reuse programs, particularly in light of emerging human health issues related to pharmaceuticals and endocrine disrupting substances.
- highlight successes and continually educate and inform the public.

The issue of wastewater reclamation and reuse has to be approached in an integrated manner as one of the facets of environmental management serving to manage both water quantity and aquatic ecosystems. In connection with water supply, water reuse needs to be addressed in conjunction with demand management; water conservation in agriculture, industry, and personal and government sectors; development of water efficient technologies and processes; and increased recycling in the industrial sector. Similarly, the protection of aquatic ecosystems may support water reuse and industrial recycling as important options reducing pollutant discharge into receiving waters. While the decision whether or not to reuse water is currently based on benefit-cost analyses, future decisions may be based on achieving sustainability in water management.

## Maintaining the Dialogue

Workshop delegates were extremely supportive of the need for continued information exchange and dialogue between the science community and policy/program managers in the emerging area of water reuse and recycling. As this report is being produced, CCME is considering options for maintaining and, indeed, expanding on the dialogue initiated during the workshop. Some options suggested at the workshop, in addition to other ideas, are highlighted below.

*Standing National Committee/Task Force on Water Reuse* - Create a committee or task force of academic, industry and government experts (*i.e.* from the fields of wastewater treatment technology, public health, plumbing, irrigation, and various other end-user sectors) to develop a Canadian context for reuse/recycling, identify short-term and long-term implementation opportunities, refine research needs, facilitate ongoing dialogue, help develop a national guidebook and foster technological innovation. Most issues related to water reuse fall under the provincial jurisdiction and will be addressed that way. However, there is an opportunity for CCME and the Federal Government to assist this process by encouraging and supporting research on fast response instruments for microorganism detection and on health risks associated with water reuse, assisting in developing model policies for water reuse on the basis of both Canadian experience and extensive experience in other countries, and providing a forum/clearing house for information exchange.

*Supporting Water Recycling in Industry* - Given the total water intakes by the agriculture, industry and the personal & government sector in Canada (9, 83 and 8%, respectively), the greatest benefits with the least ramifications for health would be derived by encouraging water recycling in industry, and wastewater reclamation and reuse for industrial purposes. Such goals would be best achieved by supportive policies (with respect to disposal of industrial effluents) and economic incentives.

*Follow-up Workshops* - Periodic follow-up workshops, or perhaps dedicated sessions at selected conferences (e.g., biennial meetings of the Canadian Water and Wastewater Association), for both the science and policy communities were viewed as desirable. Additional opportunities include future joint workshop sessions with the Canadian Water Network or CRESTech - both of which have considerable institutional and public policy mandates in their respective initiatives.

*Electronic Networking* - Various electronic media, such as dedicated or re-vamped web sites, electronic bulletin boards, moderated chat rooms, and subject-specific, subscription-based email lists could be considered as a means to ensure the flow of information continues. Although these kinds of electronic networks require sustained effort and resources, and have met with varying levels of success in the past, they may prove effective at maintaining interest in the period between workshops.

Ultimately, the logic for bringing researchers and policy managers together is to make better public policy decisions, and herein lies CCME's interest. Bringing the latest scientific knowledge to decision makers is critical in helping to demonstrate the need for programs and policies to guide water reuse and recycling in Canada. The dialogue at this workshop, reflected in these proceedings, serves as a starting point for this improved decision-making.

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## APPENDIX 1 - WORKSHOP PROGRAMME

**Linking Water Science to Policy: Water Reuse and Recycling**
**A CCME Sponsored Workshop**

**May 30 & 31, 2002**
**Alberta Room, Sheraton Cavalier Hotel, Calgary, AB**

### Day 1 – Thursday May 30

11:00-11:30 ***Welcome and Introductions***
Ken Dominie, Co-Chair, Water Coordination Committee, CCME and Assistant Deputy Minister, Ministry of Environment, Newfoundland
Jiri Marsalek and Bijan Aidun, Workshop Co-chairs
National Water Research Institute, Burlington, ON
Alberta Environment, Edmonton, AB

***Introductory Session***

11:30-11:50 Wastewater recycling and reuse in Canada: Opportunities, examples and issues *Don Waller, Dalhousie University, Halifax, NS*
11:50-12:10 Pressures, incentives, initiatives and barriers to water reuse and recycling
*Duncan Ellison, Canadian Water and Wastewater Association, Ottawa, ON*
12:10-12:30 Update on US EPA practices in water reuse
*Robert Bastian, US EPA, Washington, DC, USA*
12:30-13:00 Discussion

13:00-14:00 lunch

***Reuse and Recycling Technology***

14:00-14:20 The role of membranes in water reuse
*Pierre Cote, Zenon, Oakville, ON*
14:20-14:40 Re-use of treated sewage in Canada and elsewhere for irrigation and toilet flushing
*Craig Jowett, Waterloo Biofilter Systems, Rockwood, ON*
14:40-15:00 UV technologies for water reuse and recycling
*Bill Cairns, Trojan technologies, London, ON*
15:00-15:30 Discussion

15:30-16:00 coffee

***Municipal water reuse***

16:00-16:20 Planning and analysis for water reuse treatment systems
*John Stidwill, Totten Sims Hubicki, Ottawa, ON*
16:20-16:40 Water quality guidelines for water reuse systems
*Robert Dunn, Ottawa, ON*
16:40-17:00 Reuse of stormwater and wastewater in the City of Calgary
*Wolf Keller, The City of Calgary, Calgary, AB*
17:00-17:30 Discussion

**Day 2 – Friday May 31, 2002**

07:30-08:30 breakfast

***Industrial Recycling***

08:30-08:55 Treatment and reuse of produced water from oil recovery operations
*Abbas Zaidi, Canadian Clean Technology Institute, Hamilton, ON*

08:55-09:20 Water use and reuse in the metal finishing industry
*Derek Vachon, Canadian Finishing Systems, Burlington, ON*

09:20-09:45 Reuse and recycling of process wastewater in pulp and paper industries
*Pierre Berube, University of BC, Vancouver, BC*

09:45-10:00 Discussion

10:00-10:30 coffee

***International Perspective***

10:30-11:00 The environmental benefits of water conservation and water reuse
*John Anderson, International Water Association/Sydney, Australia*

11:00-11:30 WERF's non-potable water reuse research program
*Linda Blankenship, Water Environment Research Foundation, Alexandria, VA, USA*

***Policy issues***

11:30-12:00 Florida reuse program: linking various water programs, policies and regulations
*Lauren Walker-Coleman, the State of Florida, Tallahassee, FL, USA*

12:00-13:00 lunch

13:00-13:30 Water reuse - integral to setting a water stewardship vision for British Columbia
*Chris Jenkins, BC Environment, Victoria, BC*

13:30-14:00 Meeting the challenges of safe municipal wastewater reuse for irrigation application in Alberta
*Jock Forster, Alberta Environment, Red Deer, AB*

14:00-14:30 Barriers to greywater recycling
*Sandra Baynes, Canada Mortgage and Housing Corporation, Ottawa, ON*

14:30-15:00 Discussion

15:00-15:30 ***Concluding Comments***

## APPENDIX 2 - LIST OF ATTENDEES

**Linking Water Science to Policy: Water Reuse and Recycling**
**A CCME Sponsored Workshop**

**May 30 & 31, 2002**
**Sheraton Cavalier Hotel, Calgary, AB**

### LIST OF PARTICIPANTS

* indicates speakers

Chris Jenkins *
*British Columbia Water, Land & Air Protection*

Bijan Aidun
Jock Forster *
Murray Tenove
Karu Chinniah
Ralph Schroth
Asoke Weerasinghe
*Alberta Environment*

Thon Phommavong
*Saskatchewan Environment & Resource Management*

Paul Vanderlaan
*New Brunswick Environment & Local Government*

Lorrie A. Roberts
*Nova Scotia Environment & Labour*

Ken Dominie *
*Newfoundland & Labrador Environment*

Doug Sitland
*Government of Nunavut*

Jiri Marsalek
John Lawrence
Alex Bielak
Karl Schaefer
Quintin Rochfort
*National Water Research Institute*
*Environment Canada*

Liz Lefrançois
Danielle Rodrigue
John Cooper
*National Water Issues Branch*
*Environment Canada*

Michel Béland
*Wastewater Technology Centre*
*Environment Canada*

Zita Botelho
Daniel Millar
*Environment Canada - Pacific and Yukon Region*

Sandra Blenkinsopp
*Environment Canada - Prairie & Northern Region*

David G. Green
Teresa Brooks
*Health Canada*

Paul Milburn
John Lebedin
*Agriculture and Agri-Food Canada*

Sandra Baynes *
*Canada Mortgage and Housing Corporation*

Wolf Keller *
Terry Prince
*Municipal Government*

Duncan Ellison *
*Canadian Water and Wastewater Association*

S. Abbas Zaidi *
*CCTI*

Derek Vachon *
*Canadian Finishing Systems Ltd.*

John Stidwill *
*Totten Sims Hubicki*

Robert Dunn *
*Dunn Environmental Services Inc.*

E. Craig Jowett *
*Waterloo Biofilter Systems Inc.*

Bill Cairns *
*Trojan Technologies*

Pierre Côté *
*ZENON Environmental Inc.*

Craig Heath
*Graecam Incorporated*

George McGeachie
*Associated Engineering Alberta Ltd.*

Dan Pippard
*Newalta Corporation*

Pierre Bérubé *
*University of British Columbia*

Don H. Waller *
*Dalhousie University*

Daniel W. Smith
*University of Alberta*

John Anderson *
*Australia Department of Public Works & Services*

Robert K. Bastian *
*U.S. Environmental Protection Agency*

Linda L. Blankenship *
*Water Environment Research Foundation*

Lauren Walker-Coleman *
*Florida Department of Environmental Protection*