WATER AND WASTEWATER REUSE

An Environmentally Sound Approach for Sustainable Urban Water Management

In collaboration with:

Ministry of Land, Infrastructure and Transport of Japan (MLIT)
Public Works Research Institute of Japan (PWRI)
Osaka Municipal Government
Infrastructure Development Institute of Japan (IDI)

UNITED NATIONS ENVIRONMENT PROGRAMME

DIVISION OF TECHNOLOGY, INDUSTRY AND ECONOMICS - INTERNATIONAL ENVIRONMENTAL TECHNOLOGY CENTRE

Osaka Office
2-110 Ryokuchi koen, Tsurumi-ku,
Osaka 538-0036 Japan
Tel: +81-6-6915-4581
Fax: +81-6-6915-0304

Shiga Office
1091 Oroshimo-cho, Kusatsu City,
Shiga 525-0001 Japan
Tel: +81-77-568-4581
Fax: +81-77-568-4587

Email:ietc@unep.or.jp
URL: http://www.unep.or.jp/

Environmentally Sound Technologies (ESTs) encompass technologies that have the potential for significantly improved environmental performance relative to other technologies. Broadly speaking, these technologies protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes. The adoption and use of ESTs carefully considers both human resource development and local capacity building.

Information on ESTs is not always available in a form that can be easily understood by decision-makers and those without technical expertise. To encourage greater understanding about ESTs and their benefits, this booklet has been prepared using a minimum of technical jargon. We hope that you find the information in this booklet both interesting and useful.

ACKNOWLEDGEMENT

The development of this publication was guided by an expert panel convened by GEC, in coordination with UNEP/DTIE/IETC. We sincerely acknowledge the contributions of the following members of the Advisory Committee as well as reviewers.

ADVISORY COMMITTEE:

Dr. Takashi Asano
Professor Emeritus, Department of Civil & Environmental Engineering,
University of California at Davis

Dr. Hiroaki Tanaka
Leader of Water Quality Team, Water Environment Research Group,
Public Works Research Institute*

Mr. Yutaka Suzuki
Leader of Recycling Research Team, Material and Geotechnical Engineering Research Group,
Public Works Research Institute

Mr. Makoto Matsubara
Deputy Director, Sewerage Planning Division, Sewerage and Wastewater Management Department
City and Regional Development Bureau,
Ministry of Land, Infrastructure and Transportation

Mr. Mitsuhide Kusumoto
Manager, Machinery Department, Sewerage Division, Environment and Sewerage Bureau,
Osaka Municipal Government

Mr. Hayato Sasai
Deputy Director, 2nd Research Department,
Infrastructure Development Institute*

Reviewers:
Prof. Dr. Takashi Asano
Professor Emeritus, Department of Civil & Environmental Engineering
University of California at Davis

Dr. Blanca Elena Jiménez Cisneros
Chair of the International Water Association's Water Reuse Specialist Group
Instituto Ingeniera, UNAM, Mexico City

Authors:
Dr. Chizuru Aoki and Dr. Mushtaq Ahmed Memon
Programme Officer, UNEP-IETC

Mr. Hiroyuki Mabuchi
Deputy Manager, Project Division, GEC*
(* The titles above are those at the time of writing.)

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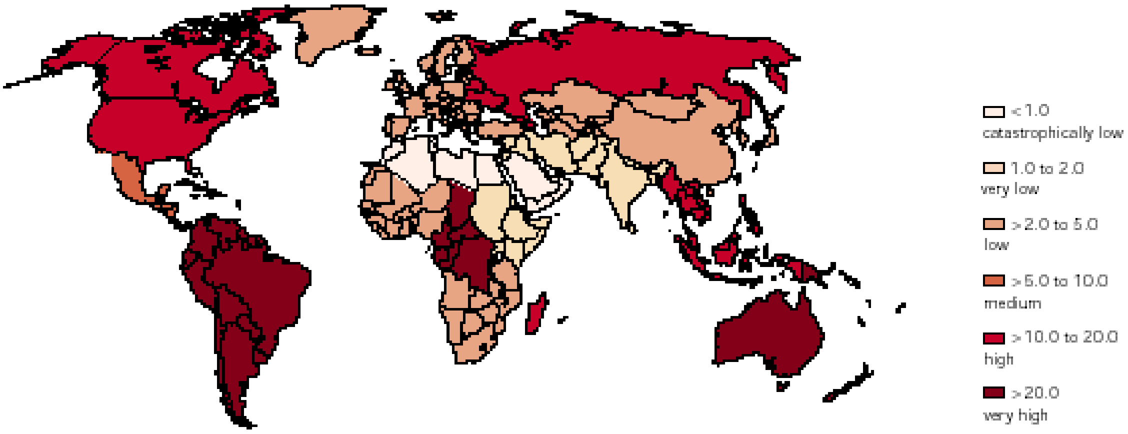
1. Introduction

Water-related problems are increasingly recognized as one of the most immediate and serious environmental threats to humankind. Water use has more than tripled globally since 1950, and one out of every six persons does not have regular access to safe drinking water. Lack of access to a safe water supply and sanitation affects the health of 1.2 billion people annually (WHO and UNICEF, 2000). The latest Global Environment Outlook of the United Nations Environmental Programme (UNEP) reports that about one third of the world's populations currently live in countries suffering from moderate-to-high water stress, where water consumption is more than 10% of renewable freshwater resources. As Figure 1 shows, many countries in Africa and Asia have very low or catastrophically low water availability (UNEP, 2002a).

These problems may be attributed to many factors. Inadequate water management is accelerating the depletion of surface water and groundwater resources. Water quality has been degraded by domestic and industrial pollution sources as well as non-point sources. In some places, water is withdrawn from the water resources, which become polluted owing to a lack of sanitation infrastructure and services. Over-pumping of groundwater has also compounded water quality degradation caused by salts, pesticides, naturally occurring arsenic, and other pollutants. In urban areas, demand for water has been increasing steadily, owing to population growth, industrial development, and expansion of irrigated peri-urban agriculture. Population growth in urban areas is of particular concern for developing countries. Population growth is expected to occur in developing nations, as developed regions are projected to see their population decrease by 6% over the next 50 years. Meanwhile, the rural population is expected to stabilize at around 3.2 billion (from 2.97 billion today), indicating that the growing population will settle in urban areas (WHO and UNICEF, 2000). Many parts of the world are facing changes in climatic conditions, such as rainfall patterns, flood cycles, and droughts, which affect the water cycle.

Figure 1: Water availability in 2000 (Measured in terms of 1000m^3 per capita/year)



（UNEP, 2002a）

Faced with these challenges, there is an urgent need to improve the efficiency of water consumption, and to augment the existing sources of water with more sustainable alternatives. Numerous approaches, modern and traditional, exist throughout the world for efficiency improvements and augmentation. Among such approaches, wastewater reuse has become increasingly important in water resource management for both environmental and economic reasons. Wastewater reuse has a long history of applications, primarily in agriculture, and additional areas of applications, including industrial, household, and urban, are becoming more prevalent. Of them all, wastewater reuse for agriculture still represents the large reuse volume, and this is expected to increase further, particularly in developing countries (UNEP, 2002a). With such an increase in applications, there is a concurrent recognition that water resource management and proper water cycle maintenance requires up-to-date knowledge about basic practices, benefits and potential risks, capacity building of practitioners and planners, and appropriate policy frameworks to protect human health and the environment.

In cities and regions of developed countries, where wastewater collection and treatment have been the common practice, wastewater reuse is practised with proper attention to sanitation, public health and environmental protection. The situation is different in many developing countries owing to the lack of appropriate capacity and resources to enforce strict wastewater treatment standards for its reuse. Wastewater reuse for irrigation is quite common in many places; therefore, the poor quality of wastewater may pose substantial health risks for the farmers as well as consumers of those agricultural products. The World Health Organization (WHO) has been working to draw up and update the guidelines for wastewater reuse in agriculture.

With this background, this booklet was prepared to introduce the basic concepts of water and wastewater reuse, and applications of Environmentally Sound Technologies (ESTs) for enabling reuse. In particular, the booklet addresses the following questions, illustrated with case studies from both developed and developing countries:

- What are the benefits of implementing water and wastewater reuse initiatives?
- Which cases and approaches of wastewater reuse result in efficient and successful management of resources?

Furthermore, the booklet aims to illustrate that sustainable water management is relevant for regions with abundant water resources as well as for those with limited water resources.

2. Wastewater Reuse as Environmentally Sound Technologies ESTs

Wastewater reuse, when appropriately applied, is considered as an example of EST applications. ESTs are defined in Chapter 34 of Agenda 21 as technologies that:

- Protect the environment;
- Are less polluting;
- Use all resources in a more sustainable manner;
- Recycle more of their wastes and products; and
- Handle residual wastes in a more acceptable manner than the technologies for which they are substitutes.

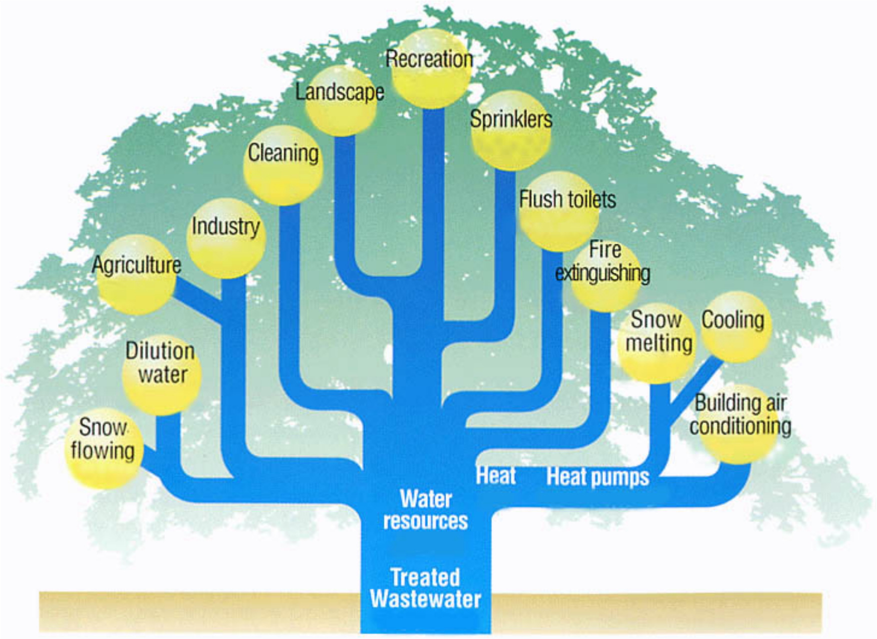
The use of ESTs plays a key role in facilitating freshwater protection and integrated water resource development and management, as recognized in Chapter 18 of Agenda 21. Wastewater reuse applications cover a wide range, including industrial, residential, recreational, and environmental enhancement purposes, as shown in Figure 2.

Water and wastewater reuse has various benefits. First, recycled wastewater can serve as a more dependable water source, containing useful substances for some applications. For example, the quantity and quality of available wastewater may be more consistent compared to freshwater, as droughts and other climatic conditions tend to have a less pronounced effect on wastewater generation. With adequate treatment, wastewater can meet specific needs and purposes, such as toilet flushing, cooling water, and other applications. The reuse of treated wastewater is particularly attractive in arid climates, areas facing demand growth and those under water stress conditions. Some wastewater streams also contain useful materials, such as organic carbon and nutrients like nitrogen and phosphorous. The use of nutrient-rich water for agriculture and landscaping may lead to a reduction or elimination of fertilizer applications.

The second benefit of wastewater reuse is that it leads to reduced water consumption and treatment needs, with associated cost savings. In many applications, reusing wastewater is less costly than using freshwater, with savings stemming from more efficient water consumption and a reduced volume of additional wastewater treatment, as well as associated compliance cost savings. The infrastructure requirements for advanced water and wastewater treatment may also be reduced. For instance, many areas with adequate water resources and a growing urban population have experienced increased water consumption, both on a per capita and total basis. Meeting such a growing demand often requires the additional development of large-scale water resources and associated infrastructure. By meeting some of the water demand through wastewater reuse and efficiency improvement, additional infrastructure requirements and the resulting financial and environmental impacts can be reduced or, in some cases, eliminated altogether.

Finally, by reusing treated wastewater for these applications, more freshwater can be allocated for uses that require higher quality, such as for drinking, thereby contributing to more sustainable resource utilization. Wastewater reuse can thus be considered as an appropriate application of ESTs as shown in Figure 2.

Figure 2: Tree of water resources recycling



(MLIT, 2001）

Wastewater can be recycled within the same industrial process or for another application such as in agricultural irrigation, with or without treatment to meet specific quality requirements. It can also be used for cascading use, which refers to a practice of using water in sequence for different applications. If the quality is not suitable for direct cascading use, wastewater can be reclaimed with adequate treatment, or used after dilution with clean water or other higher quality wastewater.

Raw wastewater reuse is an important practice in several countries, especially for agriculture, with about 20% of the world population's food being produced through this practice. However, this practice also has its risks and benefits, which should be critically analysed before taking the decision to either use the raw wastewater directly or use the wastewater after treatment. This aspect should be analysed with reference to local conditions and requirements as wastewater quality and water use is different in individual countries and regions. In some, industrial or municipal uses are the predominant ones, while in others agriculture is the predominant use. WW reuse will normally follow the main use of a local region, i.e. where industry is important, WWR will also be important for industry.

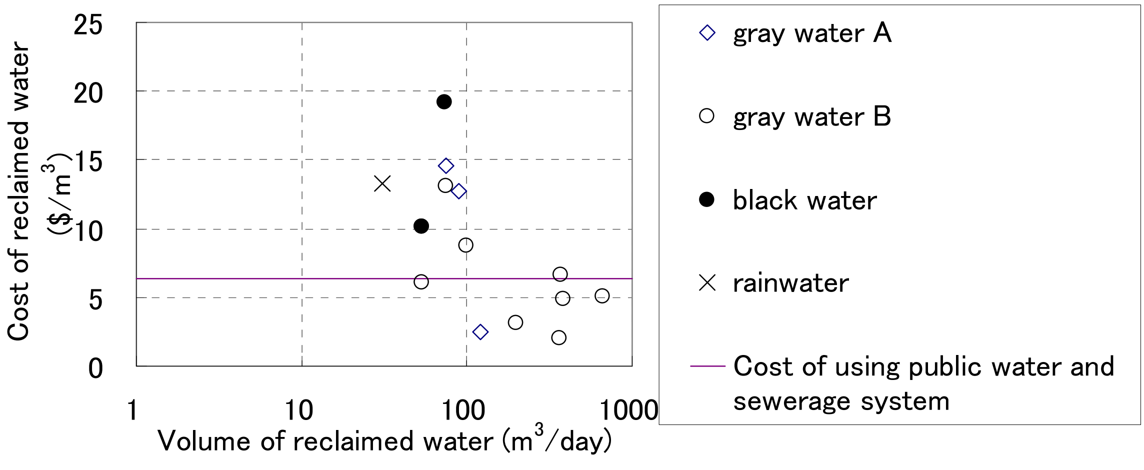
Therefore, in order to optimize water use and cost reduction potential, it is beneficial to analyse both the quality and the quantity of source wastewater against potential reuse applications and water quality requirements. Appropriate technology and its availability should also be taken into consideration. Moreover, it is important not only for new wastewater reuse techniques but also to control/improve existing practices.

Life cycle cost (LCC) analysis is useful in evaluating conditions under which water reuse ESTs can be cost effective and in comparing cost performances of different technologies. The LCC approach covers the cost of a product over its entire lifespan, from the cradle to grave, including design, production, installation, operations, maintenance, repair, and disposal (UNEP, 1996). Box 1 shows an example of an LCC analysis of wastewater reuse options in office buildings in Tokyo, Japan. The results show that if the reclaimed water volume is more than $100m^3$ per day, wastewater reuse options are more cost effective compared to the conventional freshwater and sewage treatment option. There are examples (for example from Latin America) that shows that agricultural water reuse projects with properly treated wastewater have a benefit-cost ratio from 1.2–2.2, depending on the types of crop and types of treatment involved (Yamagata *et al*., 2003).

Box 1: Lifecycle Cost of Wastewater Reuse

An LCC analysis was conducted to compare options for wastewater reuse with a conventional freshwater and sewage treatment option in office buildings in Tokyo, Japan. The cost for a conventional non-reuse option was calculated based on an infrastructure cost with a repayment schedule of 15 years and an annual interest rate of 6%, as well as on its operating and maintenance costs. Figure 3 shows that if the volume of reclaimed water exceeds $100m^3$/day, reuse options cost less than a conventional non-reuse option (Yamagata *et al*., 2003).

Figure 3: Life cycle cost comparison of wastewater reuse options



Using 120 yen = US$1

Gray water A:	Wastewater from washing hands/face, drinking, bath, and heating and cooling
Gray water B:	Wastewater from kitchen
Black water:	Wastewater from toilet

3. Requirements for Wastewater Reuse

Wastewater reuse can be applied for various beneficial purposes such as agricultural irrigation, industrial processes, groundwater recharge, and even for potable water supply after extended treatment. To ensure sustainable and successful wastewater reuse applications, the following requirements must be fulfilled:

- The potential public health risk associated with wastewater reuse are evaluated and minimized;
- The specific water reuse applications meet the water quality objectives.

In order to meet the requirements, it is necessary to treat the wastewater prior to reuse applications, and ensure an appropriate level of disinfection to control pathogens. While a comprehensive overview of wastewater treatment options and public health protection is beyond the scope of this booklet, the following sections provide brief summaries on the basic principles of wastewater treatment and options to minimize the public health risk as well as the environmental impact.

3.1. Basic Principles of Wastewater Treatment

In order to reuse wastewater, it is necessary to treat raw wastewater to meet specific needs and public safety. In this section, some basic information on wastewater treatment technologies is given and the terminology explained.

Wastewater treatment processes can be categorized into the following three:

- Physical process: impurities are removed physically by screening, sedimentation, filtration, flotation, absorption or adsorption or both, and centrifugation;
- Chemical process: impurities are removed chemically through coagulation, absorption, oxidation-reduction, disinfection, and ion-exchange;
- Biological process: pollutants are removed using biological mechanisms, such as aerobic treatment, anaerobic treatment and photosynthetic process (oxidation pond).

Conventional wastewater treatment consists of the following stages: preliminary, primary, secondary, and disinfection. Municipal wastewater treatment facilities use combinations of physical, biological and chemical treatment technologies. Preliminary and primary treatments are usually physical processes, such as screening for the removal of debris and large solids, and sedimentation. A secondary treatment may utilize biological processes, such as stabilization ponds, trickling filter, oxidation ditch, and activated sludge, which is then followed by sedimentation of biomass (sludge). Tertiary and advanced treatment is an additional treatment for higher-level removal of specific pollutants, such as nitrogen or phosphorus, which cannot be removed by conventional secondary treatments. A summary of the purposes and sample technologies of each treatment process is given in Table 1 and also illustrated in Figure 4. Wastewater reclamation and reuse can take place from any of the treatment steps as shown in Figure 4.

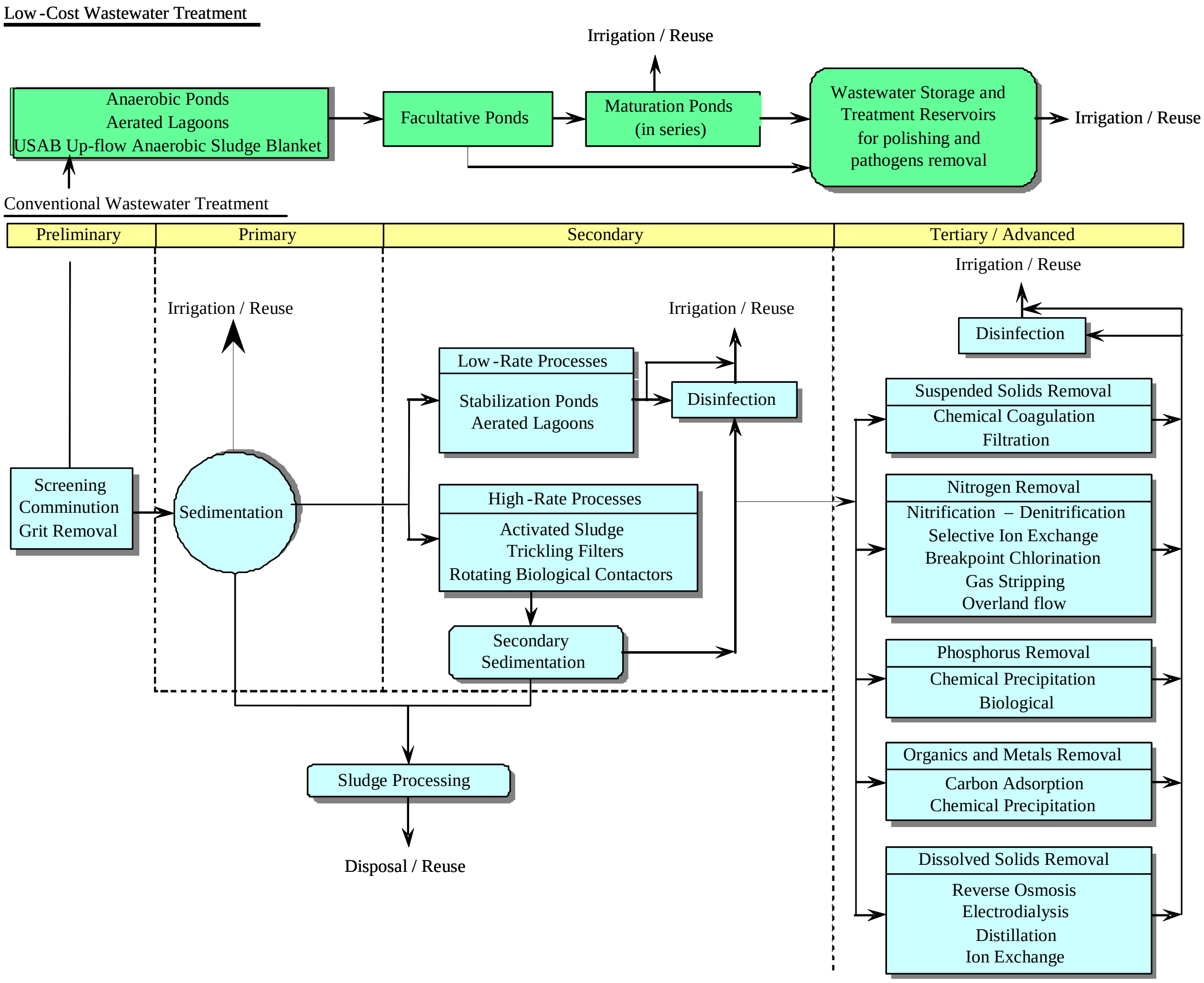
Traditional wastewater treatment, whether simple or complex, follows the above principles to some degree. Even relatively simple processes used in developing countries are capable of achieving high degrees of treatment if operated properly. In many developing countries, particularly in arid/semi-arid and warm climate regions, waste stabilization ponds are extensively used for wastewater treatment owing to their simplicity, low construction cost and minimal operational requirements, as shown in Figure 5.

Table 1: Wastewater Treatment Process

	Preliminary	Primary	Secondary	Tertiary and Advanced
Purpose	Removal of large solids and grit particles	Removal of suspended solids	Biological treatment and removal of common biodegradable organic pollutants	Removal of specific pollutants, such as nitrogen or phosphorous, colour, odour, etc.
Sample technologies	Screening, Settling	Screening Sedimentation	Percolating/trickling filter, activated sludge Anaerobic treatment Waste stabilization ponds (oxidation ponds)	Sand filtration Membrane bioreactor Reverse osmosis Ozone treatment Chemical coagulation Activated carbon

(Asano and Levine, 1998)

Figure 4: Generalized municipal wastewater treatment scheme and points of reuse



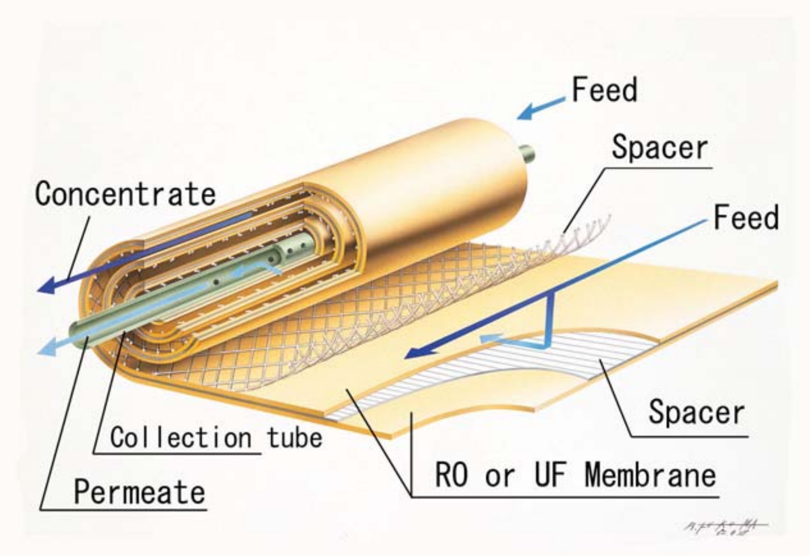
(Adapted from Asano, Smith, and Tchobanoglous, 1984; R. Tsuchihashi, 2005; Jimenez 2005)

Figure 5: Stabilization ponds as appropriate technology in developing countries
(Dandora Treatment Works, Nairobi, Kenya)

A waste stabilization pond system comprises a series of anaerobic, facultative, and maturation ponds, in which anaerobic and facultative ponds remove biological oxygen demand (BOD) and a maturation pond removes pathogens. While it needs sufficient open space, a well-designed and operated waste stabilization pond with sufficient retention time can remove BOD and pathogens to meet the World Health Organization (WHO) Guidelines for unrestricted irrigation without additional treatment (Mara, 2003). In contrast, a conventional wastewater treatment (e.g. trickling filter activated sludge) requires disinfection to meet the Guidelines (WHO, 1989).

There are also the risks of using ponds, such as a high rate of water evaporation, insufficient water infiltration to the aquifer due to bypasses, mosquitoes breeding and odours, if they are uncritically selected and also not properly designed, built and operated. Therefore the process of waste stabilization ponds, which is very common in developing countries but where an important number of the existing ponds are under-performing for such reasons, can yield better results if the proper care is taken.

Figure 6: Reverse Osmosis membrane modules



(Nitto Denko Corp., 2004)

Box 2: Membrane Filtration Technologies

Membrane filtration has increasingly been utilized as an effective measure to obtain higher quality water from wastewater and seawater. It is a process of separating materials based on their particle size and other compound properties by letting water through membranes using pressure and concentration. Membrane filtrations are classified according to the size of materials removed:

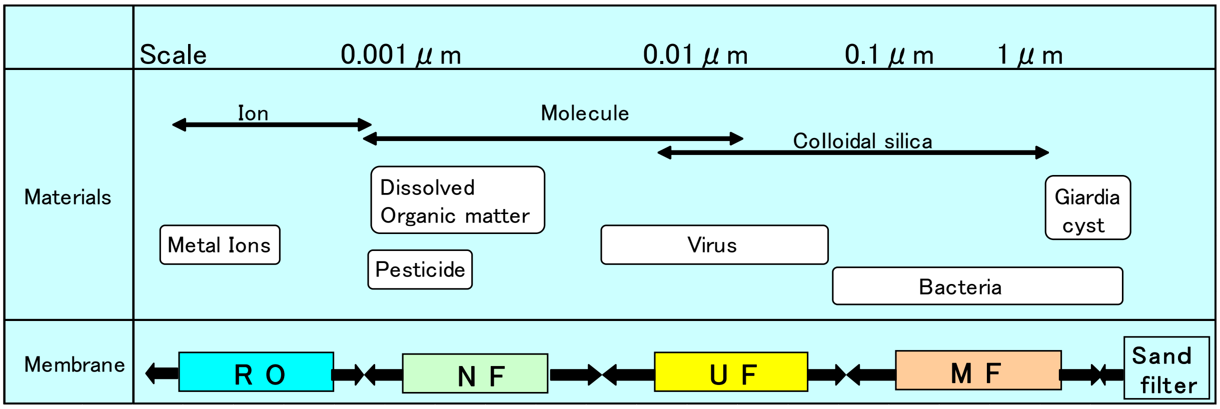
- Microfiltration (MF) membrane has pores of 0.1-1 μm in diameter. It can remove particles and is effective against bacteria, cysts, and oocysts.
- Ultrafiltration (UF) membrane has smaller pores (0.01-0.1 μm) and can remove particles and large molecules, including bacteria and viruses.
- Reverse Osmosis (RO) membrane can reject even smaller ionic solutes such as salts resulting in almost mineral-free water, based on sieving and electrochemical interaction between molecules and membrane (see Figure 5).
- Nanofiltration (NF) membrane is similar to RO and its operation pressure and salt rejection rate are low.

The widespread adoption of the membrane systems has accelerated technology advancement and also reduced the technology cost. The RO system is being used increasingly in dry regions, such as Saudi Arabia and Kuwait, where there is a high demand for seawater desalination, as well as wastewater reclamation with limited water resources. There are several membrane wastewater reclamation plants operating in Japan, the USA, and other places. UNEP is also introducing this technology for the rural communities in southern Iraq to provide safe drinking water (UNEP 2005).

The membrane system is also a promising alternative technology for a large sedimentation pond or a coagulation process using chemicals. In addition, as Figure 7 shows, filtering achieves the removal of bacteria and viruses, indicating it can contribute to minimizing health risk as well.

There are technical considerations for adopting membrane filtration. First, access to an uninterrupted power supply is necessary, as the system requires electricity to operate. Secondly, ensuring proper operation requires trained personnel and a system maintenance structure, as well as the proper disposal of brine, which is removed from the feed water.

Figure 7: Membrane process and material scale



3.2. Public Health Risk Minimization

The fundamental precondition for water reuse is that applications will not cause unacceptable public health risks. Untreated wastewater poses a serious risk of water-borne diseases, such as cholera, typhoid, dysentery, plague and helminthiasis. In the 19th century, large-scale applications of untreated wastewater for agriculture triggered epidemics of such water-borne diseases in Europe. With medical and public health advancements, links between untreated wastewater and diseases have become better understood, and measures to minimize exposure to such pathogens have been introduced.

Raw (untreated) wastewater, however, continues to be used in some regions for direct crop irrigation, despite the clear health hazards associated with it. Such practice should be discontinued and replaced with irrigation using treated water that meets public health guidelines in order to minimize the exposure of farm workers and consumers. For agricultural applications, the WHO has published guidelines for wastewater for restricted and unrestricted irrigation, which are discussed in more detail in Section 4.1. Governments have also developed more stringent criteria for agricultural applications. For non-agricultural applications, no global water quality standards exist, and various governments have issued their own standards.

Some of the key pathogens that are found in raw wastewater are summarized in Table 2. Besides these pathogens, untreated wastewater may contain chemical substances that are harmful to humans and the environment.

Table 2: Example of pathogens associated with municipal wastewater

Waterborne bacteria	Salmonella sp, Vibrio cholerae, Legionellaceae
Protozoa	Giardia lamblia, Cryptosporidium sp
Helminths	Ascaris, Toxocara, Taenia (tapeworm), Ancylostoma (hookworm)
Viruses	Hepatitis A virus, Rotaviruses, Enteroviruses

While wastewater reuse has substantial merits, a trade-off between the benefits and potential health risks of applications should be evaluated carefully. These risks can be minimized by proper treatment, disinfection, and controlled use of reclaimed water. If adequate measures to minimize risk cannot be implemented consistently, wastewater reuse should not be adopted. Proper reuse of wastewater should be encouraged also, because in some places it allows the production of crops that can be exported to other countries that have strict regulations on health risks.

Wastewater reuse has been practised for various purposes in many areas of the world. In most cases, disinfection is an essential step prior to wastewater reuse in order to minimize environmental and health risks. The purpose of disinfection is to kill or inactivate pathogenic microorganisms, viruses and parasites from treated water. Commonly, disinfection is carried out using strong oxidizers such as chlorine, ozone and bromine, but they do not inactivate helminth eggs.

Chlorine is the most common chemical widely used for disinfection since it is relatively inexpensive and can also be produced easily as a by-product of other industrial processes, such as caustic soda production. Chlorine must be injected in the appropriate dosage and for the appropriate contact time, depending on the targeted water quality and microorganisms. The effectiveness of chlorine is influenced by the presence of suspended solids, organic matter and ammonium in water. Suspended solids act as a shield for microorganisms from chlorine. In wastewater reuse, chlorine can act not only to secure the safety of recycled water but also to control biological growth such as slime formation in water distribution pipes. Chlorine residuals that remain in wastewater can prolong disinfection even after initial treatment. On the other hand, the residual chlorine may have negative effects on some applications of reuse, such as crop irrigation, as well as the aquatic environment. The injection of reducing agents such as sulphur dioxide or carbon absorption can be used for dechlorination (US EPA, 1999a; 2000). However, the dechlorination process could be costly and might increase the cost of wastewater treatment so much as to make it unaffordable for agricultural purposes, both in developing and developed countries.

Ultraviolet (UV) radiation has been recognized as one of the viable alternatives for disinfection. UV radiation is a physical disinfection. It penetrates the cell wall of a microorganism in wastewater and destroys the cell's ability to reproduce. It does not produce by-products such as Trihalomethanes and it leaves no residual effect. The effectiveness of disinfection depends on some factors including the intensity of UV radiation and the amount of exposure time (US EPA, 1999c).

Ozone is also used for disinfection. It is a strong oxidizer, and is more effective than chlorine in destroying viruses and bacteria. However, an ozone generator is relatively expensive and is not readily available in many developing countries. The effectiveness of ozone disinfection varies according to the contact time, the concentration of ozone, and the susceptibility of target organisms (US EPA, 1999b).

In addition, coagulation with high-alkaline chemicals, such as lime, can show disinfection effects, even though treated wastewater needs to be neutralized before discharge. As described in Box 2, membrane filtration also has a function of disinfection by removing bacteria and viruses.

In order for any disinfectant to be effective, it is important that wastewater is adequately treated prior to disinfection. For example, coagulation, sedimentation or sand filtration are common treatment methods prior to disinfection. While these treatments remove suspended solids, they can also remove protozoan cysts and bacteria to a significant degree. Highly treated water will maximize the effectiveness of the following disinfection process, and minimize generation of by-products in chlorine disinfection. Based on the evaluation of advantages and disadvantages, the most appropriate technology may be selected for effective disinfection.

The removal of helminth eggs is only a concern in developing countries. Helminth ova possess a shell that consists of three basic layers secreted by the egg itself: a lipoidal inner layer, a chitinous middle layer, and outer proteinic layer. All these layers give high resistance to eggs under several environmental conditions. Helminth eggs of concern in wastewater used to irrigate have a size between 20-80 µm, a relative density of 1.06-1.15 and are very sticky. All these three properties determine the helminth ova's behaviour during treatment (Jimenez, 2005). First, it is very difficult to inactivate them, unless temperature is risen above 40 ^{o}C or moisture is reduced to less than 5%, conditions that are not often achieved in wastewater treatment but are common in sludge treatment. Thus, in wastewater it is not common to inactivate helminth ova but to remove them. This is done by processes that remove particles through sedimentation (in stabilization ponds, or coagulation flocculation) or through filtration. Actually, there are correlations between the helminth ova content and the (Chavez *et al*., 2004). Helminth ova removal from different processes is shown on Table 3.

Table 3: Log unit reduction or inactivation of excreted pathogens achieved by selected wastewater treatment processes

Treatment process	Helminth ova/eggs removal
Waste Stabilization ponds	Excellent
Waste storage and treatment reservoirs	Good
Constructed wetlands	Good
Primary sedimentation	Medium
Advanced Primary treatment	Excellent
Anaerobic up flow sludge blanket	Medium
Activated sludge + secondary sedimentation	Good
Trickling filter + secondary sedimentation	Good
Aerated lagoon or oxidation ditch + settling pond	Excellent
Tertiary coagulation flocculation	Excellent
High rate or slow rate sand filtration	Excellent

FROM: El-Gohary *et al.* (1993); Feachem *et al.* (1983); Jiménez (2003, 2005); Jiménez *et al.* (2001), Landa *et al.* (1997); Lazarova *et al.* (2000); Mara (2003); Rivera (1995); Rose *et al.* (1996); Schwartzbrod *et al.* (1989); Strauss (1996); von Sperling and Chernicharo (2005).

Box 3: Wastewater reuse in dry regions, including potable use (Namibia)

Namibia, located in south-western Africa, has been suffering from severe water scarcity due to a prolonged drought. In 1968, Namibia became the first country in the world that introduced reclaimed water to supplement the source of potable water. Despite problems of various concerns over health risk and public perception, this project was launched and ever since has produced water for urban residents. Since the treatment cost for reclamation was higher than that of the existing water supply system, the reclamation plant has been operated on an intermittent basis to supplement the main supplies. The average production volume of reclaimed water depends significantly on the rainfall level per year. The reclaimed water can make up a small percentage of the blended water although this proportion is increased to a higher percentage during a period of drought.

To ensure high quality of water, industrial wastewater was separated from domestic wastewater and facilities for reclamation have been developed and improved. All of the system was reviewed in 1995 to expand the capacity from the previous 4,800m^3/day to 21,000m^3/day, the maximum attainable. This system consists of treating sewage after a secondary biological treatment with various technologies such as coagulation and flocculation, dissolved air flotation clarifier, sand filtration, ozonation, activated carbon treatment and chlorine disinfection, which can provide multiple barriers against pathogens (Haarhoff *et al.* 1996).

4. Wastewater Reuse Applications

As shown in Table 4, wastewater reuse may be applied in agriculture, industry, groundwater recharge, and urban usage, including landscape irrigation and fire protection. Wastewater reuse can be adopted to meet the water demand in different fields and contribute to the conservation of freshwater resources.

Table 4: Categories of wastewater reuse

Category of reuse	Examples of applications
• Urban use	
Unrestricted	Landscape irrigation of parks, playgrounds, school yards, golf courses, cemeteries, residential, green belts, snow melting
Restricted	Irrigation of areas with infrequent and controlled access
Other	Fire protection, disaster preparedness, construction
• Agricultural	
Food crops	Irrigation for crops grown for human consumption
Non-food crops and crops consumed after processing	Irrigation for fodder, fibre, flowers, seed crops, pastures, commercial nurseries, sod farms
• Recreational use	
Unrestricted	No limitation on body contact: lakes and ponds used for swimming, snowmaking
Restricted	Fishing, boating, and other non-contact recreational activities
• Environmental enhancement	Artificial wetlands creation, natural wetland enhancement, stream flow
• Groundwater recharge	Groundwater replenishment for potable water, salt water intrusion control, subsidence control
• Industrial reuse	Cooling system water, process water, boiler feed water, toilets, laundry, construction wash-down water, air conditioning
• Residential use	Cleaning, laundry, toilet, air conditioning
• Potable reuse	Blending with municipal water supply, pipe to pipe supply

(Asano and Levine, 1998)

Practices of wastewater reuse vary among countries, as target applications and technology options differ significantly depending on socio-economic circumstances, industrial structure, climate, culture, religious preference, as well as policy readiness. Various application areas and examples for wastewater reuse are introduced in the following sections.

4-1. Wastewater Reuse for Agriculture

Agricultural irrigation is crucial for improving the quality and quantity of production. Worldwide, agriculture is the largest user of water. Agriculture receives 67% of total water withdrawal and accounts for 86% of consumption in 2000 (UNESCO, 2000). In Africa and Asia, an estimated 85 to 90% of all the freshwater use is for agriculture. By 2025, agriculture is expected to increase its water requirements by 1.2 times (Shiklomanov, 1999). Large-scale irrigation projects have accelerated the disappearance of water bodies, such as the Aral Sea, the Iraqi Marshlands, and Lake Chad in West Africa. Thus, more efficient use of agricultural water through wastewater reuse is essential for sustainable water management.

Benefits:

The ancient practice of applying wastewater containing human excreta to the land has maintained soil fertility in many countries of Eastern Asia and the Western Pacific for over 4,000 years, and remains the only agricultural use option in areas without sewerage facilities (WHO, 1989). Potential benefits of wastewater reuse for agriculture include the following:

- Conservation and more rational allocation of freshwater resources, particularly in areas under water stress;
- Avoidance of surface water pollution;
- Reduced requirements for artificial fertilizers and associated reduction in industrial discharge and energy expenditure;
- Soil conservation through humus build-up and prevention of land erosion;
- Contribution to better nutrition and food security for many households (WHO, 1989).

Box 4: Agricultural applications of reclaimed water (Tunisia)

Tunisia is one of the very few countries that have elaborated and implemented a national policy for wastewater reuse. The first water reuse regulation was issued in 1989. The reclaimed water has been used mainly for irrigation because some underground water can no longer be used due to an overdraft and saline water intrusion, and wastewater use is now an integral part of the national water resources strategy. Treated water is used for the cultivation of citrus, olives, fodder and cotton as well as for golf courses and hotel gardens. In the wet season except agriculture period, groundwater recharge is carried out. Half of the population of Tunisia lives in the coastal area, and most sewage treatment facilities are located along the coastline to treat wastewater from domestic, tourism, and industrial sources.

In 1996, 49 treatment plants were in operation and together produced 116 million m^3 of treated wastewater. The number of treatment plants was increased to 59 by 2001 and is expected to reach 135 by 2006. The volume of reclaimed wastewater produced was also increased to 156 million m^3 by 2001 and will expand to 200 million m^3 by 2006, which will correspond to 10% of all the available groundwater. With regard to regional distribution, urban and peri-urban use of treated wastewater in the capital, Tunis, constituted about 32% of the total treated wastewater quantities used in the country in 2000 (Bahri and Brissaud, 1996; Chenini *et al.*, 2003).

Potential concerns:

While wastewater reuse for agriculture has many benefits, it should be carried out using good management practices to reduce negative human health impacts. The WHO initially published Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture in 1989 and later revised it as “Guidelines for the safe use of wastewater, excreta and grey water, volume 2: wastewater use in agriculture” (WHO 2006). The Guidelines, presented in Table 5, include recommendations for crops to be consumed uncooked, and crops to be cooked or used as feed, as well as for parks and localized irrigation. The Guidelines are set to minimize exposure to workers, crop handlers, field workers and consumers, and recommend treatment options to meet the guideline values (WHO, 2006). The Guidelines are focused on health-based targets and provide procedures to calculate the risks and related guideline values for wastewater reuse in agriculture.

Table 5: WHO guidelines for using treated wastewater in agriculture

Type of irrigation	Health-based target for helminth eggs	Required pathogen reduction by treatment (log units)	Verification monitoring level (*E. coli* per 100 ml)	Notes
Unrestricted:	≤1 per litre (arithmetic mean)[b,c]	4	$\le 10^3$	Root crops.
		3	$\le 10^4$	Leaf crops.
	High-growing crops:[d,e] No recommendation	2	$\le 10^5$	Drip irrigation of high-growing crops.
	Low-growing crops:[d] ≤1 per litre (arithmetic mean)	4	$\le 10^3$	Drip irrigation of low-growing crops.
	E	6 or 7	$\le 10^1$ or $\le 10^0$	Verification level depends on the requirements of the local regulatory agency.[a]
Restricted:	F	3	$\le 10^4$	Labour-intensive agriculture (protective of adults and children under 15).
	G	2	$\le 10^5$	Highly mechanized agriculture.
	H	0.5	$\le 10^6$	Pathogen removal in a septic tank.

[a] For example, for secondary treatment, filtration and disinfection: BOD$_5$, <10 mg/l; turbidity, <2 NTU; Cl$_2$ residual, 1 mg/l; pH, 6−9; and faecal coliforms, not detectable in 100 ml (State of California, 2001).

[b] When children under 15 are exposed additional health-protection measures should be used (see Sections 4.2.1 and 4.2.2 for details).

[c] A rolling arithmetic mean should be determined throughout the irrigation season. The mean value of ≤1 egg per litre should be obtained for at least 95 per cent of samples in order to allow for the occasional high-value sample (i.e. with >10 eggs per litre). With some wastewater treatment processes (e.g. waste stabilization ponds) the hydraulic retention time can be used as a surrogate to assure compliance with ≤1 egg per litre, as explained in Section 5.7.1 and Box 5.1.

[d] See Section 4.2.3.

[e] No crops to be picked up from the soil.

(Based on WHO, 2006)

In additions to ponds, the wastewater can be treated through reservoirs (Juanico and Shelef 1991), wetlands, physicochemical process, SAT (soil aquifer treatment), and other methods. However, the practice of stabilization ponds is more common in many developing countries.

The Guidelines state that ‘local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly’ (WHO, 1989). The microbiological quality guidelines have been used as the basis for standard setting in several countries and regional administrations. In other situations, the quality guideline levels have been adopted with specifications of additional management practices and restrictions. Standard setting in other countries has been influenced by the WHO guidelines, but often with some modification of the microbiological guidelines before adoption as standards (WHO, 2001).

Wastewater intended for reuse should be treated adequately and monitored to ensure that it is suitable for the projected applications. If wastewater streams come from industrial sources and urban run-off, toxic chemicals, salts, or heavy metals in the wastewater may restrict agricultural reuse. Such materials may change soil properties, interfere with crop growth, and cause bioaccumulation of toxic materials in food crops. While separating household wastewater and run-off from industrial effluent is preferable, this may not be feasible. Thus proper treatment and monitoring should be practised.

Wastewater reuse for agriculture needs to be planned with attention to target crops and existing water delivery methods. Nutrients in reclaimed water that are important to agriculture include nitrogen, potassium, zinc, boron and sulphur (Asano and Levine, 1998). However, excess nitrogen may cause overgrowth, delayed maturity, and poor quality of crops. While boron is an essential element for plant growth, excess boron becomes toxic (FAO, 1985). Furthermore, proper care should be taken to control the saline problems cause by wastewater reuse (Weber and Juanico 2004).

Box 5: Wastewater Reuse for Rice Irrigation (Kumamoto, Japan)

Experiments on wastewater reuse applications for rice cultivation were carried out in the City of Kumamoto, Japan. The objective of the research was to evaluate an optimal ratio of river water/wastewater and fertilizer applications for rice cultivation. The combined nitrogen content of wastewater and fertilizer is crucial for successful rice cultivation, as excessive fertilization is known to cause low pest resistance, ripening lesion, lodging (i.e. falling down) of plants due to excessive growing, as well as poor crop quality. The effluent from a treatment plant was introduced to the rice field to cultivate rice under different conditions.

The rice crop grown with treated wastewater and regular fertilizer applications resulted in crop lodging, probably from excess nitrogen. The rice crop grown with treated wastewater with no additional fertilizer was found to have sufficient growth and harvest. However, using wastewater as the only source of nitrogen was found to be inadequate, due to an eventual decline in soil fertility and uneven distributions of nitrogen caused by asymmetrical water flow and stagnation in rice fields. To address these issues, treated wastewater was blended with an equal volume of freshwater, with additional fertilizer. The resulting rice crop was satisfactory when 50 to 70% less basal fertilizer was applied to the crop. The experiments demonstrated that successful rice cultivation could be achieved with treated wastewater applications, thereby reducing river water volume as well as fertilizer applications (Kumamoto Municipal Government, 1983).

Figure 8: Rice farming with treated wastewater

(Kumamoto Municipal Government, 1983)

4-2. Wastewater Reuse for Industry

Industrial water use accounts for approximately 20% of global freshwater withdrawals. Power generation constitutes a large share of this water usage, with up to 70% of total industrial water used for hydropower, nuclear, and thermal power generation, and 30 to 40% used for other, non-power generation processes. Industrial water reuse has the potential for significant applications, as industrial water demand is expected to increase by 1.5 times by 2025 (Shiklomanov, 1999).

Benefits:

Industrial water reuse has the following specific benefits, in addition to the general environmental benefits discussed in earlier sections:

- Potential reduction in production costs from the recovery of raw materials in the wastewater and reduced water usage;
- Heat recovery;
- Potential reduction in costs associated with wastewater treatment and discharge.

Water reuse and recycling for industrial applications have many potential applications, ranging from simple housekeeping options to advanced technology implementation. Wastewater reuse for industry can be implemented through the reuse of municipal wastewater in industrial processes, internal recycling and cascading use of industrial process water, and non-industrial reuse of industrial plant effluent, as summarized below.

Table 6: Types and examples of industrial water reuse

Types of water reuse	Examples
Reuse of municipal wastewater	Cooling tower make-up water Once-through cooling Process applications
Internal recycling and cascading use of process water	Cooling tower make-up water Once-through cooling and its reuse Laundry reuse (water, heat, and detergent recovery) Reuse of rinse water Cleaning of premises
Non-industrial use of effluent	Heating water for pools and spas Agricultural applications

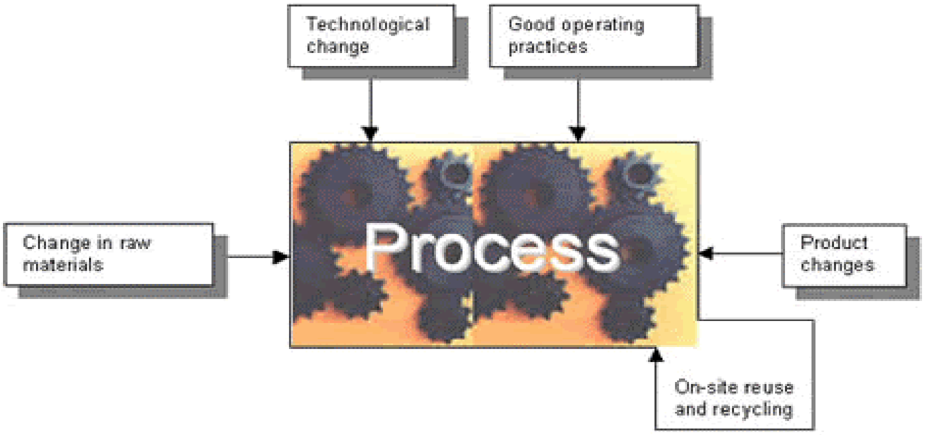
(Asano and Levine, 1998)

In particular, cooling systems may consume 20 to 50% of a facility's water usage, and also present a significant potential for reuse. Cooling systems remove heat from air-conditioning systems, power stations, oil refining, and other various industrial processes. Many facilities operate cooling towers, in which warm water is circulated and cooled continuously. Water, commonly referred to as make-up water, is added to replace evaporative loss and pollutant discharge. Some facilities also use once-through water to cool heat-generating equipment and discharge water after heat transfer. In both systems, adequately treated wastewater can be used as cooling water or make-up water, with or without mixing with tap water. Once-through cooling systems also present additional opportunities for water reuse, such as connection to a recirculating cooling system to reuse water, and cascading use of cooling water in other applications.

Water quality requirements for industry reuse differ according to application types. Obtaining the necessary quality may require secondary treatment, tertiary treatment, or specific methods to meet individual needs. For example, rinsing and cleaning for semiconductor wafer manufacturing requires ultra-pure water, which can be supplied from municipal wastewater that has undergone reverse osmosis and ultraviolet treatment (PUB, 2003a). Almost all well-managed cooling towers use a water treatment scheme such as sulphuric acid treatment, side stream filtration and ozonation to inhibit corrosion and scaling (NCDENR, 1998). The cascading of process water of non-potable quality without treatment may be sufficient for general office cleaning and rinse water. In the steel industry, the effluent from wet scrubbers of blast furnaces can be recycled after treatment to remove iron oxide, silica, carbon lime and magnesium by coagulation or high-gradient magnetic separation. In the pulp and paper industry, water reuse is an important strategy for recovering fibres, chemicals and heat from process effluent, as well as for reducing freshwater consumption and wastewater production (Bedard *et al*, 2000). Wastewater treatment, with respect to the industrial use, depends on the effluent, i.e. if teh effluent is coming from somewhere other than the industry that is reusing the it, or if the industry is recycling its effluent for reusing within the same industry.

Cleaner production (CP) assessment is an analytical method of particular relevance for evaluating options for industrial water reuse. CP has been promoted by UNEP since the late 1980s, and is defined as the ‘continuous application of an integrated, preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment’. CP can be implemented to improve industrial processes, product performance and various services provided in society. The CP assessment methodology is used for systematic identification and evaluation of CP opportunities, thereby facilitating their implementation. Figure 9 shows five areas of CP opportunities to be identified through CP assessment: changes in raw materials, technological change, good operating practices, product changes, and on-site reuse and recycling (UNEP, 2004). Water reuse and recycling in the process can be achieved by implementing good operating practices, changing to technologies that require less process water, and on-site reuse and recycling. In addition, CP assessment can be applied to reformulate industrial products to use less water. Additional information on the assessment methodology and examples of applications can be obtained from UNEP.

Figure 9: Opportunities for Cleaner Production Applications



Potential concerns:

Potential concerns for industrial water reuse include scaling, corrosion, biological growth, and fouling, which may impact industrial process integrity and efficacy, as well as product quality. These concerns are often interrelated, and may be addressed by the options summarized in Table 7.

Salt concentrations can be affected by various factors, including process operating temperatures, sources of wastewater, and areas from which wastewater is collected (e.g. coastal areas may have higher concentrations).

Table 7: Industrial water reuse: concerns, causes, and treatment options

Concerns	Causes	Treatment options
Scaling	inorganic compounds, salts	scaling inhibitor, carbon adsorption, filtration, ion exchange, blowdown rate control
Corrosion	dissolved and suspended solids pH imbalance	corrosion inhibitor, reverse osmosis
Biological growth	residual organics, ammonia, phosphorous	biocides, dispersants, filtration
Fouling	microbial growth, phosphates, dissolved and suspended solids	control of scaling, corrosion, microbial growth, filtration chemical and physical dispersants

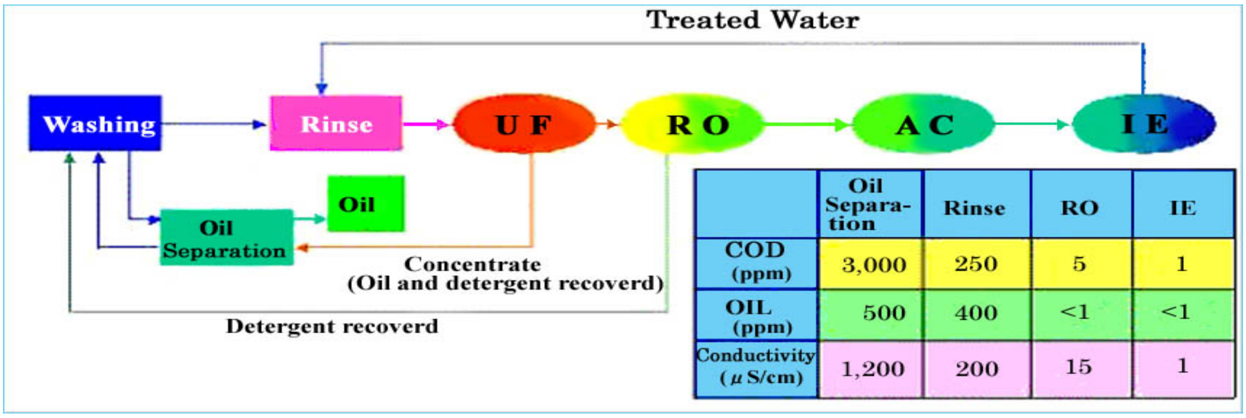
(Asano and Levine, 1998)

Box 6: Recycling of parts wash and rinse water

A Japanese chemical engineering company refined a cleaning process for parts washing, coupled with membrane technologies to recycle rinse water to minimize process cost. The need for wastewater treatment arose with the conversion to non-chlorofluorocarbons (CFC) based detergents in connection with the phase-out of ozone-depleting substances under the Montreal Protocol in the mid 1990s. The automated process utilizes various membrane technologies, as shown in the flow diagram below. For example, oil and dirt are separated from rinse water by an ultra filtration membrane. The detergent is then removed from the water by reverse osmosis, and reused in the washing process. The ion-exchange resin can be used to treat water, to be recycled as rinse water as needed.

The environmental and economic benefits of this process are significant. For example, the volume of water usage and discharge is 0.5% of the previous process. The running cost is one tenth of an alternative adsorption treatment that uses activated carbon and ion-exchange resin. The maintenance requirement is once a month or less. The key to successful implementation is the selection of appropriate types of membranes and their combinations, management of temperature and flow rate, and a suitable cleaning agent used in appropriate amounts (Asahi Engineering, 1999).

Figure 10: Flow diagram of washing process
(UF: Ultra filtration, RO: Reverse Osmosis, AC: Activated Carbon, IE: Ion-Exchange resin)



	Oil Separa-tion	Rinse	RO	IE
COD (ppm)	3,000	250	5	1
OIL (ppm)	500	400	<1	<1
Conductivity (μS/cm)	1,200	200	15	1

Occupational health concerns include exposure to aerosols that contain toxic volatile organic compounds and bacteria, such as Legionella, which causes Legionnaire's disease.

Some of the important and practical aspects for industrial wastewater reuse are:

- Usually, the industry itself decides the needs and extent of wastewater treatment for its reuse. The government does not decide how to reuse/recycle water in the industry, it only motivates industry through incentives such as the price of water or subsidies for the technology.
- Most industries select types of wastewater treatment processes that have a great level of reliability. This differs from wastewater reuse projects in municipalities, where the cost is a crucial factor to decide both the type of reuse and the type of treatment.

4-3. Urban Applications

In urban areas, the potential for introducing wastewater reuse is quite high, and reuse options may play a significant role in controlling water consumption and reducing its pollutant load on the environment. A large percentage of water used for urban activities does not need quality as high as that of drinking water. Dual distribution systems (one for drinking water and the other for reclaimed water) have been utilized widely in various countries, especially in highly concentrated cities of the developed countries. This system makes treated wastewater usable for various urban activities as an alternative water source in the area, and contributes to the conservation of limited water resources. In most cases, secondarily treated domestic wastewater followed by sand filtration and disinfection is used for non-potable purposes, such as toilet flushing in business or commercial premises, car washing, garden watering, park or other open space planting, and firefighting (Japan Sewage Works Association, 2005).

Benefits:

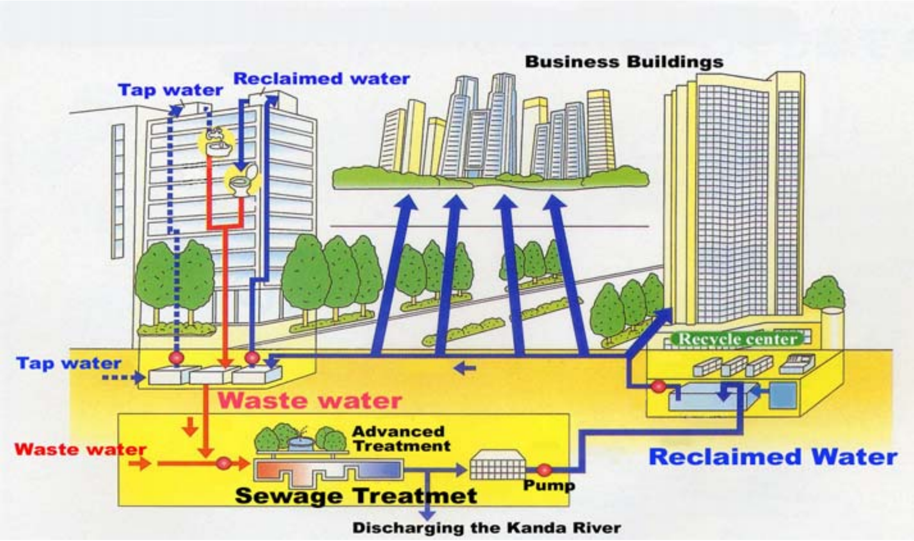
The benefits of wastewater reuse for urban applications include the following:

- High volume of wastewater generation, and a large number of potential applications and volume for water reuse, which may benefit from the economy of scale (as shown in Box 1 in Section 1);
- Reduction in the wastewater volume to be treated by municipal wastewater treatment plants, which are over-extended and in need of expansion in many developing countries' mega-cities.

Tokyo is one of the leading cities that are successfully implementing wastewater reuse, such as dual distribution systems and stream augmentation. In a water reuse project in the Shinjuku area of Tokyo, a dual distribution system has been adopted and sand-filtered water from the Ochiai Municipal Wastewater Treatment Plant is chlorinated and used as toilet-flushing water in 25 high-rise business premises and for stream augmentation, as illustrated in Figure 11. The system, which has been successfully operated since 1984, is supplying treated wastewater up to a maximum 8,000 m^3/day (Tokyo Metropolitan Government, 2001).

There is also a small-scale on-site system where the grey water is recycled as an in-building water resource, with a dual distribution system. Reclaimed water can be used for toilet flushing, car washing, stream augmentation or landscape purposes.

Figure 11: Scheme of area recycling system in Shinjuku, Tokyo, Japan



(Tokyo Metropolitan Government)

Box 7: Utilization of thermal energy of wastewater (Japan)

One of the important characteristics of water is its ability to retain heat energy, and water can warm or cool other objects when it comes into contact with them. Japan implements a unique approach by utilizing the nature of water as a heat medium. The Japanese climate has a large variation in temperature, from below zero in winter to nearly 40℃ in summer, but the temperature of effluents from sewage treatment works stays relatively constant throughout the year from 12℃ to 30℃. The temperature of wastewater is therefore lower in summer and higher in winter than the ambient temperature. Based on this feature, a heating and cooling system through heat exchange with wastewater has been developed, as shown in Figures 12a and 12b, which achieved energy savings of 20-30% (Osaka Municipal Government, 2003).

Another example of utilizing thermal energy from wastewater has been implemented in the City of Sapporo, where the average annual snowfall is 4.7 metres. Snow removal from roads and road shoulders is very important to ensure the safety of drivers and pedestrians, particularly in downtown areas. Removed snow is transported and dumped on unused land by trucks. In Sapporo, snow melting by using effluent from sewage treatment works is implemented as one of the alternative approaches. The temperature of effluent in winter reaches approximately 13℃ (Shibuya, 1999), and 600,000 to 700,000m^3 of snow is melted per year by snow flowing conduits and snow melting tanks. (Sapporo Municipal Government)

Figure 12a: Flow diagram of heat pump for heating

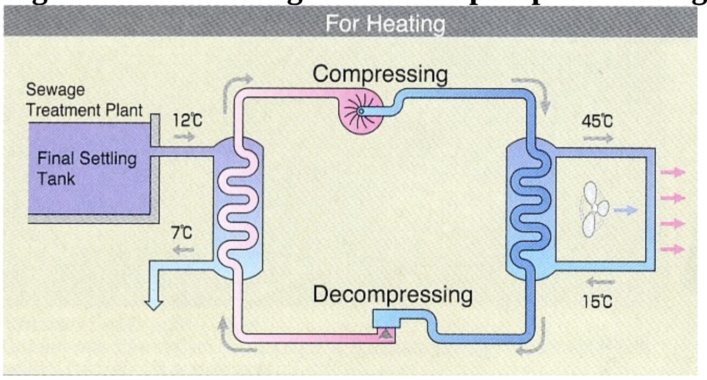
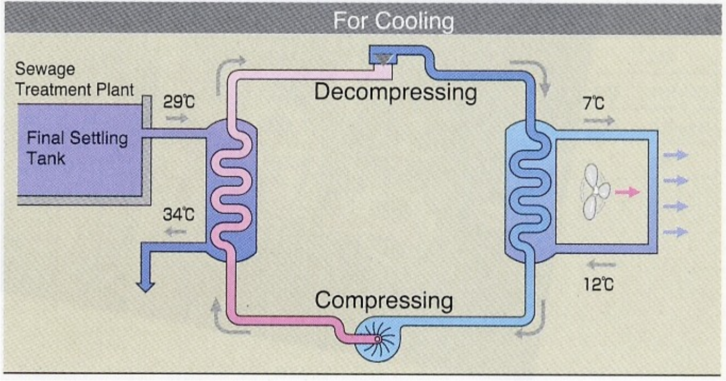


Figure 12b: Flow diagram of heat pump for cooling



(Osaka Municipal Government, 2003)

Figure 13: Kitagou snow flowing conduit tank

Figure 14: Shinkawa snow melting

Potential concerns:

One of the key concerns for wastewater reuse in urban applications is the protection of public health, as urban reuse has the potential to expose a large number of people to disease-causing microorganisms. Care should be taken to avoid contamination of drinking water by misconnection (cross connection) between potable water pipes and reclaimed water pipes, and also to disinfect reclaimed wastewater properly.

In addition, the following problems have also been identified in wastewater reuse for toilet flushing:

- Corrosion of pipe;
- Blockage of pipe and strainer;
- Biofilm (slime) formation in reservoir tank due to reduction of residual chlorine in reclaimed water (Fukuoka Municipal Government, 1999).

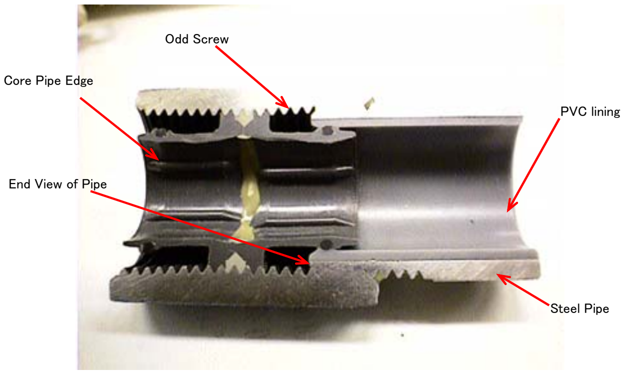
These problems, some of which are similar to concerns associated with industrial reuse, tend to occur because reclaimed water contains more salts and organics than drinking water. Pipe corrosion is seen, particularly at the joint part where galvanic corrosion occurs by an electrochemical process (Figure 16). In the end, it may result in blockage of a pipe or clogging of a strainer due to formation of iron oxide scale (e.g. Fe_2O_3) (Figure 17). Corrosion mitigation can be taken by several methods, such as application of protective coating, employing corrosion-resistant materials or adoption of screw-type fitting with inner sleeve shown in Figure 18.

Furthermore, an insufficient amount of residual chlorine in reclaimed water allows bacteria growth and biofilm formation in the reservoir tank. The reduction of residual chlorine occurs as the consumed chlorine reacts with salts and organics in reclaimed water. Therefore, the chlorine injection rate must be monitored carefully and should be kept at an appropriate level.

Figure 16: Corrosion of pipe joint

Figure 17: Blockage of pipe joint

Figure 18: Screw-type fitting with inner sleeve



4-4. Wastewater Reuse for Environmental Water Enhancement

Another area where wastewater reuse is being applied is in environmental enhancement, such as the augmentation of natural/artificial streams, fountains, and ponds. In metropolitan areas, urbanization, and the resulting increase in surface area coverage by buildings and pavements, has resulted in decreased water retention capacity. In addition, storm water is rapidly drained and discharged to a river and/or sea to prevent flooding, often leaving little water for environmental water usage.

Benefits:

The key benefit for environmental enhancement is the increased availability and quality of water sources, which provide public benefits such as aesthetic enjoyment and support ecosystem recovery. The restoration of streams or ponds with reclaimed water has been practised in many cities, contributing to the revival of aquatic life, such as fish, insects, crawfish and shellfish, and creating comfortable urban spaces and scenery. The recovery of water channels has great significance for creating 'ecological corridors' in urban areas.

As shown in Figure 19, the landscape of Osaka Castle in Japan has been beautifully restored with the moat, which is filled with reclaimed water. In this case, 5,000m^3/day of tertiary treated wastewater, by sand filtration and chlorine disinfection, is supplied from the sewage treatment works (Osaka Municipal Government, 2003).

Figure 19: Example of reclaimed water use: Moat of the Osaka Castle (Osaka, Japan)

Box 8: Reviving of flora and fauna by restoration of river flow

The Meguro River, which flows through a residential area in Tokyo, had been abandoned by residents due to the decreasing flow of water and pollution with an unpleasant odour. To solve this issue, the Tokyo Metropolitan Government released water treated with UV radiation into the river. With the drastic improvement in water volume and quality, various living species have returned to the river. As shown in Table 8, after the introduction of highly treated water, many insect and small animal populations have been re-established, and fish such as Japanese trout, striped mullets and gobies also returned to the river. Biodiversity and environmental amenities have thus been restored effectively with wastewater reuse.

Figure 20: Meguro River (Before)

Figure 21: Meguro River (After)

Table 8: Bio-indicators of before-and-after of reclaimed wastewater introduction

	before		after	
	Aug-94	Feb-95	Sep-95	Feb-96
Flatworm				3
River limpet				2
Pouch snail			12	2
Sludgeworms	2	26	296	2920
Leech			4	
Mayfly			45	1
Midgefly		26	2136	8
Black gnut			1	
Mothfly		14		2
Mosquito	1			
Total	3	66	2494	2938

(Tokyo Metropolitan Government, 2001)

Box 9: Artificial snow-making: wastewater reuse in alpine area (Australia)

Mount Buller Alpine Resort is located 200km north east of Melbourne, Australia. As one of Australia’s most popular snow sports destinations, the resort is most active during the winter season. Approximately 70% of the entire annual effluent is produced in winter. A pilot study for making snow from treated water has been in operation since 2000. As the ultra filtration system is used to remove pathogens in reclaimed water, the treated water quality has reached the US EPA’s standards for unrestricted recreational use. The installation of a full-scale plant for artificial snow-making will bring sustainable benefits to the resort in the future (Tonkovic *et al.*, 2002).

Potential concerns:

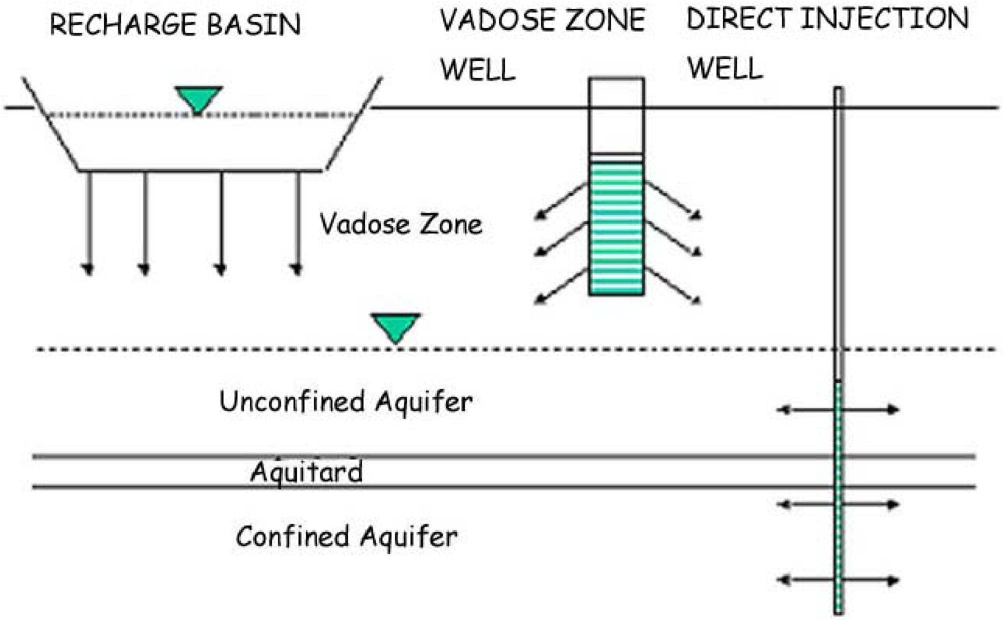
As with urban applications, public health concerns must be adequately addressed for environmental enhancement applications in order to avoid negative human health impacts. When treated wastewater is used for water augmentation in a water channel, proper water quality guidelines must be considered on the assumption that there will be human contact with the reused water, and sufficient disinfection must be carried out. Disinfection options may include chlorination or UV irradiation. In addition to the public health considerations, the removal of nutrients including nitrogen or phosphorus should be implemented since they may cause algal blooming, which spoils the appearance of streams, lakes and reservoirs.

Care must also be taken to facilitate ecosystem recovery. In the case of the restoration of aquatic flora and fauna in a stream, ozone or UV disinfection is more preferable than chlorination, since it generates fewer disinfection by-products with smaller residual effects to the flora and fauna.

4-5. Groundwater Recharge

A groundwater aquifer is important for freshwater storage and water transmission. It provides water resources that can be withdrawn for various purposes. Three common methods for aquifer recharge are illustrated in Figure 22.

Figure 22: Method for aquifer recharge



(Fox, 1999)

The use of a recharge basin requires a wide area with permeable soil, an unconfined aquifer with transmissivity, and an unsaturated (or vadose) zone without restricting layers. With this system, the vadose zone and aquifer work as natural filters and remove suspended solids, organic substances, bacteria, viruses and other microorganisms. In addition, reduction of nitrogen, phosphorus and heavy metals can also be achieved. This process is called soil aquifer treatment.

Direct injection of treated wastewater can access deeper aquifers through an injection well. Direct injection is utilized when aquifers are deep or separated from the surface by an impermeable layer. This method requires less land than the recharge basin methods, but it costs more to construct and maintain the injection well. A well wall is susceptible to clogging by suspended solids, biological activity or chemical impurities. In this method, the soil aquifer treatment effect is not observed. The method requires advanced pretreatment of applied water, including sufficient disinfection. Without treatment, the injected wastewater may pollute the aquifer, causing health concerns.

Vadose zone injection is an emerging technology that provides some of the advantages of both recharge basins and direct injection wells. This method is used when a permeable layer is not available at a shallow depth, and a recharge well has a relatively large diameter (Fox, 1999).

Benefits:

Groundwater recharge has been used to prevent the decline in groundwater level and to preserve the groundwater resource for future use. Compared to conventional surface water storage, aquifer recharge has many advantages, such as negligible evaporation, little secondary contamination by animals, and no algal blooming. It is also less costly because no pipeline construction is required. Furthermore, it protects groundwater from saltwater intrusion by barrier formation in coastal regions, and controls or prevents land subsidence.

One of the successful examples is shown in Figure 23. For over 35 years, in the Montebello Forebay Ground Water Recharge Project, recycled water has been applied to the Rio Hondo spreading grounds to recharge a potable ground water aquifer in south-central Los Angeles County in California (US EPA, 1998).

Figure 23: Groundwater recharge site (Los Angeles, California, U.S.A)

Potential concerns:

In any of the methods described above, groundwater recharge with reclaimed water presents various health concerns when water is extracted from a collection well and used for irrigation or other purposes. As the performance of soil aquifer treatment is uneven depending on hydraulic loading, each project should be carefully designed and adequate attention paid to reducing pathogens (Fox, 1999).

5. Key Factors for Establishing Initiatives

Launching a wastewater reuse initiative requires careful consideration of the local conditions, and must be based on the sufficient and well-integrated analysis of technology options, financial implications, health risks mitigation, and other factors. In this section, key factors for establishing wastewater reuse initiatives are described.

Planning to meet specific needs and conditions

During a planning process, the appropriateness of water and wastewater reuse applications needs to be carefully evaluated against the volume of available wastewater, degree of water scarcity, availability of existing infrastructure, and receptivity of potential users. The purpose of the application, such as irrigation, industrial use, landscape, and household use, needs to be evaluated together with the water quality requirements and associated health risk. Such evaluation is useful in identifying necessary treatment and disposal technologies, as well as operational and maintenance requirements. Public perception and receptivity also need to be analysed carefully. The public should be recognized as legitimate stakeholders, and their roles and responsibilities should be clearly defined in the planning process.

Analysing economic and financial requirements

Economic and financial analyses are also needed to identify viable solutions and to access financial assistance when necessary. While wastewater reuse programmes have many benefits and long-term cost effectiveness, they may have a high initial cost associated with additional treatment and infrastructure needs, such as additional treatment, pumps, pipes, reservoirs, and so on. Alternatives to address this impediment, such as public assistance, incentives, and preferential private sector financing, must be explored. The decision-makers and the users should be aware of the impact on water prices resulting from wastewater reuse projects.

Selecting options to minimize risk

One of the most important factors in water and wastewater reclamation projects is complying with water quality standards to minimize health risks, or establishing them if they do not exist. While the WHO guidelines for agricultural applications of wastewater are available, there are no international guidelines or criteria for other types of wastewater reuse. Therefore, guidelines and standards need to be developed by each country, with health risks as well as technical and economic feasibility being taken account. Technological options should be selected to meet such guidelines and standards and ensure the protection of human health and the environment.

Utilizing institutions and organizations

Wastewater reuse involves many stakeholder institutions, such as utilities and private users that implement the initiative, local environmental authorities for permits and enforcement, financial institutions for provision of funding, the national environmental ministry for setting national standards and supporting local authorities, and so on. Their responsibilities and roles for facilitating reuse programmes need to be identified and understood clearly. In many cases, institutions need to be supported or newly established.

Building capacity

Capacity is needed to successfully plan and implement wastewater reuse initiatives. Such capacity encompasses human resources, policy and legal frameworks, institutional and organizational management and financing, as well as public awareness and participation. The following sections explain in more detail the needs for various elements of capacity building, as well as concrete examples.

Meeting standards and guidelines

Standards and criteria for water reuse need to be complied with in order to protect human health and the environment. Applications need to be monitored to ensure that wastewater is being reused in a manner consistent with the intended applications and practice. As explained in Section 4-1, WHO has established guidelines for agricultural reuse, which can serve as a basis for countries without their own standards or guidelines. Standards and guidelines for other applications have also been established in various localities and countries, for example by the US Environmental Protection Agency (US EPA) and the State of California. They may also provide insight for other countries or localities.

Box 10: Example of water reuse regulation and criteria (California, U.S.A)

The State of California pioneered efforts to promote water reclamation, and established its first reuse regulations in 1918. Some of the earliest water reuse projects were implemented for irrigation in Arizona and California in the late 1920s. Since then, California has been revising its water reuse criteria based on research in treatment technology and information on public health protection. The US EPA developed guidelines for wastewater reuse in 1993, and many states now have their own specific guidelines for treated wastewater reuse. The California Code of Regulations includes water quality and also the required level of treatment, as summarized in Table 9 (Crook *et al*, 1996).

Table 9: Criteria for non-potable uses of recycled water in the State of California

Purposes of using recycled water	Minimum requirements for types of recycled water to be used
Use of recycled water for irrigation	
Surface irrigation of food crops; parks and playgrounds; school yards; residential landscaping; unrestricted access golf courses; other uncontrolled access irrigation areas	Disinfected tertiary recycled water (a)
Surface irrigation of food crops where the edible portion is produced above ground and not contacted by the recycled water	Disinfected secondary-2.2 recycled water (b)
Cemeteries; freeway landscaping; restricted access golf courses; Unrestricted access ornamental nursery stock and sod farms; pasture for animals producing milk for human consumption; controlled access non-edible vegetation	Disinfected secondary-23 recycled water (c)
Orchards and vineyards where the recycled water does not come into contact with the edible portion of the crop; non-food bearing trees; fodder and fibre crops; pasture for animals not producing milk for human consumption; seed crops not eaten by humans	Undisinfected secondary recycled water (d)
Use of recycled water for recreational impoundments	
Used as a source of water supply for non-restricted recreational impoundments	Disinfected tertiary recycled water
Used as a source of water supply for restricted recreational impoundments and for any publicly accessible impoundments at fish hatcheries	Disinfected secondary-2.2 recycled water
Used as a source of water supply for landscape improvements that do not utilize decorative fountains	Disinfected secondary-23 recycled water
Use of recycled water for cooling	
Used for industrial or commercial cooling or air conditioning that involves the use of a cooling tower, evaporative condenser, spraying or any other mechanism that creates a mist	Disinfected tertiary recycled water
Used for industrial or commercial cooling or air conditioning that does not involve the use of a cooling tower, evaporative condenser, spraying or any other mechanism that creates a mist	Disinfected secondary-23 recycled water
Use of recycled water for other purposes	
Flushing toilets and urinals; priming drain traps; industrial process water that may come into contact with workers; structural fire fighting; decorative fountains; commercial laundries; construction of backfill around potable water pipelines; artificial snow making for commercial outdoor use; commercial car washing	Disinfected tertiary recycled water
Industrial boiler feed; non-structural fire fighting; backfill consolidation around non-potable piping; soil compaction; mixing concrete; dust control on roads and streets; cleaning roads, sidewalks and outdoor work areas; industrial process water that will not come into contact with workers	Disinfected secondary-23 recycled water
Flushing sanitary sewers	Undisinfected secondary recycled water

(a) ‘Disinfected tertiary recycled water’ means a filtered and subsequently disinfected water that meets the following criteria. (1) The filtered wastewater has been disinfected in accordance with the manner prescribed in the code. (2) The median concentration of total coliform bacteria measured in the disinfected effluent does not exceed a most probable number (MPN) of 2.2 per millilitre utilizing the bacteriological results of the last seven days for which analyses have been completed, and the number of total coliform bacteria does not exceed an MPN of 23 per millilitre in more than one sample in any 30 day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 millilitre.

(b) ‘Disinfected secondary-2.2 recycled water’ means recycled water that has been oxidized and disinfected so that the median concentration of total coliform bacteria does not exceed an MPN of 2.2 per millilitre for the last seven days and the number of total coliform bacteria does not exceed an MPN of 23 per millilitre in more than one sample in any 30 day period.

(c) ‘Disinfected secondary-23 recycled water’ means recycled water that has been oxidized and disinfected so that the median concentration of total coliform bacteria does not exceed an MPN of 23 per millilitre for the last seven days and the number of total coliform bacteria does not exceed an MPN of 240 per millilitre in more than one sample in any 30 day period.

(d) ‘Undisinfected secondary recycled water’ means oxidized recycled water.

(State of California 2001, 2005)

6. Building Capacity for Water and Wastewater Reuse

Successful wastewater reuse projects are designed to reflect specific local conditions, such as water demand, urban growth, climate, socio-economic characteristics, and cultural preference, as well as institutional and policy frameworks. To do so effectively requires a capacity which is still limited in many developing countries. Capacity building can improve the quality of decision-making and managerial performance in the planning and implementation of programmes, and encompasses the following five elements (UNEP, 2002):

1. *Human resources:* Strengthening people's technical and managerial ability to evaluate limitations of current practice, potential benefits and requirements of wastewater reuse, and fostering their capability to implement new programmes;
2. *Policy and regulatory framework :* Helping to align or create policy and legal frameworks to facilitate wastewater reuse programmes, while ensuring protection of human health and the environment;
3. *Institutions :* Supporting national, regional, and local institutions and their enhancement, so that they can determine ways to improve effectiveness in regulating and managing water reuse programmes;
4. *Financing :* Expanding a range of financing services and opportunities that are available for wastewater reuse initiatives, and improving the capability of utilities and potential EST users to understand and access such services;
5. *Participation :* Encouraging civil society to participate in the decision-making process as well as actual implementation of wastewater reuse programmes, and to deliver a message to the widest possible audience.

These five elements are described in more detail below with examples of real initiatives around the world.

6-1. Capacity Building: Human Resource Development

Building technical and managerial capacity for operating water and wastewater reuse programmes is a critical necessity, due to the variable qualities of source water for wastewater reuse and the complexity of processes. Analytical and problem-solving skills, as well as the ability to maintain and manage technologies, systems and organizations, need to be fostered.

Well-trained personnel, including engineers, scientists and technicians, are necessary for successful water and wastewater recycling projects. In some organizations, resource constraints may force staff with limited training to assume supervisory and management positions, posing a challenge to implementing effective programmes. Such problems may be addressed through:

- Carrying out internal human resource development by training courses and on-the-job training;
- Developing human capabilities through hiring and retention of qualified personnel.

In addition, care should be taken to favour operations that enhance, rather than diminish, employment opportunities, and to utilize reliable mechanisms that can be maintained by a locally trained labour force. Community-level training is also important, as many water reuse and recycling techniques involve actions at a household or shop-floor level. Training materials and methods need to be tailored to meet the needs and qualifications of the target audience.

6-2. Capacity Building: Policy and Legal Framework Development

Water reuse projects must include regulatory development and implementation to ensure the protection of human health and the environment. Necessary regulations may include permit systems to authorize wastewater discharges, technical specifications on wastewater treatment, reclaimed water quality standards for various applications, and regulations on disposal of waste (sludge, brine, etc.) from treatment. In water scarce areas, water reuse requirements or the installation of a reuse infrastructure may also be introduced. Mechanisms to enforce these regulations are also necessary, including required and voluntary monitoring, inspection programmes with adequate staffing, and clear authority to assess and collect fines and penalties. Incentives, such as grants and low-interest loans, flexible permits and priority access to the infrastructure, may also be effective in increasing interest in wastewater reuse.

Examples

In Chennai, India, the Chennai Metropolitan Waste and Sewerage Service Board (CMWSSB) began to promote rainwater harvesting and wastewater reuse to alleviate water shortage in industry and households in the mid 1990s. In 1994, the CMWSSB and other regulatory authorities made the installation of suitable rainwater harvesting facilities mandatory for property developers of multistorey and special buildings. Recently, this requirement has been extended to individual households for which planning permits are to be submitted. The CMWSSB ensures the installation of such devices by inspection before water/sewer connections are made (CMWSSB).

The evaluation of an institutional support programme for water recycling in China by the Japan International Cooperation Agency (JICA) found that policy and legal framework development was crucial for success. With the emergence of a sustainable development policy, various environmental laws, regulations, standards, and their enforcement became more stringent in the 1990s. As a result, industries around the country were compelled to improve their environmental performance, which promoted wastewater treatment and efficient use of water resources, including reuse. At the same time, an increase in water tariffs increased the interest of both industry and citizens in water reuse (JICA, 2003).

6-3. Capacity Building: Institutional Development and Organizational Management

Studies on managing water supply and sanitation services in developing communities have shown that ensuring the credibility of a responsible agency within its target community, and developing a client-oriented organizational structure are two success factors (Schutte, 2001). While many countries and municipalities may already have institutions for water supply, those for wastewater collection, treatment and disposal may not be organized and managed properly. In some cases, they may not exist at all. A recent analysis revealed that one in ten countries in Asia, Africa and the Americas does not have a national institution that is identifiably responsible for either urban or rural sanitation (WHO and UNICEF, 2000). In order to undertake wastewater reclamation projects, it is necessary to examine relevant existing institutions and strengthen them, or to create new ones and assign adequate mandates and responsibilities.

It may also be worthwhile establishing collaborative frameworks with other reclamation and reuse programmes to achieve a critical mass for service provision.

Examples

In the United States, a public utility in the San Francisco Bay area called the Central Contra Costa Sanitary District (CCCSD) began a project in the mid 1990s to modernize its water reclamation facility and to expand its reclaimed water distribution system. In doing so, it established a cooperative agreement with a neighbouring utility to expand service provision to a wider area, and the pipeline systems between the two utilities were connected. This collaborative framework was an important factor in achieving 'critical mass' in dealing with stakeholders and a great degree of operational flexibility (Hermanowicz *et al*, 2001).

6-4. Capacity Building: Financing

It is costly to build and maintain wastewater treatment plants, and install water distribution lines for reuse. Expanding a range of financial services and opportunities is a key component for promoting water and wastewater recycling. In countries where water and wastewater recycling programmes are implemented within a comprehensive water resource development, policy makers may have flexibility in accessing financing. In other cases, technical assistance programmes may provide separate funding for water reuse. Locally controlled funds or small-scale financing mechanisms (i.e. microcredit schemes) may also be established to facilitate financing. Along with the introduction of financing mechanisms, a capacity to understand and access such services needs to be fostered among utilities and potential EST users.

Examples

Various bi- and multi-lateral cooperation agencies have increasingly provided financing opportunities for water and wastewater reclamation projects. For example, Japan has provided US$1.83 million in total to fund a wastewater reclamation system in Chennai, starting from 1994, as described in Section 6-2. The system, which is currently in operation, provides secondary treated sewage, with on-site tertiary treatment, for an oil refinery and fertilizer plant. The service has been expanded to a power plant recently. Chennai Municipal Water and Sewerage Service Board (CMWSSB) hopes to pursue this concept further to make more significant impacts (Ogura, 1999).

6-5. Capacity Building: Raising Public Awareness and Participation

Raising the awareness of the public about water shortages and encouraging their participation in remedial action is crucial in the implementation of wastewater reuse. The issue is of particular importance for water reuse for indirect and direct potable use, including groundwater recharge, as many initiatives have been delayed due to public resistance and legal action. To raise the awareness of stakeholders and ensure that their voices are heard, the decision-making process needs to be participatory, with clearly outlined roles and responsibilities. Proactive public outreach initiatives, such as publications, public announcements, and site visits, are some of the main means to secure wider public acceptance and support.

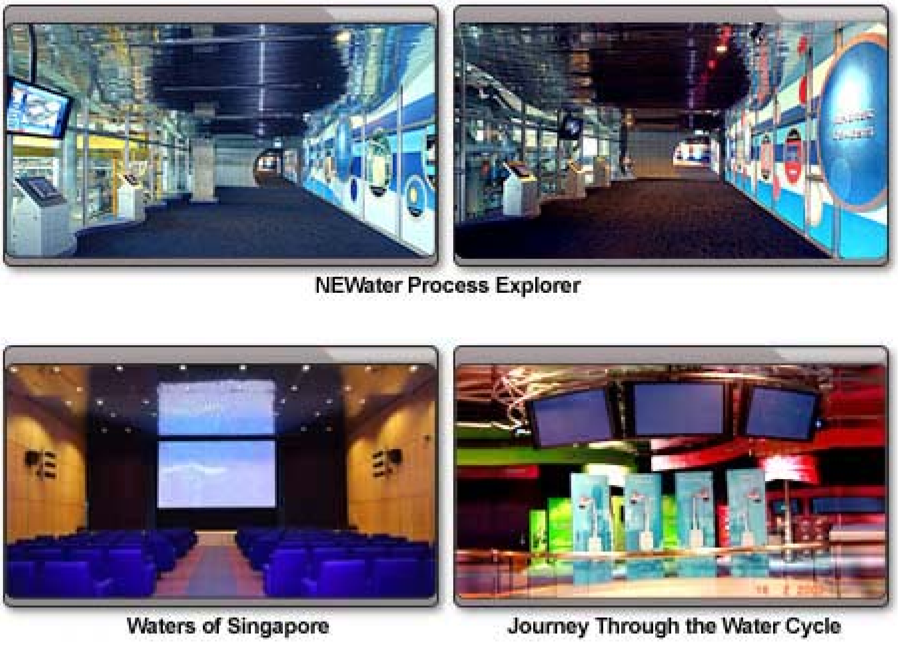
Civil society organizations usually play an important role in undertaking various activities aimed to raise public awareness. In some countries, local governments and local politicians also take part directly to raise the public awareness of water conservation, better usage to improve public health, and recycling water for secondary uses. Public participation can be scaled-up by bringing the community into the decision-making process. Their participation in the decision-making process also improves public participation in the implementation process. Public participation can be aimed at different objectives including the payment of user charges, conservation, minimizing unaccounted for water rates, recycling and reuse of water, and ownership and operation of the small projects, mainly in slums or peri-urban areas.

Example

The Public Utility Board (PUB) of Singapore opened a public education centre in early 2003 to enhance the public understanding of reclaimed water, called 'NEWater', and other water-related topics (Figure 23). The facility offers multimedia presentations and interactive games, as well as a walk-through of the plant with advanced membrane and ultraviolet technologies. PUB also embarked on an intensive public education programme on NEWater in the second half of 2002, with advertisements, posters, leaflets, the broadcast of a documentary, as well as the provision of over 1.5 million bottles of NEWater samples. As a result, an overwhelming majority of Singaporeans have expressed their acceptance of NEWater. An independent poll in October 2002 showed that 82% of citizens indicated that they were prepared to drink NEWater directly, while 16% indicated that they were prepared to drink it indirectly by mixing it with reservoir water (Ministry of Environment, Singapore, 2003).

Since 2004, 15 million gallons per day (about 57,000m^3/day) of NEWater has been processed in two factories. While 13 million gallons per day (about 50,000m^3/day) is used for non-potable usage by industrial and commercial institutions, including wafer fabrication parks, 2 million gallons per day (about 7,000m^3/day) are pumped into freshwater reservoirs for indirect potable usage, constituting less than 1% of total water consumption. The plan is to increase the NEWater share in drinking water to 2.5% by 2011 (PUB, 2003b).

Figure 24: NEWater Visitor Centre in Singapore



NEWater Process Explorer

Waters of Singapore

Journey Through the Water Cycle

(Source: PUB 2003a)

7. Moving Forward

Recognizing that water-related problems are one of the most important and immediate challenges to the environment and public health, it is important to act now. Water scarcity and water pollution are some of the crucial issues that must be addressed within local and global perspectives. One of the ways to reduce the impact of water scarcity as well as minimizing water pollution is to expand water and wastewater reuse. In this regard, ESTs are vital to implement wastewater reuse and recycling at the local level. The selection of the appropriate ESTs depends on the available quality and quantity of wastewater and the requirements for the wastewater reuse. The local conditions including regulations, institutions, financial mechanisms, availability of local technology, and stakeholder participation have a great influence over the decisions for wastewater reuse. Hence the selection of appropriate ESTs should be paramount among those factors. Factors driving future wastewater reuse are summarized in Table 10.

In cities and regions of developed countries, for example, where wastewater collection and treatment have been established over the years, wastewater reuse is practised with proper attention to sanitation, public health and environmental protection. Unfortunately, in many places in the developing countries, wastewater reuse is not being practised in a way to protect the environment and public health. Three broad scenarios can be observed: in some places untreated wastewater is being reused as some countries are obliged to resort to this despite the health risks; in other places an intermediate quality is being reused, where some treatment has been given; and lastly, in few places a level corresponding to developed-world practice is being implemented. This last level can be taken as a benchmark to meet the demand for water with minimum damage to the environment and protection of public health.

The type of reuse will govern the roadmap for achieving the highest standards. So far wastewater reuse in the agriculture sector is the highest, and stabilization ponds and artificial wetlands based on phytotechnologies are commonly used in developing countries to improve the water quality. Other methods including reservoirs and soil aquifer treatment are also in use in some places. The increasing awareness of food safety, and the influence of the countries, which import food, is influencing policy makers and agriculturists to improve the standards of wastewater reuse in agriculture. Wastewater reuse in industries is regulated mainly due to the water and wastewater charges and penalties on pollution levels. As the cost goes-up, industries try to scale-up recycling and reuse. The role of government assistance, especially economic incentives and non-commercial credit for obtaining appropriate technology, has shown good success in some countries like Japan. Recently, the environmental awareness of consumers has been putting pressure on the producers (industries) to opt for environmentally sound technologies including those which conserve water and reduce the level of pollution. Urban applications are gaining ground due to water scarcity and the increasing cost of freshwater. Secondary uses including landscaping and gardening, which consume substantial quantities of freshwater, are now reusing grey water and reclaimed wastewater. The improvements in the technologies and their affordability at municipality as well as household level will result in increasing wastewater reuse in the cities.

To promote wastewater reuse on a sustainable basis and for wider applications, some key factors should be addressed. Firstly, planning for wastewater reuse is important with reference to meeting specific needs and conditions. This could be facilitated by incorporating wastewater reuse into local plans for water management. Planning needs to take care of all the sensitive issues including public health, the role of stakeholders, and the viability of operation and maintenance. Secondly, economic and financial requirements are crucial, as less viable schemes for wastewater reuse will only create a social burden and will not last for long. Cost-effectiveness should be given high priority. Partnerships with the private sector and the community may help to improve the level of investment and also to improve efficiency during operation and maintenance, thus reducing the overall cost and making it economically and financially viable. Thirdly, local capacity, including human resources, policy and legal framework, and institutions, is very important in achieving sustainable targets of wastewater reuse plans. Capacity building should be an integrated part of the overall plan, and national and international agencies can actively assist in this.

In light of this, it may be observed that we have to move forward to implement strategies and plans for wastewater reuse. However, their success and sustainability will depend on political will, public awareness and active support from national and international agencies to create an enabling environment for the promotion of environmentally sustainable technologies.

Table 10: Wastewater reuse: rationale, potential benefits, and factors driving its further use

Rationale for wastewater reuse

- Water is a limited resource. Increasingly, society no longer has the luxury of using water only once.
- Wastewater reuse more appropriately matches water use application with water resource quality resulting in more effective and efficient use of water.
- The goal of water resource sustainability is more attainable when wastewater reuse option is implemented.

Potential benefits of wastewater reuse

- Wastewater reuse conserves freshwater supplies:
  Wastewater reuse increases the total available water supply. High-quality water supplies, such as for drinking water, can be conserved by substituting reclaimed water where appropriate.
- Wastewater reuse is environmentally responsible:
  Wastewater reuse can preserve the health of waterways, wetlands, flora and fauna. It can reduce the level of nutrients and other pollutants entering waterways and sensitive marine environments by reducing wastewater discharges.
- Wastewater reuse makes economic sense:
  Reclaimed water is available near urban development where water supply reliability is most crucial and water is priced the highest.
- Wastewater reuse can save resources:
  Reclaimed water originating from municipal wastewater contains nutrients; if this water is used to irrigate agricultural land, less fertilizer is required for crop growth. By reducing nutrient (and resulting pollution) flows into waterways, tourism and fishing industries are also helped.

Factors driving further implementation of wastewater reuse

- Proximity: Reclaimed water is readily available in the vicinity of the urban environment, where water resources are most needed and are highly priced.
- Dependability: Reclaimed water provides a reliable water source, even in drought years, as production of urban wastewater remains nearly constant.
- Versatility: Technically and economically proven wastewater treatment processes are available now that can provide water for nonpotable use and even for potable reuse.
- Safety: Non-potable water reuse systems have been in operation for over four decades with no documented adverse public health impacts in developed countries.
- Competing demands for water resources: Increasing pressure on existing water resources due to population growth and increased agricultural demand.
- Fiscal responsibility: Growing recognition among water and wastewater managers of the economic and environmental benefits of using reclaimed water.
- Public interest: Increasing awareness of the environmental impacts associated with overuse of water supplies, and community enthusiasm for the concept of wastewater reuse.
- Environmental and economic impacts of traditional water resources approaches: Greater recognition of the environmental and economic costs of water storage facilities such as dams and reservoirs.
- Proven track record: The growing number of successful wastewater reuse projects all over the world.
- A more accurate cost of water: The introduction of new water charging arrangements (such as full cost pricing) that more accurately reflect the full cost of delivering water to consumers, and the growing use of these charging arrangements.
- More stringent water quality standards: Increased costs associated with upgrading wastewater treatment facilities to meet higher water quality requirements for effluent disposal.
- Necessity and opportunity: Motivating factors for development of wastewater reuse projects such as droughts, water shortages, prevention of sea water intrusion and restrictions on wastewater effluent discharges, plus economic, political, and technical conditions favourable to wastewater reuse.

(Asano, Burton, and Tchobanoglous, 2006)

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Glossary

Activated sludge

Oxygen-dependent (aerobic) biological treatment process that serves to convert soluble organic matter to solid biomass, which is removable by gravity or filtration.

Anaerobic ponds

Constructed pond-like body of water or basin designed to receive, hold and treat wastewater for a predetermined period of time in the absence of oxygen. Anaerobic ponds are most often used to treat animal wastes from dairies and pig farms, commercial or industrial wastes or as the first treatment step in systems using two or more ponds in a series.

Aquifer

An underground geological formation or group of formations containing usable amounts of groundwater that can supply wells and springs. Aquifers are more protected from contaminants than surface waters, but may still be tainted by faecal coliform from improperly functioning septic tanks. Half of all Americans get drinking water from aquifers. Of these, roughly a third have their own wells, while the remainder use municipal water systems that draw on underground sources.

Blackwater

Wastewater that comes from a toilet. Distinct from greywater, which includes wastewater from baths, washing machines and sinks.

Biochemical Oxygen Demand (BOD)

The amount of oxygen organisms in wastewater required to decompose organic matter (under standard aerobic conditions). Used as a measure of the amount of organic matter (pollutants) in wastewater, and hence as an indicator of water quality and the performance of wastewater treatment systems. Generally measured in mg/L.

Coagulation

Destabilization of colloid particles by addition of a reactive chemical, called a coagulant. This happens through neutralization of the charges.

Cooling make-up water

Water added to cooling towers to replace the loss of water through evaporation, removal of contaminants.

Chlorofluorocarbons (CFCs)

Stable, artificially created chemical compounds containing carbon, chlorine, fluorine and sometimes hydrogen. Chlorofluorocarbons, used primarily to facilitate cooling in refrigerators and air conditioners, have been found to damage the stratospheric ozone layer, which protects the earth and its inhabitants from excessive ultraviolet radiation.

Cyst

An encysted zoospore (fungi); in nematodes, the carcass of dead adult females of the genus Heterodera which may contain eggs. In bacteria and protozoa, a resting stage in which the whole cell is surrounded by protective layer.

Facultative pond

The most common type of wastewater treatment pond used by small communities and individual households. Facultative ponds rely on both aerobic and anaerobic decomposition of waste, can be adapted for use in most climates and require no machinery to treat wastewater.

Faecal Coliform
A sub-group of coliforms, found almost exclusively in the excreta of humans and animals, and seldom found elsewhere in the environment. If detected in water, good indicator that the water has been contaminated by human wastes, sewage or improperly treated wastewater and therefore may contain disease-causing organisms. Faecal coliforms measured in colonies/100 mL. Water containing faecal coliforms is unsafe to drink.

Grey Water
Wastewater generated by water-using fixtures and appliances (baths, sinks, washing machines), excluding the toilet and sometimes the garbage disposal. Distinct from Blackwater, or toilet wastewater.

Life Cycle Cost (LCC)
Cost estimate of a piece of equipment over its entire life, including development costs, production costs, warranty costs, repair costs, and disposal costs.

Lime
Common water treatment chemical such as CaO or Ca $(OH)_2$. Calcium carbonate ($CaCO_3$) can be deposited on walls of showers and bathrooms.

Maturation pond
An aerobic waste stabilization pond used for refinining treated wastewater effluent.

Membrane
A thin barrier that allows some compounds or liquids to pass through, and impedes others. It is a semipermeable skin of which the pass-through is determined by the size or special nature of the particles. Membranes are commonly used to separate substances.

Non-point sources
Diffuse water pollution sources without a specific point of origin. The pollutants are generally carried off the land by storm water. Common non-point sources are agriculture and atmospheric disposal.

Oocysts
A part of the sporogony phase of protozoa which occurs after macro-gametes have been fertilized by micro-gametes in the intermediate host. The subsequent multiplication of cells produces an oocyst, each cell then becoming a sporozoite, which is subsequently injected into the final host.

Ozonation
Also called Ozone Disinfection, a common method of disinfecting wastewater that uses ozone (O3), an unstable gas that can destroy bacteria and viruses. Ozone is generated on-site at the treatment facility by an electrical discharge through dry air or pure oxygen. After generation, the ozone is fed into a down-flow contact chamber containing the wastewater to be disinfected. From the bottom of the contact chamber, ozone is diffused into fine bubbles that mix with the downward flowing wastewater. Ozone disinfection is generally used at medium- to large-sized plants after at least secondary treatment. Another common use for ozone in wastewater treatment is odour control.

Pathogens
Organisms (mostly microbes) that cause disease. Examples in wastewater include Salmonella, Vibrio Cholera, and Entamoeba histolytica.

Suspended Solids (SS)

Small particles of solid material (pollutants) suspended or dispersed in wastewater. Septic tank outlets are often fitted with filters to minimize the amount of suspended solids that enter the drainfield. Total Suspended Solids is one important measure of water quality/pollution level and hence treatment system performance.

Trihalomethane (THM)

One of a family of organic compounds named as derivatives of methane. THMs are generally by-products of chlorination of drinking water that contains organic material.

Volatile Organic Compounds (VOCs)

Organic chemicals that have a high vapour pressure and easily form vapours at normal temperature and pressure.

Global Environment Centre Foundation

After official approval in 1991 by the UNEP Governing Council to set up UNEP-IETC in Japan, Osaka Municipal Government formed the UNEP-IETC Osaka Establishment Preparation Office on July 3, 1991. The purpose of the office was to carry out studies and create a network of support for the proposed centre. Following initial preparation by the Preparation Office, capital endowment was received from Osaka Prefectural and Municipal Governments. The establishment of Global Environment Centre Foundation (GEC) was marked on January 28, 1992 for the purpose of supporting UNEP-IETC. GEC, a non-profit organization, gains support from the local business sector. The contributions made to GEC are exempted from taxation.

GEC collaborates in various projects and provides office space and equipment for UNEP-IETC Osaka. It also acts as a liaison between related organizations in Japan and UNEP-IETC. In this regard, it helps to ensure the smooth and efficient operation of UNEP-IETC. In addition, GEC promotes urban environmental management in developing countries through projects such as collecting and providing information, training programmes, seminars and symposia, and survey and research. In all of these ways, GEC's activities make an international contribution in the environmental field.

GEC was established to make use of the abundant accumulation of knowledge and experience in the field of environmental preservation in Japan, in particular, those in the Kansai region to support contributions of UNEP for urban environmental management in developing countries, to promote international cooperation for environmental conservation, and thereby to contribute to the conservation of the global environment.

- Providing general support for activities of UNEP for urban environmental management in developing countries;
- Undertaking survey and research which contribute to preservation of the global environment, especially in urban areas in developing countries;
- Collection and dissemination of information which contributes to the preservation of the global environment, especially in urban areas in developing countries;
- Holding of training programmes, seminars, and symposia, which contribute to preservation of the global environment, especially in urban areas in developing countries;
- Facilitating communications with international organizations, governmental organizations, and research organizations in various countries in order to contribute to preservation of the global environment, especially in urban areas in developing countries;
- Any other activities necessary to achieve the mission of GEC.