Chapter 8

Water Reuse Outside the U.S.

The need for alternative water resources, coupled with increasingly stringent water quality discharge requirements, are the driving forces for developing water reuse strategies in the world today. Water reuse enables practitioners to manipulate the water cycle, thereby creating needed alternative water resources and reducing effluent discharge to the environment. The growing trend is to consider water reuse as an essential component of integrated water resources management and sustainable development, not only in dry and water deficient areas, but in water abundant regions as well. In areas with high precipitation where water supply may be costly due to extensive transportation and/or pumping, water reuse has become an important economic alternative to developing new sources of water.

Reuse of wastewater for agricultural irrigation is practiced today in almost all arid areas of the world. Numerous countries have established water resources planning policies based on maximum reuse of urban wastewater. In many dry regions, particularly in developing countries in Asia, Africa, and Latin America, unplanned use of inadequately treated wastewater for irrigation of crops continues today and is often confused with planned and regulated reuse. This major health concern makes it imperative to governments and the global community to implement proper reuse planning and practices, emphasizing public health and environmental protection, during this era of rapid development of wastewater collection and treatment. Within the next 2 decades, 60 percent of the world's population will live in cities. As increasingly ambitious targets for sewage collection are pursued, massive and growing volumes of wastewater will be disposed of without treatment to rivers and natural water bodies. The challenges will be particularly acute in mega-cities (cities with a population of 10 million or more), over 80 percent of which will be located in developing countries.

This chapter provides an overview and examples of water reuse in countries outside of the U.S., including the implementation of reuse in developing countries where the planning, technical, and institutional issues may differ considerably from industrialized countries.

8.1 Main Characteristics of Water Reuse in the World

Increased water shortages and new environmental policies and regulations have stimulated significant development in reuse programs in the past 20 years. According to the conclusions of various water reuse surveys (Lazarova *et al.,* 2001 and Mantovani *et al*., 2001), the best water reuse projects, in terms of economic viability and public acceptance, are those that substitute reclaimed water in lieu of potable water for use in irrigation, environmental restoration, cleaning, toilet flushing, and industrial uses. The main benefits of using reclaimed water in these situations are conservation of water resources and pollution reduction.

A project commissioned by the Water Environment Research Foundation (WERF), Mantovani *et al*. (2001) surveyed nonpotable water reclamation planning and management practices worldwide. The study reviewed 65 international nonpotable water reuse projects to document planning and management approaches for agricultural, urban, and industrial water reuse projects in both advanced and developing countries in the arid and semi-arid belts around the globe. The survey findings confirmed that in addition to operational performance, sound institutional arrangements, conservative cost and sales estimates, and good project communication are the basis for project success. By the same token, institutional obstacles, inadequate valuation of economic benefits, or a lack of public information can delay projects or cause them to fail.

Table 8-1 shows the average volumes of reclaimed water produced in several countries, as well as the relative contribution of water reuse to the total water demand. Recent projections show that in Israel, Australia, and Tunisia, the volume of reclaimed water will satisfy 25 percent, 11 percent, and 10 percent, respectively, of the total water demand within the next few years (Lazarova *et al.,*

Table 8-1. Sources of Water in Several Countries

Country	Total Annual Water Withdrawal			Annual Reclaimed Water Usage			Reclaimed Water as Percent of Total
	Year	Mm^3	MG	Year	Mm^3	MG	
Algeria	1990	4,500	1,188,900	-	-	-	-
Bahrain	1991	239	63,144	1991	15	3,963	6%
Cyprus	1993	211	55,746	1997	23	6,077	11%
Egypt	1993	55,100	14,557,420	2000	700	184,940	1%
Iran	2001	81,000	21,400,200	1999	154	40,687	0.20%
Iraq	1990	42,800	11,307,760	-	-	-	-
Israel	1995	2,000	528,400	1995	200	52,840	10%
Jordan	1993	984	259,973	1997	58	15,324	6%
Kuwait	1994	538	142,140	1997	80	21,136	15%
Kyrgyzstan	1990	11,036	2,915,711	1994	0.14	37	0%
Lebanon	1994	1,293	341,611	1997	2	528	0.20%
Libya	1994	4,600	1,215,320	1999	40	10,568	1%
Morocco	1991	11,045	2,918,089	1994	38	10,040	0.30%
Oman	1991	1,223	323,117	1995	26	6,869	2%
Qatar	1994	285	75,297	1994	25	6,605	9%
Saudi Arabia	1992	17,018	4,496,156	2000	217	57,331	1%
Syria	1993	14,410	3,807,122	2000	370	97,754	3%
Tajikistan	1989	12,600	3,328,920	-	-	-	-
Tunisia	1990	3,075	812,415	1998	28	7,398	1%
Turkey	1992	31,600	8,348,720	2000	50	13,210	0%
Turkmenistan	1989	22,800	6,023,760	-	-	-	-
U. A. Emirates	1995	2,108	556,934	1999	185	48,877	9%
Yemen	1990	2,932	774,634	2000	6	1,585	0%

Sources: Adapted from World Bank, 2001 with updates from Hamdallah, 2000.
Note: (-) indicates that data was not available.

2001). In Jordan, reclaimed water volumes must increase more than 4 times by the year 2010 in order to meet demands. By 2012, the volume of reclaimed water in Spain will increase by 150 percent. The reclaimed water volume in Egypt is expected to increase by more than 10 times by the year 2025. A number of countries in the Middle East are planning significant increases in water reuse to meet an ultimate objective of reusing 50 to 70 percent of the total wastewater volume.

8.2 Water Reuse Drivers

The main drivers for water reuse development worldwide are:

- **Increasing water demands** to sustain industrial and population growth. This is the most common and important driver for dry and water-abundant regions in developed, developing, and transitional countries.

- **Water scarcity and droughts,** particularly in arid and semi-arid regions. In this case, reclaimed water is a vital and drought-proof water source to ensure economic and agricultural activities.

- **Environmental protection and enhancement** in combination with **wastewater management needs** represent an emerging driver, in a number of industrialized countries, coastal areas, and tourist regions. In areas with more stringent wastewater discharge standards, such as in Europe, Australia, and South Africa, wastewater reuse becomes a competitive alternative to advanced water treatment from both economic and environmental points of view.

- **Socio-economic factors** such as new regulations, health concerns, public policies, and economic incentives are becoming increasingly important to the implementation of water reuse projects. For example, the increase in the cost of potable water will help promote the implementation of wastewater reuse.

- **Public health protection** is the major driver in developing countries where lack of access to fresh water supplies coupled with high market access in urban and peri-urban areas, drives untreated reuse in agriculture. Public health protection and environmental risk mitigation are key components of any reuse program under these conditions.

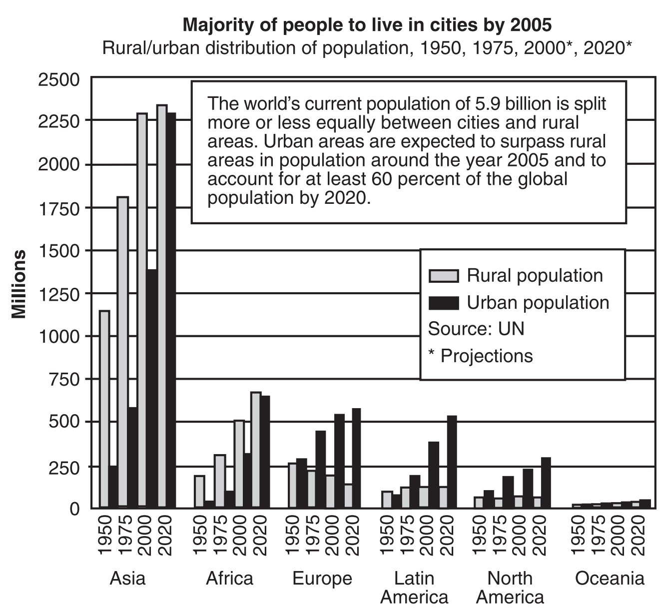
8.2.1 Increasing Water Demands

Population growth, urbanization, and industrial development contribute to water shortages by perpetually pushing up demand. In addition, these same factors increase water pollution, add to potable water treatment costs, and most likely, have adverse health effects. Urban growth impacts in developing countries are extremely pressing. Whereas only 1 in 3 mega-cities were located in developing countries in 1950, in the year 2002, 14 of 22 such cities were in developing countries. By 2020, more than half the total population of Asia, Africa, and Latin America will be living in cities, and all of these cities will need additional water supplies. (See **Figure 8-1**).

8.2.2 Water Scarcity

The most common approach used to evaluate water availability is the **water stress index**, measured as the annual renewable water resources per capita that are available to meet needs for domestic, industrial, and agricultural use. Based on past experiences in moderately developed countries in arid zones, renewable freshwater resources of 1,700 m^3/capita/year (0.45 mg/capita/year) has been proposed as the minimum value at which countries are most likely to begin to experience ***water stress,*** which may impede development and harm human health (Earth Trends, 2001). Below 1,000 m^3/capita/year (0.26 mg/capita/year) of renewable freshwater sources, **chronic water scarcity** appears. According to some experts, below 500 m^3/capita/year (0.13 mg/capita/year), countries experience **absolute water stress** and the value of 100 m^3/capita/year (0.026 mg/capita/year) is the **minimum survival level** for domestic and commercial use (Falkenmark and Widstrand, 1992 and Lazarova, 2001). Projections predict that in 2025, 2/3 of the world's population will be under conditions of moderate to high water stress and about half of the population will face real constraints in their water supply.

Figure 8-1. World Populations in Cities



Source: United Nations 2002

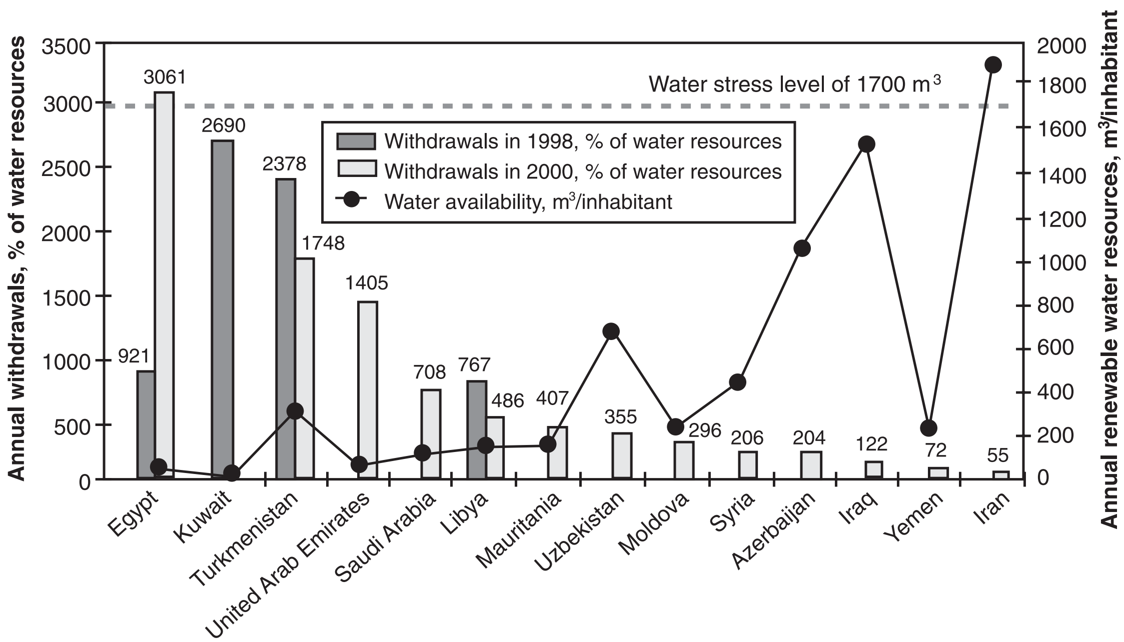
Population Action International has projected the future water stress index for 149 countries and the results indicate that 1/3 of these countries will be under water stress by 2050. Africa and parts of western Asia appear particularly vulnerable to increasing water scarcity. This data also shows that a number of Middle Eastern countries are already well below the absolute water stress of 500 m^3/capita/year (0.13 mg/capita/year) and by 2050 will reach the minimum survival level of 100 m^3/capita/year (0.026 mg/capita/year) for domestic and commercial use. In addition, numerous nations with adequate water resources have arid regions where drought and restricted water supply are common (north-western China, western and southern India, large parts of Pakistan and Mexico, the western coasts of the U.S. and South America, and the Mediterranean region).

A high concentration of population within individual countries also causes water stress. The North China Plain (surrounding Beijing and within the river basins Hai, Huai, and Yellow River) contains most of the country's population, such that the water availability is only about 5 percent of the world average, while China, as a whole, has about 25 percent of the world average.

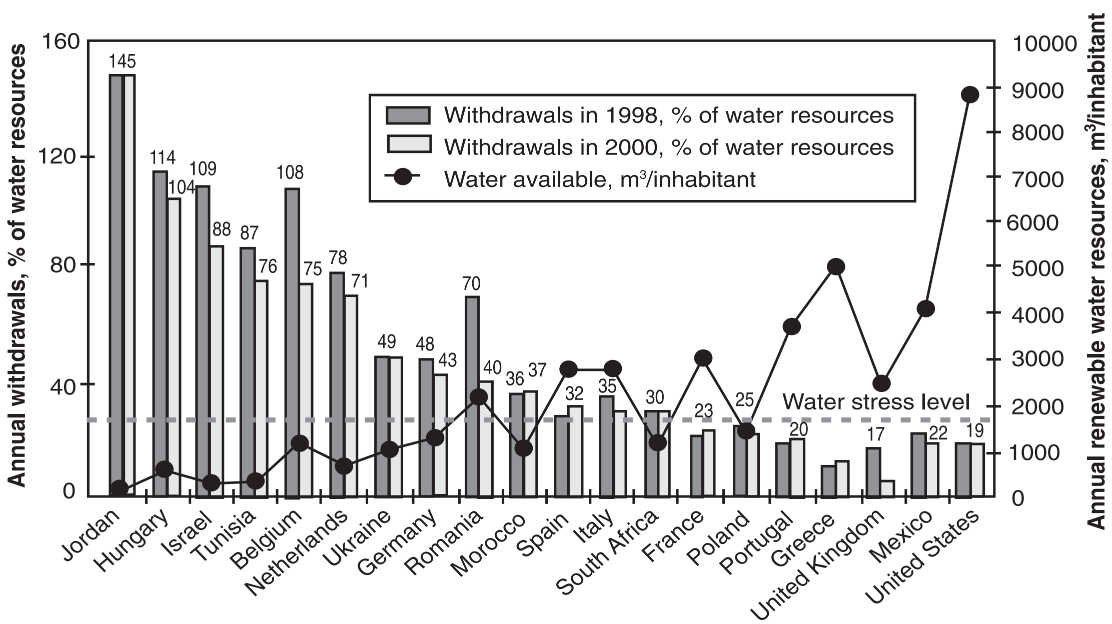
Another important criterion for evaluating water stress is water withdrawal as a percentage of the annual internal renewable water resources. Water management becomes a vital element in a country's economy when over 20 percent of the internal renewable resources are mobilized (Earth Trends, 2001). This is currently occurring in several European countries (**Figure 8-2a**) such as France, Spain, Italy, Germany, Ukraine, Belgium, the Netherlands, and Hungary. The Mediterranean region, North Africa, Morocco, Tunisia, Israel, and Jordan are facing high risks of water scarcity, meaning that in these areas, the major portion of the renewable resources are withdrawn. A number of arid and semi-arid countries meet water demands by seawater desalination or by withdrawals from non-renewable deep aquifers with extracted volumes 2 to 30 times higher than available renewable resources (**Figure 8-2b**).

Improving the efficiency of water use, water reclamation, and reducing distribution losses are the most affordable solutions to relieve water scarcity. For a number of countries in the Middle East and North Africa, where current fresh water reserves are, or will be, at the survival level, reclaimed wastewater is the only significant,

8-2a. Countries with Chronic Water Stress Using Non-Renewable Resources



8-2b. Countries with Moderate Water Stress



Source: Adapted by Lazarova, V. from Earth Trends 1999-2000, World Resource Institute low cost alternative resource for agricultural, industrial, and urban nonpotable purposes.

8.2.3 Environmental Protection and Public Health

In spite of the economic and ecological advantages associated with wastewater reuse, the key issue remains public health safety. The reuse of raw wastewater, still widely practiced in several regions in China, India, Morocco, Egypt, Pakistan, Nepal, Vietnam and most of South America, leads to enteric diseases, helminthic infections, and dangerous epidemics. In addition to public health risks, insufficiently treated effluent may also have detrimental effects on the environment. For example, high salinity levels in effluent can lead to a decrease in productivity for certain crops and destabilization of the soil structure. Another possible adverse effect is groundwater pollution. In the Mezquital Valley, north of Mexico City, 1,027 mgd (45 m^3/s, or 1.15 million acre-feet/year) of untreated wastewater from the capital city of Mexico City is used for agricultural irrigation in a 222,400-acre (90,000-hectare) area, year-round (IWA, 2002). This huge wastewater irrigation project, believed to be the largest in the world, has given rise to inadvertent and massive recharge of the local aquifers, and unintended indirect potable reuse of water from that aquifer by a population of 300,000 inhabitants.

8.3 Water Reuse Applications – Urban and Agriculture

Agriculture is the largest user of water, accounting for approximately 80 percent of the global demand. Consequently, agricultural irrigation is the major water reuse application worldwide. In a number of arid and semi-arid countries - Israel, Jordan, and Tunisia – water reuse provides the greatest share of irrigation water. Israel is the world's leader in this area, with over 70 percent of collected and treated wastewater reused for agricultural purposes (Kanarek and Michail, 1996).

Urban water reuse is developing rapidly, particularly in large cities, coastal, and tourist areas. Japan is the leader in urban water reuse, with 8 percent of the total reclaimed water (about 2,113 mgd or 8 millions m^3/year) used for urban purposes. The most common urban uses are for the irrigation of green areas (parks, golf courses, and sports fields), urban development (waterfalls, fountains, and lakes), road cleaning, car washing, and firefighting. Another major type of reuse is on-site water reuse within commercial and residential buildings. For example, Australia, Canada, Japan, and the United Kingdom use treated domestic wastewater for toilet flushing. Golf course irrigation is reported as the most rapidly growing application of urban water reuse in Europe (Lazarova, 1999), while replenishment of river flows for recreational uses is becoming increasingly popular in Spain and Japan.

There are several advantages to implementing urban reuse versus agricultural reuse:

- Most urban reuse, such as toilet flushing, vehicle washing, stack gas cleaning, and industrial processing is nonconsumptive; therefore, the water can be reused again for subsequent consumptive uses in agriculture or industry.
- The urban markets for water reuse are generally closer to the points of origin of the reclaimed water than are the agricultural markets.
- Urban reuse water generally holds a higher value than agricultural reuse because it can be metered and appropriate charges levied.

Wastewater treatment for reuse may have a lower cost than developing new water supply sources, particularly for low-quality reuse in toilet flushing and similar nonpotable urban uses. Agricultural irrigation will probably continue to dominate water reuse practices for many years into the future, especially in developing countries. However, reclamation projects are not likely to be built to serve agriculture. Over recent years, there has been increasing interest in indirect potable reuse in a number of industrialized countries (Australia, Belgium, France, Spain, South Africa, Singapore, and the U.S.) for water supply augmentation through the replenishment of surface reservoirs, aquifers, and salt intrusion barriers in coastal areas.

Untreated reuse water is a large and rapidly growing problem practiced in both low- and middle-income countries around the world. The International Water Management Institute (IWMI), based in Colombo, Sri Lanka, and the International Development Research Centre (IDRC), based in Ottawa, Canada held a workshop to discuss the use of untreated reuse water, at which a range of case studies were presented from Asia, Africa, the Middle East, and Latin America. At the workshop the Hyderabad Declaration on Wastewater Use in Agriculture was adopted.

The conference organizers are preparing an official, peer-reviewed publication based on this declaration. As previously mentioned, there are parts of the world where the wastewater management systems do not allow for the development of water reuse. In some regions untreated wastewater is improperly used for irrigation, usually illegally. The declaration recognizes that in situations where wastewater treatment to produce usable reuse water is not available, there are alternatives to improve the management of water reuse. The Hyderabad Declaration on Wastewater Use in Agriculture is reproduced below.

8.4 Planning Water Reuse Projects

Numerous state-of-the-art technologies enable wastewater to become a complementary and sustainable water

The Hyderabad Declaration on Wastewater Use in Agriculture

14 November 2002, Hyderabad, India

1. Rapid urbanization places immense pressure on the world's fragile and dwindling fresh water resources and over-burdened sanitation systems, leading to environmental degradation. We as water, health, environment, agriculture, and aquaculture researchers and practitioners from 27 international and national institutions, representing experiences in wastewater management from 18 countries, recognize that:

   1.1 Wastewater (raw, diluted or treated) is a resource of increasing global importance, particularly in urban and peri-urban agriculture.
   1.2 With proper management, wastewater use contributes significantly to sustaining livelihoods, food security and the quality of the environment.
   1.3 Without proper management, wastewater use poses serious risks to human health and the environment

2. We declare that in order to enhance positive outcomes while minimizing the risks of wastewater use, there exist feasible and sound measures that need to be applied. These measures include:

   2.1 Cost-effective and appropriate treatment suited to the end use of wastewater, supplemented by guidelines and their application
   2.2 Where wastewater is insufficiently treated, until treatment becomes feasible:
      (a) Development and application of guidelines for untreated wastewater use that safeguard livelihoods, public health and the environment
      (b) Application of appropriate irrigation, agricultural, post-harvest, and public health practices that limit risks to farming communities, vendors and consumers
      (c) Education and awareness programs for all stakeholders, including the public at large, to disseminate these measures
   2.3 Health, agriculture and environmental quality guidelines that are linked and implemented in a step-wise approach
   2.4 Reduction of toxic contaminants in wastewater, at source and by improved management

3. We declare that:

3.1 Knowledge needs should be addressed through research to support the measures outlined above
3.2 Institutional coordination and integration together with increased financial allocations are required

4. Therefore, we strongly urge policy-makers and authorities in the fields of water, agriculture, aquaculture, health, environment and urban planning, as well as donors and the private sector to:

Safeguard and strengthen livelihoods and food security, mitigate health and environmental risks and conserve water resources by confronting the realities of wastewater use in agriculture through the adoption of appropriate policies and the commitment of financial resources for policy implementation.

resource for a number of purposes in both developed and emerging countries, thus allowing utilities to reserve high quality and often scarce freshwater for domestic uses. The development and implementation of water reuse projects, however, remains difficult due to issues such as institutional discord, economics, funding, public health and environmental issues and, in some cases, a lack of public acceptance.

8.4.1 Water Supply and Sanitation Coverage

Despite increasing efforts to improve water supply and sanitation coverage in the world during the past 10 years, numerous regions and many large cities still do not have sufficient infrastructure (**Table 8-2**). According to a 2000 survey (Homsi, 2000), wastewater treatment coverage remains lower than water supply coverage and still represents an important constraint to implementing water reuse projects:

Sewage network coverage:

- Developed countries: 76 percent, except Japan, 54 percent and Portugal, 55 percent
- Developing countries: 35 percent, except Chile, greater than 90 percent

Wastewater treatment coverage:

- Developed countries: 75 percent, except Portugal, 36 percent
- Developing countries: greater than 10 percent

The situation becomes critical in a number of African and Asian countries, where water supply and sanitation coverage do not exceed 30 percent and 45 percent, respectively, including Afghanistan, Angola, Cambodia, Chad, Congo, Ethiopia, Haiti, Laos, Mauritania, and Rwanda. Despite these numbers, it is important to stress that more and more countries have effectively achieved total water supply and sanitation coverage, such as Andorra, Australia, Austria, Belarus, Bulgaria, Canada, Cyprus, Finland, South Korea, Lebanon, Netherlands, New Zealand, Norway, Singapore, Slovakia, Slovenia, Sweden, Switzerland, and the United Kingdom. Significant strides have also been made in a number of developing countries (**Figure 8-3a**) and it is expected that these figures will improve in several other countries with water resource problems (**Figure 8-3b**) due to governmental policies and increased investments.

8.4.2 Technical Issues

Treatment technology, another key aspect of the planning process, varies between planning a reuse project in an emerging country and planning a reuse system in a more industrialized country. In industrialized countries, where stringent control of water quality and operational reliability are the main requirements, modern, high cost technology may be more beneficial. In developing countries, relatively inexpensive labor and higher capital costs dictate that a facility, which can be built and operated with local labor, will be more cost effective than a facility utilizing more modern, capital-intensive technology.

Table 8-2. Wastewater Flows, Collection, and Treatment in Selected Countries in 1994 (Mm^3/Year)

Country	Generation Rate		Collection		Treatment		Treated, As Percent of Total	Treated, As Percent of Collected
	Mm^3/yr	MG/yr	Mm^3/yr	MG/yr	Mm^3/yr	MG/yr		
Cyprus	24	6,341	15	3,963	15	3,963	63%	100%
Egypt	1700	449,140	1138	300,660	950	250,990	55%	83%
Jordan	110	29,062	95	25,099	45	11,889	41%	47%
Morocco	500	132,100	400	105,680	170	44,914	34%	43%
Saudi Arabia	700	184,940	620	163,804	580	153,236	83%	94%
Syria	480	126,816	480	126,816	260	68,692	54%	54%
Tunisia	200	52,840	180	47,556	155	40,951	78%	86%
Turkey	2,000	528,400	1,700	449,140	1,100	290,620	55%	65%

Source: Table created from World Bank Working documents (UNDP, 1998)

Water Supply and Sanitation Coverage in Selected Countries

Figure 8-3a. Countries with Total Water Supply and Sanitation Coverage over 80 Percent

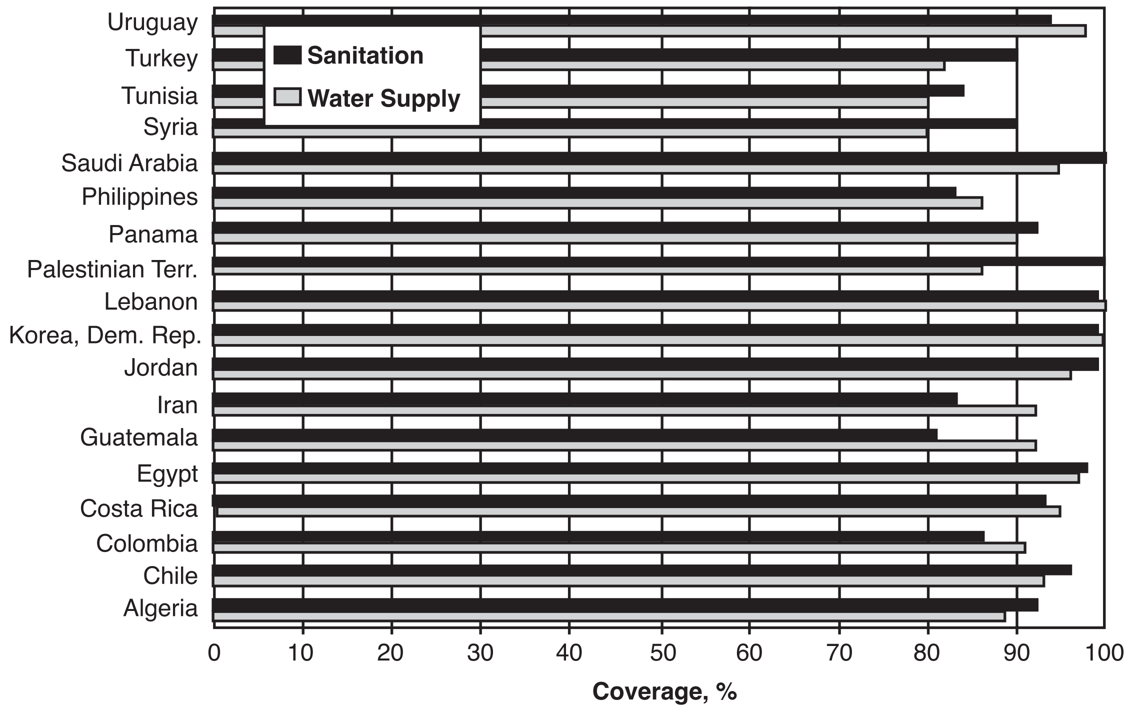
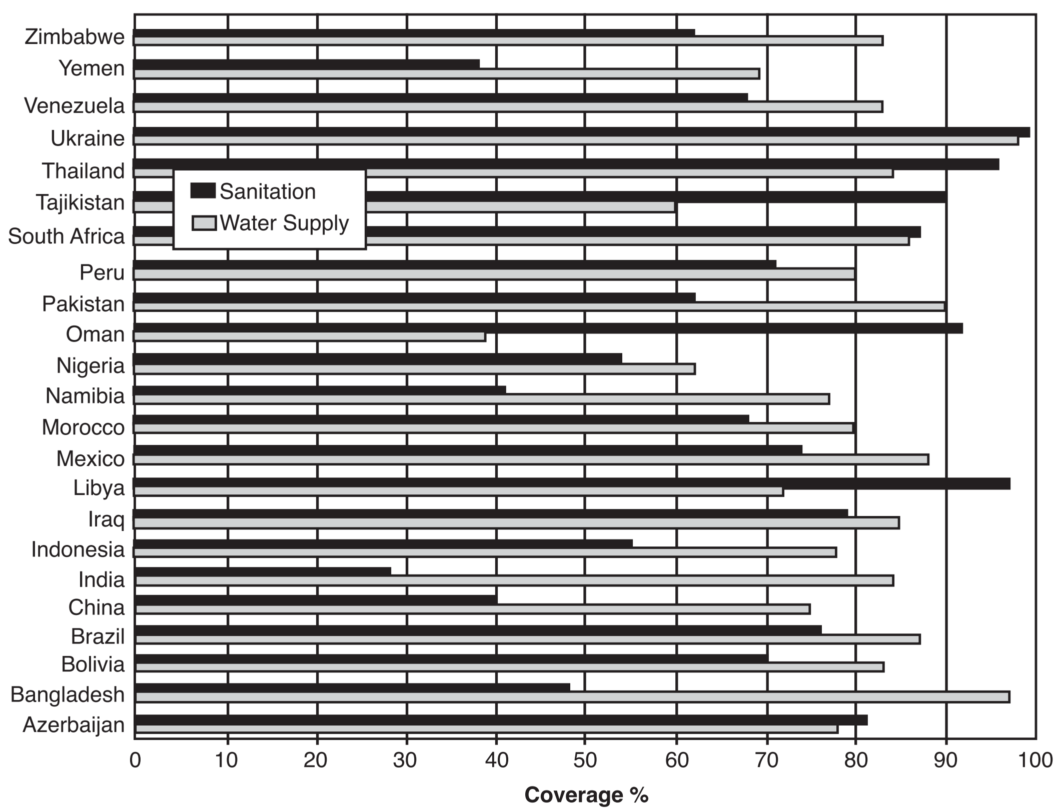


Figure 8-3b. Countries with Total Water Supply and Sanitation Coverage Over 50 Percent



Source: Figures for this table were assembled from WorldBank working documents (UNDP, 1998)

This section provides an overview of some of the technical issues associated with water reuse in developing countries that may differ from those presented in Chapter 2 for the U.S. Many of these issues result from the different technical solutions that are appropriate in a labor-intensive economy as compared with the capital-intensive economy of industrialized countries. Other differences result from dissimilarities in financial, material, and human resources, as well as in existing wastewater collection, treatment, and disposal facilities.

8.4.2.1 Water Quality Requirements

Water reuse standards or guidelines vary with the type of application, the regional context, and the overall risk perception. Depending on the project specifications, there will be different water quality requirements, treatment process requirements, and criteria for operation and reliability. However, the starting point for any water reuse project for any application is ensuring public health and safety. For this reason, microbiological parameters have received the most attention in water reuse regulations. Since monitoring for all pathogens is not realistic, specific indicator organisms are monitored to minimize health risks.

Table 8-3 provides a summary of water quality parameters of concern with respect to their significance in water reuse systems, as well as approximate ranges of each parameter in raw sewage and reclaimed water. The treatment of urban wastewater is typically designed to meet water quality objectives based on suspended solids (Total Suspended Solids (TSS) or turbidity), organic content (BOD), biological indicators (total or fecal coliforms, *E.coli*, helminth eggs, enteroviruses), nutrient levels (nitrogen and phosphorus) and, in some cases, chlorine residual. Additional water quality parameters for irrigation include salinity, sodium adsorption ratio, boron concentration, heavy metals content, and phytotoxic compounds content. The use of reclaimed municipal water for industrial purposes may require effluent limits for dissolved solids, ammonia, disinfection byproducts and other specific inorganic and organic constituents.

Different countries have developed different approaches to protecting public health and the environment, but the major factor in choosing a regulatory strategy is economics, specifically the cost of treatment and monitoring. Most developed countries have established conservatively low risk guidelines or standards based on a high technology/high-cost approach, such as the California standards. However, high standards and high-cost techniques do not always guarantee low risk because insufficient operational experience, OM&R costs, and regulatory control can have adverse effects. A number of developing countries advocate another strategy of controlling health risks by adopting a low technology/low-cost approach based on the WHO recommendations. A summary of select guidelines and mandatory criteria for reclaimed water use in a variety of U.S. states and other countries and regions is presented in **Table 8-4.**

Historically, water reuse standards are based on reuse for agricultural irrigation. The countries that have adopted the WHO recommendations as the basis for their agricultural reuse standards use both fecal coliforms (FC) and helminth eggs as pathogen indicators, respectively, at 1000 FC/100 ml and 1 helminth egg/l for unrestricted irrigation. The WHO recommends more stringent standards for the irrigation of public lawns than for the irrigation of crops eaten raw (fecal coliform count at 200 FC/100 ml, in addition to the helminth egg standard). Recent work, based on epidemiological and microbiological studies performed in Mexico and Indonesia support the WHO fecal coliform limit of less than 10^3 FC/100 ml, but recommends a stricter guideline value of less than 0.1 egg of intestinal nematode per liter (Blumenthal *et al.*, 2000). In the absence of recommendations for particulate matter, these standards use TSS at concentrations varying between 10 and 30 mg/l.

WHO recommends stabilization ponds or an equivalent technology to treat wastewater. The guidelines are based on the conclusion that the main health risks associated with reuse in developing countries are associated with helminthic diseases; therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture and aquaculture. The intestinal nematodes serve as indicator organisms for all of the large settleable pathogens. The guidelines indicate that other pathogens of interest apparently become nonviable in long-retention pond systems, implying that all helminth eggs and protozoan cysts will be removed to the same extent. The helminth egg guidelines are intended to provide a design standard, not an effluent testing standard.

The original 1973 WHO recommendations were more stringent than the 1989 recommendations. With respect to fecal coliforms, the standard rose from 100 FC/100 ml to 1000 FC/100 ml. The WHO guidelines are currently undergoing further revision. A draft guideline proposed by Bahri and Brissaud (2002) recommends massive revisions in the WHO guidelines, making them somewhat more restrictive, while maintaining the objective of affordability for developing countries. For example, in the draft guidelines, the helminth egg concentration limit is reduced from the current guideline of 1 egg/L to 0.1 egg/L for unrestricted irrigation. The proposed draft guidelines also cover various options for health protection,

Table 8-3. Summary of Water Quality Parameters of Concern for Water Reuse

Parameter	Significance for Water Reuse	Range in Secondary Effluents	Treatment Goal in Reclaimed Water
Suspended solids	Measures of particles. Can be related to microbial contamination. Can interfere with disinfection. Clogging of irrigation systems. Deposition.	5 mg/L - 50 mg/L	<5 mg SS/L - 30 mg SS/L
Turbidity		1 NTU - 30 NTU	<0.1 NTU - 30 NTU
BOD_5	Organic substrate for microbial growth. Can favor bacterial regrowth in distribution systems and microbial fouling.	10 mg/L - 30 mg/L	<10 mg BOD/L - 45 mg BOD/L
COD		50 mg/L -150 mg/L	<20 mg COD/L - 90 mg COD/L
TOC		5 mg/L - 20 mg/L	<1 mg C/L - 10 mg C/L
Total coliforms	Measure of risk of infection due to potential presence of pathogens. Can favor biofouling in cooling systems.	<10 cfu/100mL -10^7 cfu/100mL	<1 cfu/100mL - 200 cfu/100mL
Fecal coliforms		<1-10^6 cfu/100mL	<1 cfu/100mL - 10^3 cfu/100mL
Helminth eggs		<1/L - 10/L	<0.1/L - 5/L
Viruses		<1/L - 100/L	<1/50L
Heavy metals	Specific elements (Cd, Ni, Hg, Zn, etc) are toxic to plants and maximum concentration limits exist for irrigation	---	<0.001 mg Hg/L <0.01 mg Cd/L <0.1 mg Ni/L - 0.02 mg Ni/L
Inorganics	High salinity and boron (>1mg/L) are harmful for irrigation	---	>450 mg TDS/L
Chlorine residual	To prevent bacterial regrowth. Excessive amount of free chlorine (>0.05) can damage some sensitive crops	---	0.5 mg Cl/L - >1 mg Cl/L
Nitrogen	Fertilizer for irrigation. Can contribute to algal growth, corrosion (N-NH4) and scale formation (P).	10 mg N/L - 30 mg N/L	<1 mg N - 30mgN/L
Phosphorus		0.1 mg P/L - 30 mg P/L	<1 mg P/L - 20 mg P/L

Source: Adapted from Lazarova, 2001; Metcalf and Eddy, 1991; Pettygrove and Asano, 1985

such as treatment of wastewater, crop restrictions, application controls, and control of human exposure. The multi-barrier approach throughout the water cycle is also considered an important element. WHO wastewater reuse initiatives are considering 4 categories of reuse: (a) agriculture, (b) aquaculture (shellfisheries), (c) artificial recharge exclusively for potable supply, and (d) urban use.

The premise is that better health protection can be achieved by not only implementing stringent water quality limits but also by defining other appropriate practices that could provide additional barriers for pathogens depending on the type of reuse. Such an approach has been proposed in the new Israeli standards (Shelef and Halperin, 2002). In 1999, new standards were issued by the Israeli Ministry of Health (Palestine Hydrology Group, 1999), defining 5 qualities of reclaimed water, as follows:

1. Effluents of very high quality, suitable for unrestricted irrigation—no barriers required

2. Effluents of high quality—2 barriers required for irrigation

3. Oxidation pond effluents—2 to 3 barriers required for irrigation

4. Effluents of medium quality—3 barriers required for irrigation

5. Effluents of low quality—only specific “no-barrier” crops are allowed to be irrigated

These standards set a low coliform limit of less than 10 *E. coli*/100 ml for very high quality reclaimed water that does not require additional barriers (the first quality listed

Table 8-4. Summary of Water Recycling Guidelines and Mandatory Standards in the United States and Other Countries

Country/Region	Fecal Coliforms (CFU/100ml)	Total coliforms (cfu/100 ml)	Helminth eggs (#/L)	BOD_5 (ppm)	Turbidity (NTU)	TSS (ppm)	DO (%of Sat)	pH	Chlorine residual (ppm)
Australia (New South Wales)	<1	<2/50	--	>20	<2	--	--	--	--
Arizona	<1	--	--	--	1	--	--	4.5-9	--
California	--	2.2	--	--	2	--	--	--	--
Cyprus	50	--	--	10	--	10	--	--	--
EC bathing water	100 (g) 2,000 (m)	500 (g) 10,000 (m)	--	--	2 (g) 1 (m)	--	80-120	6-9	--
France	<1000	--	<1	--	--	--	--	--	--
Florida (m)	25 for any sample for 75%	--	--	20	--	5	--	--	1
Germany (g)	100(g)	500 (g)	--	20 (g)	1-2 (m)	30	80-120	6-9	--
Japan (m)	10	10	--	10	5	--	--	6-9	--
Israel	--	2.2 (50%) 12(80%)	--	15	--	15	0.5	--	0.5
Italy	--	--	--	--	--	--	--	--	--
Kuwait Crops not eaten raw	--	10,000	--	10	--	10	--	--	1
Kuwait Crops eaten raw		100		10		10			1
Oman 11A	<200	--	--	15	--	15	--	6-9	--
Oman 11B	<1000			20		30		6-9	
South Africa	0 (g)	--	--	--	--	--	--	--	--
Spain (Canary islands)	--	2.2	--	10	2	3	--	6.5-8.4	1
Texas (m)	75(m)	--	--	5	3	--	--	--	--
Tunisia	--	--	<1	30		30	7	6.5-8.5	--
UAE	--	<100	--	<10	--	<10	--	--	--
United Kingdom Bathing Water Criteria	100 (g) 2000 (m)	500 (g) 10000 (m)	--	--	2 (g) 1 (m)	--	80-120	6-9	--
US EPA (g)	14 for any sample, 0 for 90 %	--	--	10	2	--	--	6-9	1
WHO (lawn irrigation)	200 (g) 1000 (m)	--	--	--	--	--	--	--	--

Note: (g) signifies that the standard is a guideline and (m) signifies that the standard is a mandatory regulation
Source: Adapted from Cranfield University, 2001. Urban Water Recycling Information Pack, UK

above) and can be used for irrigation of vegetables eaten raw. Additional barriers are identified as:

- Physical barriers, such as: buffer zones, plastic groundcovers and underground drip irrigation

- Crops or fruits that are normally treated under high temperature and/or are eaten only cooked (e.g., wheat), as well as those with an inedible peel or shell (e.g., citrus, banana, nuts)

No-barrier crops are defined in the following categories: (1) industrial crops (such as cotton or fodder); (2) crops whose harvestable parts are dried in the sun for at least 60 days after the last irrigation (including sunflower, wheat, chickpeas intended for cooking); (3) watermelon for edible seeds or for seeds that are irrigated before flowering; (4) woody crops or plants with no public contact; and, (5) grass for sale with no public access to the plot.

The government of Tasmania, Australia, issued the tenth draft of its, "*Environmental Guidelines for the Use of Recycled Water in Tasmania*" (Tasmanian website). These guidelines are intended to provide a framework to allow sustainable water reuse in a manner that is practical and safe for agriculture, the environment, and the public while also remaining consistent with industry standards and best environmental practice management (Dettrick and Gallagher, 2002). Issues of soil sustainability, including permeability hazard, salinity hazard, groundwater protection, and crop health, are discussed in the guidelines. A comprehensive health risk management framework is provided that gives different levels of risk management for 3 quality classes of wastewater including: backflow prevention, public access and withholding, safety for workers dealing with reclaimed water, food safety issues, and grazing animal withholding. The Tasmanian guidelines identify 3 categories of reclaimed water:

- Class A **Recycled** Water: No restriction on public access less than 10 cfu /100 ml

- Class B **Reclaimed** Water: Limited restrictions apply less than 100 cfu /100 ml or less than 1,000 cfu/100 ml depending upon type of application

- Class C **Treated** Water: Access restricted less than 10,000 cfu/100 ml

No potable reuse or body contact with reclaimed water is addressed in the Tasmanian guidelines because of the high level and cost of treatment necessary to produce the requisite quality reclaimed water. Irrigation of treated wastewater to riverside land less than 6 miles (10 kilometers) upstream of a town water supply intake is generally not permitted.

8.4.2.2 Treatment Requirements

Wastewater treatment is the most effective way to reduce the health, environmental, and other risks associated with the use of reclaimed water. Choosing the most appropriate treatment technology for water reuse is a complex procedure that must take into consideration various criteria, including technical and regulatory requirements, as well as social, political, and economic considerations specific to the local conditions. It is important to stress that economic and financial constraints have to be taken into account in countries where reclaimed water is a vital water resource for sustainable development.

Depending on water quality objectives, plant capacity, land availability, and climate conditions, extensive low-tech technologies, also known as non-conventional processes, can be used in water reuse facilities. Wastewater treatment processes, such as stabilization ponds or lagooning, infiltration-percolation, soil-aquifer treatment, and wetlands, are well adapted to the climate conditions in tropical and subtropical zones. Their relatively low OM&R costs and easy upkeep are important advantages for developing countries. However, these treatment technologies require large land availability, are associated with high evaporation losses resulting in high salinity concentrations, and are recommended predominantly for small treatment units, with less than 5000 population equivalents (700 m^3/d or 0.2 mgd) (Lazarova *et al.,* 2001).

Over the last decade, an increased number of studies conducted in different countries have shown that stabilization pond systems in series can produce effluent with microbiological water quality suitable for unrestricted irrigation (WHO guidelines category A, less than 1000 FC/100 ml and less than 1 helminth egg/L) (Lazarova, 1999). The hydraulic residence time varies in the range of 20 to 90 days according to the climate conditions and the optimal lagoon depth is 1.2 to 1.5 meters. Under optimal operating conditions, the disinfection efficiency is 3 to 5 log removal, with maximum values up to 5 to 6 log removal for fecal coliforms. A removal rate of 5 to 6 log of fecal coliforms in stabilization ponds can only be achieved if maturation ponds are provided. Stabilization ponds operating in Brazil have been shown to provide a 3-log removal of intestinal nematodes (Mara and Silva, 1986).

One of the drawbacks of using a stabilization pond system is the restricted operation flexibility, especially during flow and seasonal variations. Activated sludge treatment used in conjunction with tertiary treatment ponds has proven to be a reliable and efficient method for disinfection with the elimination of fecal coliform, viruses, and helminth eggs. The ponds also provide the required storage capacity for irrigation. High evaporation rates, particularly in dry and windy zones, are the major disadvantage of this treatment technology.

The increased use of constructed wetlands in developing countries has been slow, despite favorable climate conditions. Adequate wetlands systems designs for tropical and subtropical zones have not yet been developed. Several field studies performed in constructed wetlands for secondary treatment show that the pathogen reduction (2 to 3 log reduction of fecal coliforms and coliphages) is not sufficient to satisfy the WHO water quality guidelines for irrigation.

Larger cities with existing sewage systems are the most promising locations for implementing water reuse. Conventional treatment is likely to be the treatment of choice because of limited land availability, the high cost of land, the considerable transmission distance to reach the treatment site, and lack of public acceptability, particularly as city growth nears the vicinity of the treatment sites.

With the increased concern for public health, choosing a disinfection technology is recognized as one of the critical steps in developing a water reclamation system. The treatment quality upstream of disinfection has a great impact on the doses required for a given disinfection level. Therefore, if a stringent regulation must be met, disinfection alone cannot make up for inefficient upstream treatment and often must be coupled with tertiary filtration or other advanced treatment processes. The growing use of ultraviolet (UV) technologies for disinfection in wastewater reuse plants worldwide is largely attributed to low costs, as well as the absence of toxic byproducts. One drawback to using UV disinfection in reuse systems is the lack of disinfection residual, which is mandatory in distribution tanks, holding tanks, and reservoirs.

In addition to appropriate treatment technology, adequate monitoring is also important. Although not always feasible in developing countries, on-line, real-time monitoring is preferable to sampling and laboratory analysis where the results arrive too late to take corrective action. A simple and useful measurement of water quality for reclaimed water is turbidity. Experience can relate turbidity to other parameters of interest but, more importantly, a sudden increase in turbidity beyond the operating standard provides a warning that corrective action is required. For example, practice in the U.S. often requires that, should the turbidity exceed 2 NTU for more than 10 minutes, the reclaimed water be diverted to storage to be retreated.

Treatment cost is an extremely important consideration everywhere, but especially where financial resources are very limited. A recent analysis by Lazarova (2001) summarized the unit costs of various treatment levels for a 40,000 population-equivalent size treatment plant. The results are shown in **Table 8-5**. The treatment costs for producing reclaimed water are highly influenced by local constraints, such as the price of the building site, distance between the production site and the consumers, and whether or not there is a need to install a dual distribution system or retrofit an existing system.

8.4.3 Institutional Issues

Planned water reuse is best accomplished through the collaboration of at least 2—and often more—institutions. Without collaboration, only unplanned or incidental water reuse might occur. The institutions with a stake in water reuse include those responsible for water supply, wastewater management, water resources management, environmental protection, and public health and, in many cases, agriculture. Furthermore, these agencies may have responsibilities at local, regional and national levels. More often than not, there is a wide chasm between these agencies. Acknowledging that the ideal situation rarely exists, and that there is an institutional barrier to developing a new water reuse initiative, overcoming barriers and forgoing the necessary links among agencies should be the first step in any planning effort. An administrative reorganization may be necessary to guarantee the development of water reuse into a general water management group. Examples of such changes include those taking place in developing countries like Tunisia, Morocco, and Egypt. Ideally, it would be most desirable to have just one agency in charge of the entire water cycle in a given hydrologic basin.

A critically important "partner" in a safe and successful water reuse program is the independent regulatory agency with oversight and enforcement responsibility over all the partners involved in water reuse. It would be a conflict of interest for either the water supplier or the wastewater manager to have this regulatory role; therefore, the most logical "home" for the regulatory function is with the agency charged with protection of public health and/or the environment.

8.4.4 Legal Issues

There are 2 basic types of legal issues relevant to water reuse: (1) water rights and water allocation; and (2) the protection of public health and environmental quality. Other legal issues may also be relevant in specific circumstances.

8.4.4.1 Water Rights and Water Allocation

Diverting existing wastewater flows to a treatment facility will, at a minimum, change the point at which the flow is discharged to surface waters, and may change the amount of water available to current users further downstream. A water reuse project may completely deprive existing users of their current supply if reclaimed water is sold to new users (e.g., industrial facilities) or allocated to new uses (e.g., municipal use).

Traditional practice and customary law in most developing countries recognizes that a water user acquires vested rights. Changing the amount of water that is available to a current user may entitle the user to some type of remedy, including monetary compensation or a supplemental water supply. A proposed water reuse project needs

Table 8-5. Life-Cycle Cost of Typical Treatment Systems for a 40,000 Population- Equivalent Flow of Wastewater

Treatment System	Unit Cost[1]		
	per m^3	per AF	per MG
Stabilization Ponds (Land Cost not Included)	$0.18	$222.00	$0.68
Activated Sludge (Secondary)	$0.34	$420.00	$1.29
Activated Sludge + Filtration + UV Irradiation	$0.42	$518.00	$1.59
Additional Cost of Full Tertiary Treatment (Title 22)	$0.24	$296.00	$0.91
Additional Cost of Disinfection	$0.07	$86.00	$0.26
Lime Pretreatment + Reverse Osmosis (After secondary treatment)	$0.75	$926.00	$2.84
Microfiltration + Reverse Osmosis (After secondary treatment)	$0.54	$667.00	$2.04

[1] Cost in U.S. Dollars
Adapted from Lazarova, 2001

to consider the impact on current patterns of water use and determine what remedies, if any, are available to or should be created for current users if the project interferes with their water uses.

8.4.4.2 Public Health and Environmental Protection

The use of reclaimed water for agricultural irrigation and various municipal uses may result in human exposure to pathogens or chemicals, creating potential public health problems. Water reclamation and reuse, and the disposal of sludge from wastewater treatment, may also have adverse effects on environmental quality if not managed properly.

Planning for water reuse projects should include the development and implementation of regulations that will prevent or mitigate public health and environmental problems. Such regulations include:

- A permit system for authorizing wastewater discharges
- Water quality standards for reclaimed water that are appropriate for various uses
- Water quality standards for river discharge when water reuse is seasonal, intermittent, or less than the effluent rate of the wastewater treatment facility
- Controls that will reduce human exposure, such as restrictions on the uses of reclaimed water
- Controls on access to the wastewater collection system and controls to prevent cross-connections between the distribution networks for drinking water and reclaimed water
- Regulations concerning sludge disposal and facility location
- Mechanisms for enforcing all of the above regulations, including monitoring requirements, authority to conduct inspections, and authority to assess penalties for violations

A number of other legal issues discussed in Chapter 5 are also relevant to developing countries.

8.4.5 Economic and Financial Issues

The economic justification for water reuse depends principally on either offsetting the costs of developing additional water sources or on reducing the overall wastewater treatment costs. The full cost of developing and managing the water supply, wastewater management system, and water reuse system needs to be understood in order to conduct a rigorous economic analysis.

The economic rationale for water reuse outside of the U.S. does not differ much from that set out in Chapter 6. Benefits associated with water reuse include savings from not having to develop new water sources, reduced treatment requirements, and the economic value of the reclaimed water.

The enterprises responsible for water supply services in developing countries function with varying degrees of success, but increasingly, the utility companies recover their operating costs through user fees. User fees and/or public funds also have to fund the wastewater treatment system, if provided by the same institution.

8.5 Examples of Water Reuse Programs Outside the U.S.

Based on a review of water reuse projects outside the U.S., it can be concluded that the number of countries investigating and implementing water reuse has increased over the past decade. Hence, water reuse is growing steadily not only in water-deficient areas (Mediterranean region, Middle East, Latin America), but also in highly populated countries in temperate regions (Japan, Australia, Canada, North China, Belgium, England, Germany). The suitability of water reuse, especially in arid and semi-arid regions, is now nearly universally recognized. However, the societal ability and willingness to make the necessary investment for infrastructure improvement depends on local circumstances and varies considerably from country to country.

The principal reuse application remains agricultural irrigation, especially in developing countries. Urban, nonpotable reuse, such as reuse for, landscape irrigation, road cleaning, car washing, toilet flushing, and river flow augmentation, is developing rapidly in high density urban and tourist areas. Indirect potable reuse and the use of reclaimed water for industrial purposes have also been receiving increased attention in several industrialized countries. The only existing example of direct potable water reuse remains the Windhoek plant in Namibia. There have not been any adverse public health impacts reported during the 34 years of the plant's successful operation.

This section illustrates the applications of water reuse in several industrialized countries as well as several developing countries where an interest in reuse is just beginning. This inventory is intended to be illustrative rather than exhaustive. For the convenience of the reader, the case studies have been listed in alphabetical order.

8.5.1 Argentina

Argentina is characterized by various climatic zones: tropical, humid climate in the northeastern region with large rivers such as the Parana and Uruguay; mild and humid climate in the central flat region of the pampas with few sources of surface water; and arid and semi-arid regions in the west and south.

Only 35 percent of the population is connected to sewer systems and only part of the collected sewage undergoes appropriate treatment (Pujol and Carnabucci, 2000). Large-scale reuse of untreated wastewater has been occurring since the beginning of the 20th century in densely populated areas in the western regions of the country for the purpose of agricultural irrigation. Argentina requires that water reuse practices must be in compliance with the WHO standards, but in some regions, raw wastewater or minimally treated effluent are still being used for irrigation (Kotlik, 1998). In the large cities, there are plans to use trickling filters and activated sludge systems. In the arid areas, conventional stabilization ponds are used for treatment for agricultural reuse.

Driven by water scarcity, the largest water reuse system in Argentina is located in the arid region of Mendoza, in the western part of the country near the Andes. Over 160,000 m^3/d (42.3 mgd) of urban wastewater (1 million inhabitants, 100 Mm^3/year or 26,400 mg/year) is treated by one of the largest lagooning systems in the world at the Campo Espejo wastewater treatment plant with a total area of 290 hectares (643 acres) to meet the WHO standards for unrestricted irrigation by means of facultative stabilization ponds (Kotlik, 1998). Reuse water in this region is a vital water resource, enabling the irrigation of over 3,640 hectares (8,995 acres) of forests, vineyards, olives, alfalfa, fruit trees and other crops. Improved water reuse practices are under development to avoid contamination of aquifers, including establishment of special areas for restricted crops and restrictions in the choice of irrigation technologies. An extension of this water reuse system is planned in the northern region of the Mendoza City Basin, where the treated effluent from the Paramillo wastewater treatment plant (100,000 m^3/d or 26.4 mgd, series of stabilization ponds) is diluted with the flow from the Mendoza River and used for irrigation of a 20,000-hectare (49,420-acre) oasis.

8.5.2 Australia

8.5.2.1 Aurora, Australia

Aurora is a proposed new 650-hectare development to be located in the outer northern suburbs of Melbourne, Australia. The development is intended to showcase sustainable development principles. A key feature will be water conservation, with a plan to utilize recycled treated wastewater for nonpotable use. The work undertaken so far indicates that with water reuse and demand management combined, there is the potential to reduce the demand on the potable reticulated system in the order of 70 percent. Construction was planned to commence in 2003, with an estimated 15 years before full development, at which stage, around 9,000 dwellings will exist, housing a population of 25,000.

Reuse systems completed to date convey wastewater to a decentralized treatment plant and distribute it via a separate, metered pipe system back to each dwelling. At present, Melbourne's typical separate water systems include potable water supply, wastewater collection, and storm water collection. The recycled pipes will therefore represent a fourth system that will be plumbed for irrigation and toilet flushing.

Wastewater will need to be treated to Class A standards to meet the state's Environmental Protection Agency and Department of Health requirements for the intended use. Class A standards require treated effluent to achieve the following standards:

- 10 *E.coli* per 100 ml
- 1 helminth per liter
- 1 protozoa per 50 liters
- 1 virus per 50 liters

It is envisioned that the project will utilize surface storage; however, aquifer recharge and recovery is being investigated as another mechanism for water balancing. Despite these 2 potential methods, it is anticipated that there will be continual need for the facility to discharge treated effluent into the local waterway during times of high rainfall. An environmental impact study is being conducted for both the groundwater and stream to determine adequate water quality standards for discharge to occur. At this stage, it appears that discharge targets for the stream releases will need to meet Class A standards, as well as to keep phosphorus and nitrogen below 0.1 mg/L and 1 mg/L, respectively.

8.5.2.2 Mawson Lakes, Australia

Mawson Lakes will be an innovative urban development 12 kilometers (7.5 miles) north of Adelaide, designed to integrate evolutionary strategies into economic, social, and environmental activities. The development is designed for 8,000 to 9,000 residents in 3,200 dwellings, and includes a town center and commercial properties.

A key component of the development is to create a reclaimed water supply system that will reduce household potable demand by at least 50 percent by providing reclaimed storm water and wastewater for outdoor, domestic, and municipal irrigation. Stormwater run-off from roofs, paths, roads, and the general area, as well as treated wastewater will be collected and treated, and then stored in groundwater aquifers for reuse. Houses have both a potable water main connection and a reclaimed water connection. The reclaimed water will be used for toilet flushing, garden irrigation, and car washing. Public open space will also be irrigated with reclaimed water.

Stormwater is to be harvested from the 620-hectare (1,532-acre) development site plus an equivalent area of adjoining industrial land. An established wetland adjacent to the development will augment the proposed system and provide additional storage for the harvested stormwater. Prior to entering the wetland system, the stormwater will be screened through a combination of gross pollution traps and wetland basins.

8.5.2.3 Virginia Project, South Australia

The Virginia pipeline project was built to transport over 20,000 megaliters (5,284 million gallons) of reclaimed water (approximately 20 percent of the wastewater produced in the Adelaide area) from the Bolivar Treatment Plant just north of Adelaide to the Virginia area. The secondary effluent from the treatment plant receives further treatment after transmission in a Dissolved Air Flotation Filtration (DAFF) system which improves the water quality to less than 10 *E. Coli*/ 100 ml – the Australian standard for irrigation for crops eaten raw. The reclaimed water system serves over 220 irrigators in the Virginia area - the majority of the customers are horticultural farmers who produce root and salad crops, brassicas, wine grapes, and olives.

The project was developed in response to 3 problems: nutrients in the secondary effluent were damaging an environmentally sensitive gulf, irrigators were experiencing declining yields, and there was an increase in salinity in underground aquifers. The reduced water resource was expected to cause reduced production and employment in an area which already faced high unemployment. Even though there were 3 drivers for a reclaimed water system, the project remained in the planning stages until 4 major issues were overcome: (1) project financing; (2) a public-private partnership; (3) water quality standards; and, (4) marketing. Multiple stakeholders including government, the water authority, regulatory authorities, potential customers, and the project developer further complicated the project; however, the common goal to see the project proceed overcame the individual interests of each party.

The project has been operating since 2000 and the owners are considering extending the system to meet demand that was unable to be met in the original development. There have been no public health concerns and

Table 8-6. Summary of Australian Reuse Projects

Project	Annual Volume (ML)	Annual Volume (MG)	Water Quality[1]	Application	Comment
Virginia	22,000	5,815	A	Unrestricted irrigation of horticultural crops including salad crops	Built to overcome problems from nutrient discharges and declining aquifer. Largest operating reuse project in Australia – completed in 2000.
South East Queensland	100,000+	26,420	A and C	Class A water similar to Virgina project in major horticultural region. Class C to cotton and cereal farms.	Major engineering, financial, economic, and social impact study recently completed estimating using all of Brisbane's wastewater – however, smaller project more likely to proceed.
Hunter Water	Up to 3,000	Up to 795	C and B	Coal washing and electricity generator cooling.	Operating in a location where labor relations are typically difficult.
Eastern Irrigation Scheme	10,000	2,645	C	Stage 1 - horticulture , public spaces, and golf courses. Stage 2 - distribution to homes for household gardens and toilet flushing.	Stage 1 water sold and project is under construction.
Barwon Water Sewer Mining	Up to 1,000	Up to 265		Agricultural and industrial uses.	Feasibility study only.
McClaren Vale	Up to 8,000	Up to 2,115	Class C	Application to vines for producing premium quality wine grapes.	System in operation. Annualized water price exceeds that for potable water.
Rouse Hill	Up to 1,500	Up to 400	Class A	Reclaimed water distributed to 15,000 households using a dual distribution system. Future plans to serve a total of 35,000 households.	System in operation.
Georges River Program	15,000 to 30,000	3,960 to 7,925	Varying standards based on application	50 kilometers (31 miles) Reclaimed water pipeline to serve existing potable water customers and new residential developments	Environmental Impact Statement completed and projected is to begin construction in 2004.
Other projects	---	---	All Class B or Class A	Applications include wine grapes, sugar, pasture and fodder, including that for dairy cattle, water cooling for an oil refinery, golf course and recreational area watering, tree lots, and dust suppression.	While exact numbers are not known there is likely to be more than 50 schemes and individual applications in Australia. Most state governments and water authorities have policies on reuse and devote efforts to developing new applications.

[1] Class A Water = less than 10 *E. Coli*/100 ml
Class B Water = less than 100 *E. Coli*/100 ml
Class C Water = less than 1,000 *E. Coli*/100 ml

there is continuous monitoring for environmental impacts such as accession of irrigation water to the water table and build-up of salts in the soil profile. **Table 8-6** gives a summary of this project and other reuse projects in Australia.

8.5.3 Belgium

Belgium has one of the lowest water availabilities among the countries of the European Union (EU) with 2000 m^3/capita/year (528,300 gallons/capita/year). Only 45 percent of the sewage is currently treated, with plans to treat almost all wastewater by 2006. The amount of wastewater reuse remains limited; nevertheless, using reclaimed water is becoming increasingly attractive to industries such as power plants and food processing plants. Other industries with high rates of water utilization or industries located in areas of dropping water tables or high summer water demand are also moving more towards water reuse. The elimination of wastewater discharge in environmentally sensitive areas is another incentive for developing water reuse projects.

There is one indirect potable reuse project that has proven to be a cost-effective and environmentally beneficial solution. The system not only provides additional water, but also provides a saltwater intrusion barrier. At the Wulpen wastewater treatment plant, up to 2.5 Mm^3/year (660 mg/year) of urban effluent is treated by microfiltration (MF) and reverse-osmosis (RO), stored for 1 to 2 months in an aquifer, and then used for water supply augmentation.

There was another attempt to reuse 10,000 to 24,000 m^3/d (2.6 to 6.3 mgd) of wastewater to recharge an aquifer in Heist; however, infiltration could not be achieved through the soil due to low hydraulic conductivity. The only other option was to do direct reuse. In the end, the project team decided to use surface water as the raw water source.

A third possible water reuse project is still under study. It involves the treatment of about 8,000 m^3/d (2.1 mgd) of effluent from the Waregem wastewater treatment plant for direct reuse in the neighboring textile industry. The technical feasibility study has shown that the required effluent quality can be obtained through the use of a combined process of sand filtration, MF, and RO.

8.5.4 Brazil

Brazil is one of the countries with the most abundant water resources (8 percent of the world's fresh water, equivalent to about 40,000 m^3/capita/year or 10.5 mg/capita/year in 2000). In spite of this, 80 percent of the fresh water in Brazil is in the Amazon basin in the northern region of the country, leaving 20 percent bounded to the area that concentrates about 65 percent of the population (southeastern, southern, and central-western Brazil) as seen in **Table 8-7**. Despite having a great potential of water, water conflicts occur in some areas of the country. For example, the Upper Tietê River Basin has about 18 million inhabitants and is one of the world's largest industrial complex, yet the region only has a specific water availability of only 179 m^3/capita/year (47,290 mg/capita/year). On the other hand, irrigation is growing steadily in the country, reaching a consumptive use of about 69 percent at national level.

The Law nº 9,433 of January, 1997, established the National Water Resources Policy and created the National Water Resources Management System. Since then, the country has had a legal instrument to ensure future generations the availability of water in adequate conditions. In July, 2000, the Law nº 9,984 created the National Water Agency, linked to the Ministry of the Environment, but with administrative and financial autonomy. Among several other attributions, the Agency will supervise, control, and evaluate the actions and activities resulting from compliance with the federal legislation; grant, by means of licensing, the right to use water resources in bodies of water that are in the Union domain; encourage and support initiatives to institute River Basin Committees; and collect, distribute, and apply revenues obtained by billing for the use of water resources in the Union domain, etc.

In a country with a population of 173 million in 2001, a full 60 percent of the population was not connected to sewer systems. Only 34 percent of the wastewater flow collected that was collected was treated in 1996. The situation has a clearly visible negative impact on the environmental quality of many of Brazil's urban river basins and public health. However, it is important to underline that Brazil achieved substantial progress with regard to the coverage of water supply and sanitation services over the past 3 decades, much of this effort being the fruit of the Government's National Water and Sanitation Program. In urban areas, access to potable water supplies rose from 50 percent in 1968 to 91 percent in 1997. Sewage coverage increased from 35 percent to 43 percent in the same period. The sewage coverage in urban areas was significantly improved to 85 percent in 2000.

There are a great deal of wastewater reuse planning and actions being implemented in Brazil. Most of them are associated with industrial projects: resource recovery, demand management, and minimization of effluent discharge. Municipalities recognize the benefits of nonpotable urban reuse and have started to make plans to optimize the use of local water resources. On the other hand, unplanned (and sometimes unconscious) agricultural reuse is performed in many parts of the country, particularly for the irrigation of fodder crops and vegetables. Water is diverted from heavily polluted sources to be applied to crops without treatment or adequate agronomic measures. It is expected that the new regulations to be placed into law by the Agency will regulate the practice nationwide, promoting at the same time, the implementation of public health and environmental safeguards to new projects.

8.5.4.1 São Paulo, Brazil

Metropolitan São Paulo, a city with 18 million people and a very large industrial complex, is located in a plateau in the heads of the Tietê River. A small amount of local water availability has forced the region to survive on the importation of water resources from neighboring basins. Two sources of water have been considered for reuse: municipal wastewater (which contains a significant amount of industrial effluents) and the volumes retained in flood control reservoirs. The available volumes for reuse and the corresponding quality of the treated effluents are shown in **Table 8-8**.

Three potential types of water reuse applications have been identified.

- **Industrial use**, for cooling towers, boiler feed water, process water in metallurgic and mechanical industries, floor washing, and irrigation of green spaces

Table 8-7. Water Demand and Water Availability per Region in the Year 2000

Region	Inhabitants	Specific Water Demand (m^3/capita/yr)	Specific Water Demand (gal/capita/yr)	Specific Water Availability (m^3/capita/yr)	Specific Water Availability (mg/capita/yr)	Demand (% of Available)
North	12,900,704	204	53,890	513,102	135.5	0.04%
Northeast	47,741,711	302	79,780	4,009	1.1	7.53%
Southeast	72,412,411	436	115,180	4,868	1.3	8.96%
South	25,107,616	716	189,150	15,907	4.2	4.50%
Central West	11,636,728	355	93,780	69,477	18.4	0.51%
Brazil	169,799.17	414	109,370	40,000	10.6	1.03%

Table 8-8. Effluent Flow Rate from Wastewater Treatment Plants in Metropolitan Sao Paulo

WWTP	Design Flow		Treated Flow [a]	
	(Mm^3/day)	(mgd)	(Mm^3/day)	(mgd)
ABC	0.26	68.47	0.13	35.38
Barueri	0.82	216.83	0.57	151.78
Parque Novo Mundo	0.22	57.06	0.13	33.32
São Miguel	0.13	34.24	0.05	13.69
Suzano	0.13	34.24	0.07	18.94
Total Flow	1.6	410.84	0.96	253.12

[a] data from operational data, March 2002

- **Restricted urban use**, for toilet and urinal flushing, vehicle, floor and street washing, decorative water features such as fountains, reflecting pools and waterfalls, cleaning sewer and flood galleries, preparation of concrete and soil compaction, irrigation of sports fields, parks, and gardens

- **Unrestricted urban use,** for irrigation of green areas where public access is restricted, as well as, irrigation of industrial and fodder crops and pastures.

8.5.4.2 São Paulo International Airport, Brazil

The São Paulo International Airport of Guarulhos has 2 terminals, each one handling about 7 million passengers per year. Terminal 3 will serve an additional 16 million passengers per year, to reach the saturation level of about 30 million passengers per year by 2030. An additional water demand, in the order of 3,000 m^3/d (792,500 gallons/d) will produce a total wastewater flow of 6,400 m^3/d (1.7 mgd). Groundwater is the sole source of water, and due to excessive pumping, the aquifer is recessing, increasing the potential for ground subsidence. A wastewater reuse project is in development to serve the uses listed in **Table 8-9.**

The second phase of the reuse project will include additional treatment units to provide effluents with conditions to allow for artificial aquifer recharge in the vicinity of the airport. Column testing is being conducted to design recharge basins and to define the level of pollutant removal on the unsaturated layer.

8.5.5 Chile

Water resources in Chile are abundant (61,007 m^3/capita/year or 16.1 mg/capita/year), with a strong prevalence of surface water with inhomogeneous geographical distribution. In 1997, water supply and sewage coverage were comparable to those in Europe, with over 99 percent in urban areas and 90 percent in rural areas (Homsi, 2000). Moreover, 90.8 percent of rural settlements are equipped with water supply systems. Wastewater treatment coverage is lower, at about 20 percent, with strong governmental efforts for coverage to more than double that capacity in the near future. Consequently, the driving factor for water reuse at a national level, and in particular in large cities such as Santiago de Chile, is pollution control.

Wastewater reuse has been practiced for years near the large cities. In the past, 70 to 80 percent of Santiago's raw wastewater has been collected into an open drainage canal and then distributed for irrigation. The irrigated area immediately outside the city provided almost all the salad vegetables and low-growing fruits to the population of Santiago, having a large negative impact on public health. In order to improve this situation and implement sound water reuse practices, plans have been made to treat all the wastewater from greater Santiago in 3 large and 13 smaller sewage treatment plants. The first large facility, in operation since November 2001, El Trebol, has an average capacity of 380,000 m^3/d (100 mgd). Another treatment plant, La Farfana, will have a capacity of 760,000 m^3/d or 200 mgd when completed. Five smaller sewage treatment works are also in operation, all using activated sludge processes for treatment. Treatment facilities constructed before the 1980s mainly used stabilization ponds for treatment.

8.5.6 China

Water reuse in China primarily occurs when rivers downstream from cities are used for irrigation. Most pollution is produced in the industrialized cities; therefore, pollution control was first aimed at industries. Over the last 10 years, increasing attention has been paid to municipal wastewater treatment. In 2001, there were 452 wastewater treatment plants, of which approximately 307 provided secondary or higher treatment. These plants served all or parts of 200 cities of the 667 cities in China. The total volume of wastewater generated was 42.8 billion m^3 (11,300 billion gallons), of which industry generated 20.1 billion m^3 (5,300 billion gallons) (47 percent) and non-industrial (domestic, commercial, and institutional) sources generated 22.8 billion m^3 (53 percent). In 2001, approximately 35 percent of municipal wastewater received treatment before discharge. Wastewater sector investment is rising dramatically; in 1999 the annual expenditure rose to over 12 billion RMB ($1.5 billion), an 8-fold increase from 1996.

Taiyuan, a city of 2 million people and the capital of the Shanxi Province, is located approximately 400 kilometers (249 miles) southwest of Beijing on the Fen River, a tributary to the Yellow River. The city stretches for 29 kilometers (18 miles) within the narrow valley of the Fen River, where water availability is limited, sporadic, and greatly affected by high sediment loads from the Great Loess Plateau. Terracing for agriculture and destruction of natural ground cover on this plateau create large dust storms as well as limitations on water retention during major rainstorms.

Under the $2 billion Yellow River Diversion Project (YRDP), partially funded by the World Bank, water is being conveyed 200 kilometers (125 miles) by tunnels and aqueducts from a reservoir on the Yellow River and pumped to a head of 600 meters (1,970 feet) into the Fen River, upstream from Taiyuan. Previously, the groundwater aquifer beneath the city supplied much of the domestic demand, as well as the large industrial self-supplied water demands of the steel, coal, and chemical industries in the city. Industries have made considerable progress in water reuse, with 85 percent of industrial water demand achieved through internal treatment and reuse of process water. The chemical industry has built an advanced centralized treatment facility to provide an additional source for industrial water reuse as well as 2 large power plants that reuse all effluent in slurry pipelines to ash disposal reservoirs.

Taiyuan is implementing an environmental master plan, under which 7 enhanced secondary wastewater treatment plants will be built (or existing plants upgraded and expanded) to treat about 900,000 m^3/d (238 mgd) by 2010.

Table 8-9. Water Reuse at the Sao Paulo International Airport

Use	Flow	
	(m^3/day)	(gal/day)
Toilets and Urinals in Terminal 3	2,175	574,575
Cooling Towers (Air Conditioning)	480	126,800
Airplane Washing	50	13,200
Floor Washing	15	3,960
Irrigation	10	2,640
Total Flow	2,730	721,200

Approximately 500,000 m^3/d (132 mgd) of effluent from these plants will be reused via groundwater recharge from the Fen River ponds. The ponds were built as an urban amenity under a subsidized public works program to provide work for the unemployed during a period of economic restructuring and plant closures. The Fen River ponds stretch nearly 5 kilometers (3.1 miles) along the river, for a total volume of 2 million m^3 (528 mg), and occupy about half the width of the riverbed. Inflatable dams and floodgates on the slope of the Fen River allow floods in excess of the 2-year flood flow to be passed through to the ponds. The course alluvium of the river bottom under the ponds is expected to allow sufficient recharge to meet industrial demands through the existing self-supplied wells.

Groundwater levels have been dropping rapidly, and groundwater quality has deteriorated in the upper aquifer from the buildup of nitrates from untreated municipal wastewater, as well as salinity in the concentrated wastes in industrial wastewater after extensive recycling. As a result, water reuse from the aquifer recharge system will be primarily for nonpotable, industrial process water.

In order to prevent a large buildup of salinity in the groundwater, a portion of the effluent from the municipal wastewater treatment plants will be discharged into the Fen River. However, downstream irrigation demands greatly exceed the available stream flow, and eventually Taiyuan may face restrictions on consumptive use to re-establish stream flow in the lower portions of the Yellow River. Currently the Yellow River runs dry seasonally over the last 300 kilometers (186 miles) of its length, which is detrimental to major cities and agricultural areas in the densely developed water-scarce North China Plain.

8.5.7 Cyprus

Cyprus is a mediterranean island with a population of 700,000 and a vigorous tourism industry. The country is facing 2 major obstacles in its continued development: (1) a growing scarcity of water resources in the semi-arid regions of the country and, (2) degradation of water at its beaches. The government has recognized that a water reuse program would address both problems. In addition, it is expected that reclaimed water will provide a reliable alternative resource for irrigation, which draws 80 percent of the total water demand (300 Mm^3/year or 79,250 mg/year).

The 25 Mm^3/year (6,600 mg/year) of wastewater generated by the main cities will be collected and used for irrigation after tertiary treatment (Papadopoulos, 1995). Since transmission costs will be high, most of the reclaimed water, about 55 to 60 percent, will most likely be used for amenity purposes such irrigation of greens areas in hotels, gardens, parks, golf courses and other urban uses. A reclaimed water supply of about 10 Mm^3/d (2,640 mgd) is conservatively estimated to be available for agricultural irrigation.

The provisional water reuse standards in Cyprus are stricter than the WHO guidelines. The disinfection level required for urban uses with unrestricted public access is 50 FC/100 ml (80 percent of the time, with a maximum value of 100 FC/100 ml). For other uses with restricted access and for irrigation of food crops; the standard is 200 FC/100 ml (maximum 1000 FC/100 ml), while for irrigation of fodder and industrial crops, the guideline values are 1000 and 3000 FC/100 ml, respectively.

8.5.8 Egypt

Approximately 96 percent of Egypt is desert; rains are rare, even in winter, and occur only in the north. In addition, oases and wells are limited and cannot accommodate water needs in the regions where they exist. Egypt relies heavily on the Nile River, which supplies essentially all of the country's water.

Presently, wastewater production is estimated at 4,930 million m^3/year (1.3 mg/year). There are 121 municipal wastewater treatment plants operating in Egypt treating 1,640 million m^3/year (0.43 mg/year). A total of 42,000 hectares (104,000 acres) are irrigated with treated wastewater or blended water. Since 1900, wastewater has been used to cultivate orchards in a sandy soil area at El-Gabal El-Asfar village, near Cairo. This area has gradually increased to about 1,000 hectares (2,500 acres). The most readily available and economic source of water suitable for reuse is the wastewater effluent from Greater Cairo, Alexandria, and other major cities.

No reuse guidelines have yet been adopted in Egypt, but the 1984 martial law regulation prohibits the use of effluent for irrigating crops, unless treated to the required standards for agricultural drainage water. The irrigation of vegetables eaten raw with treated wastewater, regardless of its quality level, is also forbidden. As a result, a USAID-funded project is developing new codes for safe use of reclaimed water for irrigation of crops with a focus on those that cannot be contaminated, such as wood trees, palm trees, citrus, pomegranates, castor beans, olives, and field crops, such as lupins and beans. However, despite this code development, no adequate planning, monitoring, and control measures are being taken, and, because of this, spreading of Schistomiasis is quite common.

8.5.9 France

France's water resources availability is 3,047 m^3/capita/year (0.8 mg/capita/year) (Earth Trends 2001), and therefore, is considered to be self-sufficient. However, an uneven distribution of hydraulic resources and increasing global water demand have led to seasonal deficits in parts of the country. The average water consumption has increased by 21 percent in the past 10 years. The agricultural sector has experienced the greatest increase of water use, 42 percent, mainly due to an increase in land irrigation. Water consumption has also increased in resort areas where water is needed to irrigate golf courses and landscape areas. The industrial sector is the only sector that has seen a decrease in water consumption, due to increasing efforts to reuse industrial effluents and use more water-efficient technologies. Recently, there has been a reduction in domestic water consumption.

France has been practicing nonpotable water reclamation since the 19^{th} century. Its oldest projects are the Achères water reclamation plant (near Paris) and the Reims plant**.** The main drivers for water reuse in France are to: (1) compensate for water deficiencies, (2) improve public health, (3) to protect the environment, and (4) eliminate contamination in recreational and shellfish farming areas along the Atlantic coast. The majority of water reuse projects are found in the islands and in coastal areas in the southern part of the country.

Numerous cases of unplanned indirect potable reuse exist in France, where surface water, diluted with wastewater, is used for potable water supply. An example is Aubergenville, in the Paris region, where the Seine River, which is 25 percent wastewater effluent, is treated and used to recharge the drinking water aquifer.

Clermont Ferrand is a large agricultural reuse project that was implemented in 1999 as a response to water shortages and economic concerns. The wastewater treatment facility consists of an activated sludge process and maturation ponds for disinfection. Over 10,000 m^3/d (2.6 mgd) are used to irrigate 750 hectares (1,850 acres) of maize.

One of the first examples in Europe of integrated water management with water reuse is on Noirmoutier Island. The lack of water resources, the 10-fold increase in tourist population during the summer, and the intensive agricultural activities required water reuse. Wastewater treatment on the island is achieved through 2 treatment plants with a total capacity of 6,100 m^3/d (1.6 mgd). The plants have activated sludge systems followed by maturation ponds for storage and disinfection. Thirty percent of the treated wastewater (0.33 Mm^3/year) is used for the irrigation of 500 hectares (1,235 acres) of vegetable crops. There are plans to reuse 100 percent of the wastewater flow in the near future.

The country's regulatory framework (Circular n° 51 of July 22, 1991, of the Ministry of Health) is based on the WHO guidelines (1989). But France's regulations are more stringent having additional requirements concerning irrigation management, timing, distance and other measures for preventing health risks related to human exposure and negative environmental impacts (i.e. the potential contamination of groundwater). New water reuse guidelines are under preparation with the introduction of some new microbiological indicators for unrestricted irrigation (i.e. Salmonella, Taenia eggs), as well as more stringent operational restrictions.

8.5.10 Greece

Greece has a severe water imbalance, particularly in the summer months, due to low precipitation and increased demands for irrigation and water use. Water demand in Greece has increased tremendously over the past 50 years (Tchobanoglous and Angelakis, 1996). Despite adequate precipitation, water shortages are often experienced due to temporal and regional variations in precipitation, the increased water demand during the summer months, and the difficulty of transporting water through the mountainous terrain. As a result, the integration of water reuse into the water resources management is becoming a very important issue.

In 2000, almost 60 percent of the population was connected to 270 wastewater treatment plants, with a total capacity of 1.30 Mm^3/d (345 mgd). An analysis of treated domestic wastewater distribution of showed that more than 83 percent of wastewater effluent is produced in regions with a deficient water balance (Tchobanoglous and Angelakis, 1996). This indicates that water reuse in these areas would satisfy a real water demand. Another important factor driving the use of reclaimed water is that 88 percent of the wastewater effluents are located at a distance of less than 5 kilometers (3.1 miles) from farmland needing irrigation water; therefore, the additional cost for irrigation with reclaimed water would be relatively low.

According to Tsagarakis *et al*. (2000), over 15 wastewater treatment plants are planning to reuse their effluents for agricultural irrigation. The major water reuse projects being planned or constructed are listed in **Table 8-10**. Unplanned reuse still occurs in some regions, where wastewater is discharged to intermittent rivers and, after infiltration, is pumped through adjacent wells by farmers.

Guidelines for water reuse are under consideration by the Ministry of Environment and Public Works (Angelakis

Table 8-10. Major Reuse Projects

Plant Name	Capacity		Uses
	m^3/day	mgd	
Levadia	3,500	0.925	Irrigation of cotton
Amfisa	400	0.106	Olive tree irrigation
Palecastro	280	0.74	Storage, olive tree Irrigation
Chalkida	13,000	3.434	Landscape and Forestry irrigation
Karistos	1,450	0.383	Landscape and Forestry irrigation
Ierisos	1,200	0.317	Landscape and Forestry irrigation
Agios Konstantinos	200	0.053	Landscape and Forestry irrigation
Kentarchos	100	0.026	Landscape and Forestry irrigation

et al., 2000). Six water reuse categories are being considered: nonpotable urban, agriculture, aquaculture, industrial, environmental, and groundwater recharge. The criteria are more stringent requirements than the WHO guidelines. Secondary effluent quality criteria are used for discharging purposes (No E1b/221/65 Health Arrangement Action) and are independent of the disposal, reclamation, and reuse effort.

8.5.11 India

India is the second most populous country of the world, with a current population of over 1 billion that is projected to increase to 1.5 billion by 2050 (Worldwatch Institute, 1999). Almost 30 percent of the population lives in urban mega-cities, in particular, in the 7 giant conglomerates of Mumbai (formerly Bombay) (12.57 million), Calcutta (Kolkata) (10.92 million), Delhi (8.38 million), Chennai (formerly Madras) (5.36 million), Bangalore (4.09 million), Hyderabad (6 million), and Ahmedabad (3 million). Fast depletion of groundwater reserves, coupled with India's severe water pollution, have put India in a challenging position to supply adequate amounts of water to their growing population. In 2000, India's total renewable water resources were estimated at 1,244 m^3/capita/year (328,630 gallons/capita/year) (Earth Trends, 2001) and it was estimated that 40 percent of India's water resources were being withdrawn, with the majority of that volume (92 percent), used for agricultural irrigation.

As a result of the fast-growing urban population, service infrastructure is insufficient to ensure public health. In fact, about 15 percent of the urban population does not have access to safe drinking water and about 50 percent is not serviced by sanitary sewers. In 1997, the total volume of wastewater generated in India was 17 Mm^3/d (4,500 mgd), of which 72 percent was collected and only 24 percent was ever treated. These conditions cause a high number of waterborne diseases in the country (more than 30 million life years according to the World Bank).

The capital city of Delhi is one illustration of failing service infrastructure and deteriorating environment. The growing population in Delhi has led to an increase in the volume of wastewater, yet the current treatment capacity is only about 1.3 Mm^3/d (3,400 mgd) – which is only 73 percent of the wastewater generated. Another example is Mumbai, where 2.3 Mm^3/d (608 mgd) of raw sewage is discharged into the Arabian Sea. However, there have been some attempts at rectifying these situations. The large, $300 million, Bombay Sewage Disposal Project was approved in 1995 with the financial support of the World Bank. Other efforts have been made in the Calcutta metropolitan area, where 13 sewage treatment plants have been constructed with a total capacity of 386,000 m^3/d (102 mgd) using either activated sludge processes, trickling filters, or oxidation ponds. In addition, the Ganges River program is to include treatment facilities for 6 cities in Uttar Pradesh that will incorporate reuse for agriculture and forestry.

In 1985, over 73,000 hectares (180,000 acres) of land were irrigated with wastewater on at least 200 sewage farms. There has been a dramatic increase in wastewater volumes discharged and used for agricultural irrigation in India. With its current population, Hyderabad can supply wastewater to irrigate an estimated 40,000 hectares (99,000 acres). The law prohibits irrigation of salad vegetables with wastewater, yet the prohibited practice is widespread and government agencies reportedly do not actively enforce regulations governing reuse. Furthermore, in many states there is no microbiological standard and hence no parameter to control the level of treatment. Enteric diseases, anemia, and gastrointestinal illnesses are high among sewage farm workers. Consumers of salad and vegetable crops are also at risk.

8.5.11.1 Hyderabad, India

Hyderabad, the capital city of Andhra Pradesh, is the fifth largest and the fastest growing city in India with 6 million inhabitants (2001). The city produces over 700,000 m^3 (185 mg) of wastewater per day, of which less then 4 percent receives secondary treatment. The remaining 95 percent of the wastewater is disposed, untreated in the Musi River. The Musi River is the main source of irrigation water for over 40,000 hectares (98,840 acres) of agricultural land. Agriculture is the sole livelihood of over 40,000 farming families living within a 50-kilometer (31-mile) radius of Hyderabad.

Downstream of Hyderabad, the Musi River water is diverted through a system of weirs into irrigation canals (see photo) that were originally designed to retain water for the dry season after the monsoon rain. Farming communities along the Musi River experience negative and positive impacts from the discharge of wastewater into the river. Perceived negative impacts include an increase in reported fever cases, skin rash, joint aches, and stomach problems. Positive impacts include savings in chemical fertilizer application and larger crops as a result of a year-round availability of water, which without the addition of wastewater, would have been confined to the monsoon season. The main crops grown are fodder, rice, and bananas, as well as different varieties of spinach and other vegetables. Data reported that water samples taken out of the Musi River, 40 kilometers (25 miles) downstream of Hyderabad, have normal river water quality parameter readings including a gradual reduction in BOD, COD, and coliform. The coliform counts reported were within the WHO guidelines set for unrestricted irrigation.

8.5.12 Iran

Iran is one of the largest countries in the Middle East, with an area of more than 165 million hectares (407 million acres) and a population of over 60 million (Shanehsaz *et al.,* 2001). The average annual precipitation over the country is less than 250 mm (10 inches). Distribution of rainfall in Iran is not uniform, with some very urbanized areas receiving even less than the average annual precipitation.

In 1994, the volume of municipal wastewater generated in all urban and rural areas of the country (potentially reclaimable as a water resource if a collection system were in place) was estimated to be 3,100 Mm^3/year (2.5 million acre-feet per year), and projected to increase to 5,900 Mm^3/year (4.8 million acre-feet per year) by 2021. [Agricultural return flows and industrial wastewaters are not included in these figures.] These immense volumes are now largely disposed of at the point of generation, through cesspits, without treatment. If collected, properly treated, distributed, and safely utilized, these volumes of water could go a long way toward meeting the burgeoning demands for agricultural and industrial water demand of the nation. Planned water reuse projects currently produce 154 Mm^3/year (125,000 acre-feet per year) of reclaimed water.

In fact, recently, the government of Iran approved a recommendation to establish and implement programs for, among other water-related initiatives, comprehensive reclamation and use of non-conventional water resources—such as reclaimed water. The public also accepts water reclamation and reuse as a sensible way to maximize the use of a limited resource. In the past, effluent was used primarily to fertilize the soil, but now wastewater effluent is increasingly used for improving water use efficiency, surface and groundwater pollution prevention, and to compensate for a shortage of irrigation water. Other driving forces for water reuse include expansion of greenbelts, soil erosion prevention by growing plants and improving soil quality, and control of the desertification process.

Hyderabad, India – wastewater being diverted over weir into irrigation canals. Source: International Water Management Institute

Iranian farmers generally consider wastewater an acceptable water resource for irrigation. There are studies in Iran examining the use of treated effluent for irrigation water in the suburban farms, mainly for fodder crops such as corn, millet, and alfalfa. Systematic studies have shown that there is a significant decrease in water use and fertilizer consumption due to nutrients in the effluent.

At present, there is no national standard for the reuse of treated wastewater. The only existing wastewater code in Iran is the “Effluent Discharge Standard” developed by the Department of the Environment in 1994. This standard determines the allowable effluent discharges to surface waters, cesspits, and agricultural irrigation; however, the standard does not provide any criteria for the use of reclaimed water for industrial use, fisheries, or recreational activities. Microbiological criteria in this standard are inadequate for the purposes of water reclamation and reuse; therefore, reliable international standards, such as those developed by the WHO and by the EPA, are currently used to regulate water reuse. The responsibility and authority for water reuse is scattered and fragmented, as it is in many other parts of the world. Institutions responsible for the management of various aspects of water, wastewater, water reclamation and reuse in Iran are the Ministry of the Energy, Ministry of *Jihad* and Agriculture, Ministry of Health and Medical Education, Ministry of Industries and Mines, and the Department of the Environment.

Despite governmental edicts prohibiting the use of untreated wastewater in irrigation and agriculture, there are still some places in Iran where the farmers use raw wastewater, due to a shortage of fresh water supplies. Unplanned use of wastewater is observed in cities with no sanitary sewage systems and no wastewater treatment plants. The government, at all management levels, has struggled to maximize the benefits of reuse and is working to accomplish this by giving appropriate priorities to water use in various sectors, and by encouraging wastewater reclamation and reuse through allocation of the necessary financial resources. Considering that wastewater treatment and water reclamation are relatively new in Iran, 2 of the most important approaches used by the government are economical incentives and management tools. Operational permits are issued for the use of surface water or groundwater, municipal distribution networks, and the continuance of previously issued permits. These permits are now conditioned with requirements for implementation of sewage systems and wastewater treatment plants. Until such systems are implemented, entities that consume water are required to pay penalties in proportion to their discharge volumes and based on established tariffs. A percentage of the income from the collected penalties is channeled to the Department of Energy to fund water conservation and wastewater treatment construction projects.

8.5.13 Israel

The acute shortage of fresh water throughout most of Israel prompted the development of a nationwide integrated water management system. As a result of the water crisis, with repetitive droughts between 1996 and 2002, Israel turned to water conservation and alternative water resources including the most widely practiced form of water reuse, reclaiming municipal water from medium and large cities for irrigation of agricultural crops.

In several water reuse projects in Israel, deep, surface reservoirs are used to store effluent during the winter season and the water is then used during the summer irrigation season. There are approximately 200 of these reservoirs in operation throughout the country with a total storage capacity of 150 Mm^3 (40,000 mg). Most of these reservoirs also serve as surface water storage and additional treatment. The oldest, and by far the largest reuse project, is the Dan Region Project, which incorporates soil-aquifer treatment (SAT) and storage in a groundwater aquifer.

Water reuse represents approximately 10 percent of the total national water supply and almost 20 percent of the total water supply for irrigation. Nearly 70 percent of the municipal wastewater collected is treated and reused for irrigation. As a result of this nationwide effort, Israel currently supports its increasing population, industrial growth, and intensive irrigation demand with a water supply of less than 400 m^3/capita/year (105,700 gallons/capita/year), while the benchmark value for water stress is available renewable water resources of 1700m^3/capita/year (449,000 gallons/capita/year). Israel’s objective is to treat and reuse most of its wastewater by 2010 (400 Mm^3 or 106,000 mg per year, 20 percent of the country’s total water resources). Most of the reclaimed water would be used for the irrigation of crops and animal fodder in accordance with the regulations put forth by the Ministry of Health.

Pumps transfer water from the withdrawal wells to irrigation zones in the Negev Desert, Israel. Photo courtesy of Bahman Sheikh

The 2 largest reuse projects are the Dan Region Reclamation Scheme and the Kishon Scheme. The Kishon facilities treat 32 Mm^3/year (8,450 mg/year) of wastewater from the Haifa metropolitan area using a conventional activated sludge system. After treatment, the reclaimed water is conveyed to the Yiszre'el Valley, approximately 30 kilometers (18.6 miles) east of Haifa, where it is blended with local waste and stormwater and then stored in a 12-Mm^3 (3,170-mg) reservoir for summer irrigation of 15,000 hectares (37,000 acres) of cotton and other non-edible crops. The Dan Region reuse system serves the Tel Aviv metropolitan area of approximately 1.7 million inhabitants. The facilities include a 120-Mm^3/year (31,700-mg/year) mechanical biological plant (Soreq wastewater treatment plant). After biological treatment, the wastewater is discharged to aquifer recharge basins and stored in the aquifer. The reclaimed water is then pumped from recovery wells and conveyed to irrigation areas on the southern coastal plain and the northern Negev area (see photo). Some areas only receive auxiliary irrigation of 4,000 to 8,000 m^3/hectares/year (0.4 to 0.8 mg/acres/year); while more intensely irrigated areas use 10,000 to 20,000 m^3/hectares/year (1.1 to 2.2 mg/acres/year).

There are 3 other significant reuse projects in the Jeezrael Valley (8 Mm^3/year or 2,100 mg/year), Gedera (1.5 Mm^3/year or 400 mg/year), and Getaot Kibbutz (0.14 Mm^3/year or 37 mg/year). All 3 of these reuse projects produce reclaimed water for the irrigation of over 40,000 hectares (98,840 acres) of agricultural lands.

8.5.14 Italy

Like most Mediterranean regions, southern Italy (particularly Sicily, Sardinia, and Puglia) suffers from water shortage and lack of quality water due to recurrent droughts (Barbagallo *et al.,* 2001). In addition, wastewater discharge into rivers or the sea has lead to significant environmental problems and eutrophication. Available water resources are estimated to be 2,700 m^3/capita/year (713,260 gallons/capita/year), with a water volume of about 155 billion m^3 (41,000 billion gallons). According to the recent estimates, the potential water resources in Italy are less than 50 billion m^3 (13,200 billion gallons) when considering the actual hydraulic infrastructures with relatively low water availability of about 928 m^3/capita/year (245,150 gallons/capita/year).

The deficient and unreliable supply of irrigation water, besides reducing production most years, has strongly limited irrigation development. Forecasts for irrigation water demand show steady increases in many areas, not only in southern Italy and the islands.

The reuse of untreated wastewater in Italy has been practiced since the beginning of the 20th century. Among the oldest and noted cases is the "marcite", where water from the Vettabia River, which has a high content of industrial and urban raw wastewater, is used for irrigation. However, this practice has been decreasing due to poor water quality. The only negative impact reported is an instance where a high concentration of boron damaged very sensitive crops, such as citrus.

The present lack of water resources and the growing demand for domestic, industrial, and agricultural consumption has prompted research into non-conventional supplies. Reclaimed water is beginning to be considered a cost competitive source, playing an increasingly important role in water resource management. A survey of Italian treatment plants estimated the total treated effluent flow to be 2400 Mm^3/year (634,000 mg/year), all estimated to be potential reuse water. The medium to large plants in Italy treat approximately 60 percent of the urban wastewater flow and can produce reclaimed water to an adequate quality at a reasonable cost.

Currently, reuse water is used mainly for agricultural irrigation of over 4,000 hectares (9,800 acres) of land. However, the controlled reuse of municipal wastewater in agriculture is not yet developed in most Italian regions because of stringent legislation, which ignores the findings of recent research works and experiences of uncontrolled reuse in Southern Italy. One of the largest reuse projects was implemented in Emilia Romagna where over 1,250 m^3/d (0.3 mgd) of treated effluent from the towns of Castiglione, Cesena, Casenatico, Cervia, and Gatteo are used for irrigation of more than 400 hectares (980 acres).

According to a recent survey (Barbagallo *et al*., 2001), 16 new water reuse projects for irrigation purposes have been selected for implementation in water-scarce regions. In Sicily, where uncontrolled wastewater reuse is very common, several new reuse systems have been planned, using seasonal storage reservoirs. In Grammichele, about 1,500 m^3/d (0.4 mgd) of reclaimed water will be used for the irrigation of citrus orchards. Recently, 2 other projects have been authorized and financed on Palermo and Gela, where reuse water will be used for irrigation of several thousand hectares.

Another industrial reuse project is at the Turin sewage treatment plant, which treats 500,000 m^3/d (132 mgd) with nitrogen and phosphorus removal. Approximately 8 percent of the effluent will undergo tertiary treatment, filtration and chlorination, for agricultural and industrial reuse.

8.5.15 Japan

Because of the country's density and limited water resources, water reclamation and reuse programs are not new to Japan. Only 40 percent of Japan's total population (including the rural population) is sewered; however, by 1995, 89.6 percent of cities larger than 50,000 people were sewered, and 72 percent of the inhabitants of these cities were served with a sewage collection system. Therefore, buildings being retrofitted for flush toilets and the construction of new buildings offer excellent opportunities for reuse. Initially, the country's reuse program provided reclaimed water to multi-family, commercial, and school buildings, with a reclamation plant treating all of the wastewater for use in toilet-flushing and other incidental nonpotable purposes. Later, municipal treatment works and reclaimed water systems were used together, as part of a dual system, providing more effective and economical treatment than individual reclamation facilities.

In 1998, reclaimed water use in Japan was 130 Mm^3/year (94 mgd), according to Ogoshi *et al*. (2000) with distribution as shown in **Table 8-11**. At that time, about 40 percent of the reclaimed water was being distributed in dual systems. Of this more than 1/3 was being used for toilet flushing, and about 15 percent each for urban irrigation and cleansing. A wide variety of buildings were fitted for reclaimed water use, with schools and office buildings being most numerous. In Tokyo, the use of reclaimed water is mandated in all new buildings larger in floor area than 30,000 m^2 (300,000 ft^2).

Japan offers a very good reuse model for cities in developing countries because its historical usage is directly related to meeting urban water needs rather than only agricultural irrigation requirements. In addition, the country's reclaimed water quality requirements are different from those in the U.S., as they are more stringent for coliform counts for unrestricted use, while less restrictive for other applications.

Examples of large area water reclamation systems in Japan can be found in Chiba Prefecture Kobe City, and Fukuoka City. Outside the city limits of each of these urban areas, streams have been augmented, parks and agricultural areas have been irrigated, and greenbelts established with reclaimed water (Ogoshi *et al*., 2000). The price of reclaimed water in these cities ranges from \$0.83/m^3 for residential use to \$2.99/m^3 for business and other uses. This compares with a potable water price range of \$1.08 to \$3.99/m^3.

8.5.16 Jordan

Jordan has very limited renewable water resources of only 102 m^3/capita/year (26,950 gallons/capita/year) (World Water Resources, 2000-2001), which is basically at the survival level (see Section 8.2.1). As a result, mobilization of non-conventional water resources is one of the most important measures that have been proposed to meet the increasing water demand of the growing population (3.6 percent/year, 6.5 million expected in 2010).

Over 63 percent of the Jordanian population is connected to sewage systems. Seventeen wastewater treatment plants are in operation, with an overall capacity of 82 Mm^3/year (21,700 mg/year). The largest facilities (greater than 4,000 m^3/d or 1.1 mgd) are As-Samra, Baqa's, Wadi Arab, Irbid, and Madaba. Stabilization ponds and activated sludge processes are the most common treatment processes in addition to a few trickling filter facilities.

More than 70 Mm^3 (57,000 acre-feet or 18,500 mg) of Jordan's reclaimed water, around 10 percent of the total water supply, is either directly or indirectly reused each year. By the year 2020, the expected available volume

Wadi Musa secondary treatment plant and storage ponds serving communities in the vicinity of Petra, Jordan. Photo courtesy of Bahman Sheikh

of treated wastewater is estimated to be 265 Mm^3/year (70,000 mg/year), which is about 25 percent of the total water available for irrigation. To date, the majority of the reuse has been unplanned and indirect, where the reclaimed water is discharged to the environment and, after mixing with natural surface water supplies and freshwater supplies, used for agriculture downstream, primarily in parts of the Jordan Valley. The direct use of reclaimed water in the immediate vicinity or adjacent to the wastewater treatment plants is generally under the jurisdiction of the Water Authority of Jordan (WAJ), which is the entity that plans, builds, owns, operates, and maintains the plants. The majority of these sites are pilot projects with some research and limited commercial viability. A few direct water reuse operations, such as the

Table 8-11. Uses of Reclaimed Water in Japan

Use	Percent	Mm^3/year	mg/year
Environmental Water	54%	63.9	16,882.4
Agricultural Irrigation	13%	15.9	4,200.8
Snow Melting	13%	15.3	4,042.3
Industrial Water	11%	12.6	3,328.9
Cleansing Water	9%	11.2	2,959.0

Source: Oqoshi *et al.*, 2000.

date palm plantations receiving reclaimed water from the Aqaba wastewater treatment plant, are separate and viable enterprises.

In recent years, with an increasing population and industrialization, planned water reuse is being viewed as an important component of maximizing Jordan's scarce water resources. As a result, the government of Jordan, with support from USAID, has been examining water reuse and its application in the integrated management of Jordan's water resources, particularly to alleviate the demand on fresh water. The Water Resource Policy Support activity includes policy support and broad-based stakeholder participation on water reuse, specifically in the Amman-Zarqa Basin (McCornick *et al.,* 2002). To further promote the commercial viability of direct water reuse, the government of Jordan, with support from USAID, also revisited the existing water reuse standards (Sheikh, 2001). Senior international water reuse and standards experts were consulted in coordination with government, agriculture, industry, and technical representatives, whose participation helped develop an appreciation of the constraints and concerns faced by all parties with respect to reclaimed water use. Jordan is now implementing a program that will demonstrate that direct water reuse is reliable, commercially viable, socially acceptable, environmentally sustainable, and safe. The program is focusing on 3 sites in Jordan including: Wadi Musa (see photo), Aqaba, and Jordan University of Science and Technology, each of which is at a different stage of development in wastewater treatment and reuse.

8.5.17 Kuwait

With a population estimated at about 2 million, most of Kuwait can be considered urban. The country is arid, with average annual rainfall less than 12.5 cm (5 inches). With no surface sources, water is drawn from groundwater at the rate of about 2270 m^3/d (0.6 mgd) for producing bottled water and for adding minerals to desalinized seawater from the Persian Gulf. Most water needs are met by desalination. About 90 percent of the urban population is connected to a central sewage system.

According to **Table 8-12**, irrigation accounts for approximately 60 percent of Kuwait's water use, while approximately 37 percent is withdrawn for domestic use. Irrigation water is primarily supplied from groundwater (61 percent) and reclaimed water (34 percent).

In 1994, the total volume of collected wastewater was 119 Mm^3/year (31,400 mg/year), 103 Mm^3/year (27,200 mg/year) of which was treated. The 3 main municipal treatment plants are Ardhiya, Reqqa, and Jahra, with a total capacity of more than 303,000 m^3/d (80 mgd). Tertiary treatment – activated sludge, filtration, and chlorine disinfection – is provided. And while Kuwait has been practicing water reclamation and reuse for over 20 years as a means of extending its limited natural water supply, only about 10 percent of treated effluent is reused.

While the use of reclaimed water for landscape irrigation is growing in urban areas, the main reuse application is agricultural irrigation (4,470 hectares or 11,046 acres in 1997), representing 25 percent of the total irrigated area. Reclaimed water is only allowed for the irrigation of vegetables eaten cooked (potatoes and cauliflower), industrial crops, forage crops (alfalfa and barley), and irrigation of highway landscapes. **Table 8-13** details the effluent quality standards established by the Ministry of Public Works for water reuse.

The percentage of reclaimed water used for irrigation in Kuwait is relatively high; nevertheless, groundwater supplies used for irrigation are being stressed through excessive pumping. The result is increasing salinity of irrigation water. Irrigated lands are also experiencing salinization due to evaporation. In response to these irrigation concerns, Kuwait signed a forward-looking, 30-year, build-operate-transfer (BOT) concession contract in May 2002 for the financing, design, construction, and operation of a 375,000-m^3/d (99-mgd) wastewater treatment and reclamation plant. The plant, due to commence operation in 2005, is located at Sulaibiya, near one of the most productive agricultural areas of Kuwait. Product water from the Sulaibiya plant must meet the concession contract requirements presented in **Table 8-14**.

The product water from this plant will be very high quality and will allow Kuwait several choices for end use including unrestricted irrigation and replenishment of irrigation groundwater supplies. The Sulaibiya plant will achieve the high quality product water through the application of advanced treatment processes – biological nitrogen and phosphorus removal, followed by ultrafiltration and reverse-osmosis treatment.

8.5.18 Mexico

Like other Latin American countries, Mexico faces a major challenge in terms of providing drinking water, sewage connection, and wastewater treatment, due to the need to strengthen and expand its economic and social development. Therefore, efforts to reuse water for different purposes are extremely important to solving the increasing water shortage and environmental problems. Mexico has 314 catchment areas with an average water availability of 4,136 m^3/capita/year (1.1 mg/capita/year) (Water Resources 2000-2001) with uneven distribution. Average rainfall is 777 mm (30.6 inches) per year, and most of it occurs over only 4 months per year.

At the national level, the rates of coverage for drinking water and sewage connection in December 1998 were 86 percent and 72 percent, respectively. However, high discrepancies exist for the different regions, in particular for sewer connections with 32 percent for small communities and 92 percent for large cities. Approximately 22 percent of all the wastewater flow from urban centers throughout the country, estimated at 187 m^3/s (49,400 gallons/s), are treated at 194 sewage treatment plants. The total urban wastewaters produced in Mexico are estimated to be 14.7 Mm^3/d (3,880 mgd), of which 25 percent are currently treated prior to discharge.

Towns and cities across Mexico generate wastewater that is reused in agriculture (Scott *et al,* 2000). The government has mandated treatment and wastewater quality standards that are set by the type of receiving waters. One of the major examples of agricultural reuse is Mexico City. Almost all collected raw wastewater (45 to 300 m^3/s dry and wet flows, respectively, or 11,900 to 79,250 gallons/s), is reused for irrigation of over 85,000 hectares (210,000 acres) of various crops (Jiménez, 2001). Of the total wastewater generated, 4.25 m^3/s (367,000 m^3/d or 97 mgd) is reused for urban uses (filling recreational lakes, irrigating green areas, car washing, 3.2 m^3/s (845 gallons/s) is used for filling a part of a dry lake called Texcoco, and for other local uses, and 45 m^3/s (12,000 gallons/s) is transported 65 kilometers (40 miles) to the Mezquital Valley for irrigation. The reuse of this wastewater for irrigation represents an opportunity for the development of one of the most productive irrigation districts in the country; however, health problems also are also a result from this practice.

Although the necessity to treat wastewater is obvious, when the Mexican government started a wastewater improvement program for the Valley of Mexico, the farmers from the Mezquital Valley were opposed to it. The main argument was to keep the organics and nutrients (carbon, nitrogen, phosphorus, and other micronutrients) as fertilizer for the crops.

Several projects have been conducted to determine the most appropriate treatment that would ensure adequate disinfection (to minimize epidemiological problems and illnesses), but keeping the nutrients in the reclaimed water to preserve the fertilizing property. According to the results obtained, it is concluded that advanced primary treatment (coagulation/flocculation plus disinfection) produces water of a consistent quality, independent of the

Table 8-12. Water Withdrawal in Kuwait

Water Use	Annual Quantity	
	(Mm^3)	(mg)
Agricultural	324	85,600
Domestic	201	53,100
Industrial	13	3,435

Source: Food and Agriculture Organization of the United Nations, 1997

Table 8-13. Reclaimed Water Standards in Kuwait

Parameter	Irrigation of Fodder and Food Crops Not Eaten Raw, Forestland	Irrigation of Food Crops Eaten Raw
Level of Treatment	Advanced	Advanced
SS (mg/L)	10	10
BOD (mg/L)	10	10
COD (mg/L)	40	40
Chlorine Residual (mg/L), After 12 hours at 20° C	1	1
Coliform Bacteria (count/100 ml)	10,000	100

Table 8-14. Effluent Quality Standards from the Sulaibiya Treatment and Reclamation Plant

Characteristics	Monthly Average Value
pH	6 to 9
TDS (mg/l)	<100
TSS (mg/l)	<1
VSS (mg/l)	<1
BOD (mg/l)	<1
NH_3-N (mg/l)	<1
NO_3-N (mg/l)	<1
PO_4-P (mg/l)	2
Sulfide (mg/l)	<0.1
Oil and Grease (mg/l)	<0.05
TOC (mg/l)	<2
Hardness (mg/l) as $CaCO_3$	<10
Color (unit)	<1
Enteric Viruses (Geometric Mean)	5
Total Coliforms (colonies/100 ml)	<2.2

Source: State of Kuwait, Ministry of Finance (2000).

variation in wastewater quality in the influent. This process may also be used for the treatment of wastewater destined for reuse in agriculture in accordance with the quality standards established.

Another growing issue in Mexico is the reuse of municipal wastewater in industry. For example, in the Monterrey metropolitan area, 1.2 m^3/s (317 gallons/s) of reclaimed water (104,000 m^3/d, 16 percent of the total volume of treated municipal wastewater), is reused as make-up water in cooling towers in 15 industries. Besides increasing pressure on water resources, this project is driven by economic concerns. The competitive cost of reclaimed water is \$0.3/m^3, compared to conventional sources of groundwater at \$0.7/m^3, and potable water at \$1.4/m^3.

The improvement of sanitation, water resource management and water reuse in Mexico requires appropriate administrative reorganization. One possible solution is the public-private partnership that was successfully established in Monterrey (Agua Industrial de Monterrey Sociedad de Usuarios) and more recently in Culiacan.

8.5.19 Morocco

Despite the influence of the Atlantic Ocean, which contributes to the area's relatively abundant precipitation, Morocco is an arid to semi-arid country. Out of 150 billion m^3 (120 million acre-feet/year or 40,000 billion gallons/year) of annual rainfall, only 30 billion m^3 (24 MAFY or 7,925 billion gallons/year) are estimated to be usable (70 percent as surface water and 30 percent from aquifers). In addition, these resources are unevenly distributed. The catchment areas of the Sebou, Bou Regreg, and Oum er Rbia wadis alone represent 2/3 of the hydraulic potential of the country (Food and Agriculture Organization of the United Nations, 2001).

Approximately 11.5 billion m^3 (9 million acre-feet per year or 3,000 billion gallons/year) of water are used annually, including 3.5 billion m^3 (3 million acre-feet per year or 925 billion gallons/year) from groundwater. Nearly 93 percent of this amount is used to irrigate 1.2 million hectares (3 million acres), including 850,000 hectares (2 million acres) irrigated more or less permanently throughout the year.

Most Moroccan towns are equipped with sewage networks that also collect industrial effluent. The volumes of wastewater collected were estimated at 500 Mm^3/year (360 mgd) in 1993 and are expected to reach 700 Mm^3/year (500 mgd) in 2020. For Casablanca alone, the annual production of wastewater is estimated at 250 Mm^3/year (180 mgd) in 1991, with forecasts of around 350 Mm^3 (275 mgd) in 2010. However, out of the 60 largest towns, only 7 have treatment plants, and the design and operation of those plants are considered insufficient.

Most of the wastewater produced by inland towns is reused, mainly, as raw or insufficiently treated wastewater, to irrigate about 8,000 hectares (20,000 acres). Sometimes the wastewater is mixed with water from the wadis, into which it spills. A high proportion of the remaining water is discharged to the sea. The irrigated crops are mainly fodder crops (4 harvests of corn per year around Marrakech), fruit, cereals, and produce. If irrigated with wastewater, the growing and selling of vegetables to be eater raw is prohibited.

The largest water reuse project in Morocco was implemented in 1997 in Ben Slimane (near Rabat), where 5600 m^3/d (1.5 mgd) of wastewater is treated by stabilization ponds (anaerobic, facultative, and maturation ponds) and the disinfected effluent (absence of helminth eggs, less than 20 CF/100 ml) is used for golf course irrigation during the summer (average volume of reused water 1000 m^3/d or 0.26 mgd). The country does not yet have any specific wastewater reuse regulations and usually refers to the WHO recommendations.

The lack of wastewater treatment before reuse in inland cities has resulted in adverse health impacts, and a high incidence of waterborne diseases exist in Morocco. Improvement in wastewater reuse methods and the quality of reuse water for irrigation is recognized as essential. Major improvements are urgently needed because of the strong migration of the rural population towards the towns and the very rapid demographic expansion.

8.5.19.1 Drarga, Morocco

The Morocco Water Resources Sustainability (WRS) Activity is a USAID-funded project that started in July, 1996. The objectives of WRS are: (1) to assist the government of Morocco in undertaking water policy reforms, (2) to implement pilot demonstrations that introduce technologies which will foster the sustainability of water resources, and (3) to broaden public participation in water resources management.

The Commune of Drarga, near Agadir, in southern Morocco, is rapidly expanding. The current population of 10,000 is expected to double over the next few years. Prior to the start of the WRS project, the town of Drarga had a potable water distribution and wastewater collection system; however, raw wastewater was being discharged into the environment without any treatment, creating large cesspools and contaminating drinking water sources.

The 1,000-m^3/d (0.26-mgd) Drarga wastewater treatment plant uses a re-circulating sand filtration system. After screening, the influent flow is treated in anaerobic basins with an average hydraulic retention time of 3 days. The flow is then sent to equalization storage where it is adjusted for release to sand filters. The third step of the treatment process, after the sand filters, is denitrification. Finally, the treated flow is sent to reed beds where the root systems of the reeds provide further filtration. The final effluent is stored in a storage basin before being pumped to irrigate adjacent fields.

The implementation of a public participation program has been one of the cornerstones of the Drarga project. The fact that the public was consulted throughout each step of the project has resulted in overall public support for the project. Public opinion even led to a change in the plant's location.

Another key element of the Drarga pilot project was the establishment of an institutional partnership. A local steering committee, made up of all of the institutions involved with various aspects of water management at the local level, was created at the beginning of the project. The role of the steering committee was to follow each step of the pilot project and to provide assistance, when necessary, based on their specific area of expertise. After construction, a technical oversight committee was set up to oversee plant operations.

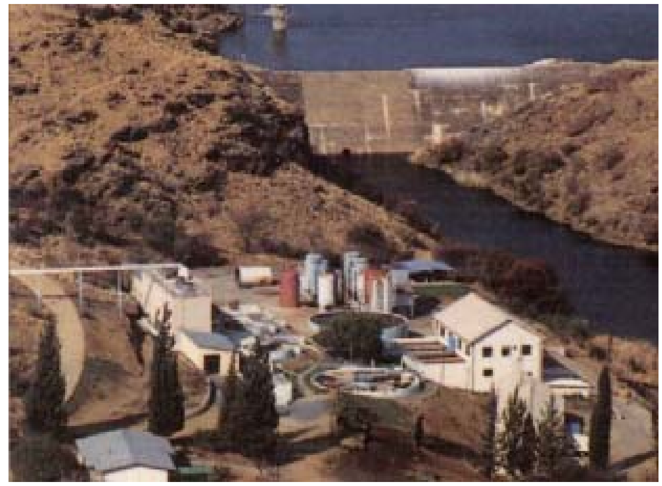
In Morocco, nearly 70 percent of all of the wastewater treatment plants are not functioning due to lack of spare parts and poor cost recovery. The Drarga project included several cost recovery features. The plant itself generates a number of products that have a market value: reclaimed water sold to farmers, reeds which are harvested and sold twice a year, dried sludge from the anaerobic basins mixed with organic wastes from Drarga to produce compost, and methane gas from the anaerobic basins, which is recovered and used to run pumps at the plant, thereby reducing electricity costs.

The plant has been operating continuously since October 2000 and has exceeded removal rate targets for the abatement of key pollution parameters such as BOD_5, nitrates, fecal coliforms, and parasites. **Table 8-15** summarizes the plant's performance.

The treated wastewater fulfills the requirements of WHO reuse guidelines, and therefore, is suitable for reuse in agriculture without restriction. The WRS project encouraged farmers to use reclaimed water for crop irrigation by developing demonstration plots using drip irrigation. Crops irrigated with reclaimed water in the demonstrations plots include cereals (wheat and maize), vegetables (tomatoes and zucchini), and forage crops (alfalfa and rye-grasses).

8.5.20 Namibia

Windhoek, the capital of Namibia, has a population of 200,000 and is located in the desert. In 1960, low rainfall (below 300 mm/year or 11.8 inches/year) caused the necessary water supply to fall short of the water demand. To meet this need, the country's water supply master plan included the long distance transport of 80 percent of its water supply from the Eastern National Water Carrier, extensive aquifer withdrawals from around the city, the development of a local surface reservoir, and the construction of a reclamation plant. The Windhoek reclamation plant has been In operation since 1968 with an initial production rate of 4800 m^3/d (1.3 mgd) (see photo) This operation is the only existing example of direct potable water production. The plant has since been upgraded in stages to its present capacity of 21,000 m^3/d (5.5 mgd).



The Goreangab Dam, adjacent to the Windhoek reclamation plant in Windhoek, Namibia. Photo courtesy of Valentina Lazarova

The wastewater from residential and commercial settings is treated in the Gammans treatment plants by trickling filters (6000 m^3/d or 1.6 mgd capacity) and activated sludge (12,000 m^3/d or 3.2 mgd capacity), with enhanced phosphorus removal. The effluents from each of these processes go to 2 separate maturation ponds for 4 to 12 days of polishing. Only the polished effluent from the activated sludge system is directed to the Windhoek reclamation facility as well as water from the Goreangab Dam (blending ratio 1:3.5), where it is treated to drinking water standards. After tertiary treatment, reclaimed water is blended again with bulk water from different sources.

Advanced treatment processes (including ozonation and activated carbon) have been added to the initial separation processes of dissolved air flotation, sedimentation, and rapid sand filtration. A chlorine residual of 2 mg/l is provided in distribution systems. Membrane treatment has been considered, as well as an additional 140 days storage of the secondary effluent from the maturation ponds in the Goreangab Dam.

Risk studies and evaluations of toxicity and carcinogenity have demonstrated that reclaimed water produced at the Windhoek facility is a safe and acceptable alternative water resource for potable purposes. Treatment capacity at the Windhoek treatment plant is currently being increased to 40,000 m^3/d (11 mgd).

8.5.21 Oman

Oman is another dry country with internal, renewable water resources estimated at 1 billion m^3/year (388 m^3/capita/

Table 8-15. Plant Performance Parameters at the Drarga Wastewater Treatment Plant

Parameter	Raw	Effluent	Reduction
BOD_5 (mg/l)	625	9	98.5%
COD (mg/l)	1825	75	95.8%
TSS (mg/l)	651	3.9	99.4%
NTK (mg/l)	317	10	96.8%
Fecal coliforms (per 100 ml)	1.6×10^7	500	99.99%
Parasites (Helminth eggs)	5	0	100%

year or 264 billion gallons/year). Surface water resources are scarce, with evaporation rates higher than annual rainfall. In 1995, total water withdrawals including depletion of non-renewable groundwater, were 1,223 Mm^3 (323,000 mg), of which 93.9 percent was used for agricultural purposes.

In 1995, the total produced wastewater was estimated at 58 Mm^3 (15,320 mg) (Food and Agriculture Organization of the United Nations, 2001), of which only 28 Mm^3 (7,400 mg) was treated and 26 Mm^3 (6,870 mg) was reused, mainly for irrigation of trees along the roads. The quantity of desalinated water produced in the same period was 34 Mm^3 (8,980 mg) and was used for domestic purposes. Since 1987, 90 percent of the treated effluent in the capital area has been reused for agricultural irrigation of tree plantations by drip irrigation.

About 262 wastewater treatment plants with capacities below 11,000 m^3/d (2.9 mgd) are currently in operation. Over 50 percent of these plants are located in the capital area around Muscat, with overall capacity of 52,000 m^3/d (13.7 mgd), and 20 percent are in Dhofar and Al-Batinat.

The largest wastewater treatment plants are Darsait, Al-Ansab, and Shatti al Qurm, which produce about 11,500 m^3/d (3 mgd), 5400 m^3/d (1.4 mgd), and 750 m^3/d (0.2 mgd), respectively. The plants use activated sludge processes with tertiary filtration and chlorination. Effluent is pumped to a storage tank that provides pressure to the water reuse transmission system.

There are 2 main Omani rules which regulate water reuse: (1) wastewater reuse, discharge and sludge disposal rules that include physico-chemical parameters such as suspended solids, conductivity, organic matters, heavy metals, etc., and (2) wastewater standards related to biological characteristics. Reuse regulations further classify wastewater use into 2 categories:

- Standard A - (200 FC/100 ml, less than 1 nematode ova/l) for irrigation of vegetables and fruit to be eaten raw, landscape areas with public access, controlled aquifer recharge, and spray irrigation

- Standard B - (1000 FC/100 ml, less than 1 nematode ova/l) for cooked vegetables, fodder, cereals, and areas with no public access

During the summer, all of the reclaimed water in the area is used, and demands are still not met. But during the winter, about 40 percent of the effluent from the Darsait plant is discharged through an outfall to the Gulf of Oman. In the future, the reuse network will be expanded so that all the effluent is reused for the irrigation of over 5,600 hectares (13,840 acres).

In the southern city of Salalah, the second largest city in Oman, an extensive wastewater collection, conveyance, treatment, and groundwater recharge project is nearing completion. The effluent from the 20,000-m^3/d (5.3-mgd) capacity tertiary treatment plant will be discharged to a series of gravity recharge wells along the coast of the Arabian Sea to form a saltwater intrusion barrier with additional wells further inland for replenishment of agricultural withdrawals.

8.5.22 Pakistan

The use of untreated wastewater for agricultural irrigation is common in Pakistan; a survey showed that it was practiced in 80 percent of all the towns and cities with populations over 10,000 inhabitants. The main crops cultivated on these lands are vegetables, fodder, and wheat. Vegetables and fodder are grown year-round to be sold at the local market, while wheat is grown in the winter season, mainly for domestic consumption. There are various reasons why untreated wastewater is used for irrigation such as: lack of access to other water sources, the high reliability of wastewater, the profits made by selling crops at the local market, and the nutrient value of the wastewater (reducing the need for fertilization). Farmers using untreated wastewater for irrigation bring in almost twice the income than farmers using normal irrigation water.

The City of Faisalabad has a population of over 2 million people, making it the third largest city in Pakistan. Located in the heart of the Punjab province, Faisalabad was founded in 1900 as an agricultural market town but since then has rapidly developed into a major agro-based industrial center. The local Water and Sanitation Agency (WASA) has identified over 150 different industrial divisions in the area, most of which are involved in cotton processing such as: washing, bleaching, dying, and weaving.

Lahore, Pakistan – Farmers installing a pump into a wastewater drain to draw water for irrigation. Source: International Water Management Institute

The use of wastewater for agricultural irrigation is common in Faisalabad. At least 9 different areas are irrigated with wastewater ranging in size from a few hectares to almost 1,000 hectares (2,470 acres). In total, over 2,000 hectares (4,940 acres) of agricultural land are irrigated with untreated wastewater in Faisalabad. The 2 main sites in Faisalabad are the Narwala Road site and the Channel 4 site. At Narwala Road, the wastewater is primarily of domestic origin while at the Channel 4 site the farmers use a mixture of industrial and domestic wastewater. One wastewater treatment plant in Faisalabad treats approximately 15 percent of the city's wastewater.

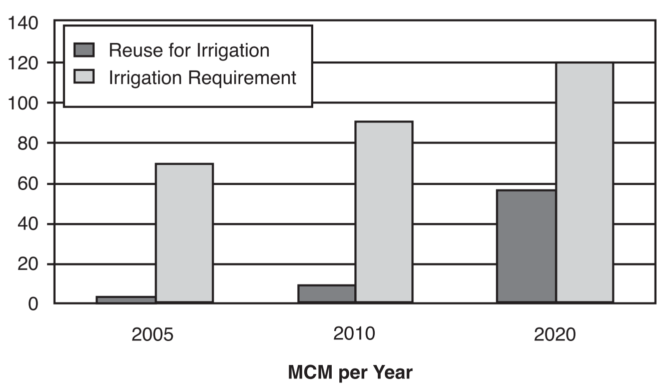
All wastewater reused in Faisalabad is used untreated. Farmers opt to use untreated wastewater over treated wastewater because it is considered to be more nutrient-rich and less saline than treated wastewater. In Faisalabad, like in many other cities in Pakistan, the local water and sanitation agency sells the wastewater to groups, or a community of farmers. The total revenue generated is mainly used for the operation and maintenance of the drinking water supply and sewage disposal systems.

The only wastewater that is currently not auctioned off is the wastewater at the Channel 4 site. The farmers at this site complain that the toxicity of the wastewater has diminished their choice in crops and forced them to use wastewater only in combination with brackish groundwater. The majority of the farmers at the Channel 4 site would prefer to use regular irrigation water (potable water), but increased water shortages in Pakistan have resulted in such low water allocations that the cultivation of crops without wastewater is no longer possible.

8.5.23 Palestinian National Authority

Currently, wastewater collection and treatment practices in the Palestinian National Authority (West Bank and Gaza Strip) are relatively low. Hence, the ability to reclaim and reuse the large volumes of wastewater generated in this highly water-deficient region is restricted. However, this situation is changing rapidly. International development aid from European countries and the U.S. is gradually strengthening the country's sanitation infrastructure, leading to the potential availability of greater volumes of reclaimed water in future years. In addition, several pilot projects have been conducted with varying results, but each project has demonstrated potential use for reclaimed water. The Ministries of Agriculture and Public Health have studied the use of reclaimed water in agriculture, landscape, industry, and groundwater recharge. As a result, the volume of reclaimed water use in Palestine is anticipated to grow over the next 20 years (**Figure 8-4**). Farmer acceptance of reclaimed water use

Figure 8-4. Future Demand for Irrigation Water Compared with Potential Availability of Reclaimed Water for Irrigation in the West Bank, Palestine



Source: Adapted from Abdo, 2001.

is relatively high, as measured in interviews with growers in both parts of the country (Abdo, 2001). Researchers found that, “the acceptance of farmers to use reclaimed water was conditional by securing water quality and getting governmental approval” (Abdo, 2001).

8.5.24 Peru

Peru is another Latin American country with serious water shortage problems. Half of the total population of 22 million live in the coastal region with an arid climate. The uneven distribution of water resources (very high inland, very short on the coast) contributes to the low water supply and sanitation coverage of the population of only 42 percent and 43 percent, respectively. Only 5 percent of the sewage in Peru is treated before discharge, mostly by stabilization ponds.

The reuse of predominantly raw sewage has been practiced for agricultural irrigation of vegetables, fodder, forest trees, cotton, and other crops. In Lima, about 5,000 hectares (12,000 acres) are irrigated with raw wastewater. A project is under development to irrigate about 4000 hectares (10,000 acres) near San Bartolo, south of Lima, with disinfected effluent from a lagoon system, including maturation ponds. Ica, located 300 kilometers (180 miles) south of Lima, uses effluent treated in facultative lagoons for restricted irrigation of 400 hectares (1,000 acres). At Tacna, Peru’s southernmost town, effluent treated in lagoons is used to irrigate 210 hectares (500 acres) of land.

Peru uses raw sewage to irrigate market vegetables to be eaten without processing. This is typical of numerous cities in developing countries (Yanez, 1992). Furthermore, the effluent produced by stabilization ponds throughout Peru is of generally low quality because of design deficiencies, operational problems, or overloading. Numerous enteric bacterial and viral infections are reported, although the many possible transmission routes preclude attributing a direct link to irrigation practices (Strauss and Blumenthal, 1990).

8.5.25 Saudi Arabia

Water is a scarce and extremely valuable resource in Saudi Arabia. The renewable water resources are only 111 m^3/capita/year (2.4 billion m^3/year or 634 billion gallons/year). As a result of agricultural, urban, and industrial growth, the country’s water demand has been increasing steadily over the past 2 decades, reaching around 20 billion m^3/year (5,283 billion gallons/year) in 2000. Irrigation consumes the largest amount of water in the kingdom. The majority of water consumption is supplied by depleting non-renewable groundwater and desalination. Saudi Arabia is now the world’s largest producer of desalinated water, which covers 70 percent of the total water demand.

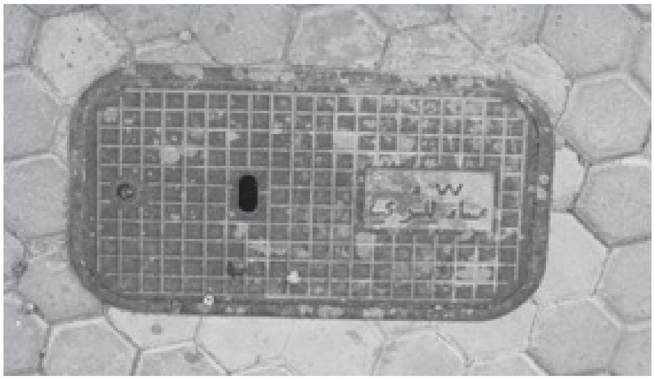
In 1985, Saudi Arabia began focusing on ways to economize and regulate the use of water through a National Water Plan. The plan provides for conservation, greater coordination between agriculture and water policies, intensive use of reclaimed waste and surface water, and better coordination of supply and distribution. As a result, Saudi Arabia is committed to a policy of complete water reuse.

Treated urban wastewater is considered a viable alternative resource for meeting water needs. It is estimated that approximately 40 percent of the water used for domestic purposes in urban areas could be recycled. In 1992, there were 22 sewage treatment plants in operation (stabilization ponds and activated sludge processes) with a total treatment capacity of 1.2 Mm^3/d (317 mgd). In 1992, 217 Mm^3 (57,300 mg) of treated wastewater were reused. Regulations require secondary treatment with tertiary treatment for unrestricted irrigation, with standards shown in **Table 8-16.**

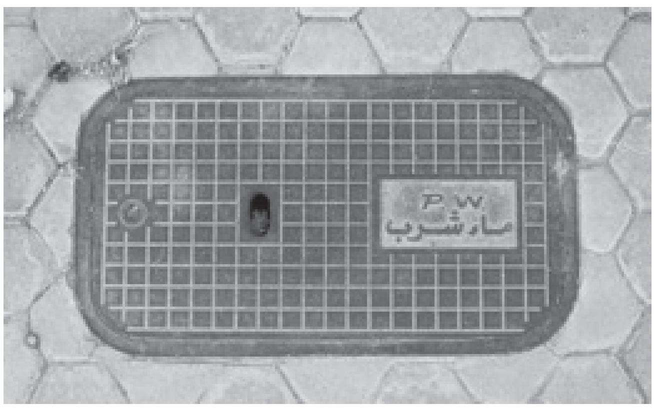
The largest water reuse scheme is in Riyadh. The most sophisticated Riyadh North treatment plant started operation at the beginning of 1994 ,with a design capacity of 200,000 m^3/d (53 mgd). Treatment at the Riyadh North plant includes a nitrification-denitrification activated sludge process with sand filtration for tertiary treatment. On the basis of this plant’s treatment experience, the Riyadh Region Water and Sewerage Authority recently adopted a policy of treating all sewage to the tertiary level to comply with the current effluent guideline standards for unrestricted agricultural reuse enforced by the Ministry of Agriculture and Water. In 2000, an average daily flow of 415,000 m^3/d (110 mgd) of tertiary treated and disinfected effluent was available to potential users free of charge (see photos). However, only about 45 percent (185,000 m^3/d or 49 mgd) of this effluent has been reclaimed, predominantly for agricultural irrigation (170,000 m^3/d or 45 mgd), and about 15,000 m^3/d (4 mgd) is used for industrial cooling purpose by the Riyadh refinery. The remaining effluent is discharged to Wadi Hanifah, where it is mixed with the natural flow of the channel. Private sector farmers can extract some of this flow for irrigation.

In Jeddah, a 38,000-m^3/d (10-mgd) activated sludge facility was designed to produce high-quality reuse water to standards similar to drinking water standards. Advanced treatment includes reverse-osmosis, desalination, filtration, and disinfection. Other plants are planned for Jeddah and Mecca. In both cities, the reclaimed water will be used for municipal, industrial, and agricultural reuse. The City of Jubail is planning to have 114,000 m^3/

d (30 mgd) of reclaimed water for nonpotable industrial, urban landscaping, and other purposes.



Reclaimed water valve access box on sidewalk on Embassy Row in Riyadh, Saudi Arabia. Photo courtesy of Bahman Sheikh



Potable water valve access box on sidewalk on Embassy Row in Riyadh, Saudi Arabia. Photo courtesy of Bahman Sheikh

A recent master planning effort studied the infrastructure needed to meet Riyadh's expected growth of an additional 7 million inhabitants by 2021 (over and above the current 3.5 million). The master plan recommended 12 satellite water reclamation plants be constructed (Sheikh and Aldu Kair, 2000). Each plant would treat wastewater from a district and return the reclaimed water (disinfected tertiary effluent) for irrigation of residential gardens, public parks, and other landscaping, in addition to industrial and commercial uses in various parts of the city. The water reuse component of the integrated water cycle system is expected to have an ultimate capacity of 1.5 Mm^3/d (400 mgd).

8.5.26 Singapore

Singapore is a city-state with a dense, growing population of almost 4 million people. Although the island receives heavy rainfall averaging 250 cm/year (100 inches/year), it has limited water resources because of its small size (680 square kilometers or 265 square miles). The island is fully served by a comprehensive wastewater infrastructure - 6 secondary (activated sludge) treatment plants discharge wastewater effluent to the sea.

Since February 2003, Singapore has been supplying high quality reclaimed water (meeting drinking water standards), called "NEWater", directly to industries and commercial and office buildings for process and other nonpotable uses such as air conditioning and cooling. The goal is to supply 245,000 m^3/d (64.5 mgd) of NEWater for nonpotable use by year 2011.

Table 8-16. Reclaimed Water Standards for Unrestricted Irrigation in Saudi Arabia

Parameter [(a)]	Maximum Contaminant Level
BOD	10
TSS	10
pH	6 – 8.4
Coliform (count/100 ml)	2.2
Turbidity (NTU)	1
Aluminum	5
Arsenic	0.1
Beryllium	0.1
Boron	0.5
Cadmium	0.01
Chloride	280
Chromium	0.1
Cobalt	0.05
Copper	0.4
Cyanide	0.05
Fluoride	2
Iron	5
Lead	0.1
Lithium	0.07
Manganese	0.2
Mercury	0.001
Molybdenum	0.01
Nickel	0.02
Nitrate	10
Selenium	0.02
Zinc	4
Oil & Grease	Absent
Phenol	0.002

Note: (a) In mg/l unless otherwise specified

The NEWater is reclaimed from municipal wastewater using the most advanced technologies, including reverse-osmosis and UV disinfection. NEWater is also being used for indirect potable use. Since February 2003, about 9,000 m^3/d (2.4 mgd) of NEWater has been discharged into reservoirs and treated again in a conventional water treatment plant before introduction into the distribution system for domestic potable use. The amount of reclaimed water for indirect potable use will increase gradually by 4,500 m^3/d (1.2 mgd) yearly to 45,000 m^3/d (12 mgd) by 2011. Currently, 2 NEWater plants are in operation with a total production capacity of 72,000 m^3/d (19.5 mgd). The cost of NEWater production is estimated to be half the cost of desalinized seawater.

Reclaimed water of lower quality than NEWater has been supplied to industries in the western part of Singapore since the 1960s. Industrial reclaimed water treatment involves conventional sand filtration and chlorination before it is pumped to a service reservoir for distribution to the industries. The current demand for industrial water is about 90,000 m^3/d (24 mgd).

8.5.27 South Africa

Limited water resources with uneven distribution, highly variable rainfall, repetitive, severe water shortages, and intensive industrial and urban development are the main factors impacting the need for water reuse in South Africa. In 1996, the population was at 38 million, of which 55.4 percent lived in urban regions. The population growth rate is estimated to be 2.4 percent per year. Based on these population figures, the water demand is expected to double in the next 30 years. In fact, projections indicate that the water demand will exceed available water resources soon after the year 2020.

Water reuse is considered a very promising alternative water resource. Over 1,000 wastewater treatment plants are in operation with biological nitrogen removal as the predominant treatment technology. However, according to Grobicki (2000), less than 3 percent of the available treated wastewater is being reused (an estimated volume of 41 Mm^3/year or 11,000 mg/year).

Aquifer recharge and industrial uses are currently the major water reuse applications. One of the country's larger reuse projects is in Durban (3 million inhabitants) where reclaimed municipal wastewater from the Southern wastewater treatment facility is used by the paper industry and petrol refineries. The tertiary treatment of the secondary effluent from the Southern wastewater treatment works consists of coagulation/flocculation with lamella settling, dual media filtration, ozonation, activated carbon, and chlorination. The reclaimed capacity is 47,000 m^3/d (12.4 mgd).

The largest aquifer storage and recharge project is in the Atlantis area (70,000 people), situated 50 kilometers (31 miles) north of Cape Town. Two infiltration basins augment the aquifer storage capacity with 4,500 m^3/d (2 Mm^3/year or 1.2 mgd) of treated wastewater. High-quality stormwater is also discharged to another aquifer. This water is subsequently abstracted after an underground residence time of about 1 year as part of a 15,000-m^3/d (4.0-mgd) groundwater supply project. In addition, treated industrial wastewater is used as a barrier against saltwater intrusion near the coast. A number of small recharge systems exist where farmers augment groundwater supply through small, earth-dams.

In addition to industrial reuse and aquifer recharge, a number of small water reuse irrigation systems are currently in place in the areas of Durban and Cape Town, mostly for landscape irrigation at golf courses (King David, Mowbray, Rondebosch, Milnerton, Steenberg, Parow, Durbanville, Cato Ridge, Langebann Country Club), sport facilities (Milnerton Racecourse, Milnerton Beachfront, Bellville South, Kraaifontein Sportsdround, Peninsula Technion, etc.), and various agricultural applications.

Since many of the country's water bodies provide little dilution capacity, there has been significant focus on water reuse initiatives involving planned indirect reuse through discharge to surface bodies. The return of treated wastewater to rivers in inland areas of South Africa has been considered an important aspect of water management. Despite the deterioration of surface water quality, the well-established, intensive, potable treatment system (86 percent water supply coverage) minimizes any potential health risk. This indirect potable reuse via surface flow augmentation accounts for several million cubic meters per day. In fact, with increasing water demand, the volume of return flows is increasing steadily and will be greater than natural run-off in a number of regions by 2020. For example, in the Gauteng area (Johannesburg-Pretoria metropolis), 60 percent of the surface water used for water supply is treated wastewater. The Hartebeespoort Dam, used to supply water to Johannesburg (10 million people), receives 50 percent of its volume from wastewater effluent. In addition to this indirect potable reuse, the effluent from Johannesburg Northern Works (200,000 m^3/d or 52.8 mgd) is also used by a power station and for the irrigation of 22,000 hectares (54,400 acres) of industrial crops.

The implementation of the National Water Act of 1997 resulted in the establishment of catchment management authorities. These authorities are helping to focus the country's water resources management enhancement. One of the major tasks of these catchment agencies will be the management of environmental compliance, while water supply and sanitation will remain the responsibility of local governments and municipalities. Effluent and environmental standards specification and enforcement are the duties of the central government, in particular the Department of Water Affairs and Forestry.

Water reuse standards are currently being revised. Existing regulations apply very stringent drinking water standard requirements for water to be used for human washing and irrigation of food crops to be eaten raw. Tertiary treatment with no fecal coliforms is required for unrestricted irrigation of sport fields, pasture for milking animals, and toilet flushing. The microbiological limits have been relaxed for discharge into river systems to 126 FC/100 ml, or sometimes even higher. The unrestricted irrigation and irrigation of non-food crops requires less that 1000 FC/100 ml.

8.5.28 Spain

Although both planned and incidental water reuse have been taking place in Spain for decades, particularly in coastal Mediterranean areas and in the Balearic and Canary inlands, planned water reuse became a viable option as a consequence of the First International Symposium on Water Reclamation and Reuse held in Costa Brava in 1991 (IAWPRC, 1991). Since then, numerous projects have been implemented across the country, mainly serving agricultural irrigation as well as landscape irrigation, environmental restoration, and urban uses such as street cleaning, urban landscape irrigation, boat washing, and fire control.

The major impetus for water reclamation and reuse has been based on the viable alternatives for cost recovery. The highly competitive water markets of the Canary Islands, the highly productive hydroponic crops of the southern Mediterranean coast, and the more recent demands for golf course irrigation, have largely contributed to the expansion of water reclamation and reuse in Spain. Farmers have begun to realize the considerable benefits from a reliable supply of good quality water, particularly during the summer season, when water shortages are most common.

The Water and Sanitation District of Costa Brava (located in the north of Barcelona) has been one of the leading agencies in developing water reuse alternatives for the last 15 years. As secondary wastewater treatment becomes a standard in most urban and rural areas, a renewed interest has developed to reclaim and reuse treated effluent, particularly in coastal areas, where tourism, environmental protection, and intensive agriculture have become top priorities. Mediterranean coastal cities, like Barcelona and Valencia, with traditional high levels of incidental reuse in agriculture, are seriously considering rehabilitation and expansion of their treatment facilities, as to satisfy the water quality requirements associated with environmental and public health protection, and include adopting microbiological quality levels that are nearly comparable to those of drinking water quality.

In 1999, the Spanish Ministry of Public Works, Transportation and Environment proposed a set of physicochemical and microbiological standards for 14 possible applications of reclaimed water. The proposed microbiological standards range from limits similar to those included in the Title 22 regulations (Californian reuse standards), for unrestricted water uses, to limits similar to those included in the WHO guidelines, where public exposure to reclaimed water is restricted. Several regional governments have adopted and are currently considering either or both of the above criteria and guidelines as a practical way to regulate and promote water reclamation and reuse.

8.5.28.1 Costa Brava, Spain

The Consorci de la Costa Brava (CCB, Costa Brava Water Agency) is a public organization, created in 1971, that deals with the management of the water cycle (wholesale purveyor of drinking water, wastewater treatment, and water reuse) in the 27 coastal municipalities of the Girona province. In Spain, CCB is considered to be a pioneer organization in the management of the water cycle. The CCB embraces biological secondary treatment of wastewater when the main option in coastal areas has been disposal into the sea through submarine outfalls. The CCB introduced the concept of planned water reuse in the late 1980s.

The CCB opted for the progressive development of this resource after a conference in 1985, where renowned specialists presented planned wastewater reclamation and reuse systems in the U.S. Being that Costa Brava itself is an area with a Mediterranean climate and periodic periods of drought, it became clear to the governing board of the CCB that treated wastewater should be considered as a resource to be developed rather than to be disposed. Despite the lack of regulations in Spain, the CCB proceeded to develop water reuse while maintaining public health. Reclaimed water initially was disinfected secondary effluent; continuing improvements to water reclamation facilities have led facilities to evolve into Title 22 reclamation treatment trains, consisting of coagulation, flocculation, sedimentation, filtration, and disinfection. The major leap forward in wastewater reclamation and reuse occurred in 1996, when several water reuse projects were approved and partially (80 percent) funded by the European Union (EU).

8.5.28.2 Portbou, Spain

The municipality of Portbou (Girona, Spain - population 1,600) is located in a remote area in northern Costa Brava, in the midst of a very mountainous area and facing the Mediterranean Sea. A small reservoir, located on the mountains on the western city limits, with a capacity of 130,000 m^3 (34.3 mg), supplies potable water to the area. The maximum drinking water demand is 160,000 m^3/year (42.3 mg/year) and the potable water supply is extremely dependent on rainfall (annual average 550 mm or 21.7 inches). There are no wells to supplement potable water supply, so the drought conditions of the period 1998 through 2001 resulted in water restrictions for nonpotable water uses including landscape irrigation. The municipality has a 360-m^3/d (95,000-gallons/d) treatment facility which includes coagulation, flocculation, direct filtration, and a UV-chlorine combined disinfection system to provide reclaimed water for a variety of urban nonpotable water uses such as: landscape irrigation, street cleaning, and fire protection. The municipality is also installing a pipeline to deliver high-quality reclaimed water for boat cleaning to a nearby marina.

8.5.28.3 Aiguamolls de l'Empordà Natural Preserve, Spain

The Aiguamolls de l'Empordà Natural Preserve (AENP) is a marsh located in Northern Costa Brava between the mouths of the Muga and Fluvià rivers. This naturally occurring marsh formed as a result of the periodical floods from both rivers, producing a rich and diverse environment, ranging from saline to freshwater ecosystems. The construction of the Boadella dam in the upper Muga River in the late 1960s and urbanization in coastal areas dramatically changed the river flow and affected the marshes, which were finally declared a natural preserve in 1984. A visitor center was created and with it an 18-hectare (44.5-acre) manmade lagoon (Cortalet lagoon), which is artificially fed by the Corredor stream from autumn to late spring. In summer both this stream and the lagoon usually dry out.

In 1995, the CCB received funding from the EU to construct a 7-hectare (17.3-acre) wetlands treatment system to reduce the nitrogen content in the secondary effluent from the Empuriabrava wastewater treatment plant, which includes extended aeration and polishing lagoons. The effluent is then reused for environmental purposes at the Cortalet lagoon. The system came into operation in 1998. Since then, 500 to 550 m^3/year (132,000 to 145,300 gallons/year) of denitrified reclaimed water have been pumped to the Cortalet lagoon, preventing its summer desiccation. Apart from this, the constructed wetland itself has become a great waterfowl attraction and is one of the favorite spots in the natural preserve for bird watching. Since the Empuriabrava community uses water from the Boadella reservoir as a potable water supply, this project returns to the AENP a portion of the flows that are naturally used to feed these marshes, thus creating a true restoration of the original habitat.

8.5.28.4 The City of Vitoria, Spain

Water reclamation and reuse has been the final step of an ambitious integrated water resources management program for the City of Vitoria (250,000 people, located in the Basque Country, northern Spain) that began in 1995. The enthusiasm and determination of the most directly affected stakeholders, the agricultural community, to promote and fund the design, construction, and OM&R of the wastewater reclamation and reuse facilities have been the driving factors for the practical implementation of this far-reaching program.

The water reclamation and reuse project includes a wastewater reclamation facility, with a capacity of 35,000 m^3/d (9.2 mgd) and an elaborate pumping, conveyance, and storage system, satisfies water quality requirements specified by Title 22 of the California Code of Regulations. The project objectives were: (1) to provide water for spray irrigation of 9,500 hectares (23,000 acres) during the summer, (2) to pump about 0.5 m^3/s (12,000 gallons/d) of reclaimed water to reservoirs, and (3) to store reclaimed water in a 6,800-m^3 (1.8-mg) reservoir for agricultural irrigation.

8.5.29 Sweden

As in other Scandinavian countries, Sweden has relatively high freshwater availability and the annual water withdrawal represents only 2 percent of the renewable water resources, 352 m^3/capita/year (93,000 gallons/capita/year) in 1997 (Angelakis *et al.,* 2001). Industry is characterized by higher water demand at 55 percent, compared to 36 and 9 percent for urban uses and agriculture, respectively.

Advanced sewage treatment, including carbon and phosphorus removal, is common practice in Sweden. The upgrading of many wastewater treatment plants for nitrogen removal has been implemented over the past years, especially in the coastal region up to the archipelago of Stockholm.

Over 40 irrigation projects have been constructed in water-scarce areas in the southeast region, where wastewater is collected in large reservoirs and stored for up to 9 months before being used for irrigation with or without blending with surface water. Agricultural demands for water in these areas are intense, as the precipitation is small. Two main benefits of these projects have been reported: (1) additional wastewater treatment in a safe and financially attractive way, including recycling of nutrients, and (2) the creation of alternative water resources for agricultural irrigation which allow groundwater resources to be dedicated for other purposes. After approximately 10 years, only positive impacts have been reported for these water reuse projects. After a minimum of 4 months storage, the water quality is adequate for swimming according to the Swedish legislation. Subsequently, there have been no sanitary problems related to water reuse.

A new environmental act in Sweden requires nitrogen reduction for most of the large wastewater treatment plants. This act may encourage future development of these water reuse irrigation systems. The increasingly stringent environmental requirements on the discharge of industrial wastewater promote byproduct recovery and industrial wastewater reclamation. Significant research and development efforts have been made on the use of membrane technologies, including industrial desalination for zero discharge.

8.5.30 Syria

In Syria, agriculture is an important economic sector. In addition to the role it plays in enhancing food security, it accounts for 60 percent of the national revenue from non-oil exports (Food and Agriculture Organization of the United Nations, 2001). The agricultural sector employs over 27 percent of the total manpower in the country. In view of the harsh climatic conditions, irrigation is given a high priority as a means to boost agricultural production and to ensure a high level of food security. The total irrigated area in Syria is in the range of 1.2 million hectares (3 million acres), with 61 percent of the water coming from groundwater and the rest from surface water sources.

Until recently, the amount of municipal wastewater was small because of the limited population in cities. Most of these waters were not reused because of their lack of quality and the availability of good quality water for irrigation. With an increase in urban population and the spread of drinking water supply connections, particularly in large cities, the volume of municipal wastewaters has increased rapidly. In fact, the volume of wastewater in Syria was estimated at 451, 650 and 1,642 Mm^3/year (365,000, 527,000, and 1,330,000 acre-feet/year or 119,000, 172,000 and 434,000 mg/year), respectively for 1995, 2000, and 2025. At the same time, the availability of good quality water has diminished around cities. This has led farmers to start using untreated wastewater. However, this wastewater is generally mixed with good quality water and is used essentially, but not exclusively, for irrigating trees and forage crops (Food and Agriculture Organization of the United Nations, 2001).

Table 8-17 shows the status of wastewater treatments in various Syrian cities. Collected raw sewage from the cities (except for a part of Damascus), villages, and other residential areas where sewage systems are in operation, is used without any treatment. The wastewater is used either for direct irrigation of agricultural crops or, if not disposed to the sea, it is discharged into water bodies which are then used for unrestricted irrigation (Food and Agriculture Organization of the United Nations, 2001).

8.5.31 Tunisia

Situated in an arid and semi-arid area, Tunisia is facing increasingly serious water shortage problems (Bahri, 2000). In 2000, water availability was 440 m^3/capita/year (116,200 gallons/capita/year) with withdrawals accounting for 78 percent of the renewable resources. These water deficits are projected to increase with population growth, an increase in living standards, and accelerated urbanization. According to recent forecasts, increased domestic and industrial water consumption by the year 2020 may cause a decrease in the volume of fresh water available for Tunisian agriculture. Moreover, water shortage problems are associated with increasing environmental pollution. To help address this situation, different mobilization infrastructures (dams, hillside-dams and lakes, recharge and floodwater diversion structures, wells) are under construction. Water transfer systems have been implemented and existing reservoirs have been integrated into a complex hydraulic system, allowing interregional transfer and spatial redistribution of water.

Most residents of large urban centers have access to various, adequate sanitation systems and wastewater treatment facilities (78 percent versus 61 percent for all of the population and 40 percent in rural areas). Of the 240 Mm^3 (63,400 mg) of wastewater discharged annually, 156 Mm^3 (41,200 mg) is treated at 61 treatment plants. Five treatment plants are located in the Tunis area, producing about 62 Mm^3/year (16,400 mg/year), or 54 percent of the country's treated effluent. As a rule, municipal wastewater is treated biologically, mainly in oxidation ditches, activated sludge processes, and stabilization ponds. Sanitation master plans have been designed for several towns. Most existing reuse programs were implemented and integrated into the scheme of al-

Table 8-17. Wastewater Treatment Plants in the Cities of Syria

City	Wastewater Flow		Status in Year 2000
	m^3/day	mgd	
Damascus	485,000	128	In Operation
Salamieh	5,800	2	In Operation
Aleppo	255,000	67	Under Implementation
Hama	70,000	18	Under Implementation
Homes	134,000	35	In Operation
Dar's	21,800	6	Studied, Ready for Implementation
Al-Swaida	18,750	5	Studied, Ready for Implementation
Idleb	30,000	8	Studied, Ready for Implementation
Lattakia	100,830	27	Invitation of Offers for Implementation
Tatous	33,450	9	Invitation of Offers for Implementation
Total	1,154,630	305	---

Source: Sa'dulla Al Shawaf, Ministry of Irrigation, Syria, 2000.

ready existing treatment plants. However, for new plants, treatment and reuse needs are combined and considered during the planning stage.

Although some pilot projects have been launched or are under study for groundwater recharge, irrigation of forests and highways, and wetlands development - the wastewater reuse policy, launched in the early 1980s favors planned water reuse for agricultural and landscape irrigation (Bahri, 2000). Approximately 7 to 10 percent of the overall irrigated area (14,500 hectares or 35,830 acres) is located around the Great Tunis. Reclaimed water is used mainly during spring and summer, either exclusively or as a complement to groundwater. About 35 Mm^3 (9,250 mg) of reclaimed water annually is allocated for irrigation. In some areas, irrigation with effluent is well established and most of the volume allocated is being used. In new areas, where irrigation is just beginning, the reclaimed water usage rate is slowly increasing. The annual volume of reclaimed water is expected to reach 290 Mm^3 (76,600 mg) in the year 2020. At that point, reclaimed water could be used to replace groundwater (18 percent) that is currently being used for irrigation, particularly in areas where excessive groundwater mining is causing seawater intrusion in coastal aquifers.

The area currently irrigated with reclaimed water is about 7,000 hectares (17,300 acres), 80 percent of which is located around Tunis, with a few other locations near Hammamet, Sousse, Monastir, Sfax, and Kairouan. By 2020, the area irrigated with reclaimed water is planned to expand between 20,000 and 30,000 hectares (49,400 and 74,100 acres). However, the availability of agricultural land is a limiting factor, especially along seashores where most of the reclaimed water is generated. The most common irrigation methods are sprinklers (57 percent of the equipped area) and surface irrigation (43 percent). Another common water reuse practice is golf course irrigation. In fact, 8 existing golf courses are irrigated with treated effluent in compliance with the WHO guidelines (1989) for water reuse on recreational areas with free access to the public (2.3 log units /100 ml) during winter and part of spring.

Water reuse in agriculture is regulated by the 1975 Water Law and by the JORT Decree No. 89-1047 (1989). The reclaimed water quality criteria for agricultural reuse were developed using the guidelines of Food and Agriculture Organization of the United Nations (1985) and WHO (1989) for restricted irrigation (less than 1 helminth egg/l), and other Tunisian standards related to irrigation or water supply. The Water Law prohibits both the use of raw wastewater in agriculture and the irrigation with reclaimed water of any vegetable to be eaten raw. The 1989 decree specifically regulates reuse of wastewater in agriculture and allows the use of secondary treated effluent for growing all types of crops except vegetables, whether eaten raw or cooked. The main crops irrigated with treated wastewater are fruit trees (citrus, grapes, olives, peaches, pears, apples, and grenades), fodder (alfalfa, sorghum, and berseem), sugar beet, and cereals. Peri-urban irrigated areas are mainly devoted to the production of vegetables eaten raw, which is a major constraint to reuse development because of the crop-type irrigation restrictions. Specifications regarding the terms and general conditions of reclaimed water reuse (and the precautions that must be taken in order to prevent any contamination to workers, residential areas, and consumers) have also been established.

Two new, large water reuse projects are planned for Tunis West and the Medjerda catchment area. The new wastewater treatment plant for the City of Tunis West will have a design capacity of 105,000 m^3/d (41 Mm^3/year or 27.7 mgd) by the year 2016, which will enable the irrigation of approximately 6,000 hectares (14,800 acres). The ongoing Medjerda catchment area sanitation program is planning to equip the 11 largest towns with sewage networks, treatment plants, and reclaimed water irrigation schemes in order to protect natural resources, particularly the Sidi Salem dam (450 Mm^3 or 119,000 mg), from contamination by raw wastewater.

The National Sewerage and Sanitation Agency is responsible for the construction and operation of all sewage and treatment infrastructure in the larger cities of Tunisia. When effluent is to be used for agricultural irrigation, the Ministry of Agriculture is responsible for execution of the projects, which include the construction and operation of all facilities for pumping, storing, and distributing the reclaimed water. Various departments of the Ministry are responsible for several functions, while regional departments supervise the Water Code and collection of charges, about \$0.01/m^3 (\$0.04/1,000 gallons), according to the World Bank (2001).

8.5.32 United Arab Emirates

The United Arab Emirates (UAE) is a federation of 7 emirates: Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Fujairah, Umm ul Quwain, and Ajman. According to the 1995 national census of the Ministry of Planning, the population is approximately 2.4 million, mostly urban (83 percent). Only a few renewable water resources are available - 200 Mm^3 or 61 m^3/capita/year (52,830 mg or 16,100 gallons/capita/year) in 2000. The annual water demand of 954 m^3/capita/year is met by depleting non-renewable aquifers and desalinization (700 Mm^3/year or 185,000 mg/year in 1997). It is estimated that about 500 Mm^3 (132,000 mg) of wastewater were produced in the urban areas during 1995, of which 108 Mm^3 (28,530 mg) were treated and reused (Food and Agriculture Organization of the United Nations, 2002).

By far the largest emirate in the United Arab Emirates is Abu Dhabi, where extensive nonpotable reuse has been practiced since 1976. The system, designed for 190,000 m^3/d (50 mgd), includes a dual distribution network which uses reclaimed water—referred to, in the UAE and other Persian Gulf states as treated sewage effluent (TSE)—for urban irrigation of 15,000 hectares (38,000 acres) of urban forests, public gardens, trees, shrubs, and grassed areas along roadways. The treatment facility provides tertiary treatment with rapid sand filtration and disinfection by chlorination and ozonation. The reclaimed water distribution system is operated at lower pressure than the potable system to reduce wind spraying. Conveyance and control elements of the system are painted purple, marked, and labeled to avoid cross-connections.

Al-Ain, with a projected population of 250,000 by the year 2000, produces reclaimed water that may be used only for restricted irrigation. The reclaimed water is pumped about 12 kilometers (7 miles) outside the city where it is used for irrigation in designated areas. Treatment includes dual-media filtration and chlorination for disinfection.

8.5.33 United Kingdom

The impact of climatic change on inland water resources has been noted in the southeast of England in the United Kingdom, where a drought had been experienced in the early 1990s. As a result, diminishing raw water supplies led water planners to develop projects to help safeguard and optimize existing raw water supplies, as well as search for future resources.

The United Kingdom has used sewage effluents to maintain river flows (and ecosystems) and, through river abstractions, to contribute towards potable water and to augment other supplie. This practice is particularly developed for the major rivers in the south and east, including the Thames River, where it is not always feasible to abstract upstream of sewage works.

For example, in the Water Resource Plan for East Anglia of 1994, the National Rivers Authority (a predecessor body of the Environment Agency) recognized the importance of reclaiming wastewater effluents to augment the flow in the River Chelmer and the water stored in the Hanningfield reservoir in Essex, United Kingdom. As a result of this decision, the first indirect potable reuse project in Europe was implemented in 1997 (Lazarova, 2001). Water quality for this project has been strictly observed including the monitoring of viruses and estrogens, as well as numerous studies of the impact of reuse on the environment (estuary ecosystem) and public health (Walker, 2001). The project was developed in 2 stages. The first stage involved a temporary system to pretreat the effluent at Langford Works with UV disinfection before pumping the effluent to Hanningfield reservoir, a large 27-Mm^3, 354-hectare (7,130-mg, 875-acre) bankside raw water reservoir with a residence time of up to 214 days. Abstraction from the reservoir is followed with advanced potable water treatment at the Hanningfield

Treatment Works. The discharge consent applied for utilizing 30,000 m^3/d (7.9 mgd) of the sewage effluent in 1997 to 1998. The second stage of the project involves more traditional water reuse - discharging the effluent back into the river and improving the wastewater treatment at the source - Langford Treatment Works. This medium/long term plan was approved in 2000 and the new tertiary treatment plant has been in operation since the beginning of 2002. The reclaimed water is discharged into the River Chelmer and then abstracted along with river water 4 kilometers (2.5 miles) downstream at Langford Treatment Works for drinking water supply.

There are also some examples of direct treated wastewater reuse in the United Kingdom, mainly for irrigation purposes such as: golf courses, parks, road verges, as well as for commerce, car washes, cooling, fish farming , and industry (power station cooling, for example). One of the more recent projects "Waterwise," was started in January, 1999, to reuse the water from the Beazer Homes district. Wastewater from 500 individual houses is treated by a conventional process; then 70 percent of the water is then discharged to the river and the remaining 30 percent undergoes tertiary treatment before being redistributed to 130 houses connected to a dual distribution network as reuse water.

There are several pilot projects being conducted to study reusing grey water from washing machines, baths, and showers for the flushing of toilets. Since domestic use accounts for over 40 percent of the total water demand in the United Kingdom, 30 percent of which is used for toilet flushing, the interest in grey water reuse is growing. In some case, run-off water is also collected from the roofs of the houses, treated, and blended with grey water to be reused.

A large in-building water reuse project, known as "Watercycle," was implemented in 2000 at the Millennium Dome in London. The design capacity of the plant is 500 m^3/d (132,000 gallons/d). Run-off water, grey water, and polluted groundwater are treated in 3 different treatment trains to a high quality standard for reuse in the more than 600 toilets and over 200 urinals on-site.

8.5.34 Yemen

Yemen has a predominantly semi-arid to arid climate with a large rural population (76 percent). The annual renewable water resources were estimated in 2000 at 4.1 billion m^3 or 226 m^3/capita/year (1,083 billion gallons or 59,700 gallons/capita/year) (surface water and groundwater). There is an increasing awareness in Yemen of groundwater depletion.

The total amount of treated wastewater is estimated at around 92,000 m^3/d (24.3 mgd) from 9 treatment facilities. The largest plants are located in Sana's, Ta'aiz, Al-Hudeidah, and Aden. The common wastewater treatment method used is stabilization ponds, with the exception being the facility of Sana's, which utilizes an activated sludge system. In addition, 3 new treatment plants with stabilization ponds will be in operation in 2002 in Aden, Yarim, and Amran with design capacities of 60,000, 3,500, and 6,000 m^3/d (15.9, 0.93, and 1.6 mgd), respectively. New plants are also planned in Beit Al-faqih, Bagel, and Zabid.

Controlled water reuse for irrigation is practiced in the coastal plain cities (Aden, Hodeidah), mainly to build the green belts, as well as for the fixation of sand dunes or control of desertification in affected areas. Unplanned and unregulated wastewater reuse is commonly practiced by the farmers to grow corn and fodder in Taiz area, or to grow restricted and non-restricted crops, like vegetables and fruits, in the Sana'a area.

In 2000, the new wastewater treatment plant for the capital city of Sana'a began operation. The activated sludge treatment plant, with a design capacity of 50,000 m^3/d (13 mgd), faces numerous operational problems. The problems are due, among other things, to a lack of sufficient operational storage and an organic load of the incoming wastewater that is higher than the load used in the plant design. The plant substantially increased the amount of reclaimed water available to farmers in 15 villages along the wadi, downstream of the plant. Farmers pump the reclaimed water with their own pumps to their fields. This has reduced the pressure on the overexploited aquifer in the area. The number of active agricultural wells was reduced from 80 to 55, mainly because pumping reclaimed water is cheaper than operating the wells. Vegetables are the main crops grown and there are no crop restrictions. Farmers have little information about the quality of the treated wastewater. Upgrades to the treatment plant are planned to make the reuse of reclaimed water safer in the future (World Bank, 2001).

Five water reuse projects are being initiated in Aden, Amran, Hajjah, Ibb, and Yarim. Funded by the German government's Kreditanstalt für Wiederaufbau (KfW), these projects will make significant volumes of secondary treated reclaimed water available, mostly for agricultural irrigation. In Aden, some of the water will be used for industrial cooling. The wastewater collection and treatment systems are already being constructed or have recently been completed for each of the cities in the program.

8.5.35 Zimbabwe

In Zimbabwe, water reuse is an established practice that has been accepted not only by engineers and environmentalists, but also by all stakeholders involved in the water resources management of the country (Hranova, 2000). This acceptance of water reuse has been influenced by 2 major factors governing the water resources systems management of the country: (1) the scarcity of available natural water resources, and (2) the watershed effect. Geographically, Zimbabwe's major towns lie on or close to the main watershed. Therefore, in order to increase the catchment yield, water supply dams are, in many cases, located downstream from the urban areas.

The present policy of wastewater management focuses primarily on 2 major types of water reuse. One is direct reuse of treated wastewater for irrigation purposes, where the treatment technologies adopted are based on classical biological treatment systems, mainly trickling filters, waste stabilization ponds, and combinations. The 2 largest direct reuse projects for irrigation purposes are located in 2 major towns of Zimbabwe – Harare and Bulawayo. The second type is indirect potable water reuse, where municipal wastewater is treated in biological nutrient removal plants and then discharged to watercourses and reservoirs that are used for potable water supply downstream from the discharge point.

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