ECONOMIC IMPLICATIONS OF WATER SUPPY SHORTAGES: LOCAL AND GLOBAL PERSPECTIVES

Dennis Wichelns[1]

ABSTRACT

The increasing demand for water in all sectors has brought new focus to the use of non-conventional water sources, for both potable and non-potable purposes. Desalination of seawater and brackish water, and advanced treatment of sewage effluent have increased in recent years, particularly in arid regions seeking to enhance their effective water supply. Desalination is used primarily to produce drinking water, although desalinated water is used also for irrigation in some countries. Most of the treated wastewater that is not discharged into receiving waters is used to irrigate landscapes and agricultural crops. In some countries treated wastewater is injected or infiltrated into groundwater as part of an aquifer storage and recovery program. In some areas, such programs expand the supply of water available for irrigation, while also extending the useful life of aquifers that might otherwise be depleted due to excessive pumping. We review some of the issues pertaining to the use of desalination and treated wastewater to expand water supplies. We describe several examples in which countries have either gained substantial experience in using desalination or wastewater treatment, or they are considering the potential role of such a program in response to increasing water scarcity. While the potential benefits of using desalinated water and treated wastewater for irrigation and other purposes are substantial, so too is the potential public concern regarding these non-conventional water sources. Educational programs and financial incentives might be required to motivate producers and consumers to begin viewing these sources as safe and affordable alternatives.

INTRODUCTION

In response to the increasing demand for water, many countries and municipalities in arid regions have implemented programs to utilize treated wastewater for potable and non-potable uses. Much of the treated wastewater is used in agriculture, while smaller amounts are used to irrigate landscapes, parks, and sporting fields (Van der Bruggen, 2010). Some is used also to recharge groundwater and to supplement industrial water supplies.

Agriculture and landscaping account for large portions of wastewater use in California and New South Wales, Australia, while environmental uses are most important in Japan (Table 1). Much of the plumbing in large buildings in major Japanese cities is designed to accommodate both treated wastewater and freshwater (Van der Bruggen, 2010). In addition, the price of treated wastewater for domestic users is 16% less than the price of potable water.

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[1] Principle Economist, International Water Management Institute, P.O. Box 2075, Colombo, Sri Lanka

Table 1. Proportional uses of treated wastewater in California, Japan, and New South Wales, Australia

California		Japan		New South Wales	
Wastewater use	(%)	Wastewater use	(%)	Wastewater use	(%)
Agricultural irrigation	47	Environmental uses	52	Agriculture (indirect)	39
Landscape irrigation	21	Snow melting	18	Agriculture (direct)	7
Aquifer recharge	9	Agriculture	13	Industrial uses	38
Recreational uses	6	Industry	5	Golf courses	11
Industrial use	5	Toilet flushing	5	Processed water	5
Seawater barrier	5	Uses in plants	5	Others	
Wildlife habitat	4	Others	2		
Others	3				
Sum	100		100		100
Source: Van der Bruggen, 2010.					

Treated and untreated wastewater is used extensively in the Middle East, where freshwater supplies are notably scarce. In Jordan, 95% of the treated wastewater volume is used each year, primarily for irrigation in the Jordan Valley (Van der Bruggen, 2010). In Kuwait, treated wastewater is used for agricultural and landscape irrigation, and for groundwater recharge.

Farmers in Israel currently use an estimated 350 million m^3 per year for irrigating fruits, vegetables, flowers, and field crops (Table 2). The estimated cost of treating wastewater to achieve the minimum level of quality required for irrigating field crops, forage crops, and sod in Israel is \$0.12 per m^3 (Fine et al., 2006). Such water may be used to irrigate fruits and vegetables only in conjunction with crop-specific barriers to prevent contact between the crop and the irrigation water. Protective barriers include plastic ground covers, the use of subsurface drip irrigation, and maintaining an aerial distance between drip system emitters and fruit trees (Fine et al., 2006).

Table 2. Estimated use of water in agriculture in Israel in 2001

Crop Category	Agricultural Water Use	Estimated Wastewater Use
	(MCM / year)	(MCM / year)
Vegetables in open fields	114	30
Vegetables that must be cooked	64	30
Herbs	9	1
Greenhouse vegetables	41	5
Flowers	50	4
Sod	4	1
Orchards (excl. citrus)	387	79
Citrus	186	100
Field crops	91	50
Fodder crops	61	50
Fish ponds	105	0
Animals	27	0
All uses	1,139	350
Note: MCM is million cubic meters.		
Source: Fine et al., 2006.		

In some applications, implementing physical barriers is a less costly approach to using treated wastewater in agriculture than treating the wastewater to the level required for unrestricted irrigation. In Israel, the estimated cost of full treatment to allow unrestricted irrigation is \$0.36 per m^3, while the estimated costs of lower level treatments range from \$0.12 to \$0.21 per m^3 (Table 3). Use of the lowest quality water is prohibited on vegetables and most fruits, but water with a medium level of treatment may be used on deciduous and citrus orchards if barrier methods are implemented. Water receiving a high level of treatment may be used on most vegetables and fruits, with similar consideration for physical barriers. The crop-specific total cost, including the high level of treatment and physical barriers, ranges from \$0.22 to \$0.30 per m^3 (Table 3). This range is notably below the \$0.36 per m^3 cost of treating wastewater to the level that allows unrestricted irrigation.

Table 3. Estimated cost of using treated wastewater, in dollars per m^3, and the number of barriers needed

	Level of Wastewater Treatment			
Crop Category	Low	Medium	High	Unrestricted Irrigation
Cost at the treatment plant	0.12	0.13	0.21	0.36
Number of barriers needed	0	3	2	0
Vegetables in open fields	Pr.	Pr.	0.28	0.36
Vegetables eaten cooked	Pr.	Pr.	0.22	0.36
Herbs	Pr.	Pr.		0.36
Greenhouse vegetables	Pr.	Pr.	0.29	0.36
Flowers in open fields	Pr.	Pr.	0.27	0.36
Sod	0.12	0.13	0.21	0.36
Orchards (excl. citrus)	Pr.	0.18	0.27	0.36
Citrus	Pr.	0.14	0.30	0.36
Grapes	Pr.	Pr.	0.22	0.36
Field crops	0.12	0.13	0.21	0.36
Fodder crops	0.12	0.13	0.21	0.36
Notes:				
Pr. Indicates a prohibited use of treated wastewater.				
Low level treatment	BOD > 60 mg/L, TSS > 90 mg/L			
Medium level treatment	BOD 20 to 60 mg/L, TSS 30 to 90 mg/L			
High level treatment	BOD < 20 mg/L, TSS < 30 mg/L			
Unrestricted irrigation	Removal of pathogens, TSS < 10 mg/L			
Source: Fine et al., 2006				

PUBLIC PERCEPTIONS OF WASTEWATER USE

Public perceptions of wastewater reuse vary across locations and with the amount of information provided to citizens regarding reuse programs. Public acceptance and support for wastewater use generally is stronger with respect to non-potable uses than potable uses (Hartley, 2006). Efforts to persuade citizens to support potable reuse of treated wastewater have failed in several American cities, due partly to inadequate public education and information programs (Hartley, 2006; Marks, 2006). By contrast, potable reuse is promoted vigorously by public officials in Singapore, where as much as 1% of the country's water supply is obtained through reverse osmosis of reclaimed wastewater (Marks, 2006).

Public support for non-potable uses varies with the reuse activity, as revealed in a set of consumer surveys conducted in three American cities and two Australian cities in the late 1990s and 2000 (Marks, 2006). More than 90% of survey respondents in Monterey, California favor wastewater reuse for industrial purposes and for irrigating parks and golf courses (Table 4). About 80% of respondents favor wastewater use on school grounds, while only two-thirds favor wastewater use on vegetable crops.

Smaller proportions of survey respondents favor wastewater use in Irvine and San Jose, California (Table 4). In Irvine, only 47% of respondents favor using wastewater to irrigate household gardens. By contrast, more than 90% of survey respondents in Sydney, Australia, and 88% of respondents in Perth, Australia favor wastewater use on household gardens. More than 90% of respondents in Sydney also favor wastewater use on vegetable crops and parks.

Table 4. Proportions of survey respondents favoring non-potable reuse of wastewater

	Monterey 1996 n=1,000	Monterey 2000 n=1,000	Irvine 1998 n=400	San Jose 1998 n=400	Sydney 1999 n=1,000
Industrial	95	90	89	79	90
Irrigation:					
Golf courses	98	91	88	83	
Parks	95	91	88	83	97
School grounds	83	76		71	
Vegetable crops	68	63	74	62	94
Household gardens			47		95
Note: The proportions shown do not account for uncertain responses.					
Source: Marks, 2006.					

Public support for wastewater reuse is influenced by perceptions of opportunity costs and information provided by public officials. The city of San Antonio, Texas gained public support for a large-scale wastewater treatment and reuse program by informing citizens that the plan would reduce demand on the fossil aquifer that provides the city's drinking water supply (Hartley, 2006).

Dolnicar and Hurlimann (2010) examine public preferences regarding treated wastewater and desalinated water in Australia. In a survey of 1,495 residents aged 18 or above, most respondents expressed greater concerns regarding treated wastewater than desalinated water. In particular, more respondents stated they were more likely to use desalinated water than recycled water for drinking, bathing, cooking, and several other activities (Fig. 1). Respondents were largely indifferent between the two sources when considering activities such as washing the car, cleaning house windows, and flushing toilets.

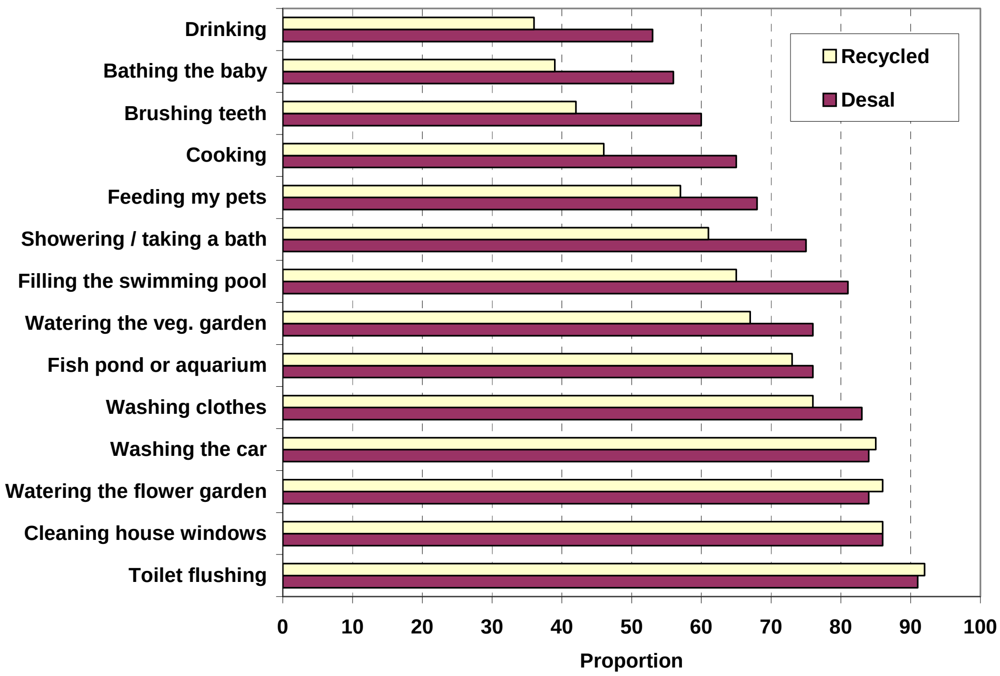

Figure 1. Stated Likelihood of Using Desalinated or Recycled Water
Source: Dolnicar and Hurlimann (2010).

Larger numbers of survey respondents agreed with negative statements regarding treated wastewater than with negative statements regarding desalinated water. For example, 43% of respondents stated they would never drink treated wastewater, while 28% stated they would never drink desalinated water (Fig. 2). Similar results were observed regarding the perceived safety of the two water sources and the perceived health risks. Of interest, more than 70% of respondents stated that wastewater and desalinated water would be suitable for use if scientists approve. Slightly larger proportions of respondents (72% for wastewater and 80% for desalinated water) stated that the water sources would be suitable if using those resources is absolutely necessary.

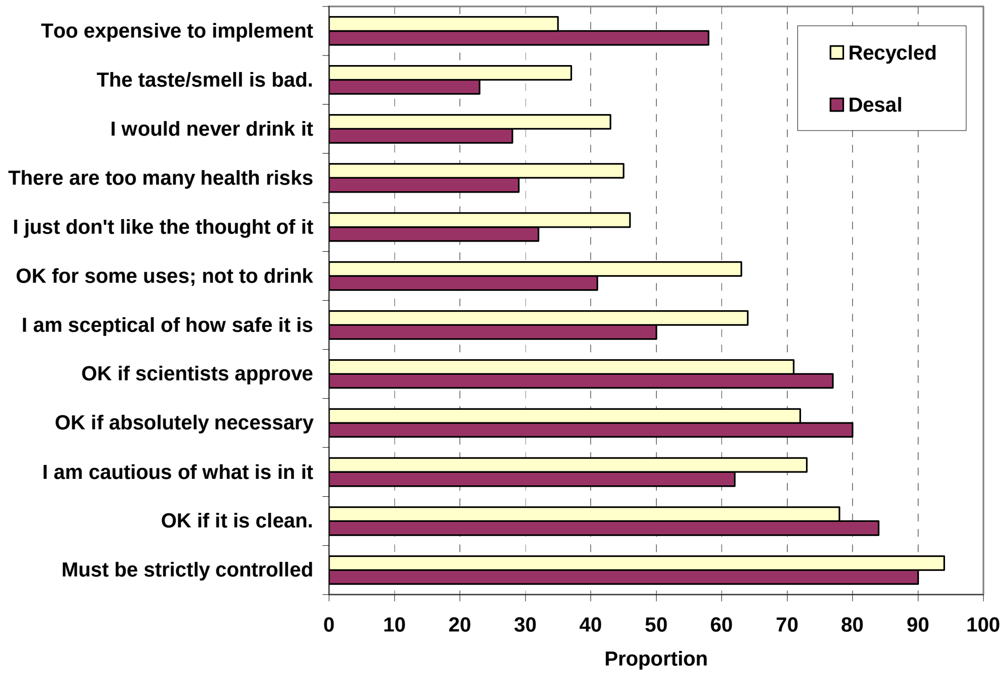

Figure 2. Proportions of Respondents Agreeing with Statements
Source: Dolnicar and Hurlimann (2010).

A COST COMPARISON FROM THE AEGEAN ISLANDS

The primary sources of potable water supply in the Aegean Islands, located between Greece and Turkey, are water imports from Greece, via tanker ships and desalination of seawater via reverse osmosis (Gikas and Angelakis, 2009: Gikas and Tchobanoglous, 2009). To date, there is very little reuse of treated wastewater for potable or non-potable uses. This option is gaining attention, however, given the large energy requirements and the high costs of shipping freshwater and desalting seawater.

Natural water sources on the Aegean Islands are quite limited. Hence, further increases in water supplies to meet increasing demands must come from a combination of water imports, desalination, and wastewater reclamation. Treated wastewater likely would be used primarily for agriculture, landscape irrigation, and non-potable domestic applications (Gikas and Tchobanoglous, 2009). The demand for water in the Aegean Islands and the supply of wastewater are highest during the summer. Thus treated wastewater could be used successfully as a reliable source for agricultural and landscape irrigation. Treated wastewater could be used also for toilet and urinal flushing in residences and hotels, with construction of the necessary distribution system infrastructure.

The estimated costs of alternative water sources in the Aegean Islands vary with the size of production facility, the infrastructure and energy requirements, and the intended final use (Gikas and Tchobanoglous, 2009). The estimated per unit costs of water production are smallest for wastewater reclamation, even when the costs of building the necessary infrastructure are considered (Table 5). The per unit costs for agricultural use range from \$0.65 to \$0.75 per m^3 for a treatment plant producing from 2,500 to 5,000 m^3/day, to \$.75 to \$1.35 per m^3 for a plant producing 100 to 1,000 m^3/day. These costs are quite high in comparison with the cost of irrigation water in most countries, but they are notably lower than the cost of water from alternative sources in the Aegean Islands.

Table 5. Estimated unit costs of water production, including capital, depreciation, energy costs, and operation and maintenance for desalination and wastewater reclamation, as a function of plant capacity, in the Aegean Islands

			Wastewater Reclamation	
Volumetric Capacity	Desalination	Water Imports	Irrigation	Toilet Flushing
(m^3 per day)	(\$ per m^3)	(\$ per m^3)	(\$ per m^3)	(\$ per m^3)
100 to 1,000	1.50 to 3.50	5.00 to 7.00	0.25 to 0.35	0.35 to 0.52
			0.75 to 1.35	0.80 to 1.50
1,000 to 2,500	1.00 to 2.00	5.00 to 6.00	0.15 to 0.20	0.22 to 0.30
			0.60 to 0.75	0.70 to 0.85
2,000 to 5,000	0.75 to 1.25	4.00 to 6.00	0.15 to 0.18	0.22 to 0.27
			0.65 to 0.75	0.75 to 0.85
Note: For wastewater reclamation, the first set of cost estimates in each entry pertains to the cost of wastewater treatment. The second set of cost estimates includes the costs of treatment, pumping, distribution, and storage.				
Source: Gikas and Tchobanoglous, 2009.				

The energy component of the cost of producing water is of interest from two perspectives: 1) Countries that import most of their energy requirements might wish to reduce their dependence on international energy markets, and 2) Countries wishing to reduce their carbon footprint might wish to produce water using relatively small amounts of fossil fuels. Energy accounts for less than 10% of the cost of producing treated wastewater for use in irrigation or domestic applications in the Aegean Islands (Table 6). The energy components in the costs of desalination and water imports are substantially higher. The amount of energy required to produce each unit of water is also substantially higher for desalination and water imports (Table 7).

Table 6. The distribution of costs between capital, energy, and operation and maintenance for alternative water production systems, in the Aegean Islands

			Wastewater Reclamation	
Cost Component	Desalination	Water Imports	Irrigation	Toilet Flushing
	(percent)	(percent)	(percent)	(percent)
Capital	30 to 37	35 to 40	35 to 50	30 to 45
			35 to 50	30 to 45
Energy	40 to 44	40 to 45	3 to 5	4 to 8
			4 to 6	4 to 9
Operation and Maintenance (excluding energy)	20 to 25	20 to 25	50 to 65	60 to 70
			45 to 60	50 to 60

Note: For wastewater reclamation, the first set of values in each entry pertains to the cost of wastewater treatment. The second set of values includes the costs of wastewater treatment, pumping, distribution, and storage.

Source: Gikas and Tchobanoglous, 2009.

In sum, the least costly source of additional water supplies in the Aegean Islands is wastewater reclamation, which also requires less energy per unit of water produced. The relative importance of the energy cost component will vary among countries with the sources and costs of energy supplies, but countries might also consider the carbon emission reduction advantages of reclaiming wastewater.

AQUIFER STORAGE AND RECOVERY

Aquifer storage and recovery provides opportunities to enhance the value of treated wastewater, while also improving the management and extending the useful life of limited groundwater resources. Treated wastewater can be injected or infiltrated into confined or unconfined aquifers, and stored there for recovery and use at a later time. Careful management of water quality parameters is required to ensure continuous operation of recharge facilities and to prevent degradation of aquifer water quality. In some cases, adding treated wastewater can improve the quality of groundwater withdrawn from the aquifer.

Table 7. Estimated energy requirements per unit of water produced, as a function of process type and volumetric capacity

			Wastewater Reclamation	
Volumetric Capacity	Desalination	Water Imports	Irrigation	Toilet Flushing
(m^3 per day)	(kWh per m^3)	(kWh per m^3)	(kWh per m^3)	(kWh per m^3)
100 to 1,000	5 to 10	12 to 16	0.08 to 0.15	0.10 to 0.20
			0.11 to 0.18	0.13 to 0.23
1,000 to 2,500	4.0 to 5.0	6 to 10	0.08 to 0.12	0.10 to 0.15
			0.11 to 0.15	0.13 to 0.18
2,000 to 5,000	3.5 to 4.0	5 to 8	0.05 to 0.10	0.06 to 0.12
			0.08 to 0.13	0.09 to 0.15
Note: For wastewater reclamation, the first set of energy estimates in each entry pertains to the energy for wastewater treatment. The second set of estimates includes the energy for treatment, pumping, distribution, and storage.				
Source: Gikas and Tchobanoglous, 2009.				

An Example from El Paso, Texas

The City of El Paso, Texas began operating an aquifer storage and recovery program, utilizing treated wastewater, in 1985. The program involves one of the City's wastewater treatment plants, which can receive up to 38,000 m^3 per day. The plant injects a portion of the water it produces into the Hueco Bolson, which is an unconfined and semi-confined aquifer, providing much of the region's water supply (Sheng, 2005). El Paso derived about one-third of its water supply from the Hueco Bolson in 2002, while the aquifer is the sole source of drinking water for Ciudad Juarez, an adjacent city located across the Rio Grande in Mexico.

Given the importance of the Hueco Bolson as a major source of drinking water and the persistent shortage of water in this arid region, the recharge program was designed to increase potable water supplies with minimum risk (Sheng, 2006). This objective generated two operational criteria: 1) Maximize the recovery of stored water to minimize costs, and 2) Ensure adequate aquifer storage time to allow for adequate purification of the stored water. The spacing and operation of injection and recovery wells were designed in accordance with these criteria.

During the first 18 years of operation, the treatment plant injected 74.7 million m^3 of reclaimed wastewater, about two-thirds of its production, into the Hueco Bolson (Sheng, 2005). The annual rate of injection, which peaked in 1990 at 7 million m3, has declined since then, due to increasing demand for treated wastewater. In 2005, the treatment plant was injecting from 35% to 50% of its production (Sheng, 2005). Drinking water quality standards have been maintained in the Hueco Bolson and the level of groundwater has been increased by about 5 meters near the center of the recharge well field. Raising the level of groundwater in the Hueco Bolson has been an additional goal of the recharge project.

Two Examples from Australia

The first aquifer storage and recovery program utilizing treated wastewater in Australia was established at the Bolivar sewage treatment plant near Adelaide in 1996 (Dillon et al., 2006). One goal of the program was to test the injection and recovery operation, using wastewater treated only to the quality required for unrestricted irrigation. The injected wastewater thus contained substantial nutrient concentrations. Between October 1999, and June 2002, 364 ML of water were injected into the aquifer and 243 ML (67%) were recovered (Dillon et al., 2006).

The estimated cost of the program, excluding the cost of water treatment and the pipeline, ranges from \$0.08 to \$0.18 per m^3 (Dillon et al., 2006). This range includes a portion of the farm-level cost range for pumping groundwater in the region, which is \$0.12 to \$0.34 per m^3. If the farm-level perception of the recovered water is positive, it should be possible to design a price structure that enables the City to recover its incremental costs of operating the aquifer storage and recovery program, by charging prices that farmers are willing to pay.

A second aquifer storage and recharge program utilizing treated wastewater was established in Alice Springs, Australia, following workshops with stakeholders that took place from 1998 through 2003 (Dillon et al., 2006). Infiltration was chosen as the method of recharge in the Alice Springs program, to avoid the more restrictive water quality guidelines pertaining to injection. Additional investigation is required in selecting a recharge site, however, as planners must consider the characteristics of both the aquifer and the overlying soils (Dillon et al., 2006).

Groundwater salinity should be reduced in both the Adelaide and Alice Springs programs, as the salinity of reclaimed wastewater is less than the salinity of typical groundwater withdrawals (Table 8). Reductions in groundwater salinity might improve the likelihood of charging a price for irrigation water that recovers a substantial portion of the aquifer storage and recovery program.

Table 8. Selected characteristics of the aquifer storage and recovery programs in Adelaide and Alice Springs, Australia

	Units	Adelaide	Alice Springs
Recharge method		Injection	Infiltration
Trial capacity	ML / year	250	600
Groundwater salinity (typical)	mg / L	2,100	1,900
Reclaimed water salinity (typical)	mg / L	1,200	1,000
Land area required	m^2	< 200	< 20,000
Notes:			
The aquifer in Adelaide is extensive, confined tertiary limestone.			
The aquifer in Alice Springs is unconfined alluvial paleo-channel.			
Source: Dillon et al., 2006.			

SUMMARY

The increasing use of desalinated water and treated wastewater for potable and non-potable uses will bring new challenges for farmers, water purveyors, and public officials in the years ahead. In many areas, new polices and programs will be needed to support the development of desalination and the treatment and wise use of wastewater. In arid regions with limited water supplies, treated wastewater is a resource that can expand the supply of water available for agricultural and landscape irrigation and other non-potable uses. Several countries also use treated wastewater in aquifer recovery and storage programs. Whether injecting wastewater into aquifers or infiltrating it through the soil, recharge programs enable timely use of treated wastewater, while also providing a helpful buffer between wastewater and the consumer.

Public preferences regarding wastewater and desalinated water have been examined in several countries. Citizens generally express health and aesthetic concerns regarding wastewater, while they have fewer concerns regarding desalinated water. Public education programs can enhance consumer acceptance of treated wastewater as a component of their water supply, particularly if the programs present supportive information based on sound science.

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