
**Feed the cities**

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# 11 Agricultural use of marginal-quality water—opportunities and challenges

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## Overview

*Millions of small-scale farmers around the world irrigate with marginal-quality water, often because they have no alternative.* There are two major types of marginal-quality water: wastewater from urban and peri-urban areas, and saline and sodic agricultural drainage water and groundwater. Around cities in developing countries, farmers use wastewater from residential, commercial, and industrial sources, sometimes diluted but often without treatment. Sometimes farmers in deltaic areas and tailend sections of large-scale irrigation schemes irrigate with a blend of canal water, saline drainage water, and wastewater. Still others irrigate with saline or sodic groundwater, either exclusively or in conjunction with higher quality surface water. Many of those farmers cannot control the volume or quality of water they receive.

*Wastewater often contains a variety of pollutants:* salts, metals, metalloids, pathogens, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products. Any of these components can harm human health and the environment. Farmers can suffer harmful health effects from contact with wastewater, while consumers are at risk from eating vegetables and cereals irrigated with wastewater. Application of wastewater has to be carefully managed for effective use.

*In contrast to wastewater, saline and sodic water contains salts that can impair plant growth but rarely contains metals or pathogens.* However, it can lead to soil salinization and waterlogging, which impair productivity on millions of hectares of agricultural land. Irrigating successfully with saline or sodic water requires careful management to prevent near-term reductions in crop yield and long-term reductions in productivity.

*Many of the small-scale farmers in developing countries using untreated or diluted wastewater for irrigation likely feel fortunate to have any water supply,* given their inability to purchase higher quality surface water or to pump groundwater. Farmers unquestionably prefer to irrigate with nonsaline water, but in many areas only saline or sodic water is available. The irrigation supply for farmers in tailend portions of irrigation schemes often includes saline drainage water from headend farmers. In some areas of industrialized countries farmers reuse saline drainage water because environmental policies prevent them from discharging the water into rivers or lakes.

> The challenge for public officials is to set policies that enable farmers to maximize the values generated with limited water resources while protecting public health and the environment

*Both the demand for and supply of wastewater for irrigation are increasing in many areas* [well established but incomplete]. Demand is driven by the attractive returns farmers can earn from producing fruits and vegetables in urban and peri-urban settings. Demand also rises with increasing competition for limited water resources in deltaic areas and large-scale irrigation schemes. The supply of wastewater expands with population growth in large cities, towns, and villages throughout the developing world. In many communities the volume of wastewater has increased faster than the ability to build and operate treatment facilities, and as a result more wastewater is released into open ditches or discharged into agricultural drains.

*Public officials in many areas likely have mixed views about the increasing demand for and supply of wastewater and its increasing use for irrigation, and the long-term health effects may eventually affect public budgets* [speculative]. Where public budgets are inadequate for treating wastewater, farmers provide a service by using untreated wastewater for irrigation. The revenue this generates enables farmers to support their families, perhaps enhancing local and regional economic activity. In addition, city residents have access to a local supply of fruits and vegetables that might not be available if farmers were unable to irrigate with wastewater. The downside of the increasing supply is the rising aggregate risk to farmers, consumers, and the environment. The long-term health effects of the increasing use of untreated wastewater might eventually weigh on public budgets, either directly through public expenditures to protect health and welfare or indirectly through the declining productivity of lands regularly irrigated with low-quality wastewater.

*The use of wastewater and saline or sodic water in agriculture increases the total volume of irrigation water in many areas, but the off-farm and long-term negative implications can be substantial* [established but incomplete]. Wastewater use can have health impacts for farmers and consumers, while sustained use of saline and sodic water can impair soil quality and productivity, reducing crop yields. The challenge for public officials is to set policies that enable farmers to maximize the values generated with limited water resources while protecting public health and the environment.

*Irrigation with wastewater is risky, although the link between specific pathogens and risk is not always clear.* The health risks of wastewater use must be evaluated in conjunction with the potential benefits *[competing explanations]*. Both private and public benefits and risks are associated with wastewater use. Optimal treatment strategies will vary by country and situation. Economics, science, and politics will influence wastewater treatment programs and use. Policies that attempt to prevent any irrigation with wastewater, if enforceable, might eliminate desirable economic benefits from the associated crop production.

*Public agencies should consider wastewater and saline or sodic water when evaluating national water management strategies to optimize the use of limited water resources* [established but incomplete]. There are three opportunities for implementing policies to improve the management of marginal-quality water in agriculture and minimize risks from its use: before marginal-quality water is generated, while the water is being used, and after crops have been irrigated and products are prepared for sale and consumption. Treatment and disposal costs can be reduced in many areas by minimizing the volume of marginal-quality water. Efforts to improve the use of wastewater and the handling of agricultural products after harvest can reduce public health impacts. Women have special roles in agriculture and in food preparation, particularly in areas where wastewater is used for irrigation, so special efforts should be made to include women in education programs that promote hygiene and address risk minimization methods.

*Two features complicate policies pertaining to wastewater use in agriculture: most wastewater is generated outside the agricultural sector, and many individuals and organizations have policy interests pertaining to wastewater use [established but incomplete].* Strong institutional coordination is vital, accompanied by flexible control and regulation mechanisms. Public concern regarding wastewater reuse varies with the types of water involved, treatment levels, and information available. Effluent standards, taxes, and tradable permits can motivate improvements in water management by households and industries discharging wastewater from point sources. Pertinent policies include effective water allocation and pricing, water rights, restrictions on groundwater pumping, full-cost energy pricing, and incentives for farm-level investments in water-saving irrigation methods.

**Worldwide, marginal-quality water will become an increasingly important component of agricultural water supplies, particularly in water-scarce countries**

*Public agencies in several countries already implement policies on marginal-quality water* [well established]. Egypt plans to increase its official reuse of marginal-quality water from 10% in 2000 to about 17% by 2017 (Egypt MWRI 2004). In Tunisia in 2003 about 43% of wastewater was used after treatment. Wastewater use will increase in India, as the proportion of freshwater in agricultural deliveries declines from 85% today to 77% by 2025, reflecting rising demand for freshwater in cities (India CWC 2002). Worldwide, marginal-quality water will become an increasingly important component of agricultural water supplies, particularly in water-scarce countries (Abdel-Dayem 1999). Water supply and water quality degradation are global concerns that will intensify with increasing water demand, the unexpected impacts of extreme events, and climate change in resource-poor countries (Watson, Moss, and Zinyowera 1998).

## Situation and outlook

This section examines the main types of marginal-quality water: wastewater from urban and peri-urban areas and saline or sodic agricultural drainage water and groundwater (box 11.1).

### Wastewater—minimizing risks while achieving livelihood goals

Water use by households, cities, and industries generates wastewater containing undesirable constituents. Industrial wastewater often contains metals, metalloids, and volatile or semivolatile compounds, while domestic wastewater often contains pathogens. Wastewater box **11.1** **Marginal-quality water resources**

Marginal-quality water includes urban wastewater, agricultural drainage water, and saline or sodic surface water and groundwater.

- *Urban wastewater* usually refers to domestic effluent, wastewater from commercial establishments and institutions, industrial effluent, and stormwater. Many farmers use treated or untreated wastewater for irrigation. In some areas wastewater is discharged into agricultural drains, and farmers use the commingled water for irrigation.
- *Agricultural drainage water* includes surface runoff and deep percolation that move through surface ditches or are collected in artificial drainage systems. Drainage water often contains salts, agricultural chemicals and nutrients, and soil amendments such as gypsum.
- *Saline or sodic surface water and groundwater* contain salts that originate from reactions that occur as water moves through the soil profile and reactions that occur within the layers where groundwater is located. Saline and sodic water also can contain metals, metalloids, and pathogens that enter groundwater from land-based activities.

from households, cities, and industries must be treated before disposal or reuse to prevent negative health and environmental impacts, particularly where farmers use wastewater for irrigation.

The volume of wastewater increases with urbanization, improved living conditions, and economic development. Large volumes of wastewater are returned to the hydrologic system in urban areas, where only 15%–25% of water diverted or withdrawn is consumed. In most cities in developing countries there is little or no wastewater treatment (WHO and UNICEF 2000). In Asia 35% of wastewater is treated; in Latin America, 14% is treated.

Photo by Liqa Raschid-Sally

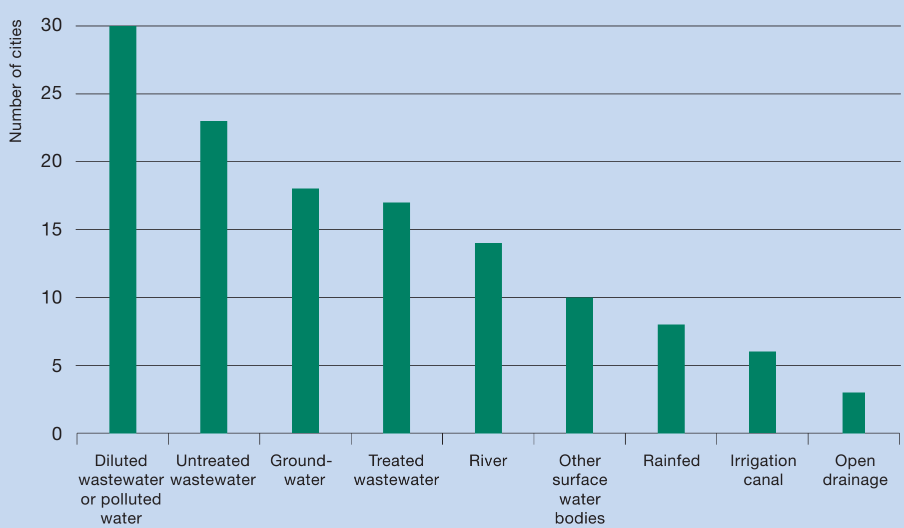
Photo 11.1 Vietnamese women harvest edible aquatic plants from polluted water sources

**box 11.2** | **Urban and peri-urban agriculture and wastewater use**

Worldwide more than 800 million farmers are engaged in urban and peri-urban agriculture (UNDP 1996). Many of the 200 million farmers who specialize in market gardening depend on irrigation. In developing countries these farmers rely on raw or diluted wastewater when higher quality sources are unavailable (see figure).

Irrigated agriculture is important in hot climates of the developing world where refrigerated transport and storage are limited. Farmers enhance household income by producing perishable crops such as leafy vegetables for sale in local markets, providing a supply of vitamin-rich vegetables. In many cities 60%–90% of vegetables are produced within the city or at the city's edge. Although salads diversify urban diets, many residents are at risk when consuming vegetables irrigated with wastewater. This is a major concern for city authorities. Interim health risk reduction strategies are needed where wastewater treatment facilities are not yet available.

**Sources of irrigation water in urban and peri-urban areas**




Source: Raschid-Sally and Jayakody forthcoming.

Urban drainage systems in developing countries mix domestic and industrial wastewater and stormwater, often discharging the wastewater into natural waterways, polluting water used by farmers and other downstream users (Scott, Faruqui, and Raschid-Sally 2004). Such water pollution and the use of this wastewater for irrigation in urban and peri-urban areas are rising in many countries (photo 11.1 and box 11.2).

**Government priorities influence wastewater treatment and management.** In many cities in Asia and Africa population growth has outpaced improvements in sanitation and wastewater infrastructure, making management of urban wastewater ineffective. In India only 24% of wastewater from households and industry is treated, and in Pakistan, only 2% (IWMI 2003; Minhas and Samra 2003). In Accra, Ghana, only 10% of wastewater is collected in piped sewage systems and receives primary or secondary treatment (Drechsel, Blumenthal, and Keraita 2002; Scott, Faruqui, and Raschid-Sally 2004). Even these small volumes of wastewater are not always adequately treated because of lack of capacity or treatment plants that are out of commission. Most developing countries cannot afford to build and operate treatment plants or sewer systems with sufficient capacity, so most wastewater is discharged into waterways without treatment.

**Reliable estimates of projected wastewater use are needed for planning and management.** Except for a few assessments conducted in India, Pakistan, and Viet Nam, limited information on the extent of wastewater use in agriculture makes estimating future use difficult. Data collection and comparison are challenging, in part because of the lack of a universally accepted typology (Van der Hoek 2004). In some cases information on agricultural use of wastewater exists, but government policies make access difficult or the information is available only in local or national literature. Jimenez and Asano (2004) suggest that at least 2 million hectares (ha) are irrigated with untreated, partly treated, diluted, or treated wastewater. The estimated area would be larger if the land irrigated from rivers and canals that receive wastewater were considered. Box 11.3 gives examples of the importance of wastewater use in some countries.

**Wastewater is used for agriculture, aquaculture, and nonagricultural purposes.** In addition to the use of wastewater by small-scale farmers to produce fresh vegetables and other crops in urban and peri-urban areas, wastewater is used to produce grains,

box **11.3** | **The importance of wastewater use in selected countries**

Wastewater has been recycled in agriculture for centuries as a means of disposal in cities such as Berlin, London, Milan, and Paris (AATSE 2004). In China, India, and Viet Nam wastewater has been used to provide nutrients and improve soil quality. In recent years wastewater has gained importance in water-scarce regions. In Pakistan 26% of national vegetable production is irrigated with wastewater. Any changes to this practice would reduce the supply of vegetables to cities (Ensink and others 2004). In Hanoi 80% of vegetable production is from urban and peri-urban areas irrigated with wastewater and water from the Red River Delta, which receives drainage effluent from the city (Lai 2000). Around Kumasi, Ghana, informal irrigation involving diluted wastewater from rivers and streams occurs on an estimated 11,500 ha, an area larger than the reported extent of formal irrigation in the country (Keraita and Drechsel 2004). In Mexico about 260,000 ha are irrigated with wastewater, mostly untreated (Mexico CNA 2004).

In the United States municipal water reuse accounted for 1.5% of water withdrawals in 2000. California residents reuse 656 million cubic meters of municipal wastewater annually. In Tunisia reclaimed water accounted for 4.3% of available water resources in 1996 and could reach 11% by 2030. In Israel wastewater accounted for 15% of water resources in 2000 and could reach 20% by 2010.

fodder, and industrial crops. In developed countries treated wastewater is used in parks, on sporting grounds, and on road plantings. Wastewater is used in aquaculture in Africa, Central Asia, and South and Southeast Asia (Bangladesh, Cambodia, China, India, Indonesia, and Viet Nam). Treated wastewater is also used for environmental purposes (wetlands, wildlife refuges, riparian habitats, urban lakes and ponds), industrial functions (cooling, boiling, processing), nonpotable applications (fire fighting, air conditioning, dust control, toilet flushing), and groundwater recharge (Asano 1998; Lazarova and Bahri 2005).

**Emphasizing livelihoods sometimes leads to neglect of wastewater regulations in agriculture.** Many farmers in developing countries irrigate with diluted, untreated, or partly treated wastewater. Some farmers know the health risks, but not all do. Wastewater is the only reliable or affordable source of irrigation water for many farmers. Farmers who cannot purchase supplemental fertilizer appreciate the nutrient content of wastewater. Public officials recognize the employment opportunities and livelihood benefits made possible by wastewater irrigation (Jimenez and Garduño 2001; IWMI 2003; Keraita and Drechsel 2004). Where farmers already face substantial risks to their welfare and livelihoods, some farmers and public officials likely discount the incremental risk of exposure to wastewater.

Farmers who cannot purchase supplemental fertilizer appreciate the nutrient content of wastewater

In many areas there is a laissez-faire attitude toward wastewater use, as authorities face more important challenges of urbanization and poverty alleviation. With little allocation of funds for wastewater collection and treatment, countries cannot enforce bans on agricultural use of wastewater. Some public officials regard agricultural use as a viable disposal option for wastewater. Some agencies sell wastewater to farmers. However, officials occasionally expel farmers from their fields or uproot vegetables irrigated with wastewater. Officials are challenged to find ways to minimize potential health and environmental risks while allowing communities to achieve livelihood goals. There are also potential impacts on international trade. Some countries might reject shipments of agricultural commodities produced with polluted water.

### Saline and sodic water—rising use with increasing competition for freshwater

Surface runoff and subsurface drainage water can be reused for irrigation, provided sufficient care is taken to minimize harm to crops and maintain salt balance. Artificial drainage systems have been installed in many arid areas to prevent crop damage from saline high water tables. In some areas increases in cropping intensities, excessive use of agricultural chemicals, inappropriate irrigation methods, and irrigation of saline soils have caused increases in the salinity of drainage water (Skaggs and Van Schilfgaarde 1999). To maintain salt balance in the root zone, drainage water salinity must be higher than irrigation water salinity. Where drainage water flows through saline geologic deposits or displaces saline groundwater, the salt load in drainage water exceeds that projected to occur from irrigation alone. In some cases drainage water may dissolve and displace potentially toxic elements.

**With increasing competition for freshwater many communities in water-scarce countries use saline and sodic groundwater for household needs and irrigation.** Groundwater resources are overexploited in many areas, due partly to increasing competition for surface water supplies and partly to policies that encourage excessive use, such as free or cheap electricity for pumping groundwater. In some areas groundwater quality has deteriorated with increasing rates of withdrawal. In India an estimated 32 billion of the 135 billion cubic meters of groundwater withdrawn annually are saline (Minhas and Samra 2003). Saline groundwater results from reactions that occur as water moves through the soil profile and from reactions that occur within groundwater layers. Irrigating with saline groundwater can degrade land quality, causing long-term impacts on crop growth and yields. Substantial investments in land reclamation are needed to restore productivity in some areas.

> The reuse of agricultural drainage water has increased with the expansion of irrigated agriculture

In Bangladesh and West Bengal in India groundwater contains elevated levels of arsenic, a potentially toxic metalloid (Adeel 2001). Persistent use of arsenic-contaminated water for drinking causes health problems whose full effects become apparent only at later stages of development. In India about 66 million people drink groundwater containing excessive fluoride, which causes mottling of teeth and, in severe cases, crippling skeletal deformities and other health problems.

**No regional or global estimates are available of the volumes of saline drainage water and groundwater or the areas irrigated with them.** The reuse of agricultural drainage water has increased with the expansion of irrigated agriculture, particularly since 1950. Global irrigated area has grown from 140 million ha in 1960 to about 270 million ha today. About 20% of the global irrigated area is affected by varying levels of salinity and sodicity (Ghassemi, Jakeman, and Nix 1995). Globally, irrigation efficiency is on the order of 50%, suggesting the use of substantial volumes of drainage water in agriculture. Saline groundwater is also used increasingly for irrigation in water-scarce areas. Analysts generally agree that agricultural use of these waters will gain importance in the overall water balance. With pressures to produce more, the overexploitation of good-quality water in many developing countries and the alarming rate of decline in groundwater levels are putting aquifers at risk of contamination from adjoining poor-quality aquifers. In addition, recent trends in climate change and salt-water intrusion suggest the influence of even greater volumes of these waters in agricultural production in coastal areas in coming years.

**Use of saline and sodic drainage water and groundwater varies greatly among countries.** Egypt uses an estimated 5 billion cubic meters of drainage water for irrigation in the Nile Delta, mixing drainage water with freshwater. In addition, farmers at the tailends of irrigation schemes reuse an estimated 2.8 billion cubic meters of drainage water unofficially. The drainage system also collects treated and untreated wastewater (APP 2002). In India, as noted, an estimated 32 billion cubic meters of saline and sodic groundwater are withdrawn annually.

In agriculture saline or sodic water is used to produce many conventional grain, forage, and feed crops and salt-tolerant plants and trees, particularly in Bangladesh, China, Egypt, India, Iran, Pakistan, Syria, and the United States. Recently, as areas have been

| box 11.4 | Drainage water use in aquaculture and horticulture |
|---|---|

Agricultural drainage water has been used for fish production for more than 20 years in the southern part of Lake Edko, Egypt. Fish ponds cover more than 3,200 ha of land that is too saline to support crop production. Typical pond size is 4 ha, and the average annual production of tilapia, silver carp, and eels is 0.8 tons per hectare, generating annual revenue of about $400 per hectare.

Farmers in the coastal area near Lake Edko use drainage water to irrigate vegetables and fruits, including onions, tomatoes, peppers, cucumbers, watermelons, apples, guava, pomegranates, and grapes. Land is enhanced by adding sand from nearby dunes to the topsoil. The annual rainfall of about 200 millimeters occurs in winter. Wastewater irrigation with drip systems supports crop production in other seasons. The average investment cost is about $2,700 per hectare (IPTRID 2005).

abandoned for agriculture because of waterlogging and salinity, inland saline aquaculture has been adopted on a small scale in several developing countries, as in the Nile Delta of Egypt (Stenhouse and Kijne 2006; box 11.4).

## Impacts of using marginal-quality water

Risk management is essential for preventing adverse impacts when irrigating with wastewater or saline and sodic water. Untreated wastewater disposal pollutes freshwater and causes harmful health and environmental impacts, while inappropriate use of saline and sodic water causes soil salinization and water quality degradation that can limit crop choices and reduce yields.

### Wastewater—human health, environmental, and economic impacts

**Disposal of untreated wastewater pollutes freshwater, affecting other potential beneficial uses, and causes human health and environmental impacts.** The failure to properly treat and manage wastewater generates adverse health effects (table 11.1). In low-income countries women and children are most vulnerable to waterborne diseases. In India the Ganges River receives about 120,000 cubic meters of sewage effluent per day, affecting downstream domestic and agricultural use and threatening human health. In addition, groundwater is contaminated by land disposal of wastewater (Foster, Gale, and Hespanhol 1994).

**Risk management is needed to prevent adverse environmental, health, and gender-related impacts.** Irrigation with wastewater without applying risk management measures may cause contamination of groundwater beneath irrigated fields or during groundwater recharge, particularly when wastewater contains untreated industrial effluent (Ensink and others 2002); accumulation of pathogens with high associated risk where groundwater is used for drinking (Attia and Fadlelmawla 2005); and gradual accumulation of salts, metals, and metalloids in the soil solution and on cation exchange sites to levels that might become toxic to plants.

table **11.1** **Annual global mortality and disability-adjusted life years lost due to some diseases of relevance to wastewater use in agriculture**

| Disease | Number of deaths | DALYs[a] | Comments |
|---|---|---|---|
| Diarrhea | 1,798,000 | 61,966,000 | Almost all (99.8%) deaths occur in developing countries, most (90%) of them among children |
| Typhoid fever | 600,000 | — | Estimated 16 million cases a year |
| Ascariasis | 3,000 | 1,817,000 | Estimated 1.45 billion infections; 350 million suffer adverse health effects |
| Hookworm disease | 3,000 | 59,000 | Estimated 1.3 billion infections; 150 million suffer adverse health effects |
| Lymphatic filariasis | 0 | 5,777,000 | Mosquito vectors of filariasis breed in contaminated water; does not cause death but leads to severe disability |
| Hepatitis A | — | — | Estimated 1.4 million cases a year; serological evidence of prior infection ranges from 15% to nearly 100% |

— not available

Note: The table considers diseases potentially attributable to pollution caused by wastewater use in agriculture.

a. DALYs, or disability-adjusted life years lost due to disease, reflect the time lost due to disability or death from a disease, compared with a long life free of disability in the absence of the disease. DALYs describe the health of a population or burden of disease due to a specific disease or risk factor.

Source: Adapted from WHO 2006.

Human health risks from wastewater include exposure to pathogens, helminth infections, and heavy metals. Leafy vegetables, eaten raw, can transmit contamination from farm fields to consumers. Hookworm infections are transmitted by direct exposure to contaminated water and soils. A survey along the Musi River in India revealed the transfer of metal ions from wastewater to cow's milk through fodder (para grass) irrigated with wastewater. About 4% of grass samples showed excessive amounts of cadmium, and all samples showed excessive lead. Milk samples were contaminated with metal ions ranging from 1.2 to 40 times permissible levels (Minhas and Samra 2004). Leafy vegetables accumulate greater amounts of certain metals like cadmium than do nonleafy species. Generally, metal concentrations in plant tissue increase with metal concentrations in irrigation water, and concentrations in roots usually are higher than concentrations in leaves.

Farmers and their families using untreated wastewater are exposed to health risks from parasitic worms, viruses, and bacteria. Many farmers cannot afford treatment for some of the health problems caused by exposure. Generally, farmers irrigating with wastewater have higher rates of helminth infections than farmers using freshwater, but there are exceptions (Trang and others 2006). In addition, skin and nail problems occur more frequently among farmers using wastewater (Van der Hoek and others 2002). The relationship among possible health risks, pathogen concentrations, and water quality guidelines is described in box 11.5.

The gender implications of wastewater use arise from women's roles in agriculture. Women provide much of the labor required to produce vegetables, particularly in developing countries. They also perform much of the weeding and transplanting, tasks that can expose them to long periods of contact with wastewater. Women also are more susceptible than other household members to health impacts when domestic water supplies are polluted by wastewater. Women generally prepare meals, creating the opportunity for transferring pathogens to other family members unless good hygiene is maintained. The incremental risk of pathogen transfer is larger in households that normally practice good hygiene. In many areas of low-income countries wastewater is just one of several sources of pathogens. Nonetheless, improvements in the hygiene of food preparation can reduce the risk of health impacts due to consuming crops irrigated with wastewater. Women also have the opportunity to promote risk reduction interventions in vegetable production and marketing, given their key roles in those activities.

**The size of area irrigated with wastewater and the volume of water used are not sufficient statistics for judging the potential implications of wastewater use in agriculture.** Fear of economic repercussions in the trade of agricultural products may make

### box **11.5** Health risk and water quality guidelines

The general perception among policymakers and the public is that using untreated wastewater in agriculture is unsanitary and unhealthy and that the practice should not be promoted. Shuval and others (1986) and Blumenthal and others (2001) showed that wastewater use can increase the risk of intestinal nematode infections, particularly *Ancylostoma* (hookworm) and *Ascaris,* in farmers in India and Mexico. Others have shown that in Egypt, Germany, and Israel consumption of vegetables irrigated with wastewater can increase the risk of *Ascaris* and *Trichyris* infections in the general public (Khalil 1931; Krey 1949; Shuval,Yekutiel, and Fattal 1984). Outbreaks of typhoid fever and an increased risk of enteric disease also have been associated with the consumption of vegetables irrigated with wastewater.

Many studies showing negative health impacts lack statistical rigor, however (Blumenthal and Peasey 2002), and have not measured the concentrations of pathogens in the water used. In addition, most studies that have investigated the risk from consumption of vegetables irrigated with wastewater have linked a high prevalence of infection in a population with the widespread use of wastewater in agriculture. The studies are epidemiologically flawed, as they do not assess the risk of exposure at the individual level. Too few studies have combined an epidemiological component with a water quality assessment and a quantitative microbial risk assessment. Some of the studies meeting that criterion have been conducted under different environmental, cultural and climatic conditions, making comparison and extrapolation of findings difficult.

An expert committee of the World Health Organization first examined the health concerns of wastewater use in aquaculture and agriculture in 1971. Microbial water quality guidelines for irrigation water were established (WHO 1973) but were relaxed in 1989 to 1,000 fecal coliforms per 100 milliliters, based on the findings of epidemiological studies of wastewater irrigation. In addition, a quality guideline for intestinal nematodes was recommended as less than 1 intestinal nematode egg per liter (WHO 1989). The revised guidelines were criticized as being both too lenient and too strict. Recent studies conducted in India, Pakistan, and Viet Nam have challenged the validity of the global (helminth) water quality guideline.

The latest guidelines (2006) for the safe use of wastewater in agriculture have been revised considerably. The fecal coliform guideline has been replaced by a focus on attributable risks and disability-adjusted life years. In addition, governments in developing countries have been given greater flexibility in applying the guidelines (WHO 2006).

governments reluctant to acknowledge the use of wastewater for irrigation and so prevent them from implementing mitigation measures. Jordan's export market was seriously affected in 1991 when countries in the region restricted imports of fruits and vegetables irrigated with inadequately treated wastewater (McCornick, Hijazi, and Sheikh 2004). Jordan implemented an aggressive campaign to rehabilitate and improve wastewater treatment plants and introduced enforceable standards to protect the health of fieldworkers and consumers. The government continues to focus on this sensitive situation, given the importance of international trade. This example reveals that the impacts of wastewater use can be indirect and wide-ranging.

> Many farmers in low-income countries irrigating with wastewater do not understand the risks or the potential environmental consequences

**Most farmers, consumers, and government agents in developing countries are not fully aware of the impacts of using wastewater for irrigation.** Many farmers in low-income countries irrigating with wastewater do not understand the risks or the potential environmental consequences. Many farmers are illiterate, lack adequate information, and have been exposed to poor sanitary conditions for most of their lives. Poverty also motivates many farmers to use any available water for irrigation, regardless of its quality. Many consumers are not aware that farm products have been irrigated with wastewater, while the authorities often have insufficient knowledge of the technical and management options available for reducing environmental and health risks.

### Saline and sodic water—impacts on soil, crop choices, and yields

Water allocation policies in many countries have not been sufficiently rigorous to prevent the overirrigation that causes salinization and waterlogging. Many large-scale irrigation systems have been constructed without adequate drainage systems.

**The risks of using saline and sodic water inappropriately include soil salinization and water quality degradation.** Inappropriate irrigation with saline or sodic water causes salt accumulation in soils, resulting in secondary salinity or sodicity. Salinity affects crop growth through increased osmotic pressure and lower availability of water in the soil to plants and through the specific effects of some elements on plants. Sodicity, as measured by the sodium adsorption ratio or exchangeable sodium percentage, is primarily a soil problem. Sodic soils exhibit structural problems created by certain physical processes (slaking, swelling, and dispersion of clay) and surface crusting that affect erosion, seedling emergence, root penetration, tillage operations, water and air movement, and plant-available water-holding capacity. In addition, imbalances in plant-available nutrients in salt-affected soils impair plant growth.

Elevated levels of salts in irrigation water and soils may restrict planting to crops that can withstand ambient salinity levels. Farmers using saline water must manage irrigation carefully to minimize potential losses due to crop sensitivity to salinity, chloride toxicity, plant-available nutrient deficiency, and structural deterioration of soils (Ayers and Westcot 1985).

**Disposal of saline or sodic water into freshwater bodies impairs environmental quality.** The disposal of saline drainage water into canals and rivers disperses salts and potentially toxic substances over a much wider area. About 1 billion cubic meters of saline drainage water are discharged annually into the Euphrates River in Syria, causing a doubling of salinity (from about 0.5 to 1.0 deciSiemen per meter) when the river enters Iraq. In Jordan water quality in the Amman-Zarqa Basin and the Jordan Valley has been affected for several decades, with consequences for irrigated agriculture (McCornick, Grattan, and Abu-Eisheh 2003). Anticipated increases in the region's population and growth in economic activity will exacerbate the situation. National agencies have gathered extensive datasets, including water quality data, for many years at strategic locations (Grabow and McCornick forthcoming). Analysis of those data will enhance understanding of salinity dynamics and guide the development of policies to minimize the negative impacts of salinity and other wastewater constituents on irrigated agriculture.

In most developing countries wastewater treatment is a long-term strategy; interim solutions may be needed to protect farmers and public health

## Response options and management strategies for marginal-quality water

Many options are available to manage the risks in using marginal-quality water.

### Wastewater—reducing risk

**In resource-poor situations it might be wiser to manage or minimize risk, rather than trying to eliminate risk.** Wastewater needs treatment prior to its use or discharge to the environment (Pescod 1992, Ongley 1996). Public agencies usually determine water quality objectives by considering health risks and requiring wastewater treatment to achieve those goals. The goal of treatment is to remove or reduce unwanted toxic substances, pathogens, and nutrients. Most public agencies evaluate potential risks to individuals and communities when establishing water quality goals. Risk assessments are revised over time with improvements in science and changes in public preferences (see box 11.5).

In many developing countries the costs of operation and maintenance and the lack of required skills are the primary limitations on wastewater treatment capacity. In these situations treatment can be phased in by first introducing primary treatment facilities, particularly where wastewater is used directly for irrigation. Secondary treatment can be implemented in some areas using low-cost options, such as waste-stabilization ponds, constructed wetlands, and up-flow anaerobic sludge blanket reactors (Mara 2003).

Because constraints are greater for large, centralized wastewater collection and treatment systems, decentralized systems that are more flexible and compatible with local demands for effluent use have emerged in many areas. Some communities prefer to operate and maintain local systems to ensure long-term operation and financial sustainability (Raschid-Sally and Parkinson 2004). However, small-scale treatment plants are ineffective when their capacity is exceeded.

Water quality can be improved by storing reclaimed water in reservoirs that provide peak-equalization capacity, which increases the reliability of supply and improves the rate of reuse. Long retention times in the King Talal Reservoir in the Amman-Zarqa Basin of

Jordan reduce fecal coliform levels in water downstream of the dam, although it was not initially intended for that purpose (Grabow and McCornick forthcoming).

In most developing countries wastewater treatment is a long-term strategy. Interim solutions may be needed to protect farmers and public health (IWMI 2006). Though unpopular, protective measures such as wearing boots and gloves can reduce farmers' exposure. Farmers also can wash their arms and legs after immersion in wastewater to prevent the spread of infection. Improvements in irrigation methods and in personal and domestic hygiene can be encouraged through public awareness campaigns. Drip irrigation can protect farmers and consumers by minimizing crop and human exposure, but pretreatment of wastewater is needed to avoid clogging of emitters. A combination of farm-level and post-harvest measures can be used to protect consumers, such as producing industrial or nonedible crops or products that require cooking before consumption. Farmers also can stop applying wastewater long before harvest, to reduce potential harm to consumers. Vegetables can be washed before sale or consumption, and storage methods can be improved. Public agencies can implement child immunization campaigns against diseases that can be transmitted through wastewater use and target selected populations for periodic antihelminthic campaigns (USEPA and USAID 2004; WHO 2006).

The farm-level nutrient value of wastewater will vary with constituent loads, soil conditions, crop choices, and the cost and availability of inorganic fertilizers

**The nutrients in municipal wastewater can contribute to crop growth, but periodic monitoring is needed to avoid imbalanced nutrient supply.** Excessive nutrients can cause undesirable vegetative growth and delayed or uneven maturity (Jensen and others forthcoming), reduce crop quality, and pollute groundwater and surface water. Periodic monitoring is required to estimate the nutrient loads in wastewater and adjust fertilizer applications. The amount of nutrients in 1,000 cubic meters of wastewater irrigation per hectare can vary considerably: 16–62 kilograms (kg) total nitrogen, 4–24 kg phosphorus, 2–69 kg potassium, 18–208 kg calcium, 9–110 kg magnesium, and 27–182 kg sodium. Nitrogen and sodium levels often exceed plant requirements. The farm-level nutrient value of wastewater will vary with constituent loads, soil conditions, crop choices, and the cost and availability of inorganic fertilizers. Studies of the farm-level and aggregate implications of nutrient uptake from untreated wastewater are rare. One study in Viet Nam reports a 40% increase in rice grain protein content in a wastewater irrigation system (Jensen and others forthcoming).

Farmers in Mexico's Mezquital (Tula) Valley appreciate wastewater because it allows agricultural development in an area with annual precipitation of just 550 millimeters and soils that are low in organic matter. Irrigation and supplemental nutrients are required to ensure productivity. Wastewater irrigation in the valley provides 2,400 kg of organic matter, 195 kg of nitrogen, and 81 kg of phosphorus per hectare per year, contributing to significant increases in crop yields (Jimenez 2005). Farmers in the valley oppose wastewater treatment because they do not want nutrients removed from the water they use for irrigation. The farmers may be wrong, however, as even secondary treatment, while removing organic matter, leaves enough nutrients (nitrogen and potassium) to satisfy crop requirements. Box 11.6 provides insight into the costs and benefits of using wastewater in agriculture.

**box 11.6 The costs and benefits of using wastewater in agriculture**

Market prices and standard analytical methods can be used to assess the financial implications for farmers, any negative environmental and health impacts, and any benefits society might derive from wastewater use (Hussain and others 2001; Ul-Hassan 2002; Ul-Hassan and Ali 2002; Scott, Zarazua, and Levine 2000). Ul-Hassan and Ali (2002) estimated the direct benefits to farmers from nutrient reuse and fertilizer savings in Haroonabad, Pakistan. They compared vegetable production with freshwater and untreated wastewater and found that the gross margins with wastewater were significantly higher ($150 per hectare), because farmers spent less on chemical fertilizer and achieved higher yields. No other costs or benefits were measured, but a potential tradeoff calculation showed that each cubic meter of wastewater used for irrigation released three to four times the volume of freshwater for use elsewhere, generating a net monetary gain for society.

Scott, Zarazua, and Levine (2000) estimated nutrient enrichment gains from wastewater application in Guanajuato, Mexico. The estimated cost of replacing the nitrogen and phosphorus received from the wastewater after construction of a treatment plant was $900 per hectare. This was an overestimate as the nutrients in the wastewater exceeded plant requirements; a more realistic value is $135 per hectare. With the plant in operation the total cost to farmers was estimated at $18,900 a year in forgone nutrients (Drechsel, Giordano, and Gyiele 2004).

Estimates of nonmarket costs and benefits, such as health and environmental effects, can inform policies on regulatory targets and intervention programs (WHO 2005). In developed countries most nonmarket evaluations pertain to environmental rather than health issues. The most common is contingent valuation, which uses measures of willingness to pay or willingness to accept to quantify nonpriced goods and services, including nonbeneficial ones, in cases where health and environmental impacts interact in order to evaluate policy choices more comprehensively. Topics to explore include:

- Valuation of the benefits of environmental and health risk reduction, with an emphasis on health disparities within a population and in the context of many risk sources, including irrigation with wastewater.
- Assessment of the full costs and benefits (including productivity impacts) of
  - Environmental technology choices that affect human health at the individual or household level.
  - Policy choices for wastewater management with environmental and health impacts at the aggregate or city level.
- Assessment of how cultural and social factors and individual socioeconomic status affect the discounting of future health and environmental costs and benefits.

Hussain and others (2001, 2002) present a framework and review the literature on the economic impacts of wastewater use.

**With safeguards to protect groundwater quality, treated wastewater can be used for groundwater recharge.** Aquifer recharge with wastewater can occur through deep percolation in irrigated fields (as in Mexico's Mezquital Valley) or through intentional recharge programs. Recharge with wastewater should be conducted under controlled conditions and with continuous monitoring and, if wastewater is injected into an aquifer, treatment. The estimated unintentional recharge due to deep percolation beneath irrigated fields is as large as 1 meter in Jordan, Mexico, Peru, and Thailand, a depth that exceeds average annual rainfall in some areas (Foster and others 2004). Studies in Tula Valley, Mexico, suggest that almost half of the untreated wastewater infiltrates through soil, which acts as a filter and removes pollutants. However, salinity and nitrate levels in groundwater are increasing. Continuous monitoring of the aquifer is needed to identify emerging health problems (Jimenez and Chávez 2004).

Aquifers have been recharged intentionally with treated wastewater for many years in the United States, with no recorded unacceptable impacts. Israel has been recharging an aquifer south of Tel Aviv with reclaimed wastewater for 20 years. About 120 million cubic meters of reclaimed water have been infiltrated into the aquifer each year, using intermittently operated spreading basins (Idelovitch 2001). Water withdrawn from the aquifer is used for unrestricted irrigation of crops.

Groundwater recharge through soil percolation removes microorganisms provided that an appropriate flooding-drying cycle and an adequate microbiological population are maintained. California has proposed criteria for groundwater recharge with reclaimed water combining aspects such as source control, wastewater treatment processes, water quality, recharge methods, recharge area, depth to groundwater, underground retention time of the recharged water, reclaimed water contribution to the aquifer, and extraction well proximity (Asano and Cotruvo 2004).

**Untreated wastewater should not be used on crops that are likely to transmit contaminants or pathogens to consumers.** In many developing countries restrictions on crops (particularly those consumed raw) that are most likely to transmit contaminants and pathogens to consumers are helpful in reducing human health hazards. In the Aleppo region of Syria less than 7% of the area under wastewater irrigation is cultivated with vegetables because government restrictions are enforced by officials who uproot any vegetables found to be growing there. Usually, restrictions are difficult to enforce because demand for vegetables is high in cities and because only vegetables achieve the level of profits farmers need to maintain their livelihoods. A recent global survey found that vegetables (32% frequency of responses) and cereals (27%) are the most common crops produced by farmers using wastewater for irrigation (Raschid and Jayakody forthcoming).

**Pragmatic approaches are needed to protect water quality and achieve sustainable use of wastewater.** Many developing countries have adopted legislation and policies to protect water quality and regulate wastewater use. However, the inclusion of unrealistic criteria makes implementation difficult. A more pragmatic approach would combine provisional guidelines with continuing improvements to enhance wastewater quality or the ability to use wastewater in an environmentally safe manner. Meaningful criteria need to be established in accordance with local, technical, economic, social, and cultural contexts (IWMI 2006). Several countries are integrating management of wastewater reuse to reduce costs and increase agricultural productivity (box 11.7).

Strategies for managing mixed marginal-quality water (wastewater mixed with saline or sodic water) should apply a multiple-barrier approach that incorporates more than one intervention at various points in the water cycle and in crop handling (box 11.8). The multiple-barrier approach has recently been adopted in new Israeli standards and guidelines and

**box 11.7** **Integrated wastewater treatment and use for irrigation in Morocco and Tunisia**

Integrating management of wastewater reuse to minimize treatment costs and increase agricultural productivity is gaining interest in many countries. In Drarga, Morocco, untreated wastewater was being discharged into the environment, contaminating drinking water supplies. To deal with this problem a public participation program created an institutional partnership involving local water management stakeholders, urban water users, and farmers water user groups (USEPA and USAID 2004). Wastewater treatment now includes screening, anaerobic basins, sand filters, and denitrification. To ensure the sustainability of the treatment and reuse program, a fee was imposed for domestic water supply and other cost-recovery mechanisms have been implemented.

Tunisia launched a national water reuse programme in the early 1980s to increase the country's usable water resources. Most municipal wastewater is from domestic sources and receives secondary biological treatment. Several treatment plants are located along the coast to protect coastal resorts and prevent marine pollution. In 2003, 187 million cubic meters of the 240 million cubic meters of wastewater collected in Tunisia received treatment. About 43% of the treated wastewater was used for agricultural and landscape irrigation. Reusing wastewater for irrigation is viewed as a way to increase water resources, provide supplemental nutrients, and protect coastal areas, water resources, and sensitive receiving bodies. Reclaimed water is used on 8,000 ha to irrigate cereals, vineyards, citrus and other fruit trees, and fodder crops. Regulations allow the use of secondary-treated effluent on all crops except vegetables, whether eaten raw or cooked. Regional agricultural departments supervise the water reuse decree and collect charges (about $0.01 per cubic meter). Golf courses also irrigate with treated effluent, while industrial use and groundwater recharge opportunities are being investigated.

**box 11.8** **Integrated approaches to managing mixed wastewater**

The concentration of salts in sewage, soils, and aquifers in some areas of Israel has increased in recent decades. There are no inexpensive ways to remove salts from sewage. The government and farmers are coping with the problem by reducing the salt content of water supplies and treated effluent; reducing salt addition during industrial and residential water use; reducing evaporation losses during wastewater storage; using drip irrigation; adequately draining irrigated fields; discharging saline, first-flood waters of the rainy season; applying calcium soil amendments; and planting salt-tolerant crops (Weber and Juanicó 2004).

in guidelines developed by the World Health Organization. Wastewater treatment levels are categorized on a scale of 1 to 5, with level 5 the lowest quality and usable only on crops that require no barriers. Barriers can be either physical (buffer zones, plastic mulches, or subsurface drip) or process oriented (selecting the right crops; processing, cooking, or peeling prior to consumption). No-barrier crops include cotton, forages, and those harvested at least 60 days after the last irrigation with wastewater (USEPA and USAID 2004).

## Saline and sodic water—improving management

**Leaching and drainage are required to maintain salt balance in the soil profile and to sustain crop yields in arid areas.** Irrigation is essential in arid areas, but it generates saline drainage water that must be disposed of or reused. The salinity of drainage water is a function of the salinity of the applied water, soil salinity, and the salinity of shallow groundwater (Ayers and Westcot 1985; Pescod 1992). In water-abundant areas farmers prefer to discharge saline drainage water. In arid, water-scarce areas drainage water is a resource that can extend farm-level and regional water supplies. Careful management is required to maximize the value of saline drainage water while minimizing negative impacts on downstream areas (Minhas and Samra 2003).

There are different types of drainage systems: natural drainage, subsurface drainage systems (tiles or perforated pipes), tubewell-based drainage, and biodrainage. The choice of drainage system influences the quality of drainage effluent (Tanji and Kielen 2002). Subsurface drainage systems that enhance water flow through the soil quickly remove soluble salts and toxic trace elements from the root zone. The potential for reusing drainage water is reduced by the high salt content of the effluent. Drainage water can be reused if it is blended with freshwater or used to irrigate salt-tolerant crops.

Most subsurface drainage systems are installed 1–3 meters below the surface. Most tubewell-based drainage systems operate at 6–10 meters, but some reach depths of 100 meters, such as the deep tubewell drains in India and Pakistan. The quality of subsurface drainage water is influenced by the type and concentration of salts in irrigation water, the agricultural chemicals used, and the quality of shallow groundwater. With tubewell drains the quality of drainage water is affected by salt-water intrusion, the type and concentration of salts in groundwater, and to a lesser extent the quality of irrigation water (Tanji and Kielen 2002).

Biodrainage involves deep-rooted crops and trees that modify water flux through evapotranspiration. Biodrainage is less costly than conventional drainage and can provide fuel wood, timber, fruit, windbreaks, shade and shelter, and organic matter (Heuperman, Kapoor, and Dencke 2002). Biodrainage also can remove ponds that form along canal embankments. The sustainability of biodrainage is not guaranteed in all settings. The gradual accumulation of salinity might eventually harm deep-rooted crops and trees, reducing their effectiveness. In addition, the decline or harvesting of biodrainage plants will enable salts that have accumulated below the root zone to move upward through capillary action. A combination of biodrainage and a conventional drainage system might delay or minimize the impacts of salt accumulation.

**Water conservation and drainage water reuse, treatment, and disposal can improve management of agricultural drainage water.** Water conservation can reduce the volume of drainage water and constituent loads and make water available for other beneficial uses. Strategies include source reduction, minimization of deep percolation, and groundwater management. Land retirement should be considered where competition for water is intense and where disposal of drainage water is constrained (as in a closed basin) or threatens ecologically sensitive areas.

Drainage water can be reused in conventional agriculture or in saline agriculture and in wildlife habitats and wetlands (Rhoades and Kandiah 1992). Reuse can be combined with conservation measures, particularly when drainage water management cannot be achieved by source reduction alone. Attention must be given to measures that minimize long- and short-term effects of elevated salinity on soil productivity and water quality. Integrated planning and management approaches at district or basin scales can maximize social and economic benefits while safeguarding ecological values (Abdel-Dayem and others 2004).

The cost of drainage water treatment usually exceeds the incremental value of water use in agriculture. However, treatment might be sensible when environmental regulations prevent drainage water disposal or when water scarcity justifies the high cost of treatment. Desalination of drainage water is suitable for high-value purposes only, such as drinking water (box 11.9). Constructed wetlands are a relatively low-cost option for protecting aquatic ecosystems and fisheries, either downstream from irrigated areas or in closed basins.

The volume of drainage water requiring disposal can be reduced by treatment and cyclic reuse. Disposal options include direct discharge into rivers, streams, lakes, deserts, and oceans and discharge into evaporation basins.

**Saline and sodic waters can be used directly or blended with freshwater, but careful management is required to sustain productivity.** Many farmers irrigate with a mixture of saline or sodic water and higher quality water in large areas of Egypt, India, Pakistan, the United States, and Central Asia (Ayers and Westcot 1985; Tanji and Kielin 2002). As long as the salinity of applied water does not exceed threshold levels and good drainage exists, use of saline water will not severely reduce yields. In areas such as India heavy rainfall during a portion of the year prevents the long-term accumulation of salts in the soil.

Where drainage water salinity exceeds crop threshold levels the water can be blended with freshwater. Blending, which can be done before or during irrigation, enables farmers to extend the volume of water available (Rhoades 1999; Oster and Grattan 2002).

In Egypt almost all agricultural land is served by surface or subsurface drainage systems that control soil salinity and reduce crop losses from direct use of saline water. A monitoring program was started in the 1970s to identify spatial and temporal changes in drainage water volume and quality. In 1995 a program was initiated in the Nile Delta to

### box **11.9** | **Desalination of seawater and highly brackish groundwater**

Seawater desalination has been practiced for more than 50 years, mainly in oil-rich Middle Eastern countries. Elsewhere, a few countries with dense populations, substantial industry and tourism, and inadequate drinking water resources also produce freshwater from seawater and brackish groundwater. Desalination plants worldwide produce about 30 million cubic meters of freshwater daily, about two-thirds from seawater and the rest from brackish groundwater.

Distillation, the oldest process for desalting seawater, separates the water from salt and other impurities through evaporation and condensation. Reverse osmosis, which involves tightly bound semipermeable membranes that separate freshwater from seawater, has been used since the 1970s and is more energy efficient than distillation. Interest in desalination has increased in recent years as the cost of producing freshwater has declined from about \$5.50 per cubic meter in the late 1970s to \$0.50–\$0.60. Desalination is not yet affordable for agricultural purposes in most countries.

assess the impacts of drainage water use on soil and water quality and crop yields. According to government policy the salinity of blended water should not be higher than 1.56 deciSiemen per meter. Crop yields using blended water are similar to those obtained using freshwater (table 11.2). Where drainage water is the only irrigation source, however, crop yields are 20%–60% lower (El-Guindy 2003).

The cyclic approach involves crop rotations that include both moderately salt-sensitive and salt-tolerant crops. Typically, nonsaline water is used before planting and during initial growth stages of the salt-tolerant crop while saline water is used after seedling establishment (Rhoades 1999). A crop rotation plan is needed to optimize the use of saline and nonsaline water, given the salt sensitivities of crops at different growth stages. Examples of yields obtained when irrigating with saline water in cyclic and blended fashion are shown in table 11.3 (Minhas, Sharma, and Chauhan 2003). There were nonsignificant losses in wheat yield when two initial canal water irrigations were followed by two saline water irrigations. For a given amount of salt input, yields were higher with cyclic use than when blending saline water and canal water. In addition, cyclic use likely is less costly than blending, which might require infrastructure for combining water from two sources.

table **11.2** **Average irrigation water salinity, soil salinity, and yields of selected crops in the Nile Delta, 1997**

| | Eastern delta | Middle delta | Western delta |
|---|---|---|---|
| *Irrigation water salinity (deciSiemens per meter)* | | | |
| Freshwater | 0.75 | 0.71 | 0.65 |
| Blended water | 1.70 | 1.75 | 0.97 |
| Drainage water | 2.87 | 2.07 | 2.89 |
| *Soil salinity (deciSiemens per meter)* | | | |
| Freshwater | 2.03 | 2.63 | 2.15 |
| Blended water | 2.70 | 4.06 | 2.27 |
| Drainage water | 4.16 | 3.96 | 3.68 |
| *Cotton yield (metric tons per hectare)* | | | |
| Freshwater | 1.73 | 1.82 | 2.40 |
| Blended water | 1.51 | 1.68 | 2.30 |
| Drainage water | 1.06 | 1.56 | 2.09 |
| *Wheat yield (metric tons per hectare)* | | | |
| Freshwater | 9.36 | 5.76 | 5.52 |
| Blended water | 8.40 | 4.32 | 5.28 |
| Drainage water | 5.52 | 4.56 | 4.80 |
| *Maize yield (metric tons per hectare)* | | | |
| Freshwater | 5.52 | 5.04 | 3.60 |
| Blended water | 3.84 | 6.24 | 3.36 |
| Drainage water | 3.60 | 6.96 | 2.40 |

Source: Adapted from DRI, Louis Berger International, Inc., and Pacer Consultants 1997.

table **11.3** **Crop yields under varying modes of irrigation with canal water and saline water, 1990s**
(metric tons per hectare)

| Treatment | Deep water table (more than 6.0 meters) | | | | | | Shallow water table (1.5–2.0 meters) |
|---|---|---|---|---|---|---|---|
| | Cotton-wheat rotation | | Pearl millet-mustard rotation | | Mustard-sunflower rotation | | |
| | Cotton | Wheat | Pearl millet | Mustard | Mustard | Sun-flower | Wheat[a] |
| Canal water only | 1.63 | 4.88 | 3.15 | 2.07 | 2.42 | 1.34 | 6.0 |
| *Cyclic mode* | | | | | | | |
| Pre-planting irrigation with canal water and rest with saline water | 0.98 | 4.05 | 2.99 | 1.88 | 2.25 | 0.71 | 5.3 |
| Pre-planting irrigation with saline water and rest with canal water | ni | ni | ni | ni | 2.39 | 0.99 | ni |
| One irrigation each with saline and canal water and rest with saline water | 0.72 | 4.08 | 2.80 | 1.67 | ni | ni | ni |
| Alternate irrigations with canal and saline water, starting with canal water | 1.23 | 4.72 | 2.96 | 1.96 | 2.54 | 0.99 | 5.8 |
| Alternating two irrigations with canal water and saline water, starting with canal water | 1.28 | 4.62 | ni | ni | ni | ni | 5.1 |
| Alternating two irrigations with canal water and one with saline water, starting with canal water | ni | ni | ni | ni | 2.47 | 0.98 | ni |
| Alternate irrigations with saline water and canal water, starting with canal water | 0.76 | 4.02 | ni | ni | 2.31 | 0.81 | ni |
| Alternating two irrigations with saline water and one with canal water, starting with canal water | ni | ni | 2.91 | 1.41 | ni | ni | ni |
| *Blended mode* | | | | | | | |
| Irrigation with a blend of canal water and saline water in a 1:1 ratio | 1.04 | 4.37 | 2.80 | 1.81 | ni | ni | ni |
| Irrigation with a blend of canal water and saline water in a 1:2 ratio | ni | ni | ni | ni | 2.60 | 0.72 | ni |
| Irrigation with a blend of canal water and saline water in a 2:1 ratio | ni | ni | ni | ni | 2.50 | 0.89 | ni |
| All irrigations with saline water | 0.46 | 3.59 | 2.91 | 1.18 | 2.52 | 0.29 | 4.5 |
| Least square difference ($p = 0.05$) | 0.32 | 0.35 | ns | 0.36 | ns | 0.15 | ni |

ni is not included in the respective treatment; ns is not significant.

Note: Salinity of canal water is 0.4–0.7 deciSiemens (dS) per meter. Saline water is 9 dS per meter for cotton and wheat, 12 dS per meter for pearl millet and mustard, 8 dS per meter for mustard and sunflower, and 12–17 dS per meter for wheat.

a. Under shallow water table conditions, cyclic use is for post-plant irrigations since wheat received pre-plant irrigation with canal water.

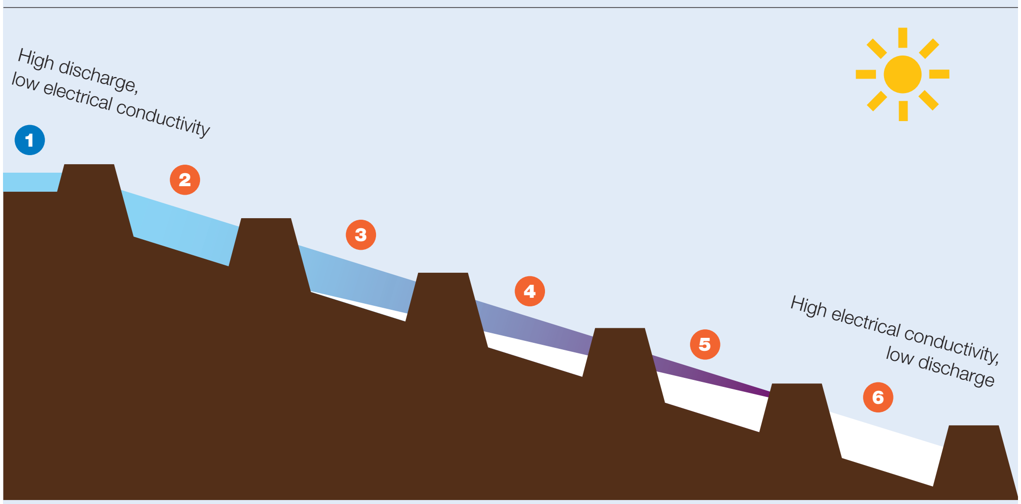
Source: Minhas, Sharma, and Chauhan 2003.

The cyclic option involves applying relatively better quality water to a crop with low salt tolerance, then using drainage water from that field to irrigate crops with greater salt tolerance. This strategy minimizes the volume of drainage water requiring disposal by reusing drainage water on fields located downslope of those where drainage water is first collected (Rhoades 1999). The number of cycles depends on the concentrations of salt and other elements in drainage water, the volume of water available, economic values, and acceptable yields (figure 11.1). Implementing cyclic reuse on a regional scale, rather than on individual farms, enhances long-term feasibility. Drainage water reuse can be concentrated on a small portion of a regional irrigation scheme, minimizing the areal extent of land degradation from salt accumulation. In every reuse sequence the volume of drainage water decreases and the salt concentration increases. The final sequence produces brine that can be discharged to a solar evaporator or an alternative repository.

**Cropping choices are key decisions when irrigating with saline or sodic water.** Crops vary considerably in their ability to tolerate saline conditions (table 11.4). Factors such as the type and concentration of salts, expected rainfall and its distribution, groundwater levels and quality, and irrigation management practices must be considered when irrigating with saline or sodic water. Irrigation with saline water can improve the quality of some crops, as the sugar content in sugarbeets, tomatoes, and melons is increased (Moreno and others 2001).

figure **11.1** **Sequential reuse of drainage water on drainage-affected lands as proposed in the San Joaquin Valley Drainage Implementation Program, California**

1 Drainage water
2 Salt-sensitive crops
3 Salt-tolerant crops
4 Salt-tolerant trees
5 Halophytes
6 Solar evaporator




Source: Adapted from Tanji and Kielen 2002.

table **11.4** **Yield potential of selected crops as a function of average root zone salinity**

| Common name | Botanical name | Average root zone salinity at specified yield potentials (deciSiemens per meter) 50% | 80% | 100% |
|---|---|---|---|---|
| Triticale (grain) | *X Triticosecale* | 26 | 14 | 6 |
| Wheat (forage) | *Triticum aestivum* L. | 24 | 12 | 4 |
| Kallar grass | *Leptochloa fusca* (L.) Kunth | 22 | 14 | 9 |
| Durum wheat | *Triticum durum* Desf. | 19 | 11 | 6 |
| Tall wheat grass | *Agropyron elongatum* (Host) Beauv. | 19 | 12 | 8 |
| Barley (grain) | *Hordeum vulgare* L. | 18 | 12 | 8 |
| Cotton | *Gossypium hirsutum* L. | 17 | 12 | 8 |
| Rye (grain) | *Secale cereale* L. | 16 | 13 | 11 |
| Sugar beet | *Beta vulgaris* L. | 16 | 10 | 7 |
| Bermuda grass | *Cynodon dactylon* L. | 15 | 10 | 7 |
| Sudan grass | *Sorghum sudanese* (Piper) Stapf | 14 | 8 | 3 |
| Sesbania | *Sesbania bispinosa* (Jacq.) W. Wight | 13 | 9 | 6 |
| Wheat (grain) | *Triticum aestivum* L. | 13 | 9 | 6 |
| Barley (forage) | *Hordeum vulgare* L. | 13 | 9 | 6 |
| Sorghum | *Sorghum bicolor* (L.) Moench | 10 | 8 | 7 |
| Alfalfa | *Medicago sativa* L. | 9 | 5 | 2 |
| Corn (forage) | *Zea mays* L. | 9 | 5 | 2 |
| Rice (paddy) | *Oryza sativa* L. | 7 | 5 | 3 |
| Corn (grain) | *Zea mays* L. | 6 | 3 | 2 |

Note: The data on yield potential serve only as a guideline to relative tolerances among crops. Absolute salt tolerances vary and depend on climate, soil conditions, and cultural practices.
Source: Adapted from Maas and Grattan 1999.

**Chemical or biological amendments are needed over time to prevent soil structural degradation when irrigating exclusively with sodic water.** Farmers irrigating with sodic water must apply supplemental calcium to offset the effects of sodium on soils and crops. Many farmers use gypsum ($CaSO_4{\cdot}2H_2O$), which usually is available and affordable, and the amount needed can be estimated using simple analytical tests.

On calcareous soils that contain appreciable amounts of precipitated or native calcite ($CaCO_3$), the dissolution of calcite in the root zone is enhanced by adding acid formers and by the actions of plant roots that increase the levels of carbon dioxide, thereby providing soluble calcium to offset sodium effects (Qadir and others 2005). Sodic soils can also be improved by leaving plant residues and adding organic matter from other sources (box 11.10).

**Saline drainage water can support wildlife habitat and wetlands.** Drainage water can be reused to support water birds, fish, mammals, and aquatic vegetation. Typical native marsh plants grown with drainage water include smartweed (*Polygonum lapothefolium*), swamp

**box 11.10** **Sesbania improves soil conditions in India**

Sesbania, a legume, has shown promise for biomass production and biological amelioration of soils degraded by irrigation with sodic water, in part because nitrogen is a limiting nutrient in many saline areas. If grown for 45 days and used as a green manure, sesbania improves soil fertility and enriches soils by creating up to 120 kg of nitrogen per hectare. Sesbania decomposes rapidly, producing organic acids and increased levels of carbon dioxide, which enhance dissolution of calcite in sodic soils. The fibrous stems help open voids and channels, and young branches of the tree provide fodder. Sesbania is gaining popularity among farmers who use saline and sodic groundwater from tubewells in India.

timothy (*Heleochloa schenoides*), tule or hardstem bulrush (*Scirpus fluviatilis*), cattails (*Typha spp*), alkali bulrush (*Scirpus robustus*), brass buttons (*Cotula corinopifola*), salt grass (*Distichilis spicata*), and tules (*Scirpus acutus*). Water is applied in autumn and held until spring. When the soil begins to warm, the ponds are drained to mudflat conditions to stimulate seed germination.

It is not always economically feasible to use highly saline water for agriculture, especially on degraded lands. The planting of permanent vegetation might be the best use of land in those situations, including such tree species as *Tamarix articulata, Prosopis juliflora, Acacia nilotica, Acacia tortilis, Feronia limonia, Acacia farnesiana* and *Melia azadirach*. Halophytic plant species have also been identified for use in biosaline agriculture (Minhas and Samra 2003).

## Policies and institutions relating to marginal-quality water

Policies to improve the management of marginal-quality water in agriculture can be implemented before marginal-quality water is generated, while it is being used, and after crops have been irrigated and products are prepared for sale and consumption. Reducing the volume of marginal-quality water can reduce treatment and disposal costs, but where wastewater is not treated, reducing the volume could increase its concentration, with negative impacts.

Two features complicate policymaking pertaining to wastewater use in agriculture: most wastewater is generated outside the agricultural sector, and many individuals and organizations have an interest in policies pertaining to wastewater use. In addition, public concern varies with the type of water involved, treatment levels, and the amount of information available (Toze 2006). Where possible, it is helpful to distinguish between industrial and domestic wastewater. Removing pathogens from domestic wastewater can be less costly than removing chemicals from industrial wastewater.

Particularly in industrialized countries, households, communities, and industries generate excessive volumes of wastewater because there is little incentive to minimize volume or to reuse wastewater. Improving the institutions and policies that influence the use of freshwater can reduce the cost of treating and managing wastewater. Often the institutional framework is adequate, but public agencies have overlapping jurisdictions that prevent optimal implementation of desirable policies. Effluent standards, taxes, and tradable permits can be used to motivate improvements in water management by households and firms discharging wastewater from point sources.

The discharge of saline drainage water into surface water and groundwater is a nonpoint source pollution problem. The policy challenge is to motivate many diffuse farmers to reduce surface runoff and deep percolation by improving water management. Helpful policies include taxes and standards involving inputs such as irrigation water, fertilizer, and other chemicals. Financial incentives including low-interest loans and cost-sharing can also encourage desirable production methods.

The volume of saline and sodic drainage water can be reduced through policies affecting water withdrawals and deliveries. Pertinent policies include effective water allocation and pricing, assignment of water rights, restrictions on groundwater pumping, full-cost energy pricing, and incentives for farm-level investments in water-saving irrigation methods.

### Establish property rights to wastewater

In regions where farmers and others compete for a limited supply of wastewater, assigning property rights can motivate efficient use. Property rights can be coupled with responsibility for using wastewater appropriately and managing discharges from irrigated farmland. Special attention is needed in areas where wastewater is treated by a municipality or water company. If a water treatment agency assumes property rights after treating the wastewater, the agency might view treated wastewater as a new resource, for allocation to new users, without consideration of the farmers who previously used the wastewater for irrigation.

### Consider wastewater a resource requiring good management

Within the framework of integrated water resources management wastewater can be viewed as both an effluent and a resource. Where wastewater is used for irrigation, society gains value from the crops produced and the improvements in livelihoods in urban and peri-urban farming using wastewater. Irrigation also provides a method of using wastewater that might otherwise require further treatment or disposal.

The challenge for public agencies is to determine the best mix of policies to reduce wastewater generation and ensure safe and efficient use of wastewater (Huibers and Van Lier 2005; Martijn and Redwood 2005; Raschid-Sally, Carr, and Buechler 2005). There are costs to reducing wastewater volume. The optimal treatment strategy will vary with wastewater source and constituents, and with the crops being irrigated (Emongor and Ramolemana 2004; Fine, Halperin, and Hadas 2006; Tidåker and others 2006).

### Implement economic incentives

Incentives for reusing treated wastewater are helpful in areas where water users can choose among water sources of different quality. Lower water prices and subsidies for purchasing new equipment can speed the pace at which farmers and firms begin using marginal-quality water. Incentives can be combined with monitoring to ensure compliance with incentive programs and safe use of wastewater.

Farmers facing low prices or abundant supplies of irrigation water will not strive to reduce the volumes of saline or sodic drainage water leaving their farms. Water prices and allocations that reflect water scarcity and externalities will encourage farmers to consider the off-farm impacts of their irrigation and drainage activities.

In some areas subsidies for farm-level investments in irrigation equipment will be more effective than higher water prices in reducing effluent. For example, farmers can be encouraged to use drip systems instead of sprinklers when irrigating with water that is saline or contains other undesirable constituents (Oron and others 1999a, 1999b, 2002; Capra and Scicolone 2004).

> The challenge for public agencies is to determine the best mix of policies to reduce wastewater generation and ensure safe and efficient use of wastewater

### Improve financial management

Public agencies in many developing countries have limited ability to invest in wastewater treatment plants and programs to optimize wastewater reuse. Policies and institutions can be helpful in raising the funds needed for those activities. Volumetric charges for wastewater will encourage reuse and discourage discharge into natural waterways or facilities operated by a wastewater agency. There is conceptual justification for programs that generate revenue by charging water users a fee per unit of effluent they generate (the polluter pays principle), particularly when the revenue is used to construct facilities for collecting, treating, and reusing wastewater.

### Protect and compensate the poor

Policies to protect the poor will be needed in conjunction with successful reductions in wastewater volume and improvements in wastewater management. Public officials must consider potential impacts on the poor when designing policies and programs. The greatest challenge might be ensuring that low-income residents of peri-urban and rural areas who rely on wastewater for crop production are not deprived of their livelihoods. Many poor farmers have been using wastewater for years without formal water rights. Improving water management practices in upper portions of a watershed or urban area, to reduce wastewater volume, will also reduce a portion of the irrigation supply for those farmers. Improvements in water treatment can also reduce water supply if the treated water is transferred from its original point of use. Policies can be implemented to compensate poor farmers by providing them with alternative sources of irrigation water or giving them payments or training that would enable them to pursue alternative livelihood activities. Policies that enable the poor to reduce wastewater use gradually, while seeking other livelihood activities, might be wiser than policies that cause sharp disruptions in wastewater supply.

### Consult widely with individuals and organizations

Public agencies must consult broadly with individuals, firms, and organizations that might be affected by policies on wastewater generation and use. Stakeholder involvement can improve the dissemination of information and enhance the success of wastewater reuse projects (Janosova and others 2006). Much of the wastewater used in crop production in peri-urban areas in developing countries is applied untreated by small-scale farmers. Their knowledge and experience might be helpful in designing effective policies. Improvements in communication among government agencies and environmental organizations with expertise in wastewater issues also can enhance public policies for wastewater management.

### Conduct public awareness programs

Many farmers and consumers in developing countries are not aware of the potential health impacts of wastewater. Many also lack information on appropriate food hygiene practices. Public programs that inform farmers and consumers about potential health impacts and mitigation measures can reduce health problems and social costs. Information on post-harvest handling practices will also enhance consumer safety. Context-sensitive guidelines need to describe the types and amounts of wastewater that can be used effectively for irrigation (IWMI 2006), while in many areas inspection and certification programs are needed to ensure consumer safety regarding vegetables and other produce sold in urban markets.

Policies to protect the poor will be needed in conjunction with successful reductions in wastewater volume and improvements in wastewater management

Special attention should be paid to gender when designing these education programs on farmer and consumer safety. Educational efforts pertaining to wastewater will be most successful if they are designed to match the roles and availabilities of men and women in farming communities. In many farm households women are directly involved in agriculture besides being responsible for food preparation. Women also might have limited time for attending special classes or training sessions.

### Support research, development, and outreach

Many farmers might use the nutrient content of wastewater more effectively if they had better information about constituent loads in their water supply and nutrient levels in soils. Public funding of research, development, and outreach on farm-level reuse strategies is justified by the public benefits gained from using wastewater more effectively in agriculture.

Better data on the nature and extent of wastewater use for irrigation can enhance the efforts of public agencies and researchers. Information describing the volume and quality of wastewater used and the geographic distribution of wastewater use within peri-urban areas can be helpful when designing policies to improve water management and protect public health. Incentives might be offered to small-scale farmers to report wastewater reuse, yields, and observable impacts on humans, plants, and soils. Public agencies also might work with farmers to establish wastewater monitoring programs.

### Strengthen political will

Inadequate efforts to improve wastewater management, treatment, and reuse cannot be attributed only to a lack of technical information or inadequate knowledge of policy impacts. In many areas inadequate public involvement reflects a lack of political will, inadequate investment, or insufficient institutional capacity or coordination.

There is no simple formula for strengthening political will. Public officials must appreciate the scarcity value of water and the impacts of poor water quality and inefficient use on public health, economic growth, the environment, and rural and urban households. Leaders must appreciate the potential for improving livelihoods and enhancing public welfare by improving land and water management practices. International agencies, donors, and nongovernmental organizations can provide political leaders with information, encourage innovative policy choices, and motivate greater public involvement in water management efforts.

### Minimize risk and uncertainty

Some of the implications of irrigating with wastewater are uncertain. Farmers, consumers, and researchers will gain knowledge of the potential impacts of wastewater and on health and the environment as experience increases. Given the inherent uncertainty and potential social costs, public agencies should adopt the precautionary principle when designing policies for wastewater use. Policies should minimize the potentially harmful long-term impacts, even at the cost of lower near-term financial gains to farmers and consumers. Public awareness campaigns might be helpful in gaining support for policies that reflect the precautionary principle. Special efforts will be needed in areas where many residents are not literate and where farmers depend on wastewater to support their livelihoods.

> Much of the wastewater used in crop production in peri-urban areas in developing countries is applied untreated by small-scale farmers. Their knowledge and experience might be helpful in designing effective policies

### Improve the management of saline and sodic water

Policies such as requiring farmers to reuse or dispose of saline drainage water within their farming operation can motivate farmers to improve their management of saline and sodic water. Water quality agencies might limit the discharge of drainage water to surface streams or enforce ambient water quality standards pertaining to drainage water. In many areas enforcement of water quality standards will encourage farmers and water user associations to improve water management practices.

The discharge of saline drainage water by farmers at the headends of many irrigation schemes degrades the quality of water available to farmers at the tailends. Salt accumulation in the soils of tailend farmers causes yield to decline and reduces crop choices. Scheme-level planning is thus required. Aggregate productivity in many irrigation schemes can be increased by improving water management on headend farms. Policies that improve the distribution of higher quality water among headend and tailend farmers can reduce drainage water volume and enhance crop production in tailend portions of irrigation schemes.

Research and development of new methods for using saline and sodic water will also be helpful. More research is needed on the optimal management of salt-tolerant crops, particularly when high- and low-salt content irrigation water is combined. Blending irrigation water is appropriate in some applications, while cyclic reuse is appropriate in others. Improvements in extension services are also needed to inform farmers about new methods of using saline and sodic water.

### Strengthen regional policies and institutions

Regional institutions such as federations of water user associations will be helpful in motivating farmers to minimize harmful impacts on downstream users (Beltrán 1999). Regional associations can be formed to encourage farmers to reduce surface runoff and subsurface drainage. In some areas existing water user associations can expand their activities to include drainage water management. Regional associations can manage the generation, collection, and reuse of drainage water.

River basin authorities can implement data collection programs and coordinate analysis to enhance policy efforts. In areas lacking institutional support for a river basin authority, it might be necessary to improve coordination among ministries and agencies responsible for managing land and water resources.

### Invest in infrastructure and institutional capacity

Optimal management of wastewater and saline and sodic water requires supporting infrastructure. Public investments are needed in many areas to enhance the ability of water users to improve management practices. Improvements in physical infrastructure are needed in some areas to increase the efficiency of water delivery systems and the management and disposal of wastewater. In other areas institutional capacity must be increased to enable efficient use of existing infrastructure and natural resources.

## Reviewers

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