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RESOURCE RECOVERY & REUSE SERIES 4

Global Experiences in Water Reuse

4

Jonathan Lautze, Emilie Stander, Pay Drechsel, Allegra K. da Silva and Bernard Keraita

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Global Experiences in Water Reuse

Jonathan Lautze, Emilie Stander, Pay Drechsel, Allegra K. da Silva
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SUMMARY[1]

This report is a slightly updated version of the 'Global Experiences in Water Reuse' chapter of the Guidelines for Water Reuse, published in 2012 by the U.S. Environmental Protection Agency (USEPA 2012) in collaboration with the U.S. Agency for International Development. The primary objectives of this globally oriented chapter were to (1) review a range of drivers, barriers, benefits, and incentives for water reuse and wastewater use outside of the United States; (2) outline the state of, and geographic variation in, water reuse and wastewater use; and (3) review paths for expanding the scale of safe and sustainable water reuse and wastewater use in different contexts as also discussed in the frame of the Sustainable Development Goals (SDGs).

Discussion draws on experiences from 41 global case studies[2] that provide an array of approaches to safe and sustainable water reuse. The cases show that pressure on the world's water resources has been growing dramatically, and climate change is accentuating patterns of droughts and floods. Water scarcity is affecting communities around the world, presenting an incredible opportunity for collaboration on technical solutions, including low-cost, low-energy innovation or multi-purpose schemes as being described in several case studies. Some of the notable recent developments in global water reuse include advances in agricultural reuse, Singapore's advanced reuse technology, and experiences with stakeholder participation in reuse planning, notably in Australia. Current challenges in reuse, including economic models for partial or full cost recovery and technical challenges in nutrient recovery and energy efficiency, are also opportunities for international exchange.

Several cases flag the need for reuse installations which ensure that the water produced has the appropriate water quality for the intended use. Water reuse market growth is projected to take this approach—designing reuse for a specific purpose to achieve economic efficiency. Both high- and low-tech solutions are imminently relevant to tuning our approaches and, as mentioned above, multiple endpoints may be appropriate for multi-purpose systems. The case studies show an encouraging spectrum of options where increased sanitation and wastewater management efforts in resource-constrained countries can move unplanned wastewater use to planned reuse, while taking advantage of modern treatment and non- or post-treatment options for safeguarding public health. With increasing population pressures for more available water resources, increasing recovery of the water resource from wastewater can help in meeting the total water needs of many nations.

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[1] The original chapter had no summary. This summary has been compiled for this print from the original chapter.

[2] Throughout the text, case studies are introduced and referenced by a [code name] in brackets. Case studies are online in Appendix E of http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf

INTRODUCTION

This report provides an overview of global experiences in water reuse. The primary objectives of this report are to (1) review a range of drivers, barriers, benefits, and incentives for water reuse and wastewater use outside of the United States; (2) outline the state of, and geographic variation in, water reuse and wastewater use; and (3) review paths for expanding the scale of safe and sustainable water reuse and wastewater use in different contexts. Discussion is provided to address these objectives; it draws on experiences from 41 global case studies that provide an array of approaches to safe and sustainable water reuse. While the USEPA guidelines focus on water reuse, the global abundance of wastewater use and the gray lines dividing water reuse and wastewater use have led the contributors to broaden the scope of this report to discuss both water reuse and wastewater use outside of the United States.

The planning, technical, institutional, and socio-economic settings in which water reuse is practiced varies both among and within countries as a function of specific geographic and economic conditions. As a result, it is important to define the context of these practices, as well as provide case study examples of these practices.

Defining the Resources Context

As this report examines water reuse across a spectrum of resource contexts, it is necessary to draw a distinction between resource-endowed and the resource-constrained countries. For the purposes of this report, the term "resource-endowed" countries or settings will refer to locations in high-income or "developed" countries, and "resource-constrained" countries or settings will refer to locations in low-income or "developing" countries. Locations in middle-income countries or settings may fall into either category depending on the context.

Most resource-endowed countries have established human health risk guidelines or standards that involve high-technology/high-cost approaches. This enables the institution of practices that extend beyond protecting human health to providing environmental protection and restoration. Many resource-constrained countries have considered adopting an approach to protecting human health based on the World Health Organization (WHO) recommendations in the WHO *Guidelines for the Safe Use of Wastewater, Excreta, and Greywater*, which usually entail a fit-for-purpose, gradational process toward reducing health risks (WHO 2006).

Planned Water Reuse and Wastewater Use

For this original chapter 9 of USEPA (2012) which is reproduced in this report, it was necessary to make a distinction between 'water reuse' and 'wastewater use' (see Appendix A).

As defined in USEPA (2012), *water reuse* is the use of treated municipal wastewater. Globally, water reuse occurs both in resource-constrained settings using low-cost methods[3], as well as in resource-endowed settings, where the more typical high-tech applications are seen[4].

Wastewater use is the intentional or unintentional use of untreated, partially treated, or mixed wastewater that is not practiced under a regulatory framework or protocol designed to ensure the safety of the resulting water for the intended use. This practice does not occur in the United States, as wastewater treatment is ubiquitous. Wastewater use occurs mainly for agricultural irrigation, and often it is officially prohibited, yet unofficially tolerated (informal irrigation sector) because many people derive their livelihoods from access to untreated or partially treated wastewater. Wastewater use

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[3] as illustrated in case studies: [Palestinian Territories-Auja] and [Philippines-Market].

[4] as illustrated in case studies: [China-MBR], [India-Bangalore], [Japan-Building MBR], [South Africa-eMalahleni Mine], and [Spain-Costa Brava].

may occur, for example, where wastewater is knowingly taken from outfall pipes or drainage canals because it is easily accessible at no cost or can confer benefit over other sources because of its high nutrient content when water is used for irrigation. Wastewater use can also occur where water is taken from natural streams or river channels that contain large loads of untreated wastewater mixed with freshwater. It should be noted that these definitions do not include any judgment about water quality and related health risks. In resource-constrained countries, for example, the quality of "treated" wastewater in a planned reuse project can be worse than that of untreated, but diluted, wastewater collected from streams.

Although wastewater use can have various livelihood benefits and support food security, it presents serious risks to human health from a range of pathogens that may be contained in the wastewater, as described, for example, in USEPA (2012, chapter 6). In addition, where urban or agricultural runoff or industrial wastes impact wastewater, chemical pollutants may also be present. Exposure to untreated wastewater is a likely contributor to the burden of diarrheal disease worldwide (WHO 2004). Epidemiological studies suggest that the exposure pathways to the use of wastewater in irrigation can lead to significant infection risk for the following groups:

- **Farmers and their families**—Several epidemiological investigations have found excess parasitic, diarrheal, and skin infection risks in farmers and their families directly in contact with wastewater. There is, in particular, a high prevalence of hookworm disease and ascariasis infections among those who do not use protective gear as the organisms that cause those infections (hookworm and roundworm) are common in hot climates (WHO 2006).

- **Populations living near wastewater irrigation sites, but not directly involved in the practice**—Populations, particularly children, living within or near wastewater irrigation sites using sprinklers may be exposed to aerosols from untreated wastewater and at risk of bacterial and viral infections (Shuval et al. 1989).

- **Consumers of raw produce irrigated with wastewater**—Excess diarrheal diseases and cholera, typhoid, and shigellosis outbreaks have been associated with the consumption of wastewater-irrigated vegetables eaten uncooked (WHO 2006). In Ghana, for example, a burden of disease of 12,000 disability-adjusted life years (DALY) annually, or 0.017 DALY per person per year was estimated, which represents nearly 10 percent of the WHO-reported DALYs occurring in urban Ghana due to various types of water- and sanitation-related diarrhea (Drechsel and Seidu 2011). The contribution of wastewater use, and in particular its impact on consumer food safety, has not been quantified so far at larger scale.

In cases where wastewater treatment prior to use is not possible, alternative strategies for protecting human health need to be evaluated and applied (Scott et al. 2010; Amoah et al. 2011). In such cases, guidelines for the development, contracting, and implementation of water reuse can facilitate the transition from wastewater use to planned reuse systems. A table with links to international regulatory websites is provided in Appendix B.

International Case Studies

A broad range of global water reuse practices are discussed in this report and in accompanying case studies. The geographic location and reuse application associated with each case study is displayed in Figure 1. As a group, the 41 cases illustrate water reuse experiences in a variety of contexts and demonstrate the possibilities for expanding the scale of safe and sustainable water reuse practices across geographies and resource settings. Throughout the text, the case studies are referenced by a code name in brackets. All cases can be found in Appendix E of the free online version of USEPA (2012). In addition, over sixty case studies from only the United States are presented in USEPA (2012), which are not considered in this report.

FIGURE 1. GEOGRAPHIC DISPLAY OF INTERNATIONAL WATER REUSE. CASE STUDIES CATEGORIZED BY APPLICATION.

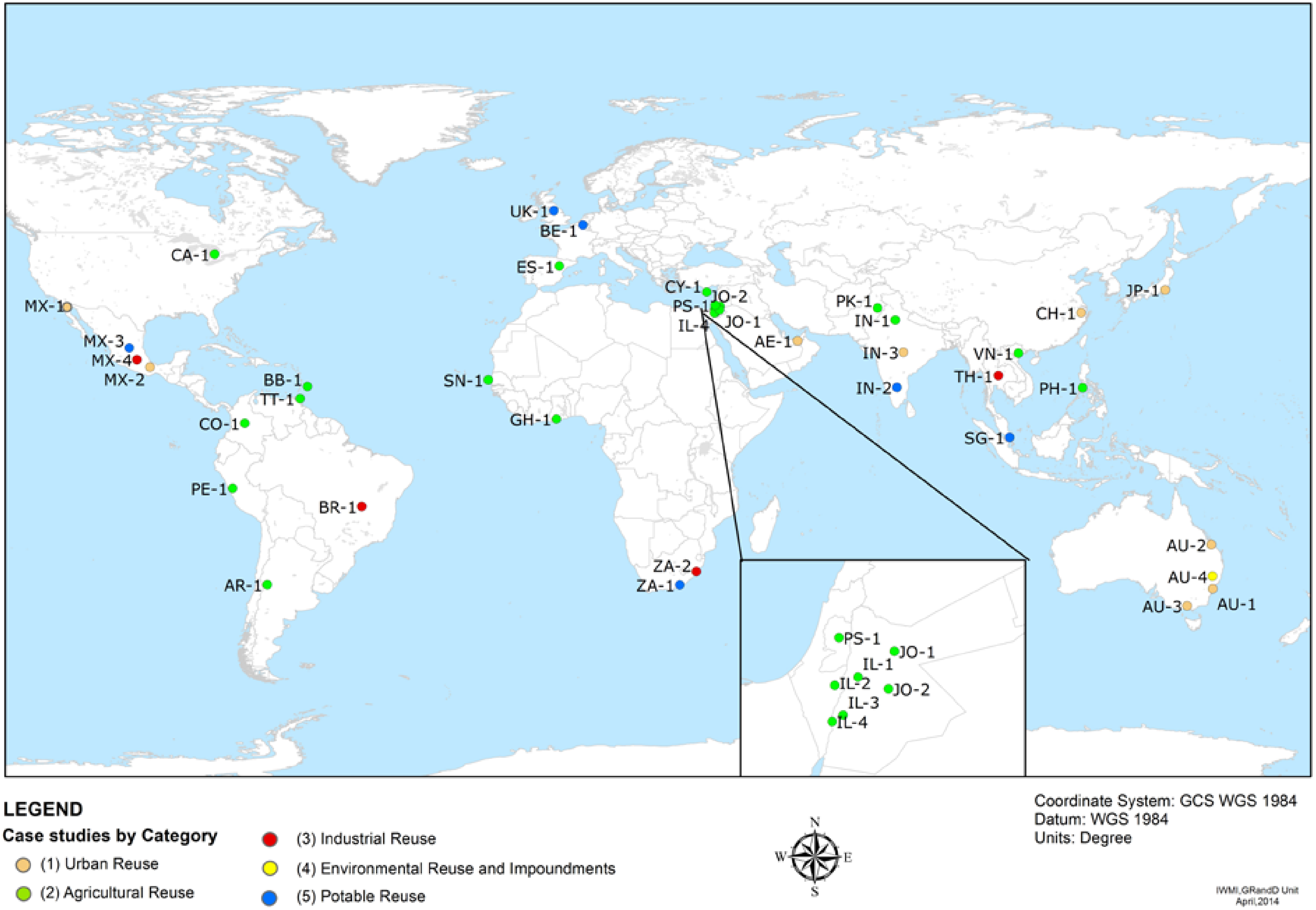


FIGURE 1 LEGEND

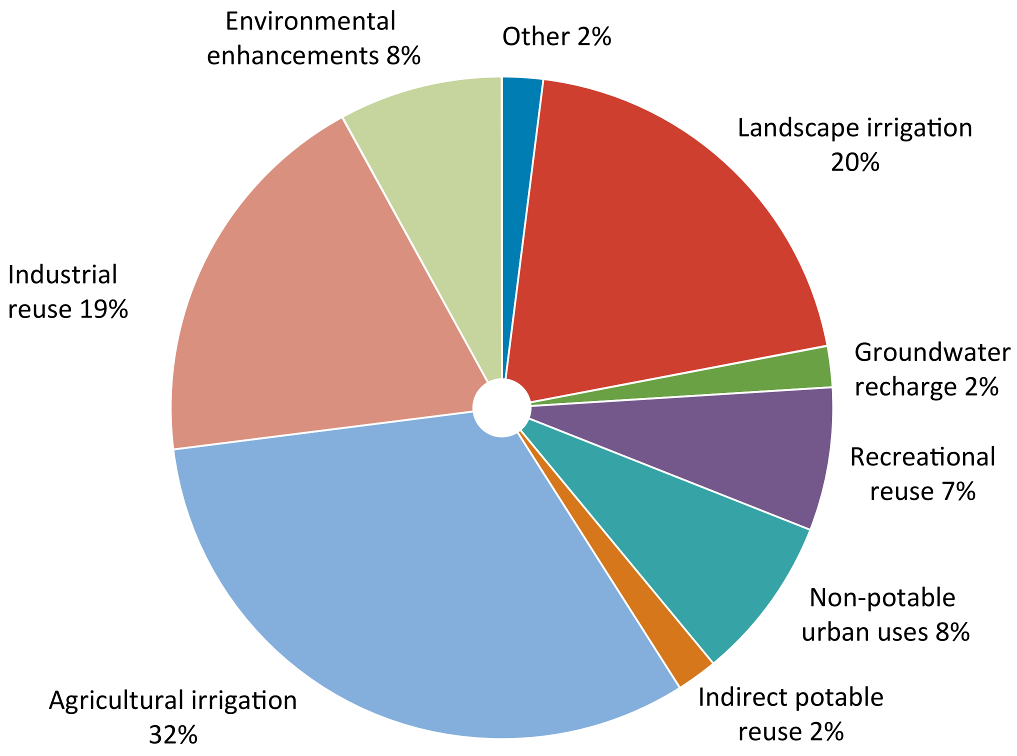
MAP CODE	TEXT CODE	CASE STUDY NAME
AR-1	Argentina-Mendoza	Special Restricted Crop Area in Mendoza, Argentina
AU-1	Australia-Sydney	Sewer Mining to Supplement Blackwater Flow in a Commercial High-rise
AU-2	Australia-Graywater	Retirement Community Graywater Reuse
AU-3	Australia-Victoria	End User Access to Recycled Water via Third Party-Owned Infrastructure
AU-4	Australia-Replacement Flows	St Marys Advanced Water Recycling Plant, Sydney
BB-1	Barbados-Economic Analysis	Economic Analysis of Water Reuse Options in Sustainable Water Resource Planning
BE-1	Belgium-Recharge	Water Reclamation for Aquifer Recharge in the Flemish Dunes
BR-1	Brazil-Car Wash	Car Wash Water Reuse - A Brazilian Experience
CA-1	Canada-Nutrient Transfer	Water Reuse Concept Analysis for the Diversion of Phosphorus from Lake Simcoe, Ontario, Canada
CN-1	China-MBR	Water Reuse in China
CO-1	Colombia-Bogotá	The Reuse Scenario in Bogotá
CY-1	Cyprus-Irrigation	Water Reuse In Cyprus
GH-1	Ghana-Agriculture	Implementing Non-conventional Options for Safe Water Reuse in Agriculture in Resource Poor Environments
IN-1	India-Delhi	Reuse Applications for Treated Wastewater and Fecal Sludge in the Capital City of Delhi, India
IN-2	India-Bangalore	Valley Integrated Water Resource Management: the Bangalore Experience of Indirect Potable Reuse
IN-3	India-Nagpur	City of Nagpur and MSPGCL Reuse Project
IL-1	Israel/Jordan-Brackish Irrigation	Managing Brackish Irrigation Water with High Concentrations of Salts in Arid Regions
IL-2	Israel/PalestinianTerritories/Jordan-Olive Irrigation	Irrigation of Olives with Recycled Water
IL-3	Israel/Jordan-AWT Crop Irrigation	Advanced Wastewater Treatment Technology and Reuse for Crop Irrigation
IL-4	Israel/Peru-Vertical Wetlands	Treatment of Domestic Wastewater in a Compact Vertical Flow Constructed Wetland and its Reuse in Irrigation
JP-1	Japan-Building MBR	A Membrane Bioreactor (MBR) Used for Onsite Wastewater Reclamation and Reuse in a Private Building in Japan
JO-1	Jordan-Irrigation	Water Reuse and Wastewater Management in Jordan
JO-2	Jordan-Cultural Factors	Cultural and Religious Factors Influence Water Reuse
MX-1	Mexico-Tijuana	Water, Wastewater, and Recycled Water Integrated Plan for Tijuana, Mexico
MX-2	Mexico-Mexico City	The Planned and Unplanned Reuse of Mexico City’s Wastewater
MX-3	Mexico-Ensenada	Maneadero Aquifer, Ensenada, Baja California, Mexico
MX-4	Mexico-San Luis Potosi	Tenorio Project: A Successful Story of Sustainable Development
PK-1	Pakistan-Faisalabad	Faisalabad, Pakistan: Balancing Risks and Benefits
PS-1	Palestinian Territories-Auja	Friends of the Earth Middle East’s Community-led Water Reuse Projects in Auja
PE-1	Peru-Huasta	Assessing Water Reuse for Irrigation in Huasta, Peru
PH-1	Philippines-Market	Wastewater Treatment and Reuse for Public Markets: A Case Study in Sustainable, Appropriate Technology in the Philippines
SN-1	Senegal-Dakar	Use of Wastewater in Urban Agriculture in Greater Dakar, Senegal: “Adapting the 2006 WHO Guidelines”
SG-1	Singapore-NEWater	The Multi-barrier Safety Approach for Indirect Potable Use and Direct Non-potable Use of NEWATER
ZA-1	South Africa-eMalahleni Mine	Turning Acid Mine Drainage Water into Drinking Water: The eMalahleni Water Recycling Project
ZA-2	South Africa-Durban	Durban Water Recycling Project
ES-1	Spain-Costa Brava	Risk Assessment for *Legionella* sp. in Reclaimed Water at Tossa de Mar, Costa Brava, Spain
TH-1	Thailand-Pig Farm	Sam Pran Pig Farm Company: Using Multiple Treatment Technologies to Treat Pig Waste in an Urban Setting
TT-1	Trinidad and Tobago-Beetham	Evaluating Reuse Options for a Reclaimed Water Program in Trinidad, West Indies
UK-1	United Kingdom-Langford	Langford Recycling Scheme
AE-1	United Arab Emirates-Abu Dhabi	Water Reuse as Part of Holistic Water Management in the United Arab Emirates
VN-1	Vietnam-Hanoi	Wastewater Reuse in Thanh Tri District, Hanoi Suburb, Vietnam

OVERVIEW OF GLOBAL WATER REUSE

Types of Water Reuse

Water is reused worldwide for agriculture, aquaculture, industry, drinking water, non-potable household uses, landscape irrigation, recreation, and groundwater recharge. These uses are described in greater detail in Lazarova et al. (2013) and USEPA (2012, chapter 3). Figure 2 shows types of reuse after advanced (tertiary) treatment, which describes a portion of the actual reuse practiced worldwide.

FIGURE 2. GLOBAL WATER REUSE AFTER ADVANCED (TERTIARY) TREATMENT: MARKET SHARE BY APPLICATION (GWI 2009).



Agricultural Applications

Consistent with the high proportion of fresh water use in the agricultural sector, most reclaimed water used globally serves crop production. Many of the case studies describe applications of using reclaimed water or wastewater for irrigation or other agricultural applications, such as projects highlighted in the following case studies from around the world. In Victoria, reclaimed water is used to irrigate vineyards, tomatoes, potatoes, and other crops in addition to traditional landscape irrigation [Australia-Victoria case]. Citrus and olive trees and fodder crops use approximately 90 percent of the available reclaimed water in Cyprus [Cyprus-Irrigation case]. Constructed vertical wetlands are being tested and applied for irrigation of fruit trees and gardens in decentralized treatment systems [Israel/Peru-Vertical Wetlands case]. In Mexico City, nearly 46 million gallons (174 million liters) per day of reclaimed water is used for irrigation of green areas, recharge of recreational lakes and agriculture [Mexico-Mexico City case]. Fodder crop irrigation predominates in Jordan with some application for irrigation of date palms and olives [Jordan-Irrigation case].

Urban and Industrial Applications

Technology-driven approaches that promote advanced reuse include the NEWater project in Singapore [Singapore-NEWater case], sensitive manufacturing operations in South Africa [South Africa-Durban case], high-rise office treatment and recycling in Sydney [Australia-Sydney case], retirement center toilet flushing and landscape irrigation in Australia [Australia-Graywater case], and in high-rise buildings in Japan [Japan-Building MBR case], other industrial reuse including vehicle washing ([Brazil-Car Wash] and [Mexico-Mexico City]), and cooling for manufacturing operations or energy production as demonstrated in several case studies throughout the world. In the Philippines, reclaimed water from a satellite plant serving the produce market is used for toilet flushing, street washing and plant watering [Philippines-Market case]. Reclaimed water is used in Spain for traditional non-potable irrigation, street washing, fire hydrants, and washdown at the community dog shelter [Spain-Costa Brava case].

A wide variety of industries, including commercial laundries, vehicle-washing establishments, pulp and paper industries, steel production, textile manufacturing, electroplating and semiconductor industries, boiler-feed water, water for gas stack scrubbing, meat processing industries, brewery and beverage industries, and power plants, have the capability to use reclaimed water in their operations (Jimenez and Asano 2008). In the food and beverage industry, reclaimed water is used for cooling and site amenities. Internal process water may also be recirculated or reused with appropriate treatment. Urban amenities, such as stream restoration and other features, may involve reclaimed water, thus representing elements of "cities of the future" visions for sustainable cities (Jimenez and Asano 2008). In the case study from Barbados, the economic, environmental, and social trade-offs of various reuse schemes were considered [Barbados-Economic Analysis case].

Aquifer Recharge

Groundwater or aquifer recharge, both planned and *de facto*, is likewise practiced globally (Jimenez and Asano 2008). Documented cases of aquifer recharge are reported in Israel, South Africa, Germany, Belgium [Belgium-Recharge case], Australia, Namibia, India, Italy, Mexico, China, Barbados [Barbados-Economic Analysis case], and Cyprus [Cyprus-Irrigation case]. Indirect potable recharge following advanced treatment has been studied in Tijuana but not yet implemented [Mexico-Tijuana case]. Planned recharge with reclaimed water provides subsurface storage and can enable additional treatment (USEPA 2012, chapters 3 and 6). In addition to storage for non-potable reuse (e.g., for agricultural or landscape irrigation, industrial use, etc.) or indirect potable reuse, replenishment of aquifers experiencing higher rates of withdrawal than natural recharge can prevent saltwater intrusion in groundwater supply in coastal areas and supplement groundwater base flows to promote ecosystem health. On a de facto basis, wastewater-impacted aquifer recharge is widespread. Often highly polluted and only partially treated (if at all) wastewater drains to rivers or drainage canals connected to underlying unconfined aquifers that may be used for drinking water.

Regardless of the type of reuse application, water quality issues are an important dimension. Ideally, the wastewater source and type of treatment should be matched to the eventual reuse application, also known as "Fit for Purpose" (USEPA 2012, chapter 1). Reclaimed water suppliers may need to be certified and provide proof of compliance with water quality specifications before they are allowed to supply water to consumers, and systems should be in place to store and retreat water that fails to meet standards and to avoid cross-connection between the distribution systems for reclaimed water and potable drinking water.

Magnitude of Global Water Reuse

The total volume of domestic wastewater generated in the world every day is estimated to be between 180 and 250 billion gallons (680 and 960 million m^3), as shown in Table 1 (GWI 2009; FAO 2010). The current global capacity to treat wastewater to advanced levels (like tertiary treatment) is approximately 8 billion gallons per day (32 million m^3/day), or only 4 percent of the total volume of wastewater that is generated (GWI 2009). The volume of wastewater treated beyond secondary treatment for reuse has grown by an average of 500 million gallons per day (2 million m^3/day) each year since 2000, allowing a greater proportion of water to be safely reused (GWI 2009). Wastewater production is likely to increase with population growth; with expanded sewerage networks there is great potential for expanding the magnitude of global water reuse, especially for high-end usages.

TABLE 1. GLOBAL DOMESTIC WASTEWATER GENERATED AND TREATED (IN BILLION GALLONS PER DAY AND MILLION CUBIC METERS PER DAY).

	VOLUME (BILLION GALLONS PER DAY)	VOLUME (MILLION M^3/DAY)
Total volume of domestic wastewater generated as of 2009	180-250	680-960
Current global capacity to treat wastewater to advanced levels as of 2009	8	32
Total volume of domestic wastewater that is not treated to advanced levels as of 2009	172-242	648-928
Growth in global capacity to treat wastewater to advanced levels (per year since 2000)	0.5	2

Sources: GWI 2009; FAO 2010

There is limited reliable data documenting quantities of water reuse and wastewater use in the agricultural sector. The limited evidence that does exist, which is not geographically comprehensive, suggests that the area of land irrigated with untreated wastewater is more than 10 times as great as the area irrigated with reclaimed water (Scott et al. 2010). Rough estimates suggest that about 20 million ha of agricultural land is irrigated with mostly untreated wastewater globally (Figure 3), and crops produced from such irrigation comprise 10 percent of global agricultural production from irrigation (Scheierling et al. 2010; Drechsel et al. 2010). As such, the proportion of wastewater used in agriculture may be far greater than that shown in Figure 3, which only summarizes documented cases.

Growth in the global water reuse sector is expected to migrate from being dominated by agricultural reuse toward higher-value applications, mostly in municipal applications, such as potable, industrial, and landscape irrigation reuse. China, the United States, Spain, Mexico, India, Australia, Israel, Kuwait, Japan, and Singapore lead the world in total installed advanced water reuse capacity to date (GWI 2009). GWI projects that global capital expenditure in advanced water reuse is expected to grow 19.5 percent annually between 2009 and 2016 (GWI 2009). The countries that are projected to add the greatest additional advanced water reuse are shown in Table 2. Many of these countries have recently completed major investments in desalination and are now turning to growth in the water reuse sector to meet needs, particularly in growing urban populations.

Direct potable use and planned indirect potable reuse (IPR) still account for a minor proportion of water reuse worldwide, but the proportion is growing. Of all advanced reuse, approximately 2.3 percent is potable reuse (GWI 2009). Growth in potable reuse applications is driven by pressures on water supply, along with increased public acceptance because of successful records of performance demonstrated by notable installations in the United States, Namibia, South Africa, and Singapore (GWI 2009; NRC 2012; Lazarova et al. 2013). Singapore has made water reuse a national priority [Singapore-NEWater case]. Decision-makers in Bangalore, India, are developing plans to include IPR as part of an overall approach to narrow gaps between water supply and the demands of a growing population [India-Bangalore case]. In South Africa, a novel partnership between a mining company and a township is turning acid mine drainage into drinking water [South Africa-eMalahleni Mine case]. Note that countless other planned IPR applications exist where reclaimed water is deliberately recharged to a groundwater aquifer using rapid infiltration basins or injection wells or to a drinking water reservoir. A representative example of this is from Wulpen, Belgium, where reclaimed water is returned to the aquifer before being reused as a potable water source [Belgium-Recharge case]. An example of *de facto* IPR comes from Langford, UK, where reclaimed water is returned upstream to a river that is the potable water source [United Kingdom-Langford case].

TABLE 2. PROJECTED REUSE CAPACITY IN SELECTED COUNTRIES.

COUNTRY	**ADDITIONAL ADVANCED REUSE CAPACITY (2009-2016)**	
	BILLION GALLONS PER DAY	**MILLION M^3/DAY**
USA	2.8	10.7
China	1.6	5.9
Saudi Arabia	0.9	3.5
Australia	0.7	2.5
Spain	0.6	2.1
Mexico	0.6	2.1
United Arab Emirates	0.5	1.9
Oman	0.4	1.6
India	0.3	1.2
Algeria	0.3	1.1

Source: GWI 2009

OPPORTUNITIES AND CHALLENGES FOR EXPANDING THE SCALE OF GLOBAL WATER REUSE

While the opportunities for expanding reuse are quite significant, there are some challenges related to the country-specific drivers, the regional variation of climate, social acceptance, and financial resources. While some of these factors are barriers to reuse, the benefits of expanding the water reuse will likely outweigh the challenges, ultimately paving the way for reuse to become an ever-growing part of the global water resource/water supply solution.

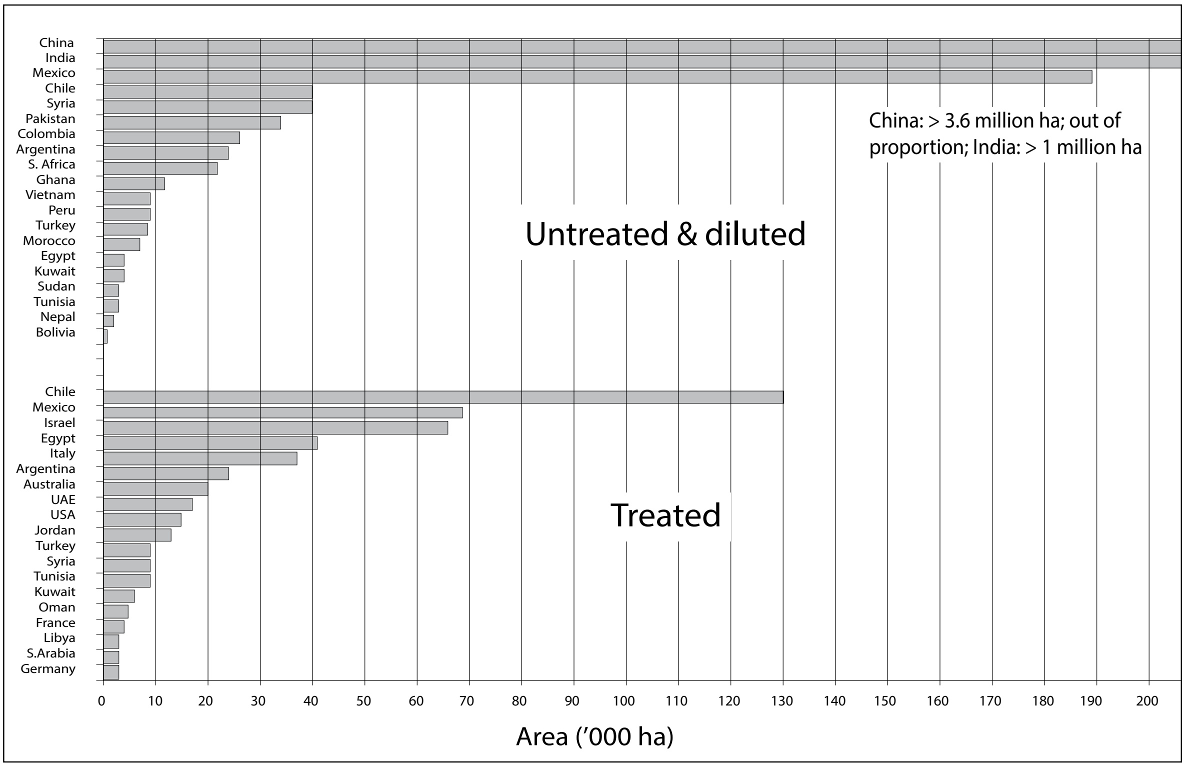
Global Drivers

Global *water reuse* is primarily driven by two main factors. First, reuse is a response to rising demand for water and limitations on freshwater availability. Second, water reuse is driven by a desire to capture and harness the economic benefits of wastewater. *Wastewater use*, on the other hand, is usually driven by the lack of wastewater collection and/or treatment facilities, resulting in untreated wastewater being discharged into the environment where, especially in urban and peri-urban areas of resource-constrained settings, safer water sources are difficult to find (Jimenez et al. 2010; Scott et al. 2010).

The first group of drivers for water reuse typically catalyzes reuse in areas of physical water scarcity, such as the Middle East and North Africa region, Australia, Singapore, and parts of southern Africa. Thus, poor water resources management and climate change may exacerbate conditions of scarcity in some countries and create conditions of scarcity in others. In resource-endowed settings, a desire to protect freshwater resources has fostered the creation of environmental regulations that limit the quantity of water available for human use and uphold standards for the quality of effluent resulting from such use. Application of these regulations has, in turn, promoted greater reuse of existing water rather than development of new water sources.

Economic considerations are also beginning to drive water reuse in high-resource contexts, as the possibility of marketing reclaimed water as a commodity holds the promise of partial return on investment for wastewater treatment (Jimenez et al. 2010). Trends in resource-endowed settings are moving toward the use of treated water at increasingly higher water quality standards for higher-value uses, such as industrial and municipal uses. The prospect of water scarcity begins to discourage lower-value uses, such as agricultural irrigation and aquifer recharge and free or heavily-subsidized use of reclaimed water (GWI 2009). Economic benefits associated with formal water reuse projects are more likely to be achieved over longer timeframes compared to shorter-term gains from transporting water from distant sources, groundwater mining, and reservoir construction (GWI 2009).

FIGURE 3. COUNTRIES WITH GREATEST IRRIGATED AREAS USING TREATED AND UNTREATED WASTEWATER (ADAPTED FROM SCOTT ET AL. 2010).



Wastewater use is often driven by resource constraints and high rainfall variability; wastewater may constitute a large proportion or even all of the flow in water bodies during the dry season. Scarcity of safe water due to the pollution of water resources with wastewater is common in low-resource contexts across any climate, leading to wastewater use. Indeed, in resource-constrained settings, untreated wastewater can serve as an economic resource for poor urban and peri-urban farmers. In many instances, these farmers have no viable alternative to the use of wastewater for their livelihood needs, yet use of such wastewater or polluted stream water often poses a significant threat to the public health of producers and consumers of farm products if not appropriately addressed. An interesting case of wastewater use comes from Pakistan, where local farmers, following extensive legal cases and now with permission from the local water and sanitation authority, have installed a permanent conveyance of untreated wastewater to their irrigation networks. While there is an existing wastewater stabilization pond farmers have been opposed to using treated effluent, as it was much lower in nutrients and much higher in salinity (as a result of massive evaporation from the waste stabilization pond) than untreated wastewater—evidenced, for example, in the [Pakistan-Faisalabad case].

Regional Variation in Water Reuse

Factors affecting the regional dynamics of water reuse include economic development priorities, water management options, environmental and climatic factors, social acceptance, and availability of financial resources. Water reuse in the Middle East and North Africa region is typically driven by water scarcity. Some high-income countries in the region use desalination to meet drinking water supply needs and use reclaimed water for agricultural and landscape irrigation using standards based on California Title 22. Middle- and low-income countries in the region use partially-treated or untreated wastewater primarily for specific restricted types of agricultural irrigation and utilize the previous WHO (1989) guidelines to inform approaches to improve human health and safety of water reuse practices (Jimenez and Asano 2008).

Analysis of reuse patterns in sub-Saharan Africa is hampered by a lack of reliable data. Limited existing evidence suggests that water reuse is driven by water scarcity (Jimenez et al. 2010). In this region, wastewater serves as a reliable water supply for multiple uses and as a source of high nutrient content for agricultural irrigation. Although much of the wastewater use in this region is informal and occurs in the agricultural sector, one of the most high profile and pioneering examples of potable water reuse is a 40-year ongoing project in Namibia involving direct human consumption of highly-purified reclaimed water (Lazarova et al. 2013).

In northern Europe, water reuse is practiced primarily for environmental and industrial applications, whereas in southern Europe, environmental and agricultural applications dominate. Practices generally follow the WHO (1989) guidelines or regulations that closely emulate California Title 22 standards.

Across Central and South America, water reuse is driven by water scarcity and by a desire to recycle wastewater nutrients in areas of poor soil quality. Water scarcity is, for example, the main driver for planned reuse in the drier areas of the Caribbean islands, Mexico, and Peru. But lack of sanitation is also leading to some of the largest areas of wastewater use globally, like in Mexico and Chile. Agricultural irrigation is the primary application. Wastewater use dominates, although there are many documented cases of planned reuse projects. WHO (1989) guidelines are used to improve the safety of reuse practices, but implementation is not universal.

The situation in Asia varies among its subregions. While China and India show significant progress in high-quality reuse (GWI 2009), both countries are still among the global leaders of unplanned use of wastewater (Figure 3), often via contaminated streams. Poor sanitation is also driving wastewater use across Central Asia and, to an even greater degree, Southeast Asia, where, in addition to agriculture, wastewater-fed aquaculture is also common.

Reuse in Australia is driven by both water scarcity and high environmental standards. Key applications include industrial mining, agricultural irrigation, and recreation. National coordinated water policies have incentivized expansion of water reuse practices, and regulations recognize a combination of natural treatment and advanced technology approaches, but also the need for full stakeholder participation in the planning process.

Global Barriers to Expanding Planned Reuse

From a technical standpoint, water reuse is a logical part of the overall water supply and water resources management solution. However, there are projects that are technically feasible but do not get implemented. In these cases, the barriers to implementing reuse are often related to public perception/ education, institutional, or economic concerns. Thus, a discussion of these non-technical barriers to expanding planned reuse is provided in this section.

Institutional Barriers

A basic driver of wastewater use—and barrier to wastewater treatment and planned reuse—in much of the world is the dearth of effective collection and treatment systems for fecal matter and sewage (Table 3). In resource-endowed urban areas, comprehensive sewer system coverage serves as a conduit for wastewater to be channeled to treatment plants in order to be safely released or reused. In resource-constrained settings, however, such infrastructure often either does not exist or does not terminate in functional treatment plants. While developing an extensive sewerage network is often a recommended step toward improving water reuse, it is important to recognize that improvements in on-site sanitation systems and related collection services can also significantly reduce the environmental burden and health risks associated with wastewater management.

While lack of appropriate infrastructure poses a constraint on water collection, treatment, and safe reuse in some areas, there are at least two broader institutional barriers to planned water reuse. They are 1) limited institutional capacity to formulate and institutionalize enabling legislation and to subsequently conduct adequate enforcement and monitoring of water reuse activities, and 2) lack of expertise in health and environmental risk assessment and mitigation. One limiting factor is a lack of political will to formalize an existing use of untreated or partially treated wastewater due to the institutional and enforcement hurdles that must be put in place to monitor planned reuse. Governments may feel they lack the capacity and budget to adequately implement these necessary reforms and thus risk causing farmers to lose access to existing sources of irrigation water. An underlying basis for these barriers, in turn, has been a funding bias towards conventional infrastructure investments, which may not always be fit-for-purpose (Nhapi and Gijzen 2004; Libhaber and Orozco-Jaramillo 2013). A critical issue, highlighted in subsequent sections, is adapting regulations and institutional capacities to local contexts to achieve the achievable rather than adopting over-ambitious policies that spur few sustainable, on-the-ground improvements.

In view of Table 3 it is worth noting that China has placed a strong emphasis on installing urban wastewater treatment over the past decade. As of 2010, 75 percent of Chinese cities are now connected to wastewater treatment, according to official governmental estimates (Xinhua 2011).

Public Perception/Educational Barriers

One of the key reuse barriers is public perceptions that may drive fear of the dangers of consuming water or food produced with reclaimed water, spurring a preference for use of freshwater. Concerns about the failure of conventional treatment technologies to remove trace organic compounds, such as pharmaceuticals and endocrine disruptors, are also a growing impediment to reuse especially for drinking water supply purposes (GWI 2009). However, successful potable reuse projects and increased familiarity with advanced treatment technologies, such as Ultrafiltration, Reverse Osmosis, and Ultraviolet disinfection, signal a possibility that public discomfort with potable reuse may be declining (GWI 2009). As described in USEPA (2012, chapter 8), public outreach programs to build awareness and involve community members in planning can change resistance to reuse. In San Diego, California, for example, intense public opposition to water reuse changed over a period of many years, largely because of public outreach and stakeholder involvement, in addition to the economic driver of local water scarcity (USEPA 2012).

In resource-constrained settings, public attention to risks of using untreated wastewater has not reached the level of attention as in resource-endowed settings. However, public attitudes are subject to change, particularly in response to real or perceived failures or contamination events and associated media attention (Wintgens and Hochstrat 2006). Establishing a regulatory framework for water reuse practices and health- or environmental-based standards or guidelines, ideally based on internationally-recognized guidelines, should be a first step (Jimenez and Asano

TABLE 3. PERCENT OF URBAN POPULATIONS CONNECTED TO PIPED SEWER SYSTEMS IN 2003-2006 (REGIONAL AVERAGES).

REGION	**NUMBER OF COUNTRIES WITH AVAILABLE DATA**	**CONNECTED URBAN POPULATION (%)**
United States and Canada	2	94
European Union*	18	90
Australia*	1	87
Central Asia	5	83
Middle East and North Africa	7	83
Namibia, South Africa, Zambia, Zimbabwe	4	68
Latin America and the Caribbean	21	64
China	1	56
South Asia	6	31
Sub-Saharan Africa**	24	9
South-East Asia	5	3

Source (all countries except United States): Modified after Evans et al. 2012; based on Joint Monitoring Programme 2012; United Nations Department of Economic and Social Affairs 2011; United Nations Statistics Division 2011; and Eurostat 2006. US data: GWI 2009 (population served in 2004); and Joint Monitoring Programme 2012 (population in 2004).

* Rural and urban population; ** Excluding Namibia, South Africa, Zambia, Zimbabwe

Note: Sewer connection does not automatically imply wastewater treatment.

2008). To promote risk awareness and behavior change, educational campaigns and social marketing techniques will be required where obvious benefits are not perceived (Karg and Drechsel 2011).

As discussed in USEPA (2012, chapter 8), proper use of language that does not stigmatize reclaimed water is also important when water professionals communicate water reuse ideas to the public. Words such as “wastewater reuse,” “reused water,” etc., are stigmatizing and negative to the public while “water recycling,” “new water,” “purified water”—and to a lesser extent “reclaimed water”— might be more appealing and likely to promote public acceptance (Macpherson 2012). To clarify the appropriateness of reclaimed water to the faithful, certain Muslim scholars have issued Fatwas declaring that reclaimed water is clean enough for ablution and other purposes, as long as technical experts attest to its purity and safety for such uses. Examples of these Fatwas can be viewed in original Arabic and in English translation and are described in a case study from Jordan [Jordan-Cultural Factors] (Senior Scholars Board in the City of Taif 1978; Abu Dhabi Islamic Court 1999).

Economic Barriers

The long-term economic viability of reuse projects also represents an important barrier to water reuse. Reclaimed water is often priced just below the consumer cost of drinking water to make it more attractive to potential users, but this may also affect the ability to recover costs (Jimenez and Asano 2008). Distortion in the market for drinking water supply complicates the pricing of reclaimed water, as does the lack of accounting for externalities, including water scarcity and social, financial, and environmental burdens of effluent disposal in the environment (Wintgens and Hochstrat 2006; Sheikh et al. 1998). Although there is a movement towards increased or even full operations and maintenance cost recovery in the large markets of agriculture water reuse such as Morocco, Tunisia, and Jordan, this is still the exception among many state-run service providers. There may, however, be opportunities to set different tariff levels for different classes or types of users, thus subsidizing the resource for the poor while recovering costs from groups that are able to pay. Finally, financing of up-front costs remains an important barrier to introducing new reuse programs and often requires government intervention in the form of grants or subsidies combined with eventual revenues.

Organizational Barriers

Fragmentation of responsibilities for and authority over different parts of the water cycle is another impediment that must be overcome before water reuse projects can go forward. In many regions the authority over the water supply sector resides in an entirely different organization than that over wastewater management. This separation of powers leads to long periods of inaction, stalemate, disagreement, negotiation, and complex interagency agreements that make the resulting water reuse project far more costly and complex than need be. Regions where the same authority manages water, wastewater, stormwater, and the watershed are far more nimble, implementing their water reuse projects quickly, efficiently, and at much lower cost (Sheikh 2004).

Benefits of Expanding the Scale of Water Reuse

Similar to the factors driving current levels of water reuse, a range of incentives for increasing, especially, planned water reuse in the coming years appear to exist. Indeed, there are at least several economic, environmental, and social benefits that can be achieved through expanding safe and sustainable reuse of water.

First, there is an opportunity to increase water availability and reliability without tapping new water sources, which either may not exist or may carry adverse consequences. For example, as there has been increased opposition on environmental grounds to dam-building projects, new desalination plants, and groundwater mining as a means of securing new water supplies, water reuse has emerged as a viable and more environmentally-sound alternative (GWI 2009). Water reuse also avoids environmental pollution caused by releasing wastewater, treated or not, to receiving streams. Reclaimed water is available continuously, even during drought periods, and is produced where people live. Additionally, the use of reclaimed water may augment natural flows in surface waters (with cascading positive effects on ecosystem health and biodiversity) and may contribute to rising groundwater tables where reclaimed water is used for crop or landscaping irrigation, as has been documented in parts of Mexico (IWMI 2006). Second, reuse provides opportunities to recover valuable resources, including water, energy, and nutrients. Third, expanding safe and sustainable water reuse helps reduce the human health costs associated with unplanned wastewater use. Finally, increasing water availability through reuse may help to reduce conflicts over water due to scarcity or resource limitations.

Some benefits are specific to or more commonly occur in resource-endowed or resource-constrained settings. For example, recreational (contact or non-contact) or aesthetic benefits may be experienced in resource-endowed settings when water is reused in urban water features and stream restoration projects. Benefits that are more likely to occur in resource-endowed contexts include partial recovery of treatment costs; savings on production costs in industrial reuse scenarios; and cost savings when treatment is matched to eventual reuse applications. In resource-constrained settings, likely benefits include increased nutrition, food security, and income (Keraita et al. 2008) for farmers, as well as other groups along the urban/peri-urban agricultural value chain, including women who are often traders of urban agricultural products in Sub-Saharan Africa (IWMI 2006).

IMPROVING SAFE AND SUSTAINABLE WATER REUSE FOR OPTIMAL BENEFITS

There are different options for optimizing benefits of safe and sustainable water reuse. In areas where wastewater use is currently being practiced, there are ways to reduce the associated risks without treating wastewater prior to use. It may also be possible to begin transitioning to wastewater treatment and water reuse when certain factors are present. Finally, in areas where water reuse is currently occurring, there are ways to optimize benefits of reuse by transitioning to higher-value uses and imposing stricter regulations for environmental conservation.

Importantly, the sheer scale of the opportunity (or challenge) for increasing safe and sustainable water reuse may call for use of any combination or all of these approaches. There is indeed tremendous potential to increase the scale of safe and sustainable water reuse, for at least two reasons. First, as highlighted above, only a small proportion of wastewater that is currently generated is used in a planned context for high-value applications. Second, given trends in population growth and urbanization, the quantity of wastewater generated is likely to increase substantially in the future.

Reducing Risks of Unplanned Reuse: The WHO Approach

Improving safe and sustainable water reuse in areas of currently unplanned practice has been greatly influenced by the WHO guidelines (1989, 2006). In 2006 the WHO released a four-volume report titled *Guidelines for the Safe Use of Wastewater, Excreta and Greywater*. The first volume focuses on policy and regulatory aspects of wastewater, excreta, and graywater use; the second volume focuses on use of wastewater in agriculture; the third volume focuses on wastewater and graywater use in aquaculture; the fourth volume focuses on excreta and graywater use in agriculture. The discussion in the WHO guidelines is limited to wastewater, excreta, and graywater from domestic sources that are applied in agriculture and aquaculture.

Rather than relying on water quality thresholds as in past editions (WHO 1989), the most current WHO guidelines (2006) adopt a comprehensive risk assessment and management framework. This risk assessment framework identifies and distinguishes among vulnerable communities (agricultural workers, members of communities where wastewater-fed agriculture is practiced, and consumers) and considers trade-offs between potential risks and nutritional benefits in a wider development context. As such, the WHO approach recognizes that conventional wastewater treatment may not always be feasible, particularly in resource-constrained settings, and offers alternative measures that can reduce the disease burden of wastewater use. The specific approach utilized by the WHO (2006) guidelines is to 1) define a tolerable maximum additional burden of disease, 2) derive tolerable risks of disease and infection, 3) determine the required pathogen reduction(s) to ensure that the tolerable disease and infection risks are not exceeded, 4) determine how the required pathogen reductions can be achieved, and 5) put in place a system for verification monitoring.

Table 4 presents an overview of selected treatment and non- or post-treatment health protection measures in agricultural water reuse and their potential to reduce pathogen loads (WHO 2006; Amoah et al. 2011). While each of the risk mitigation measures can be employed in isolation, comprehensive risk reduction is best achieved when measures are used in combination - the multi-barrier approach. To protect farmers themselves, awareness campaigns on the invisible risk of pathogens should accompany the promotion of protective clothing (boots, gloves, etc.), hygiene, and where possible, a shift to irrigation methods that minimize human exposure, like drip irrigation. Compared to conventional wastewater treatment, on- and off-farm risk mitigation measures are usually cheaper and more cost-effective, indicating suitability for resource-constrained contexts. For example, estimates from Ghana show that some of these measures can avert up to 90 percent of the estimated disease burden related to wastewater irrigation at a cost-effectiveness below $100 per averted DALY (Drechsel and Seidu 2011).[5] The health protection measures listed in Table 4 could be implemented to improve the unsafe use of diluted wastewater for vegetable production pictured in Figure 4. Safety measures which require on-farm infrastructure might however require more tenure security than urban farmers usually have as the [Senegal-Dakar case] shows.

The most effective health protection recommendation is to ensure that the crops produced are not eaten raw. However, this option requires appropriate monitoring capacity and viable crop alternatives for farmers. Other options include on-farm treatment and application techniques, as well as the support of natural die-off[6] and natural attenuation in non-edible aquatic plants lining irrigation canals[7]. There is reported success of blending of wastewater with higher-quality water to make it more suitable for production[8].

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[5] See also [Ghana-Agriculture case study].

[6] See [Ghana-Agriculture] and [Senegal-Dakar] case studies.

[7] As illustrated in [Vietnam-Hanoi] case study.

[8] As evidenced in the following case studies: [Vietnam-Hanoi], [Senegal-Dakar], [India-Delhi], [Jordan-Irrigation], and [Israel/Palestinian Territories/Jordan-Olive Irrigation].

TABLE 4. SELECTED HEALTH-PROTECTION MEASURES AND ASSOCIATED PATHOGEN REDUCTIONS FOR WASTEWATER REUSE IN AGRICULTURE.

CONTROL MEASURE	PATHOGEN REDUCTION (LOG UNITS)	NOTES
A. Wastewater treatment	1–6	Pathogen reduction depends on type and degree of treatment technology selected.
B. On-farm options		
Alternative land and water source	6-7	In Ghana, authorities supported urban farmers using wastewater by drilling wells. In Benin, farmers were offered alternative land with access to safer water sources.
Crop restriction (i.e., no food crops eaten uncooked)	6–7	Depends on (a) effectiveness of local enforcement of crop restriction, and (b) comparative profit margin of the alternative crop(s).
On-farm treatment:		
(a) Three-tank system	1–2	One pond is being filled by the farmer, one is settling and the settled water from the third is being used for irrigation.
(b) Simple sedimentation	0.5–1	Sedimentation for ~18 hours.
(c) Simple filtration	1–3	Value depends on filtration system used.
Pathogen die-off (fecal sludge)	in line with WHO 2006	Raw fecal sludge used in cereal farming in Ghana and India should be dewatered on-farm for ≥ 60 days or ≥ 90 days depending on the application method spread vs. pit) (to minimize occupational health risks.
Method of wastewater application:		
(a) Furrow irrigation	1–2	Crop density and yield may be reduced.
(b) Low-cost drip irrigation	2–4	2-log unit reduction for low-growing crops, and 4-log unit reduction for high-growing crops.
(c) Reduction of splashing	1–2	Farmers trained to reduce splashing when watering cans used (splashing adds contaminated soil particles on to crop surfaces which can be minimized).
Pathogen die-off (wastewater)	0.5–2 per day	Die-off support through irrigation cessation before harvest value depends on climate, crop type, etc.).
C. Post-harvest options at local markets		
Overnight storage in baskets	0.5–1	Selling produce after overnight storage in baskets (rather than overnight storage in sacks or selling fresh produce without overnight storage).
Produce preparation prior to sale	1–2	(a) Washing salad crops, vegetables and fruit with clean water.
	2–3	(b) Washing salad crops, vegetables and fruit with running tap water.
	1–3	(c) Removing the outer leaves on cabbages, lettuces, etc.
D. In-kitchen produce-preparation options		
Produce disinfection	2–3	Washing salad crops, vegetables and fruit with an appropriate disinfectant solution and rinsing with clean water.
Produce peeling	2	Fruits, root crops.
Produce cooking	6–7	Option depends on local diet and preference for cooked food.

Sources: EPHC, NRMMC and AHMC 2006; WHO 2006; Amoah et al. 2011; modified from Mara et al. 2010

FIGURE 4. REDUCING THE PATHOGENIC HEALTH RISKS FROM UNSAFE USE OF DILUTED WASTEWATER.

(Pictured left) The use of diluted untreated wastewater is prevalent in vegetable production in West Africa, such as here from a wastewater canal (Photo credit: IWMI). In the absence of wastewater treatment, possible pathogenic health risks from unsafe wastewater use could be reduced by implementing on-farm, post-harvest, and in-kitchen protection measures. (Pictured right) One on-farm option is the use of settling basins prior to irrigation. Comprehensive risk reduction is best achieved when multiple measures are used in combination (Photo credit: Andrea Silverman).

In addition to the risks from pathogen contamination, wastewater may have chemical contaminants from industrial discharges or stormwater runoff. The WHO (2006) guidelines provide maximum tolerable soil concentrations of various toxic chemicals based on human exposure through the food chain. For irrigation water quality, WHO refers to the FAO guidelines, which focus on plant growth requirements and limitations (Ayers and Westcot 1985; Pescod 1992).

The WHO guidelines do not specifically address how to reduce chemical contaminants from wastewater for use in irrigation. Resource-constrained countries may have historically been less prone to heavy metal contamination that is associated with industrial activities; with notable exceptions (e.g. tanneries). But where industries are emerging, industrial source control measures are required to avoid potential contamination of water bodies used for irrigation. Likewise, where required, stormwater should be diverted and treated to remove pollutants. Alternative options for low-income countries to reduce the potential risk of chemical contamination, like through phytoextraction, crop selection, and soil treatment are limited (Simmons et al. 2010).

Expanding and Optimizing Planned Water Reuse

As countries or municipalities in resource-constrained settings build operational and financial capacity, reuse safety should progress incrementally from on-farm and off-farm safety options to centralized or decentralized wastewater treatment, while establishing sound regulatory and monitoring protocols (Von Sperling and Fattal 2001; Drechsel and Keraita 2010; and Scheierling et al. 2010). This step-wise approach, recommended by WHO (2006), provides local public health risk managers with flexibility to address wastewater irrigation risks with locally viable options matching their capacity within a multi-barrier framework (Figure 5), instead of struggling to achieve water quality threshold levels as the only regulatory option (Von Sperling and Chernicharo 2002).

When treatment capacity has increased and irrigation water quality can be managed, the introduction of water quality standards should follow a similar incremental approach. The shift from water quality standards (WHO 1989) to health-based targets (WHO 2006), has helped to support a much broader range of measures for improving safe water reuse.

Reuse schemes often evolve from household and decentralized systems to eventual centralized urban systems (Scheierling et al. 2010). However, it is important to remember that household and decentralized schemes may continue to be desirable in high-resource settings for some applications, such as graywater reuse for toilet flushing and sewer mining ([Palestinian Territories-Auja] and [Australia-Graywater]).[9] The regulatory framework for reuse in these contexts should continue to support small-scale and potentially low-cost options where appropriate and where health and environmental risks can be minimized.

Wastewater quality regulations and standards from 28 countries are compiled by GWI (2011). Common challenges associated with establishing and implementing standards, especially in countries with limited resources, are summarized in Table 5, along with options to overcome these challenges.

Appropriate technologies and practices for wastewater treatment for agricultural reuse are one way to reduce risks to public health where direct wastewater use is prevalent. There is a wide range of wastewater treatment options for safe water, nutrient recovery, and irrigation with particular relevance for resource-constrained countries. Many experts in the field have summarized appropriate treatment

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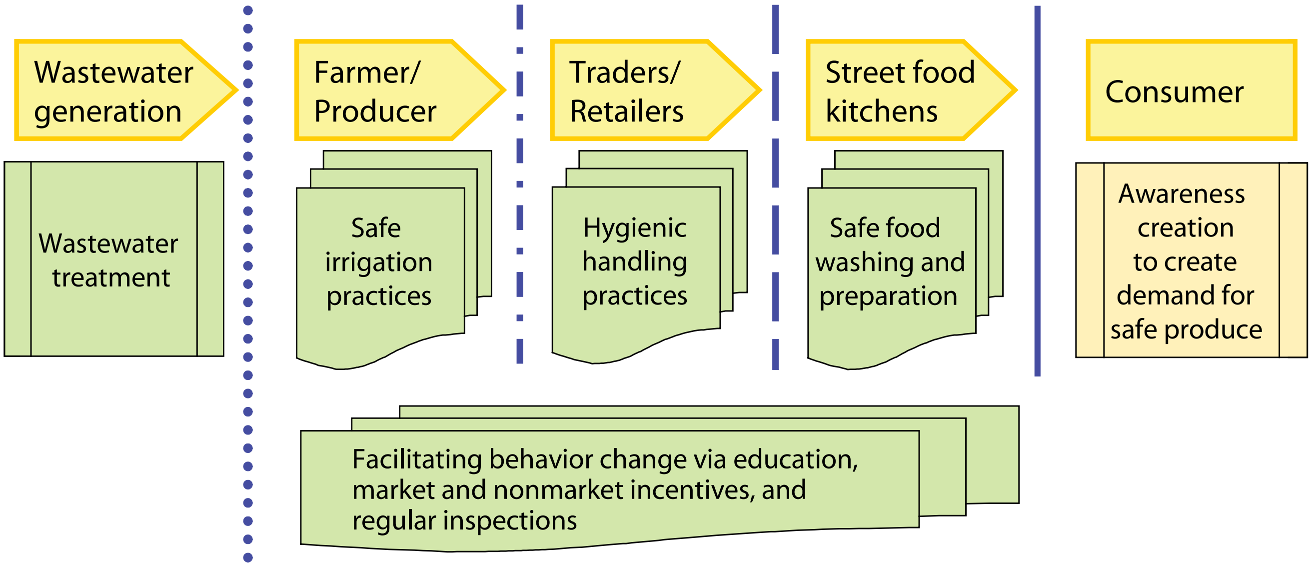
[9] Evidenced in [Japan-Building MBR] and [Australia-Graywater] case studies.

FIGURE 5. MULTI-BARRIER APPROACH TO SAFEGUARD PUBLIC HEALTH WHERE WASTEWATER TREATMENT IS LIMITED (AMOAH ET AL. 2011).



options, including Mara (2004), Laugesen et al. (2010), Von Sperling and Chernicharo (2005), and Libhaber and Orozco-Jaramillo 2013. As advances are made to drive down the cost of centralized and decentralized treatment technologies in resource-endowed contexts, some of the "high-tech" technologies may be adapted to lower-resource settings. Advances in decentralized wastewater treatment technologies and schemes may be particularly relevant in rapidly growing urban contexts where installation of centralized collection and treatment infrastructure is not cost-effective. However, decentralized systems are not a panacea where institutional capacities are generally low (Murray and Drechsel 2011).

When transitioning from wastewater use to planned reuse, it is important to consider a country or city's readiness to sustain investments in wastewater collection and treatment and the value added by treatment versus risk reduction through non-treatment barriers. There is no shortage of sanitation infrastructure that has fallen into disrepair, for example, and restrictions associated with reuse of treated wastewater has at times caused farmers to return to using untreated wastewater (Scheierling et al. 2010). It is therefore necessary to move toward planned reuse in a circumspect, phased approach whereby initial implementation is monitored for efficacy and sustainability before a larger-scale initiative is undertaken. Moving from wastewater use toward planned reuse requires a context-specific approach in light of institutional limitations and resource constraints. The following lessons of transitioning to wastewater collection, treatment, and reuse can be drawn from global experiences:

Consider overall infrastructure needs. In many cities of the world without functioning wastewater collection systems, stormwater and wastewater flow through unlined engineered or natural drainage paths. The cost of upgrading or constructing a collection system must be considered.

Consider local capacities. A key consideration in choosing appropriate treatment technologies is operator capacity. If a water reuse scheme is being planned and institutionalized at the municipality level, as exemplified in several case studies from India[10], as opposed to a community or small institution scale[11], a different set of technologies and practices will be appropriate and perhaps required in consideration of differing operator capacity, sophistication, and resource levels. Treatment and reuse schemes should therefore be designed to align with the social, environmental, technological, and economic circumstances of the target location/operator to achieve maximum sustainability (Von Sperling and Chernicharo 2002; Nhapi and Gijzen 2004).

Match treatment approach with reuse application at design stage. Several considerations should be taken into account when choosing an appropriate set of technologies to incorporate into the design of a planned reuse scheme. The treatment approach should be chosen to match the intended reuse application at the design stage rather than retrofitted after construction (Huibers et al. 2010; Murray and Buckley 2010). This approach may represent a departure from conventional approaches that treat wastewater immediately to meet water quality standards for discharge to receiving waters. This goal may not be achievable

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[10] [India-Nagpur], [India-Delhi], and [India-Bangalore].

[11] See the following case studies: [Palestinian Territories-Auja], [Israel/Peru-Vertical Wetlands], and [Peru-Huasta].

TABLE 5. CHALLENGES AND SOLUTIONS FOR REUSE STANDARDS DEVELOPMENT AND IMPLEMENTATION.

OBSERVATION	RECOMMENDATION
Guidelines, frequently copied from developed countries, are directly adopted as national standards.	Each country should adapt the guidelines, based on local conditions, and derive the corresponding national standards. In developed countries, these resulted from a long period of investment in infrastructure, during which standards were progressively improved. Cost and maintenance implications of too strict standards in the short term should be taken into account.
Guideline values are treated as absolute values, and not as target values.	Guideline values should be treated as target values, to be attained on a short, medium or long term, depending in the country's technological, institutional or financial conditions.
Treatment plants that do not comply with global standards do not obtain licensing or financing.	Environmental agencies should license and banks should fund control measures which allow for a stepwise improvement of water quality, even though standards are not immediately achieved. However, measures should be taken to effectively guarantee that all steps will be effectively implemented.
There is no affordable technology to lead to compliance of standards.	Control technologies should be within the countries' financial conditions. The use of appropriate technology should always be pursued.
Standards are not actually enforced.	Standards should be enforceable and actually enforced. Standard values should be achievable and allow for enforcement, based on existing and affordable control measures. Environmental agencies should be institutionally well developed in order to enforce standards.
Discharge standards are not compatible with water quality standards.	In terms of pollution control, the true objective is the preservation of the quality of the water bodies. Discharge standards should be based on practical and justifiable) reasons, assuming a certain dilution or assimilation capacity of the water bodies.
Number of monitoring parameters are frequently inadequate (too many or too few).	The list of parameters should reflect the desired protection of the intended water uses and ocal laboratory and financial capacities, without excesses or limitations.
There is no institutional development that could support and regulate the implementation of standards.	The efficient implementation of standards requires an adequate infrastructure and institutional capacity to license, guide, and control polluting activities and to enforce standards.
Reduction of health or environmental risks due to compliance with standards is not immediately perceived by decision makers or the population.	Decision makers and the population at large should be well informed about the benefits and costs associated with the maintenance of good water quality, as specified by the standards.

where there is an existing wastewater treatment plant and no capability to convey treated wastewater directly to the reuse application. It also may not apply where the reuse application can only absorb a small amount of the discharged wastewater. However, where there is an opportunity to design a new facility with a reuse component, there is potential to achieve significant cost and energy savings by matching the level of treatment (and thus the investment in treatment technology and construction) to the intended reuse, as water quality standards for uses such as irrigation of forest plantations and cooling water for industrial processes may be much lower than standards for aquatic discharge. Also, for some irrigation applications it is necessary to reduce fertilization rates based on the increased nutrient content found in reclaimed water. Where possible, it will be important to implement a design flexible enough to accommodate future increases in demand for reclaimed water for the same application, as well as additional applications. This may require a phased approach to constructing treatment capacity and a design that does not preclude potential future treatment processes required for a broader range of water reuse applications.

Consider overall costs and benefits. As highlighted in the Hyderabad Declaration of 2002, wastewater irrigation can have significant positive livelihood implications for poor smallholder farmers (USEPA 2004). These cost benefits can be considerable—even where wastewater is used without ideal treatment, especially in a low-resource context where households are facing multiple health risks. These economic benefits might outweigh health risks to the farmer and his/her family. Overly strict standards in these circumstances might be counterproductive, even for public health. In Ouagadougou and Lima, for example, farmers are not allowed to use treated wastewater as it does not meet ideal standards. As a result, farmers continue using untreated wastewater for crop production.

Where planned reuse is already being undertaken, there are at least two ways to strengthen its safety and sustainability for optimal benefits:

1. Transition to higher-value planned water reuse
2. Give greater consideration to environmental protection

Both options for strengthening planned water reuse imply moving beyond the WHO guidelines focus on protecting human health. The first point above calls for a shift from viewing treatment of wastewater as an obligation, either to protect human health or to satisfy environmental regulations, to viewing it as an opportunity to exploit a valuable economic resource. There is, indeed, growing recognition on the part of governments, from Arizona to Saudi Arabia, that the sale of treated wastewater can generate valuable revenues (GWI 2009).

However, the greatest revenues come almost entirely from advanced water reuse applications, like potable water, which require more advanced treatment and as such are better suited to applications other than agriculture. A major constraint to unlocking the market potential of water reuse are policies in many countries that force utilities to provide treated wastewater - even wastewater treated to an advanced level - to the agriculture sector. A major key to tapping the high value potential of water reuse, therefore, is overcoming strict government regulations and the public perceptions that often drive them, in order to open the domestic and industrial sectors to greater use for treated water (GWI 2009).

It should be noted that liberalizing the allocation of reused water could result in a greater proportion of wastewater allocation to high-value, non-agriculture uses, possibly resulting in less water for agriculture. However, it is important to remember that this is not a zero-sum game. As highlighted above, there are large quantities of wastewater that are currently untreated and/or unused. It may very well be possible with treatment of growing volumes of wastewater, for example, to continue to provide reclaimed water to agriculture in addition to fostering increased reuse for higher-value applications, such as industrial and municipal applications.

Nonetheless, transitioning to higher-value uses can be hampered by the often low, subsidized price of drinking water, which drives down the sale price of recycled water, as well as the subsidized cost of sanitation and treatment services (Jimenez and Asano 2008). Water pricing policies may need to be adopted that promote total water management, cost recovery of treatment, and service provision as a means of incentivizing water reuse. Comparing the cost of highly-treated recycled water with the price of highly-subsidized potable or irrigation water is an economic fallacy. This common comparison ignores both the numerous benefits inherent in water reuse and externalized costs of potable water under nearly all circumstances. The more appropriate comparison takes into account both sets of economic values and services using sophisticated quantification methods that go beyond simplistic benefit/cost ratios or price-versus-cost comparisons.

In addition to transitioning to higher-value uses, a second way to strengthen the safety and sustainability of planned water reuse is to give greater consideration to environmental protection, enhancement, and restoration. Indeed, countries may decide to graduate from the WHO model and address environmental concerns along with public health issues. In particular, water quality standards and guidelines for environmental flows may be instated to promote a desired level of treatment and volumes to divert for reuse. Standards are often set to reflect the degree of pathogen and contaminant removal possible with best-available treatment technologies. An overall regulatory strategy for water reuse is typically driven by the economics of treatment and monitoring, as well as enforcement capacity (Jimenez and Asano 2008). In the agricultural sector, water quality standards for water reuse on export crops may also be influenced by standards required by the importing countries or regions. These improvements would build on previous low-cost steps to reduce public health risks and toxic contamination at the source, as outlined in the Hyderabad Declaration (IWMI and IDRC 2002).

FACTORS ENABLING SUCCESSFUL IMPLEMENTATION OF SAFE AND SUSTAINABLE WATER REUSE

Global experiences have demonstrated that choosing an appropriate set of technologies or regulations is not in itself sufficient to ensure the safety and sustainability of a given water reuse project, especially under resource-constrained conditions. A set of factors must be established to support the long-term functioning of the water reuse program to achieve sustainability. Some of these factors are discussed in this section.

Stakeholder process. Although participatory processes can take more time compared with less-participatory approaches, risk of failure will be reduced by explicit integration of all relevant institutions and stakeholders in the planning and design phases of water reuse schemes. This applies in particular to water reuse in agriculture, which links different sectors (sanitation, agriculture, health, and environment). While regulatory frameworks that govern wastewater treatment and reuse schemes are typically crafted at the national or regional level of government, it is usually the responsibility of local or municipal institutions to implement the programs, including long-term financing, cost recovery, operations and maintenance, and performance monitoring. In the case of Ghana, for example, treatment plants at universities, hospitals, and military camps were operated by the Ministries of Education, Health, and Defense, respectively (Murray and Drechsel 2011). This places a significant responsibility on local institutions without ensuring their improved capacities. National-level frameworks are indeed a key enabling factor, as illustrated in the Nagpur, India case study [India-Nagpur].

Another critical element of the multi-stakeholder planning process is involving the end users in the planning and design phases. If end-user preferences for reclaimed water volumes and quality are not taken into account during the planning phase, the end users may simply reject the plan or not be able to make full use of the provided water or not accept paying for the service. Also, the treatment technology selected for the project should consider local experience in what works and what does not. Involving representatives from the communities that both supply and use the treated water will facilitate negotiations and “water swaps.” For example, farmers may be willing to transfer a portion of their freshwater allocations to meet urban water demand if they are provided access to treated, nutrient-rich, and reasonably-priced reclaimed water for agricultural activities (Winpenny et al. 2010; Huibers et al. 2010). Transitioning from a traditional top-down approach to a user-centered approach for planning and design has the potential to achieve more sustainable outcomes (USEPA 2012, chapter 8).

Sustainable Financial and Institutional Capacity Management. Forward-minded consideration of financing and capacity building is critical to sustainability. Operation and maintenance costs are often underestimated, and high staff turnover is a key challenge of public sector projects such as those related to water reuse. These factors often drive a run-to-failure trajectory (Murray and Drechsel 2011). Development of a longer-term strategy and/or involvement of the private sector could help avoid such an outcome. Although wastewater treatment plants are often publicly financed, the public-private partnership model is being piloted (e.g., Scheierling et al. 2010; Murray et al. 2011). Cost-recovery from irrigation is usually limited (Morris et al. 2005) unless the value propositions from wastewater treatment are extended to high end uses, or includes also energy recovery, fertilizer and soil ameliorants.

Public Outreach. A successful and sustainable water reuse program must integrate a public involvement campaign, particularly where the involved public will be consumers of the reclaimed water or the product developed using the reclaimed water (USEPA 2012, chapter 8). Just as a water reuse project may fail due to a lack of early stakeholder involvement, failure to garner public acceptance of water reuse through a well-conceived and implemented communication campaign can limit market demand for the product. There are several good examples of public acceptance campaigns for water reuse associated with potable reuse, irrigation and industrial reuse[12]. Public outreach will be more challenging where risk awareness is low or hazards of multiple origins (water-borne, food-borne) affect households, such as in many low-resource settings. In these circumstances, a significant investment in risk education is required. Lessons can be learned from hand-washing campaigns.

GLOBAL LESSONS LEARNED ABOUT WATER REUSE

We have a common challenge. Pressure on the world’s water resources has been growing dramatically, and climate change is accentuating patterns of droughts and floods. Water scarcity is affecting communities around the world, presenting an incredible opportunity for collaboration. And

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[12] In potable water: [Singapore-NEWater] and [India-Bangalore]. In irrigation: [Spain-Costa Brava], [Palestinian Territories-Auja], [Israel/Peru-Vertical Wetlands]. In industrial reuse: [India-Nagpur].

as solutions are developed in one context, they can be adapted to new contexts. For example, the U.S. is one of the world's leaders in advanced water reclamation technologies and stands to benefit from taking advantage of low-cost, low-energy solutions being demonstrated as described in several case studies from outside of the U.S.[13]. Likewise, advances in salinity management and drip irrigation in agricultural reuse is a key topic for scientific exchange between the United States and countries in the Middle East and other arid regions. The world has learned a lot from Singapore's advanced reuse technology as well as its leadership in integrated management and holistic planning under its long-term water supply strategy called "Four National Taps." Regulators in the United States have gained insight from the experience of other countries setting national guidelines and regulations, notably Australia. Current challenges in reuse, including economic models for partial or full cost recovery and technical challenges in nutrient recovery and energy efficiency, are also opportunities for international exchange.

Fine tuning the treatment. The concept of "fit-for-purpose" is illustrated in many of the international case studies (see also Murray and Buckley 2010; Libhaber and Orozco-Jaramillo 2013). In these reuse installations, careful study was conducted to ensure that the water produced would have the appropriate water quality for the intended use. Water reuse market growth is projected to take this approach—designing reuse for a specific purpose to achieve economic efficiency (GWI 2009). Both high- and low-tech solutions are imminently relevant to tuning our approaches, and as mentioned above, multiple endpoints may be appropriate for multi-purpose systems. Global experiences can help reuse planners answer the following questions: *Is proposed solution matched to developmental context? Are we choosing the easiest solution or the best solution? How carefully have the options been weighed?*

Increasing dialogue about water reuse in all corners of the world. Confidence in water and wastewater treatment technologies has grown among scientists and engineers, regulators and, increasingly, the general public such that the public and the decision-makers have security in the safety of reclaimed water. As the market grows, public awareness will increase, which has been shown to improve acceptance of and investment in reuse. Countries with only emerging wastewater collection and treatment systems will benefit from this dialogue if their opportunities and constraints are taken into account, for example, in view of any wastewater related target under the SDGs. The presented case studies show an encouraging spectrum of options where increased sanitation and wastewater management efforts in resource-constrained countries can move unplanned wastewater use to planned reuse, while taking advantage of modern treatment and non- or post-treatment options for safeguarding public health. With increasing population pressures for more available water resources, increasing recovery of the water resource from wastewater can help in meeting the total water needs of many nations.

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[13] [Brazil-Car Wash], [Israel/Peru-Vertical Wetlands], [Philippines-Market].

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Appendix A: Terminology

The terminology associated with treating municipal wastewater and reusing it varies both within the United States and globally. For instance, although the terms are synonymous, some states and countries use the term reclaimed water while others use the term recycled water. Similarly, the terms water recycling and water reuse have the same meaning. In this document, the terms reclaimed water and water reuse are used. Definitions of terms used in this document, with the exception of their use in case studies, which may contain site-specific terminology, are provided below.

De facto reuse: A situation where reuse of treated wastewater is, in fact, practiced but is not officially recognized (e.g., a drinking water supply intake located downstream from a wastewater treatment plant discharge point).

Direct potable reuse (DPR): The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a drinking water treatment plant, either collocated or remote from the advanced wastewater treatment system.

Indirect potable reuse (IPR): Augmentation of a drinking water source (surface water or groundwater) with reclaimed water followed by an environmental buffer that precedes drinking water treatment.

Non-potable reuse: All water reuse applications that do not involve potable reuse.

Potable reuse: Planned augmentation of a drinking water supply with reclaimed water.

Reclaimed water: Municipal wastewater that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes. The term recycled water is synonymous with *reclaimed water*.

Water reclamation: The act of treating municipal wastewater to make it acceptable for reuse.

Water reuse: The use of treated municipal wastewater (reclaimed water). Other alternate sources of water, including graywater and stormwater, are discussed in USEPA (2012, chapter 2).

Wastewater: Used water discharged from homes, business, industry, and agricultural facilities.

Appendix B: Websites of Selected International Regulations and Guidance on Water Reuse

Australia
Guidelines for Environmental Management: Use of Reclaimed Water
http://epa.vic.gov.au/ourwork/publications/publication/2003/november/464-2
Australian Guidelines for Water Recycling http://www.clearwater.asn.au/resource-library/policy-and-guidelines/australian-guidelines-for-water-recycling-phase-2-stormwater-harvest-and-reuse.php

Brazil
RESOLUÇÃO No 54, DE 28 DE NOVEMBRO DE 2005
http://www.aesa.pb.gov.br/legislacao/resolucoes/cnrh/54_2005_criterios_gerais_uso_agua.pdf

Cyprus
Τομέας Ελέγχου της Ρύπανσης
http://www.moa.gov.cy/moa/environment/environment.nsf/All/26C40CAAAAEF746CC22578D1003B1FEA?OpenDocument

FAO Wastewater treatment and use in agriculture
http://www.fao.org/docrep/t0551e/t0551e00.htm

India
General Standards for Discharge of Environmental Pollutants Part-A: Effluents http://cpcb.nic.in/GeneralStandards.pdf

Israel
Effluents and Waste http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Water-Quality/Pages/treated_waste_water.aspx?P=print
תונקתה קובי http://www.justice.gov.il/NR/rdonlyres/DF355FDA-0616-4D36-B8D3-64F706C494C9/19866/6886.pdf

Mexico
Normas Oficiales Mexicanas ordenadas por Materia
http://www.semarnat.gob.mx/leyes-y-normas/noms
Norma Oficial Mexicana Nom-001-Semarnat-1996, Que Establece Los Límites Máximos Permisibles De Contaminates En Las Descargas De Aguas Residuales En Aguas Y Bienes Nacionales
http://www.bvsde.paho.org/bvsacd/cd38/Mexico/NOM001ECOL.pdf
NOM-003-Semarnat-1997 www.conagua.gob.mx

Spain
Spanish Regulations for Water Reuse http://www.asersagua.es/legislacion/

Thailand
Water Quality Standards http://www.pcd.go.th/info_serv/en_reg_std_water04.html

Vietnam
National Technical Regulation on Water Quality for Irrigated Agriculture
http://www.epe.edu.vn/file/C__Documents%20and%20Settings_CQ%2040_Local%20Settings_Application%20Data_Mozilla_Firefox_Profiles_6zquphxp.pdf

WHO
Guidelines for the safe use of wastewater, excreta and greywater
http://www.who.int/water_sanitation_health/wastewater/gsuww/en/

RESEARCH PROGRAM ON
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CGIAR Research Program on Water, Land and Ecosystems

The **CGIAR Research Program on Water, Land and Ecosystems (WLE)** combines the resources of 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO) and numerous national, regional and international partners to provide an integrated approach to natural resource management research. WLE promotes a new approach to sustainable intensification in which a healthy functioning ecosystem is seen as a prerequisite to agricultural development, resilience of food systems and human well-being. This program is led by the International Water Management Institute (IWMI) and is supported by CGIAR, a global research partnership for a food secure future.

Resource Recovery and Reuse (RRR) is a sub-program of WLE dedicated to applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams. This SRP aims to create impact through different lines of action research, including (i) developing and testing scalable RRR business models, (ii) assessing and mitigating risks from RRR for public health and the environment, (iii) supporting public and private entities with innovative approaches for the safe reuse of wastewater and organic waste, and (iv) improving rural-urban linkages and resource allocations while minimizing the negative urban footprint on the peri-urban environment. This sub-program works closely with the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP), United Nations University (UNU), and many national and international partners across the globe. The RRR series of documents present summaries and reviews of the sub-program's research and resulting application guidelines, targeting development experts and others in the research for development continuum.

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