WATER RECLAMATION AND REUSE

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Summary

Water reclamation and reuse can enable communities to strategically link the distribution and use of locally available water resources with specific water quality and quantity goals, particularly in areas where there are concerns about water supply sustainability. Reclaimed water can be used to meet non-potable water needs including irrigation, industry, and sanitation. In addition, reclaimed water can be used to replenish surface or ground water resources. These activities can serve to improve the sustainability of aquatic ecosystems by decreasing the diversion of freshwater and reducing discharges of nutrients, pathogens, and other waterborne contaminants entering waterways. Changes in approaches for water resources management need to be accompanied by sound engineering controls and appropriate oversight for protecting public health.

While steady progress has been made since the 1960s to promote the safe reclamation and reuse of water, there are still challenges that must be addressed including institutional and social barriers to implementation, regulatory approaches and their effectiveness, public acceptance, competing water and energy needs, and socio-economic factors. Important issues related to planning and implementation of water reclamation and reuse are presented in this article.

1. Introduction

For more than half a century, a recurring thesis in environmental and water resources engineering has been that municipal wastewater can and should be recovered as a water resource. In light of increasing concerns about water supply availability, it is no longer appropriate to consider treated municipal wastewater as a “waste” that requires “disposal”, but rather as a resource that can be put to beneficial use (see *Unconventional Sources of Water Supply*). This conviction in linking responsible engineering and water sustainability has gained practical experience in many parts of the world. Water pollution control efforts have advanced to the point that treated effluent from municipal wastewater treatment plants is suitable and economical for augmenting traditional water supplies, particularly when compared to the alternatives such as importing water through costly conveyance systems or constructing dams and reservoirs. These traditional water resource management approaches can pose significant water quality, public health, safety and security issues and are becoming increasingly expensive, and environmentally destructive.

The successful development of reclaimed water resources depends upon close examination and synthesis of elements from infrastructure and facilities planning, wastewater treatment plant siting, treatment process reliability, economic and financial analyses, public acceptance, and water utility management. Whether water reuse is appropriate for a specific locale depends upon careful economic considerations, potential uses for the reclaimed water, and the relative stringency of waste discharge requirements. Public policies can be implemented that promote water conservation and reuse rather than the costly development of additional water resources with considerable environmental expenditures. Through integrated water resources planning, the use of reclaimed water may provide sufficient flexibility to allow a water agency to respond to short-term water shortages as well as increase the reliability of long-term water supplies.

2. Water Reuse Terminology and Definitions

To facilitate communication among different groups associated with water reuse, it is important to understand the terminology used in the arena of water reclamation and reuse. Water reclamation and reuse definitions commonly used are summarized in the glossary. The starting point is *wastewater reclamation*, which refers to the treatment or processing of wastewater to control biodegradable organics, nutrients and pathogens thereby making it reusable, and *water reuse* is the use of treated wastewater for beneficial purposes that include non-potable uses such as agricultural irrigation and industrial cooling. *Reclaimed water* is a treated effluent that is considered to be of appropriate quality for an intended water reuse application. In addition, *direct* water reuse requires the existence of pipes or other conveyance facilities for delivering reclaimed water to the end-user. *Indirect* reuse, through discharge of an effluent to a receiving water or groundwater for assimilation and withdrawals downstream, is recognized to be important but does not constitute *planned direct* water reuse. In contrast to direct water reuse, *water recycling* normally involves only one use or user and the effluent from the user is captured, treated, and redirected back into the original use or a use that has lower water quality requirements. It should be noted that the terminology, *water recycling*, is sometimes used synonymously with water reuse, particularly in California.

3. Evolution of Water Reclamation and Reuse

Early developments in the field of water reuse stem from the historical practice of land application for the disposal of wastewater. With the advent of sewerage systems for urban sanitation in the nineteenth century, domestic wastewater was used at "sewage farms" and by 1900 there were numerous sewage farms across Europe and the United States. While the purpose of these sewage farms was removal of wastes from population centers to prevent spread of disease, incidental use was made of the water for crop production or other beneficial uses. During the twentieth century, the growing need for reliable water coupled with environmental concerns about discharge of wastewater into fragile ecosystems and the increasing costs and energy requirements of wastewater treatment has spurred progress in water reclamation and reuse.

The purpose of this section is to provide a brief overview of the evolution of water reclamation and reuse. Topics considered include (1) a brief historical review of water reuse prior to 1960, and (2) significant water reclamation and reuse in the United States post 1960. The year 1960 is considered to be a transition point because significant water pollution control activities and key policies were implemented in the United States leading to the modern era of water reclamation and reuse, which began more than half a century ago.

3.1. Historical Development Prior to 1960

The reuse of wastewater can be traced back approximately 3,000 years to the Minoan Civilization in Crete, Greece where wastewater provided a local water source for food-crop irrigation under the arid conditions that existed during the growing season. Key events that have contributed to the evolution of water reclamation and reuse up to about 1960 are summarized in Table 1. The mid-nineteenth century was pivotal for water reuse as wastewater collection systems became more prevalent and served to improve sanitation by conveying household wastes away from urban dwellings into the nearest water courses. Unfortunately this practice of using "dilution" as a "solution" to pollution, still persists in the 21st century water management paradigm. The considerable pollution of the Thames River as it passed through London, UK, not only caused nauseating conditions in the city but also was responsible for repeated epidemics of cholera because the public water supply was derived from the same water source without supplemental treatment. The solution was the construction of a vast interceptor along the Thames, which, following the admonition of Sir Edwin Chadwick - *the rain to the river and the sewage to the soil*, carried the wastewater downstream for spreading on sewage farms. Such land disposal schemes were widely adopted by large cities in Europe and the United States up to the early 20th Century.

Period	Location	Events
~ 3000 BC	Crete, Greece	Minoan civilization: use of wastewater for agricultural irrigation.
97 AD	Rome, Italy	The City of Rome has a water supply commissioner, Sexus Julius Frontinus.
1500 ~	Germany	Sewage farms are used for wastewater disposal.
1700 ~	United Kingdom	Sewage farms are used for wastewater disposal.
1800-1850	France, England, U.S.A.	Legal use of sewers for human waste disposal in Paris (1880), London (1815), and Boston (1833) instituted.
1850-1875	London, England	Cholera epidemic is linked to polluted well water by Snow.
1850-1875	England	Typhoid fever prevention theory developed by Budd.
1850-1875	Germany	Anthrax connection to bacterial etiology demonstrated by Koch.
1875-1900	France, England	Microbial pollution of water demonstrated by Pasteur. Sodium hypochlorite disinfection by Down to render water “pure and wholesome” advocated.
1890	Mexico City, Mexico	Drainage canals are built to take untreated wastewater to irrigate an important agricultural area

		north of the city, a practice that still continues today. Untreated or minimally treated wastewater from Mexico City is delivered to the Valley of Mexico where it is used to irrigate about 90,000 ha of agricultural lands including vegetables.
1906	Jersey City, NJ	Chlorination of water supply.
1906		Disinfection kinetics elucidated by Chick.
	Oxnard, CA	The earliest reference related to a public health viewpoint of water quality requirements for the reuse of wastewater appears in the *Monthly Bulletin, California State Board of Health,* February, 1906 on the Oxnard septic tank system of sewage disposal.
1913-1914	United States and England	Activated sludge process is developed at the Lawrence Experiment Station in Massachusetts and demonstrated by Ardern and Lockett in England.
1926	United States	In Grand Canyon National Park treated wastewater is first used in a dual water system for toilet flushing, lawn sprinkling, cooling water and boiler feed water.
1929	United States	The City of Pomona, CA initiated a project utilizing reclaimed water for irrigation of lawns and gardens.
1932-1985	San Francisco, CA	Treated wastewater is used for watering lawns and supplying ornamental lakes in Golden Gate Park and continued with better quality effluent.
1955	Japan	Industrial water is supplied from Mikawajima wastewater treatment plant by Tokyo Metropolitan Sewerage Bureau.
1968	Namibia	Direct potable reuse begun at Windhoek's Goreangab Water Reclamation Plant.

[a] Adapted in part from; Metcalf and Eddy, 1928; Ongerth and Jopling, 1977; Barty-King, 1992; Okun, 1997; Cooper, 2001; Angelakis *et al*., 2003; Asano *et al*., 2007.

Table 1. Historic and milestone events related to the evolution of water reclamation and reuse[a]

When the link between the quality of water supplies and the spread of disease-causing pathogens became clearer, engineering solutions were implemented that included the development of alternative water sources using reservoirs and aqueduct systems, the relocation of water intakes to upstream of wastewater discharges, and the progressive introduction of water filtration during the 1850s and 60s. Microbiological advances in the late 19th century precipitated the *Great Sanitary Awakening* and the advent of chlorine disinfection. The development of the activated sludge process around 1913 was a significant step towards advancement of wastewater treatment and, specifically, the development of biological wastewater treatment systems.

The earliest reference related to a public health viewpoint of water quality requirements for the reuse of wastewater appears in the *Monthly Bulletin, California State Board of Health*, February, 1906 on the Oxnard septic tank system of sewage disposal. "Why not use it for irrigation and save the valuable fertilizing properties in solution, and at the same time completely purify the water? The combination of the septic tank and irrigation seems the most rational, cheap, and effective system for this state." In a 1915 US Public Health Service Bulletin, it was noted that if effluent from a septic tank were disposed of in a shallow trench located 30 cm below the soil surface the effluent "…may be used advantageously to cultivate an attractive hedge of roses or other shrubs or to cultivate a row of corn or other plants, the edible parts of which are produced well above the surface of the ground."

One of the earliest cases of industrial reuse in the United States was the use of chlorinated wastewater effluent for steel processing at the Bethlehem Steel Company in Baltimore, MD, which was practiced from 1942 until the company ceased operations in the late 1990s. In the 1960s, planned urban water reuse systems were developed in response to rapid urbanization in California, Colorado, and Florida.

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Bibliography and Suggestions for further study

Anderson, J.M. (2005) Integrating Recycled Water into Urban Water Supply Solutions, Khan,S.J, M.H. Muston, and A.I. Schäfer (ed.), *Integrated Concepts in Water Recycling*, 32-40, University of Wollongong, Australia. [Integrated water resources planning considerations]

Angelakis, A. N., M. H. F. Marecos do Monte, L. Bontoux, and T. Asano (1999) "The Status of Wastewater Reuse Practice in the Mediterranean Basin: Need for Guidelines," *Water Res.*, 33, 10, 2201-2217. [Status of water reuse]

Angelakis, A., T. Asano, E. Diamadopoulos, and G. Tchobanoglous, (Issue eds.) (1996) "Wastewater Reclamation and Reuse 1995," *Water Sci. Tech*., 23, 10-11. {Summary of issues in water reuse]

Angelekis, A.N., N.V. Paranychianakis, and K.P. Tsagarakis (Issue eds.) (2003) "Water Recycling in the Mediterranean Region," *Water Sci. Tech.,* 3, 4. [Status of water reuse]

Asano, T. (ed.) (1998) *Wastewater Reclamation and Reuse*, Water Quality Management Library, 10, CRC Press, Boca Raton, FL. [Comprehensive background on water reuse]

Asano, T. and A. D. Levine (1996) "Wastewater Reclamation, Recycling and Reuse: Past, Present, and Future," *Water Sci. Tech.*, 33, 10-11, 1-14. [Integrated water resources planning considerations]

Asano, T., and Levine, A.D. (1995). Wastewater Reuse: A Valuable Link in Water Resources Management. *Water Quality International*, No. 4, pp. 20-24. [Integrated water resources planning considerations]

Asano, T., F. L. Burton, H. Leverenz, R. Tsuchihashi, and G. Tchobanoglous (2007) Water *Reuse: Issues, Technologies, and Applications*, McGraw-Hill, New York. [Comprehensive background on water reuse]

AWWA (1981) *The Quest for Pure Water*, Vol. 1 and 2, 2nd ed., American Water Works Association, Denver, CO. [Water quality issues in water reuse]

AWWA (1994) Dual Distribution Systems, AWWA Manual M24, 2nd ed., American Water Works Association, Denver, CO. [Development of water reuse infrastructure]

Bahri A. and F. Brissaud (2004) "Setting up Microbiological Water Reuse Guidelines for the Mediterranean," *Water Sci. Tech.*, 50, 2, 39-46. [Guidelines for water reuse]

Baron, J. S., N. L. Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N. G. Hairston, R. B. Jackson, C. A. Johnston, B. D. Richter, and A. D. Steinman (2002) "Meeting Ecological and Social Needs for Freshwater," *Ecol. Appl.*, 12, 5, 1247-1260. {Applications for water reuse]

Barty-King, H. (1992) *Water: the Book, an Illustrated History of Water Supply and Wastewater in the United Kingdom*, Quiller Press, Ltd., London. [Historical development of water reuse]

Bixio, D., J. De Koning, D. Savic, T. Wintgens, T. Melin, and C. Thoeye (2005) Water Reuse in Europe, Khan,S.J, M.H. Muston, and A.I. Schäfer (ed.), *Integrated Concepts in Water Recycling*, 80-92, University of Wollongong, Australia. [Status of water reuse]

Blumenthal, U., D. D. Mara, A. Peasey, G. Ruiz-Palacios, and R. Stott (2000) "Guidelines for the Microbiological Quality of Treated Wastewater Used in Agriculture: Recommendations for Revising WHO Guidelines," *Bulletin of the World Health Organization*, 78, 9, 1104-1116. [Guidelines for water reuse]

Bonomo, L., C. Nurizzo, R. Mujeriego, and T. Asano, Eds. (1999) "Advanced Wastewater Treatment, Recycling and Reuse," *Water Sci. Tech.*, 40, 4-5. [Treatment technologies for water reuse]

Brissaud, F., J. Bontoux, R. Mujeriego, A, Bahri, C. Nurizzo, and T. Asano, (Issue eds.) (2001) Wastewater Reclamation, Recycling and Reuse, *Water Sci. Tech.*, 43, 10. {Summary of issues in water reuse]

Buechler, S., W. Hertog, and R. Van Veenhuizen (2002) "Wastewater Use for Urban Agriculture," *Urban Agric. Mag*., 8, 12, 1-4. {Applications for water reuse]

California State Water Resources Control Board (2003) *Recycled Water Use in California*, Office of Water Recycling, California State Water Resources Control Board, Sacramento, CA, Accessed at: http://www.swrcb.ca.gov/recycling/recyfund/wrreclaim1_attb.pdf [Status of water reuse]

Carr, R.M., U.J. Blumenthal, and D.D. Mara (2004) "Guidelines for the Safe Use of Wastewater in Agriculture: Revising WHO Guidelines," *Water Sci. Tech.*, 50, 2, 31-38. [Guidelines for water reuse]

Chen, C-L., J. F. Kuo, and J. F. Stahl (1998) "The Role of Filtration for Wastewater Reuse", 219-262, in T. Asano (ed.) *Wastewater Reclamation and Reuse*, Water Quality Management Library, 10, CRC Press, Boca Raton, FL. [Treatment technologies for water reuse]

Cooper, P. F. (2001) "Historical Aspects of Wastewater Treatment," 11-54, in P. Lens, G. Zeeman, and G. Lettinga (eds.) *Decentralised Sanitation and Reuse: Concepts, Systems and Implementation*, IWA Publishing, London. [Development of water reuse infrastructure]

Crites, R and G. Tchobanoglous (1998) Small & Decentralized Wastewater Management System, WCB/McGraw-Hill, New York, NY. [Design of decentralized systems for water reuse]

Crook, J., J. Mosher, and J. M. Casteline (2005) *Status and Role of Water Reuse: An International View*, Global Water Research Coalition, London, UK. [Status of water reuse]

Dryden, F.D., C-L. Chen, and M.W. Selna (1979) "Virus Removal in Advanced Wastewater Treatment Systems," *J. WPCF*, 51, 8, 2098-2109.

EEC (1991) European Communities Commission Directive (91/271/EEC), The Council of the European Community. [Guidelines for water reuse]

Fair, G. M. and J. C. Geyer (1954) *Water Supply and Waste-Water Disposal*, John Wiley & Sons Inc., New York. [Historical development of water reuse]

Faruqui, N., S. Niang, and M. Redwood (2002) "Untreated Wastewater Reuse in Market Gardens: A Case-Study of Dakar, Senegal," Paper presented at the International Water Management Institute

Workshop on Wastewater Reuse in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities, International Water Management Institute, Hyderabad, India. {Applications for water reuse]

Harhoff J. and B. van der Merwe (1996) "Twenty-five Years of Wastewater Reclamation in Windhoek, Namibia" Water Science &Technology, Vol. 33, No. 10-11, pp.25-35. [Historical development of water reuse]

Hutson, S.S., Barber, N.L., Kenny, J.F., Lumia, D.S., and Maupin, M.A. (2004) *Estimated Use of Water in the United States in 2000*: Reston Virginia, U.S. Geological Survey, Circular 1268. [Integrated water resources planning considerations]

Japan Sewage Works Association (2005) *Sewage Works in Japan 2005: Wastewater Reuse*, Tokyo, Japan. [Status of water reuse]

Jimenez, B. and T. Asano (2004) "Acknowledge All Approaches: The Global Outlook On Reuse," *Water 21*, 6, 32-37. [Status of water reuse]

Jimenez, B. and T. Asano (eds.) (2008) *Water Reuse: An International Survey of Current Practice, Issues and Needs*, Scientific and Technical Report No. 20, IWA Publishing, London, UK. [Status of water reuse]

Johnson, S. (2006). *The Ghost Map: The Story of London's Most Terrifying Epidemic and How It Changed Science, Cities, and the Modern World*, Riverhead Books, Published by the Penguin Group, New York. [Historical development of water supply and wastewater disposal]

Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace, and M.A. Maupin (2009). Estimated Use of Water in the United States in 2005, Circular 1344, U.S. Geological Survey, Reston, VA. [Integrated water resources planning considerations]

Kurian J., and C. Visvanathan (2001) "Sewage Reclamation Meets Industrial Water Demands in Chennai," *Water Lines*, 19, 4, 6-9. [Applications for water reuse]

Lazarova V. and A. Bahri (ed). (2005) *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, CRC Press, Boca Raton, FL. [Applications for water reuse]

Levine, A.D., and T. Asano (2004) "Recovering Sustainable Water from Wastewater," *Environ Sci. Tech.*, 38, 11, 201A-208A. [Summary of issues in water reuse]

Lumsden, L. L., C. W. Stiles, and A. W. Freeman (1915) *Safe Disposal of Human Excreta in Unsewered Homes*, Public Health Bulletin No. 68, United States Public Health Service, Government Printing Office, Washington, DC. [Historical development of water reuse]

Mara, D. (2003) *Domestic Wastewater Treatment in Developing Countries*, Earthscan, London. {Design of water reuse systems in developing countries]]

Marecos do Monte, M.H.F. (1998) "Agricultural Irrigation with Treated Wastewater in Portugal," Chap. 18, in T. Asano (ed.) *Wastewater Reclamation and Reuse*, Water Quality Management Library, 10, CRC Press, Boca Raton, FL. [Status of water reuse]

Metcalf, L., and H. P. Eddy (1928) *American Sewerage Practice*, Vol. 1, Design of Sewers, McGraw-Hill Book Co., Inc., New York. [Historical development of water reuse]

Mujeriego, R. and T. Asano (1999) "The Role of Advanced Treatment in Wastewater Reclamation and Reuse," *Water Sci. Tech.*, 40, 4-5, 1-9. [Applications for water reuse]

Mujeriego, R. and T. Asano, (Issue eds.) (1991) "Wastewater Reclamation and Reuse," *Water Sci. Tech.*, 24, 9. [Summary of issues in water reuse]

Odendaal, P. E., J.L.J. van der Westhuizen, and G.J. Grobler (1998) "Water Reuse in South Africa," 1163-1192, in T. Asano (ed.) *Wastewater Reclamation and Reuse*, Water Quality Management Library, 10, CRC Press, Boca Raton, FL. [Status of water reuse]

Okun, D. A. (1997) "Distributing reclaimed water through dual systems," *J. AWWA*, 89, 11, 52-64. [Development of water reuse infrastructure]

Ongerth, H. J., and W. F. Jopling (1977) "Water Reuse in California," Chap. 8 in H. I. Shuval (ed.) *Water Renovation and Reuse*, Academic Press, Inc., New York. [Status of water reuse]

Ongerth, H.J., and J.E. Ongerth (1982) “Health Consequences of Wastewater Reuse,” *Annu. Rev. Public Health*, 3, 419-444. [Guidelines for water reuse]

Radcliffe, J. C. (2004) *Water Recycling in Australia*, Australia Academy of Technological Sciences and Engineering, Parkville, Victoria, Australia. [Status of water reuse]

Sala, L., L. Mujeriego, M. Serra, and T. Asano (2002). “Spain Sets the Example,” *Water 21*, 4, 18-20. [Status of water reuse]

Sanitation Districts of Los Angeles County (1977), *Pomona Virus Study Final Report*, Prepared for California State Water Resources Control Board and U.S. Environmental Protection Agency, Los Angeles, CA. [Water quality issues in water reuse]

Shelef, G. (2000) Wastewater Treatment, Reclamation and Reuse in Israel, in *Efficient Use of Limited Water Resources: Making Israel a Model State*, Begin-Sadat (BESA) Center for Strategic Studies, Bar-Ilan University, Ramat Gan 52900 Israel [Status of water reuse]

Shelef, G., and Y. Azov (1996) "The Coming Era of Intensive Wastewater Reuse in the Mediterranean Region," *Water Sci. Tech*., 33, 10-11, 115-125. [Status of water reuse]

Shende, B, C. Chakrabarti, R. P. Rai, V. J. Nashikkar, D. G. Kshirsagar, P. B. Deshbhratar, and A. S. Juwarkar (1988) “Status of Wastewater Treatment and Agricultural Reuse with Special Reference to Indian Experience and Research and Development Needs,” 185-209, in Pescod, M B and A. Arar (eds) *Treatment and Use of Sewage Effluent for Irrigation*, Butterworths, London. [Status of water reuse]

Smit, J., and J. Nasr (1992) “Urban Agriculture for Sustainable Cities: Using Wastes and Idle Land and Water Bodies as Resources,” *Environ. Urban.*, 4, 2, 141-152. [Integrated water resources planning considerations]

Solley, W.B., R.R. Pierce, and H.A. Perlman (1998). *Estimated Use of Water in the United States in 1995*, U.S. Geological Survey Circular 1200, U.S. Geological Survey, Reston, VA. [Integrated water resources planning considerations]

State of California (1978) *Wastewater Reclamation Criteria*, *An Excerpt from the California Code of regulations*, *Title 22*, *Division 4*, Environmental Health, Department of Health Services, Berkeley, CA. [Guidelines for water reuse]

State of California (2002) Statewide Recycled Water Survey, Office of Water Recycling, State Water Resources Control Board, Sacramento, CA. [Status of water reuse]

State of California (2003a) California Code – Water Code Section 13050, subdivision (n). (http/www.leginf.ca.gov/) [Guidelines for water reuse]

State of California (2003b) *Water Recycling 2030: Recommendations of California’s Recycled Water Task Force*, Department of Water Resources, Sacramento, CA. [Guidelines for water reuse]

Takizawa, S. (2001). Water reuse by a natural filtration system in a Vietnamese rural community, *Water Lines*, 19, 4, 2-5. [Treatment technologies for water reuse]

Tchobanoglous, G., F. L. Burton, and H. D. Stensel (2003) *Wastewater Engineering: Treatment and Reuse*, 4th ed., McGraw-Hill, New York. [Comprehensive background on water reuse]

U.S. EPA and U.S. AID (1992) *Manual - Guidelines for Water Reuse*, EPA/625/R-92/004, Washington, D.C. [Guidelines for water reuse]

U.S. EPA and U.S. AID (2004) 2004 *Guidelines for Water Reuse*, EPA/625/R-04/108, August 2004, Washington, D.C. [Guidelines for water reuse]

UNEP and GEC (2005) Water and Wastewater Reuse: An Environmentally Sound Approach for Sustainable Urban Water Management, United Nations Environment Programme and Global Environment Centre Foundation, Osaka, Japan. Accessible at http://www.unep.or.jp/Ietc/Publications/Water_Sanitation/wastewater_reuse/index.asp [Integrated water resources planning considerations]

Wegner-Gwidt, J. (1998). Public Support and Education for Water Reuse, Chap. 31, 1417-1462, in T. Asano (ed.), *Wastewater Reclamation and Reuse*, Water Quality Management Library, 10, CRC Press, Boca Raton, FL. [Status of water reuse]

WHO (1989) *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*, Report of a WHO Scientific Group, Technical Report Series 778, World Health Organization, Geneva, Switzerland. [Guidelines for water reuse]

WHO (2005) *Meeting Report: Final Expert Review Meeting for the Finalization of the Third Edition of the WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater: 13-17 June, 2005*, World Health Organization, Geneva, Switzerland. [Guidelines for water reuse]

WHO (2006) *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Third Edition, Volume II: Wastewater Use in Agriculture*, World Health Organization, Geneva, Switzerland. [Guidelines for water reuse]

Wilderer, P.A., E.D. Schroeder, and H. Kopp (ed.) (2004) *Global Sustainability*, Wiley-VCH, Germany. [Integrated water resources planning considerations]

Biographical Sketches

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Dr. Harold Leverenz is a Professional Engineer (P.E.) with an emphasis on promoting sustainable engineering practices. He has been actively involved in water reuse engineering for over 10 years and has authored or co-authored multiple publications on this topic. His research interests include decentralized wastewater infrastructure, systems for water reuse, and nutrient and energy recovery from waste streams. He holds an undergraduate degree in Biosystems Engineering from Michigan State University, masters and doctoral degrees in Environmental Engineering from the University of California (UC) at Davis. Harold has extensive experience writing and editing reference and educational materials, preparing data and statistical plots, and preparing conceptual and technical illustrations.

Dr. Takashi Asano is a Professor Emeritus at the University of California at Davis. Professor Asano has more than 40 years of academic and professional experience in environmental and water resources engineering. During 1978-1992, he served as the Water Reclamation Specialist for the California State Water Resources Control Board (SWRCB) in Sacramento. He has conducted major water reclamation and reuse studies at the SWRCB and the University of California at Davis, many of which became the scientific and technical basis for California's Title 22 regulations (State of California Water Recycling Criteria). His research on quantitative microbial risk analysis and groundwater recharge was awarded the 1999 Jack Edward McKee Medal by the Water Environment Federation (WEF) which was shared by his colleagues and a former graduate student at the University of California at Davis.Dr. Asano was the U.S. representative for the International Association on Water Quality (IAWQ) as Vice-Chairman, and former Chairman and Honorary Chairman of the International Water Association's Water Reuse Specialist Group.Professor Asano is the 2001 Stockholm Water Prize Laureate and the member of the European Academy of Sciences and Arts, Vienna, Austria, and the International Water Academy, Oslo, Norway.

Professor Asano is a member of the IWA Council of Distinguished Water Professionals. He was conferred The Order of the Sacred Treasure, Gold and Silver Star in Japan in 2009; Doctor *Honoris Causa* from the University of Cadiz, Cadiz, Spain in 2008; and Honorary Doctorate from his *alma mater* Hokkaido University, Sapporo, Japan in 2004.