WATER RECLAMATION AND REUSE

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water reclamation, water reuse, wastewater.

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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
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.

<table>
<thead>
<tr>
<th>Period</th>
<th>Location</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 3000 BC</td>
<td>Crete, Greece</td>
<td>Minoan civilization: use of wastewater for agricultural irrigation.</td>
</tr>
<tr>
<td>97 AD</td>
<td>Rome, Italy</td>
<td>The City of Rome has a water supply commissioner, Sexus Julius Frontinus.</td>
</tr>
<tr>
<td>1500 ~</td>
<td>Germany</td>
<td>Sewage farms are used for wastewater disposal.</td>
</tr>
<tr>
<td>1700 ~</td>
<td>United Kingdom</td>
<td>Sewage farms are used for wastewater disposal.</td>
</tr>
<tr>
<td>1850-1875</td>
<td>London, England</td>
<td>Cholera epidemic is linked to polluted well water by Snow.</td>
</tr>
<tr>
<td>1850-1875</td>
<td>England</td>
<td>Typhoid fever prevention theory developed by Budd.</td>
</tr>
<tr>
<td>1850-1875</td>
<td>Germany</td>
<td>Anthrax connection to bacterial etiology demonstrated by Koch.</td>
</tr>
<tr>
<td>1875-1900</td>
<td>France, England</td>
<td>Microbial pollution of water demonstrated by Pasteur. Sodium hypochlorite disinfection by Down to render water “pure and wholesome” advocated.</td>
</tr>
<tr>
<td>1890</td>
<td>Mexico City, Mexico</td>
<td>Drainage canals are built to take untreated wastewater to irrigate an important agricultural area</td>
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</tbody>
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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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Event</th>
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<tbody>
<tr>
<td>1906</td>
<td>Jersey City, NJ</td>
<td>Chlorination of water supply.</td>
</tr>
<tr>
<td>1906</td>
<td>Oxnard, CA</td>
<td>Disinfection kinetics elucidated by Chick.</td>
</tr>
<tr>
<td>1913-1914</td>
<td>United States and England</td>
<td>Activated sludge process is developed at the Lawrence Experiment Station in Massachusetts and demonstrated by Ardern and Lockett in England.</td>
</tr>
<tr>
<td>1926</td>
<td>United States</td>
<td>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.</td>
</tr>
<tr>
<td>1929</td>
<td>United States</td>
<td>The City of Pomona, CA initiated a project utilizing reclaimed water for irrigation of lawns and gardens.</td>
</tr>
<tr>
<td>1932-1985</td>
<td>San Francisco, CA</td>
<td>Treated wastewater is used for watering lawns and supplying ornamental lakes in Golden Gate Park and continued with better quality effluent.</td>
</tr>
<tr>
<td>1955</td>
<td>Japan</td>
<td>Industrial water is supplied from Mikawajima wastewater treatment plant by Tokyo Metropolitan Sewerage Bureau.</td>
</tr>
<tr>
<td>1968</td>
<td>Namibia</td>
<td>Direct potable reuse begun at Windhoek’s Goreangab Water Reclamation Plant.</td>
</tr>
</tbody>
</table>

*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

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


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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]


Biographical Sketches

Dr. Audrey D. Levine is a Professional Engineer (P.E.) with over 25 years broad-based technical experience within academic, government, industry, and consulting settings. She has worked with the US Environmental Protection Agency’s Office of Research and Development as the National Program Director for Drinking Water Research. She has extensive practical design, field, and research experience with municipal water and wastewater treatment systems, industrial wastewater treatment, water distribution systems, reclaimed water systems, and ultrapure water systems. She has taught graduate and undergraduate courses in civil and environmental engineering and environmental science and policy at several universities. She holds an undergraduate degree from Bates College, a Master’s Degree in Public Health from Tulane University, and a Ph.D. from the University of California at Davis. Her research interests include integrated water resources management, water reclamation and reuse, sustainable engineering practices, optimizing public health protection relevant to surface and subsurface sources of water, reclaimed water, and water infrastructure, water and wastewater systems in small communities and developing countries, source control and management of waterborne contaminants (pathogens, pharmaceuticals, endocrine disruptors, toxins, etc.) in water and wastewater, biogeochemical reactions in natural and engineered systems, microbiological community structure in engineered systems (biofilms, landfill leachates, distribution systems, biosolids), groundwater recharge and aquifer storage and recovery, energy-water nexus including linkages between water quality and quantity in the context of the built environment, geologic sequestration, hydraulic fracturing, biofuels, geothermal systems, and thermoelectric power generation.

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.