Preface

About the Topic

Water and sanitation can underpin a healthy society when solutions are effective in protecting public health and preserving environmental quality while being affordable, socially acceptable, and sustainable. In the United States, water and sanitation infrastructure evolved during the 20th century in response to a growing recognition that providing safe drinking water and adequate treatment of wastewaters were needed to protect public health and preserve water quality. During this evolution, there was always a mix of onsite systems serving individual homes and businesses in rural and peri-urban areas, decentralized systems serving suburban residential and mixed-use developments, and larger centralized systems serving densely populated urban areas. However, the relative proportion of the population and development served by different types of infrastructure has varied and evolved over time.

During much of the 20th century, some viewed onsite and decentralized wastewater systems as a means of providing temporary service until sewers and a centralized treatment plant became available to provide permanent service. Early versions of onsite systems (e.g., pit privy and cesspool) were often designed with simple and short-term goals of human waste disposal to prevent human exposure to infectious waste materials and to achieve basic public health and environmental protection. As water-using fixtures and appliances became commonplace, system designs evolved to include raw wastewater treatment through solids separation and anaerobic digestion in a tank-based unit (e.g., a septic tank) followed by effluent disposal to the land (e.g., a soil drainfield). Continuing to evolve, onsite and decentralized systems were increasingly designed and implemented to achieve wastewater treatment as well as disposal and even considered for beneficial water reuse. But many designers and regulatory officials continued to view onsite and decentralized systems as inherently deficient compared to centralized systems. As a result, during the latter half of the 20th century, there were major Federal and State programs that provided funding for construction of wastewater collection systems and centralized treatment plants. But the push to expand service areas and increase the percentage of the population connected to centralized wastewater systems eventually faded for a number of reasons. The construction grants program that provided funding for centralization ended plus there was a growing realization that large centralized systems were not appropriate for all rural and many suburban and peri-urban areas and there were growing concerns about the sustainability of large infrastructure. By the end of the 20th century, about 25 % of the US population was served by onsite and decentralized wastewater systems and approximately one-third of new development was being supported by such systems. This amounted to roughly 25 million existing systems with about 200,000 new systems being installed each year.

Near the end of the 20th century and into the 21st century, a series of activities and events in the United States helped catalyze a reevaluation of how water and wastewater infrastructure could be made more sustainable. There was growing interest in how onsite and decentralized systems could help provide more sustainable infrastructure by:

- Reducing the use of drinking water to flush toilets and transport waste to remote wastewater treatment plants.
- Preventing pollutant discharges from large centralized systems including sanitary sewer overflows, combined sewer overflows, and leaking sewers.
- Recharging water near the point of water extraction and avoiding water export and depletion of local water resources.
- Enabling recovery and reuse of wastewater resources including water, organic matter, nutrients, and energy.
- Lowering consumption of energy and chemicals and reducing greenhouse gas emissions.
- Providing infrastructure that is more robust and resilient to natural disasters and climate change.

During this period, there was also a growing recognition that the capabilities of 21st century onsite and decentralized systems should not be judged based on the performance of older 20th century systems. The early versions of onsite and decentralized systems (e.g., cesspools, seepage pits, leachfields, and septic systems) were designed to be simple and cheap but not to achieve long-term treatment or reuse goals. During the latter decades of the 20th century, increased water use and wastewater generation and more widespread use of disposal-based systems in a growing suburban America led to hydraulic malfunctions, groundwater contamination, and surface water quality deterioration. As a result, these older disposal-based systems became known as “legacy systems.”

Based on major research and development efforts over the past two decades or more, 21st century onsite and decentralized systems (hereafter referred to as decentralized systems) have evolved and modern systems can include a growing array of approaches, devices, and technologies that can achieve wastewater treatment and enable resource conservation and reuse. Ultraefficient fixtures and source separation plumbing can minimize water and energy demands, enable resource recovery and reuse, and reduce wastewater flows and loadings. Wastewater treatment can be achieved using engineered reactor-based unit operations (e.g., aerobic bioreactors, porous media biofilters, and membrane bioreactors) or engineered natural system unit operations (e.g., constructed wetlands, subsurface soil infiltration, and landscape dispersal). Nutrient reduction strategies and technologies can remove and, in some cases, recover nitrogen and phosphorus. Reuse of reclaimed water can occur through garden and landscape irrigation, toilet flushing, and other functions. Sensors and monitoring devices can be used to verify performance and enable remote monitoring and process control to correct a system malfunction.

Today, decentralized systems involving wastewater treatment and water reclamation can be used to serve buildings and developments with design flows of less than 100 to 100,000 gal/day or more. Common and emerging applications within the United States and similar industrialized countries include approaches, technologies, and systems that are deployed for one or more of the following purposes:

- To provide effective wastewater treatment for homes and businesses in rural and peri-urban areas and residential, commercial, and mixed-use developments in suburban areas.
- To provide effective wastewater treatment for buildings and developments while also producing reclaimed water for nonpotable reuse purposes such as toilet flushing, cooling, or irrigation.
- To recover valuable wastewater resources including nutrients, organic matter, and energy.
- To earn points for a green building or sustainability rating through the low impact water and wastewater management options enabled by decentralized systems.
- To provide appropriate treatment and recovery of stormwater runoff in suburban and urbanized areas.

Decentralized systems are also critical to providing safe drinking water and adequate sanitation in developing regions of the world. In developing regions worldwide, concerns about sustainability of large water and wastewater infrastructure are not yet paramount. Rather, concerns are still focused on how best to provide solutions for safe drinking water and effective sanitation—solutions that are effective, affordable, and socially acceptable.

For nearly a generation now, the virtues and varied benefits of decentralized systems have been increasingly recognized and approaches, technologies, and systems have been advocated as critical components for a 21st century water infrastructure in the United States and worldwide. Translating this recognition and advocacy into meaningful impacts requires a portfolio of education and training activities that target different audiences to achieve different outcomes.

About This Workbook

Decentralized Water Reclamation Engineering—A Curriculum Workbook was developed to present technical information and materials concerning the engineering of decentralized infrastructure for wastewater treatment and water reclamation in a form suitable for classroom lectures or self-study. The approaches, technologies, and systems are targeted for sustainable infrastructure across the United States and similar industrialized nations, but they are also applicable in developing regions around the world.

The intended audience for this Workbook includes educators and students engaged in curriculum concerned with water and sanitation and the scientists and engineers seeking to improve the state of the art and standard of practice. This Workbook should also be highly informative for design professionals, contractors, technology developers, regulators, policy makers, and others involved in, or just interested in, the subject of sustainable infrastructure for water and sanitation.

The subject of decentralized water reclamation engineering spans a wealth of approaches, technologies, and systems too numerous to properly cover in a single curriculum workbook. This Workbook was intentionally crafted to provide in-depth information about a selected number of key topics. The presentation is intentionally concise so the information can be efficiently conveyed through course lectures or self-study. The intended outcome is for the reader to increase their understanding and know-how such that they are able to complete an engineering design of a decentralized system for a particular project. Topics covered in this Workbook include:

- Introduction to decentralized infrastructure for wastewater treatment and water reclamation and reuse (Chap. 1).
- Selection, design, and implementation of decentralized systems to satisfy project goals and requirements including sustainability (Chap. 2).
- Characteristics of contemporary water use and wastewater generation and methods to predict flow and composition data for use in design (Chap. 3).

- Water use efficiency and source separation as a means to reduce water use, energy consumption, and greenhouse gas emissions and enhance treatment and enable resource recovery (Chap. 4).
- Alternative methods of wastewater collection and conveyance that are well suited to decentralized system applications (Chap. 5).
- Tank-based treatment operations including septic tanks, aerobic treatment units, porous media biofilters, and membrane bioreactors that can be used to produce primary to tertiary quality effluents (Chaps. 6–9).
- Wetland-based treatment operations including free water surface and vegetated subsurface bed constructed wetlands that can be used to produce advanced secondary quality effluents (Chap. 10).
- Land-based treatment operations involving subsurface soil infiltration that can be used to treat wastewater and assimilate the reclaimed water into a local hydrologic system (Chap. 11).
- Land-based treatment operations involving landscape drip dispersal that can be used to treat wastewater and, in many cases, beneficially recover the water and nutrients for their fertilizer value (Chap. 12).
- Approaches and technologies that can be used as needed to achieve nutrient reduction (and resource recovery in some cases) and pathogen destruction to enable a particular discharge or reuse plan (Chaps. 13 and 14).
- Management requirements and methods for process solids, sludges, and residuals that are generated during decentralized wastewater treatment and water reclamation (Chap. 15).

The Workbook contains 15 chapters, each of which comprises a summary section and a conceptual and technical details section. The summary section presents the scope and key concepts of the chapter topic and provides definitions of terminology and acronyms abbreviations and symbols and a list of references. There are also short-answer questions and calculation problems relevant to the topic of the chapter. The conceptual and technical details section is presented in a slide format that was developed for teaching and then embellished and expanded to provide detailed coverage of a topic. The slides section of each treatment technology chapter (Chaps. 6–14) is divided into major parts that consist of a technology description, treatment performance, principles and processes, design and implementation, summary, and example problems. The Workbook contains over 300 figures and illustrations of technologies and systems and over 150 tables of design and performance data. There are also more than 200 questions and problems relevant to the topics covered including more than 50 example problems that have solutions to illustrate decentralized system assessment and design.

The author developed and refined the contents of the Workbook over the past decade to support delivery of a 15-week long course focused on engineering design for decentralized water reclamation and reuse. This university level course was developed for education of upper level undergraduate and graduate students at the Colorado School of Mines in Golden, Colorado, in the United States. The contents of the Workbook have also been used for delivery of seminars, guest lectures, and professional development workshops.

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