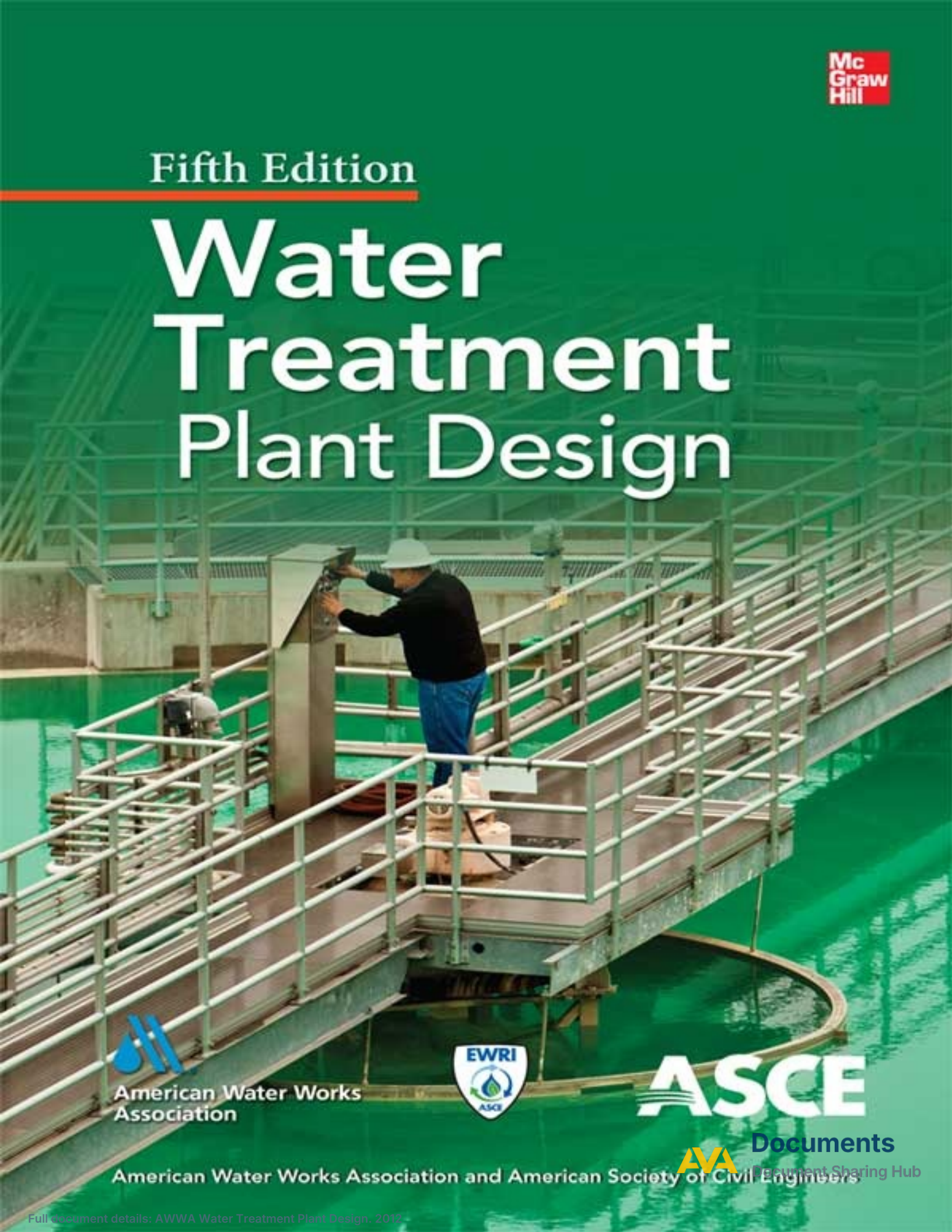
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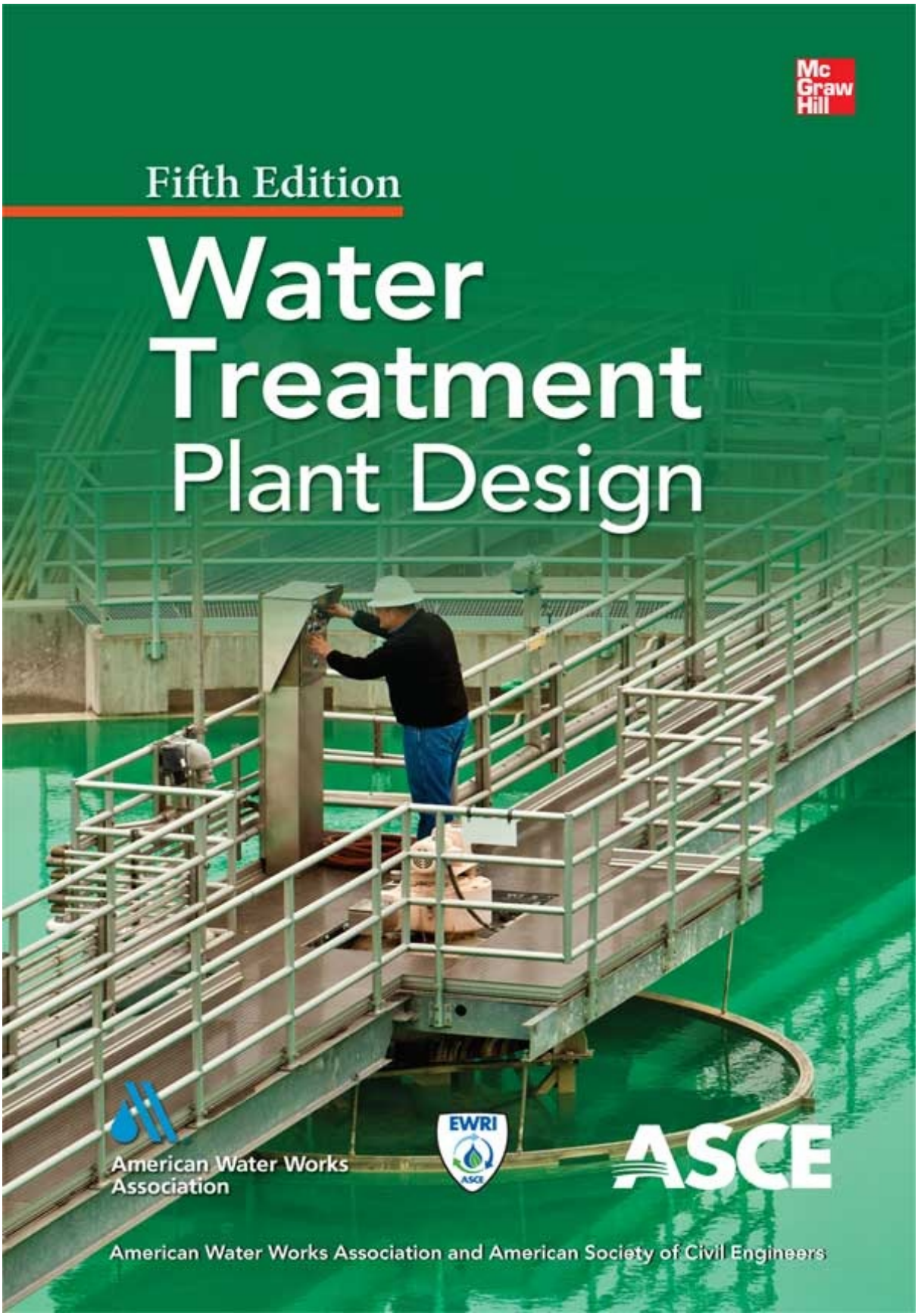
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PREFACE

Design practices for water treatment plants continue to evolve at a rapid pace. Technologies considered new 10 or 15 years ago, such as membrane processes and ultraviolet (UV) disinfection, are now commonplace. Biological processes are gaining popularity as new and better ways are found to exploit the ability of microorganisms to transform a variety of regulated and unregulated contaminants, including biodegradable products of ozone and advanced oxidation processes. The growing emphasis on sustainable design to conserve energy and material resources and reduce the environmental impacts of water treatment facilities is addressed in a new chapter in this fifth edition and in other chapters throughout this handbook.

The first version of *Water Treatment Plant Design* was published in 1939 as a manual of engineering practice for ASCE. In 1969, the manual assumed book form and was updated to include a discussion of developments in pretreatment and filtration processes. That edition was the result of a joint effort between committees of ASCE, AWWA, and the Conference of State Sanitary Engineers (CSSE), and was published by AWWA. The next edition, considered the second edition of the book, was produced in 1990 through a joint effort of AWWA and ASCE and published by McGraw-Hill, which has continued to publish the book. The material for each chapter was prepared by one or more authors and reviewed by a joint committee of AWWA and ASCE members.

The third edition, published in 1998 and also a joint AWWA and ASCE effort, was essentially a complete rewrite of the previous edition. A steering committee made up of members from both associations guided the revision process. The fourth edition, published in 2005, provided significant new information on many important topics, including new chapters on UV technologies and security.

This fifth edition further expands the book's scope and substantially updates the knowledge in most apsects of the water treatment plant design field. A dedicated group of 90 authors from engineering firms, water utilities, universities, and service companies revised existing

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chapters and wrote three new chapters—one on sustainability, one on biological processes, and one on HVAC (heating, ventilating, and air conditioning), plumbing, and air supply systems. Providing support to the chapter authors was a large group of volunteers, individually identified in the contributors section that follows this preface, who evaluated the chapters in the fourth edition and reviewed the new or revised chapters for the fifth edition. Gay Porter De Nileon, the AWWA senior manager of editorial development and production, supported both the chapter authors and the technical editors and provided coordination with ASCE, McGraw-Hill, and other AWWA staff members.

Guiding the development of the fifth edition was a joint committee of AWWA and ASCE members. The AWWA members were drawn from the Water Treatment Facilities Design and Construction Committee of the Engineering & Construction Division of AWWA, and the ASCE members of the joint committee were drawn from two technical committees of ASCE's Environmental & Water Resources Institute (EWRI). The members of the joint committee and the organizations they represented on the committee (some are members of both organizations and all are representing their profession as a whole) were:

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Dennis R. Martenson, P.E., BCEE, F.ASCE, coordinated the participation of many ASCE members, including those drawn from two EWRI committees (the Water Supply Engineering Technical Committee and the Water Systems Security Committee), who contributed by serving as chapter evaluators and reviewers. Others contributing to the work of the joint committee included: **James K. Edzwald, Ph.D., BCEE** (Professor Emeritus, University of Massachusetts), who provided valuable advice and helped coordinate preparation of this handbook with the sixth edition of *Water Quality & Treatment*, for which he served as the technical editor; **Douglas F. Reed, P.E.** (SEA Consultants), who served as an advisor to the joint committee on behalf of AWWA's Engineering & Construction Division; **Arnold Strasser, P.E., M.ASCE** (Denver Water), who served as an advisor to the committee on behalf of EWRI's Water Supply Engineering Technical Committee; **Edward E. Baruth** (AWWA), technical editor for the fourth edition, who helped develop the scope of the fifth edition; and **Claire Arnault** (Associated Engineering), who arranged meetings, prepared minutes, and coordinated communications for the joint committee.

For the convenience of readers, the chapters are organized as follows:

- Chapters 1 through 4 provide an overview of the design process and address master planning, process selection, final design, and engineering needs during project construction and initial operation. Chapter 2 is new to this edition and outlines the overall approach to incorporating sustainable practices.
- Chapters 5 through 17 address design practices for the major categories of unit treatment processes applicable to water treatment plants. Chapter 17 is new to this edition and addresses biological processes for potable water treatment.
- Chapters 18 through 21 cover the process support systems associated with the design of water treatment facilities. Chapter 21, on hydraulics, has been expanded significantly and now covers pumping more completely, including energy efficiency considerations.
- Chapters 22 and 23 cover site development, environmental impact assessment, and permitting for water treatment facilities.
- Chapters 24 through 28 cover design of other support systems associated with water treatment facilities. Chapter 25 is new to this edition and covers aspects of building and process support systems applicable to water treatment facilities.

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- Chapters 29 through 33 discuss general topics essential to developing a successful water treatment plant project.

Because of the rapid changes that the water treatment engineering industry is undergoing, many chapters include a discussion of current trends and anticipated future developments. These discussions attempt to inform the reader of developments not yet in general practice, but that may be soon.

Water Treatment Plant Design is a companion reference to the AWWA handbook *Water Quality & Treatment*. *Water Quality & Treatment* provides more in-depth coverage of drinking water standards, regulations, and treatment objectives, and it emphasizes treatment principles (theory) and applications (practice) rather than design, which is the primary focus of *Water Treatment Plant Design*.

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Many individuals helped make the fifth edition of *Water Treatment Plant Design* a valuable resource for the drinking water community and especially for those involved in the design and construction of drinking water treatment facilities. Credit for the content and quality of the fifth edition of this handbook belongs first and foremost to the 90 authors who prepared the book's 33 chapters:

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CHAPTER 1
THE CHALLENGE OF WATER TREATMENT PLANT DESIGN

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THE PURPOSE OF THIS HANDBOOK

Water Treatment Plant Design is intended to serve as the primary reference for engineers who take on today's challenges of water treatment plant design. It covers the organization and execution of a water treatment plant project from planning and permitting through design, construction, and start-up.

The book is aimed at project engineers and managers: those professional engineers who lead the group of specialists who make up the design team. Generally, these individuals are graduates of civil or environmental engineering programs and are registered professional engineers.

For certain topics, especially the practical application of water treatment unit processes, this book aims to be an authoritative reference for use by design engineers. For other topics, only a general discussion of major concepts and issues is provided, and the reader is referred to more specialized references for detailed information.

Many books in circulation address water supply, water treatment, and related topics. As a joint publication of the American Water Works Association (AWWA) and the American Society of Civil Engineers (ASCE), *Water Treatment Plant Design* attempts to present an industry consensus on current water treatment plant design practices.

BACKGROUND

As water treatment engineering evolved in the early part of the twentieth

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century, its main goal was to ensure that infectious organisms in drinking water supplies were removed or inactivated. Chlorination and filtration practices were applied with tremendous success to the point that major death-causing waterborne disease outbreaks in the United States were almost entirely eliminated by the 1930s.

As a result, for engineers trained in the 1960s, 1970s, and 1980s, both education and industry belief was that all concerns of microbiological contamination in surface waters could be eliminated by providing filtration (with suitable pretreatment) to produce water of sufficient clarity, followed by chlorination. Groundwater was thought to be already filtered, requiring only chlorination to maintain a distribution system residual. Any additional treatment was generally considered necessary only to address non-health-related parameters, such as excessive hardness or water discoloration caused by iron and manganese.

The principal challenge to water treatment engineers in the 1960s and 1970s was engineering cost-effectiveness: how to accomplish these simple treatment goals at the lowest total cost to the water utility. Thus, in these decades many new techniques and processes were developed to clarify surface water economically.

In the 1970s and 1980s a new drinking water concern arose: the potential long-term health risks posed by trace amounts of organic compounds present in drinking water, including disinfection by-products (DBPs). A wave of regulations ensued, with new maximum contaminant levels (MCLs) established for total trihalomethanes (TTHMs), synthetic organic chemicals (SOCs), and volatile organic chemicals (VOCs). This trend continues today. In response to this concern and resulting treatment needs, water treatment engineers successfully devised new methods of water treatment to remove organic compounds. These methods included processes such as air stripping, activated carbon adsorption, and enhanced coagulation.

In the 1990s the old concern about microbiological contamination reemerged as a primary focus of water treatment engineers. The main driving forces behind this development were:

- The promulgation of the Surface Water Treatment Rule and Total Coliform Rule by the U.S. Environmental Protection Agency (USEPA) and the monitoring and enforcement actions that have occurred since 1989, when they went into effect.
- Documented outbreaks of waterborne disease, mainly giardiasis and

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cryptosporidiosis, caused by contamination of drinking water supplies by cysts and oocysts rather than bacteria or viruses.

New approaches and processes were applied to address these concerns. These approaches included renewed emphasis on source water protection, optimizing plant performance, and recycle stream management, plus consideration of new technologies, especially membrane treatment, ozonation, and ultraviolet (UV) irradiation.

The new millennium brought a series of new challenges. The terrorist attacks in September 2001 resulted in far greater emphasis on security of water infrastructure and risk management, such as reducing the transport of hazardous chemicals. Research into the health effects of several inorganic contaminants such as arsenic and lead resulted in reduced MCLs. The concerns with lead are often related to piping and fixture corrosion, so there is increased emphasis on water stability in the distribution system and premises plumbing. Related to this was the introduction of regulations that move the point of quality monitoring from the plant effluent to the customer's tap. New, emerging pathogens are being discovered and their potential occurrence and treatability in water supplies are being evaluated.

There is concern over the possible health effects of numerous microconstituents, including new classes of constituents emanating from modern human life, such as pharmaceutical compounds, personal care products (PCPs), and endocrine disrupting chemicals (EDCs). In the last few years, substantial media attention has brought these categories of pollutants into the center spotlight. While these chemicals may have been in the environment for a while, detection technology has improved, and trace amounts are now being routinely detected in water supplies. Yet the science of their impact on humans and the environment has not kept up, and little is known about their actual effects. Planned and unplanned recycling of municipal wastewater into raw water sources is also gaining increased attention as a potential source of these compounds.

The impacts of these recent developments on the design requirements for water treatment facilities are yet to be determined.

In the last decade, new water treatment technologies have continued to be developed and older technologies improved. Notable advancements include:

- Continued development and maturing of membrane technologies. Microfiltration and ultrafiltration are frequently being used in lieu of granular media filtration for particle removal. Nanofiltration is being

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used increasingly for water softening and removal of organic carbon. Reverse osmosis has new emphasis for desalination applications and for removal of inorganic contaminants (e.g., arsenic).
- Increased use of biologically active granular media filters, often following ozonation, for removal of organics; and the development of biological processes for applications such as removal of iron from groundwater.
- Development of new and improved advanced oxidation processes that increase formation of the hydroxyl radical, resulting in the ability to break down many contaminants of concern.
- Refinement of UV disinfection system performance such that the applied dose can usually be reduced from that required several years ago to achieve a given process objective.

TODAY'S CHALLENGES

Engineers who design water treatment systems today face many challenges. Not only are there new challenges, but the past challenges are cumulative and must all still be addressed. Some challenges are conflicting, such as the need for more effective disinfection and the need to reduce disinfection by-products. However, the greatest challenges today are not treatment process driven but can have a huge effect on treatment process selection and water supply development. The most important of these are described as follows.

Limited Water Resources

Increased competition for water resources has resulted in a drive to maximize the use of the available water resources. This has produced a number of new challenges:

1. There is an increased focus on selecting the most water-efficient processes.
2. The water in the produced residuals is increasingly being recovered and either recycled or reused.
3. Lower quality source waters increasingly have to be employed.
4. The available water inventory has to be managed carefully, sometimes using techniques such as aquifer storage and recovery, which may also present new treatment challenges.

Sustainable Water Supply and Treatment Facilities

There is growing emphasis on designing and delivering water supply and treatment facilities that are far more sustainable. Today's engineers are often called upon to optimally use or reuse existing infrastructure and materials; to limit or reduce a facility's physical and environmental

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footprints; to conserve and recover energy; to minimize chemical use and solids production; to evaluate and perhaps incorporate alternative sources of energy, especially those able to produce a net reduction in greenhouse gas emissions; to develop plans to economically manage residuals in an environmentally sound manner; and to consider various environmental benchmarking and accounting procedures such as carbon footprinting. All this, while meeting the process and budgetary objectives.

Climate Change Unknowns

Climate change concerns are closely interrelated with the challenges of limited water resources and the need to deliver sustainable plants. However, because much remains unknown, the impacts of climate change are difficult to design for. For example: Will the source water area experience more or less precipitation? Will flood zones be altered? Will the region see an increase in average temperatures or more extremes? To what degree should the design engineer make provisions for these potential changes, recognizing that such provisions may result in increased project cost or undesirable social impacts?

Other Environmental Changes

Human activity, climate change, and sometimes the need to use water sources with competing uses have increased the number of environmental conditions that must be addressed. For example: Introduction of non-native species, such as zebra mussels or quagga mussels, to a watershed may result in additional process elements being needed. Thermal or chemical pollution may result in different species being present or in treatment process impacts.

There is increased sensitivity to the ultimate impact of wastes from water treatment plants on the environment. While traditionally the major concerns have been with residual suspended solids, the dissolved constituents in waste streams are now receiving considerable attention. For example: The impact of discharges from desalination and ion-exchange softening processes on receiving bodies of water or on municipal wastewater slated for beneficial reuse may be a major factor affecting plant design.

Public Interest and Participation

In past decades, water treatment projects and the resulting drinking water quality were generally out of the public limelight. However, media attention to water issues and the explosion of global communication capability have resulted in far more interest by the public in their drinking water. As a result, the design engineer needs to be able to effectively

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communicate the aspects of the project of interest to the public. There may also be new requirements as a result of public perception or values that do not align with the purely technical requirements. A good example is the increased public pressure to remove certain microconstituents where presently no scientific evidence exists that shows these materials pose a threat to public health at the levels found in the source water.

Increasingly, the public is demanding that utilities pay more attention to the aesthetic quality of the water delivered. At many locations, treatment process trains are being modified or expanded to reduce tastes and odors, iron and manganese, color and hardness.

Asset Management

It has become increasingly important to recognize that the design and delivery of a plant is but part of the total life cycle of the asset, and this is closely connected with the challenge of designing sustainable facilities. For new facilities, asset management may mostly involve optimizing the life-cycle cost, much as was done in the past but with the addition of facility management resources such as component databases. However, most projects involve changes to existing infrastructure. Deciding what to change and when and how to implement changes to an existing plant to achieve the best value of the asset over its life is far more challenging when the objective is to find the optimum combination of life-cycle cost, performance, constructability, and risk management.

Regulatory Uncertainties

The majority of the USEPA drinking water regulations promulgated during the 1990s are now in place. In the coming years, a major emphasis for water treatment engineers in the United States will be plant modifications to help utilities comply with the USEPA's Stage 2 Disinfectants and Disinfection By-Products Rule and the Long-Term 2 Enhanced Surface Water Treatment Rule. In many cases, the challenge will be to develop and implement more efficient methods for removing disinfection by-product precursors from the raw water. This will mean optimization of the traditional processes of coagulation, ozonation, and granular activated carbon (GAC) adsorption, as well as consideration of new processes such as magnetic ion exchange. In other cases, the primary challenge will be to increase disinfection, to reduce the risk of protozoan infections, without significantly increasing DBP formation.

The science of drinking water continues to advance, and development of knowledge regarding the risks to public health due to emerging contaminants and pathogens is being closely monitored. After

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considering more than 7,500 potential new contaminants for regulation, the USEPA has recently developed a short list (the final third drinking water Contaminant Candidate List, or CCL3) of 116 for further consideration for possible rule making. Thus, today's treatment system engineer, in addition to addressing current drinking water standards, must anticipate potential future requirements. A water system designed today must be designed with sufficient flexibility to be modified to meet these potential requirements.

Regulatory uncertainties extend to other environmental concerns important to water treatment plant design, including waste management practices, chemical storage and feed operations, energy conservation, workplace safety, and security.

New Technologies

The state of the art of water treatment plant design is continually changing as new technologies emerge, offering new unit processes for water treatment or making currently used processes more efficient or economical. In addition, advances in information technology and building materials are rapidly changing and improving the support systems associated with water treatment plants. Many new treatment processes are proprietary, and the detailed design of these processes is performed by the manufacturer. This leads to challenges in obtaining competitive pricing for the process and also in incorporating the process into the overall plant. When a process from a single manufacturer is employed in a new facility, a design/ build project delivery may be preferable. However, when several proprietary processes are involved or the work involves a complex retrofit, then other approaches may be preferable.

Advancement continues in materials of construction applicable to all aspects of water treatment plant design. Many of these materials move away from the traditional ferrous metals, copper, and alloys. They offer advantages in terms of corrosion resistance, weight, and cost. However, they can be more fragile and less durable, with uncertain service lives and possibly unforeseen health or environmental impacts. Water treatment engineers must stay informed of developments and industry experience and make balanced decisions in this important area.

Multidiscipline Teams

A water treatment plant engineering design team traditionally consisted simply of a small group of civil engineers. This single-discipline team performed the majority of design work for virtually all plant components. Support disciplines of architects and structural, electrical, and mechanical

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engineers were used to execute the basic decisions made by the design team.

Today, the complexity of project and regulatory requirements dictates that a far more multidisciplined approach be used. Typically, a small group of civil engineers remain as the project engineers, but this group uses the expertise and resources of many different specialists to execute the design. In addition to traditional design support disciplines, these may include.

- Process engineers
- Plant operations specialists
- Instrumentation and control engineers
- Health and safety specialists
- Environmental scientists
- Specialists in environmental permitting and public participation

Major design decisions today are no longer made unilaterally by the project team. Instead, a consensus is reached after participation by members of the design team and by individuals outside the team, including owners, operators, regulatory agencies, and the general public.

Project Delivery

The traditional procedure for construction of a new water treatment plant was for the engineering design and specifications to be prepared by an engineering firm or the owner's in-house staff. Bids were then taken, and the contract was awarded to the lowest responsible bidder. The design team usually monitored construction to see that the design intent was carried out, and after construction was completed, the facilities were operated by the owner.

Today, a number of changes and variations to this traditional approach are being implemented. Common alternatives include design/build, design/build/operate, engineer/procure/ construction-management, and full privatization. All of these have various advantages and disadvantages that should be carefully evaluated for each situation where alternative forms of delivery are being contemplated.

In addition, a global marketplace for water treatment engineering has developed. Ideas, practices, products, and services are being exchanged among countries all over the world. In North America, there is increasing consideration of European and Australian treatment practices, technologies, and firms, and similar changes are occurring on other continents.

Two new trends are affecting design of all types of capital projects,

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including water treatment plants. The first is the rapid advancement of building information modeling (BIM). BIM offers the designer, constructor, and operator great features, including: 1) the ability to create 3D visualizations as the design is developed; 2) the ability to share aspects of the model among the designer, equipment suppliers, contractors, and operators; and 3) the ability to integrate the asset and maintenance management needs of the owner into the model. The second trend is the growing practice of following formal, documented procedures in the development of the design. These include documentation of design calculations and assumptions, full quality management plans, and more detailed and transparent construction cost estimating.

DEVELOPMENT OF WATER TREATMENT DESIGN PROJECTS

Thus, the challenge for today's design engineer is to collaborate with the owner, major stakeholders, and all members of the design team to conceive, design, and help implement a successful water treatment project. The trends and issues discussed in this chapter must be taken into account throughout the design process.

The design process extends from the time when the need for a project is identified to the time that the completed project is placed into service. For the traditional project delivery procedure, the period before construction commences can generally be divided into the following phases:

1. *Master planning*. Quantity and treatment needs, and feasible options for attaining those needs, are established in a report. In subsequent phases, this report may be periodically updated to adjust to both system and regulatory changes.
2. *Process train selection*. Unless reliable data are already available and the process is well-proven for the application, viable treatment options are subjected to bench, pilot, and full-scale treatment investigations. This testing program provides background data sufficient in detail to enable decisions on selecting the more advantageous options for potential implementation. These tests also provide design criteria for major plant process units.
3. *Preliminary design*. In this fine-tuning procedure, feasible alternatives for principal features of design, such as location, treatment process arrangement, type of equipment, and type and size of building enclosures are evaluated. In this phase, preliminary designs are prepared in sufficient detail to permit development of meaningful project cost estimates. These estimates help in evaluating and

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selecting options to be incorporated into the final design and allow the owner to undertake the required project financial planning.

4. *Final design*. Contract documents (drawings and specifications) are prepared that present the project design in sufficient detail to allow for gaining final regulatory approvals, obtaining competitive bids from construction contractors, and actual facility construction.

The process train selection phase is only briefly covered in this book. Theory and procedures needed for this phase are the focus of *Water Quality & Treatment* (AWWA, 2010b). It is important that the interface between design phase 1 and phase 2 and between phase 2 and phase 3 be carefully coordinated to allow uninterrupted continuity of design. In other words, viable options developed for consideration in phase 1, master planning, should provide a base for developing unit process test studies in phase 2. The process train selected in phase 2 provides the basis for phase 3, preliminary design, in which other factors influencing design are included in the evaluations before criteria for the final design are developed and finalized.

Many technical and nontechnical individuals must be involved, not only during the four phases of project development, but also between these phases to ensure that a project proceeds without undue delay. In addition to the engineer's design staff and the owner, participants may include public health and regulatory officials, environmental scientists, and the public—who may be affected by both the proposed construction and the future water supply services to be provided. Where other forms of project delivery are used, the owner's engineer may take the project through the first two or three phases and then issue performance specifications and other documentation for use by the private consortium or other entity. The reader is directed to AWWA Manual of Water Supply Practices M47, *Capital Project Delivery* (AWWA, 2010a), for additional details.

Careful coordination of the various phases and entities involved provides the owner and the engineer with the opportunity to develop the most advantageous treatment solutions and designs, and helps avoid pitfalls in the schedule and decisions that might add to the cost of the project.

REFERENCES

AWWA (American Water Works Association) (2010a). Manual of Water Supply Practices M47, *Capital Project Delivery*, 2nd ed. Denver: AWWA.

AWWA (2010b). *Water Quality & Treatment: A Handbook on Drinking*

Documents
Document Sharing Hub

Full document details: AWWA Water Treatment Plant Design. 2012

Water, 6th ed. J. K. Edzwald, editor. New York: McGraw-Hill.

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CHAPTER 2
SUSTAINABILITY

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INTRODUCTION

The engineering and scientific achievements in water treatment in the last 100 years have immensely improved the quality and safety of potable water. Engineers and scientists have become proficient and creative in functional water treatment designs; however, we must now do our part in helping society address other environmental challenges, including climate change, ecological impacts such as deforestation, and various forms of pollution. Conventional water treatment processes can consume significant amounts of energy and material resources, and they can generally be considered contributors to these environmental problems.

Sustainable design is based on a holistic approach that considers source water extraction and protection, water conservation, residual waste management, optimal resource utilization, and energy conservation. The intent of such design is to minimize environmental impact while continuing to provide sufficient, safe drinking water.

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This chapter offers the reader some sustainable engineering considerations when designing a water treatment plant. It provides an overview, can serve as the basis for technical discussions, and makes reference to other chapters of this handbook and other published works for more detailed information regarding related subjects.

SUSTAINABLE ENGINEERING

The World Commission on Environment and Development (Brundtland Commission) in its report, "Our Common Future: Report of the World Commission on Environment and Development" (Brundtland Commission, 1987) said of sustainable development, "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." In this report, the scientific community unanimously agreed that the aggressive industrialization of the first-world countries had caused havoc to the environment, and new approaches must be designed and implemented to better manage environmental resources and sustain human development.

Poor environmental resource management and heavy reliance on nonrenewable resources result in negative impacts such as ozone depletion; soil, water, and air pollution; deforestation; and climate change. The devastating effects on our natural world include loss of habitat, loss of plant and animal species, and deterioration of human health. On a social behavioral level, this leads to labor exploitation and conflicts over natural resources, including water.

Sustainable engineering observes the practice of minimal impact to the environment, avoids resource depletion and pollution, conserves energy, and potentially improves the current condition of the environment.

MAJOR ENVIRONMENTAL ISSUES

The practice of engineering for sustainability requires a good understanding of the environmental issues that we are currently facing. The following discusses the two main stressors that have negative environmental consequences on water supply.

Water Stress

The earth's surface consists of approximately 30 percent land mass and 70 percent water. Of the 70 percent water, only about 3 percent is freshwater, two-thirds of which is stored in glaciers and as groundwater; the remaining 1 percent is stored in surface water bodies such as lakes, streams, and rivers. While most of this water is naturally replenished,

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there is a finite amount of freshwater available for consumption at any specific time.

Several reports from the U.S. Census Bureau and the United Nations (United Nations Department of Economic and Social Affairs, 2011) concurred that the current world human population is 7 billion and is estimated to grow to 9 billion by 2040. This exponential population growth and aggressive demand for water in daily consumption, manufacturing, mining, and agriculture has put a tremendous stress on both hydrological and social systems.

Freshwater from groundwater and surface water is being consumed faster than the rate at which the earth can replenish itself. Water pollution from inadequately treated sewage and chemicals in the natural water sources has rendered some lakes and river systems unsafe for human/animal consumption or contact. Wetlands, which are the “lungs and kidneys” of the water sources, are slowly being stressed or destroyed due to development, diversion, and overconsumption.

It is estimated that more than 1 billion people do not have access to safe drinking water, and the vast majority of these people are living in developing countries. This is increasingly the subject of conflict, as the demand for freshwater increases with population growth.

Climatic Stress

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period” (IPCC, 2007). The United Nations Framework Convention on Climate Change (United Nations, 1992) defines climate change in Article 1 of the Convention as “a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.” Whether or not climate change is a result of anthropogenic (human) activity is not without controversy; however, the scientific community agrees on the reported evidence of increased global air and ocean temperature, widespread melting of snow and ice, and rising global average sea level regardless.

The increase in global temperature is believed by many scientists to be related to increased emissions of greenhouse gases and their subsequent accumulation in the atmosphere. An assessment by the IPCC, in the Climate Change Synthesis Report (IPCC, 2007), indicated

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that greenhouse gas (GHG) emissions due to human activities increased 70 percent between 1970 and 2004 with approximately 56 percent of the increase attributed to fossil fuel consumption, mainly in manufacturing, agriculture, mining, construction, and transportation. Absorption of solar energy can also be affected by the rapid changing of the earth's surface; urbanization, deforestation, air pollution, and intensive agriculture are altering earth's energy balance.

Climate change is believed to be causing changes in extreme weather patterns and in the extent of glaciation. Global extreme weather events such as floods or extended periods of drought can dramatically affect the ability of a water supply system to provide freshwater. Rising global temperatures are believed to be causing glaciers and ice to rapidly melt, thus diminishing this freshwater resource for communities that depend on them.

Long-term adverse effects of climatic stress can include loss of habitat, reduction in food sources and availability of freshwater, and extinction of plant and animal species. Both acute and chronic changes in climate can also have unforeseen impacts on existing water treatment infrastructure.

ANALYTICAL TOOLS

Several tools and guidelines are available to aid designers and engineers in achieving or striving toward sustainability. These tools are described in the following sections.

Carbon Footprints

Carbon footprint is a term used to describe the total amount of greenhouse gas emitted through the use of nonrenewable energy during the use or production of material, or while operating equipment, devices, or a system. A carbon footprint inventory provides a summary of how much greenhouse gas is emitted from a system and its components, which is useful in devising strategies to reduce the GHG emissions.

Carbon footprints are usually measured and reported in units of carbon dioxide equivalents in metric tons (e.g., tCO_2 e). As a measurable quantity, carbon footprints are often used in triple bottom line analysis, life-cycle cost analysis, and carbon trading. Emission trading that mainly targets carbon dioxide creates a market to provide economic incentive to reduce emissions.

Many carbon emission calculation tools are available online that can be used to estimate carbon emission; however, the results may vary in

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the level of accuracy, as some calculations may be oversimplified, and specific environmental conditions may not be considered. Environmental conditions may include the types and size of equipment, types and quality of fuel, and environmental temperature and pressure. The level of accuracy needed in the calculation will depend on the end use of data by the organization. Regardless of how the data are used, the calculation method should be consistent.

Carbon dioxide (CO_2) equivalent is calculated based on the types of fossil fuel combusted, its quantity, and the CO_2 emission coefficient (tCO_2/mass or volume) of the fuels. The emission coefficient of the types of fuel can be estimated based on the chemical composition of the fossil fuel, or the net calorific value (joules or GJ/mass or volume unit) [United Nation Framework Convention on Climate Change (UNFCCC), 2008]. In terms of electricity consumption, the emission coefficient will vary depending on the geographic location and the types of fuel used.

In general, the formula can be described as:

$$tCO_2 = \sum \text{fuel combusted (mass or volume unit)} \times \text{carbon emission coefficient } (tCO_2/\text{mass or volume unit})$$

Databases for carbon emission coefficients can be found in key reference sources such as the following:

1. Clean Energy, Calculations and References (USEPA, 2011)
2. National Inventory Report 1990–2008, Parts 1, 2, and 3. (Environment Canada, 2011)

Single to Triple Bottom Line

Life-cycle cost analysis is often conducted as part of the planning and evaluation of a capital improvement project (or any business endeavor) and is usually used when comparing the costs of alternatives. Life-cycle cost analysis typically includes a full accounting of capital costs (perhaps including the costs of future project phases or upgrades) as well as operation and maintenance (O&M) costs such as salaries and energy costs. Life-cycle cost analysis does not explicitly consider how people and the environment will be impacted, though such considerations may be informally taken into account by the decision makers. Since social and environmental metrics are not formally taken into consideration, there is a tendency for decision makers to focus primarily or solely on economics and to disregard social and ecological impacts that could steer the assessment in an alternate direction.

In recent decades, the detailed formal evaluation of all three metrics—economic, social, and environmental—has become a preferred tool in

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accounting, planning, and decision making. This type of evaluation is referred to as the triple bottom line (TBL) analysis. This phrase was first established by John Elkington, a founder of a British consultancy called "SustainAbility," in his 1998 book, *Cannibals with Forks: The Triple Bottom Line of 21st Century Business* (Elkington, 1998). He indicated that companies should prepare three types of analyses:

- A "bottom line" accounting of profit and loss
- A "people" accounting that measures how socially responsible an organization has been through its operations
- A "planet" accounting that measures how environmentally responsible the organization's operations are

This analysis can assist a water utility in measuring the performance of its water treatment facility and other operations, and in planning for future development.

TBL analysis provides a systematic assessment of the social, economic, and environmental costs and benefits. It is best applied in projects that require evaluation of multiple options involving one or multiple scenarios. In such cases, TBL analysis is commonly conducted using multi-criteria decision analysis tools; these tools can range from simple spreadsheets to commercially available computer programs, such as Criterium® DecisionPlus®.

The analysis is often a numerical exercise, and the process involves choosing one from a number of alternatives that are evaluated based on how well they numerically rate against a chosen set of criteria. The criteria are weighted in terms of importance to the decision maker. The overall score of an alternative is the weighted sum of its rating against each criterion. The alternatives are then ordered by their decision scores, which can be displayed graphically on a chart. The decision maker will then make decisions based on the outcome of the scoring, recognizing that the result of the evaluation only provides a basis of comparison to help facilitate a selection of the preferred or satisfactory option.

As indicated, the criteria are established based on discussion and agreement among the decision makers. This allows numerous stakeholders to participate in the analysis and to collectively assist in the decision-making process. In a numerical TBL evaluation, the stakeholders can assign a consensus weighting factor based on the importance to each criterion. The assessment of three criteria—social, economic, and environmental—can be expanded to include other categories such as legal, political, technological, and functional.

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Chapter 22 provides an explanation of multi-attribute analysis techniques for site evaluation and selection. This analysis uses a numerical calculation approach similar to TBL analysis. In a sustainable design discussion, a simple TBL analysis can be illustrated as follows:

1. Develop the alternatives of the project to ensure that they represent the best current and future options to achieve the goals of the project. A simple example could be to determine what renewable energy source can be used in a water treatment plant's heating and ventilation system in a cold climate region. In this step, alternative suggestions could be utility electricity, solar, and geothermal energy.
2. Identify potential TBL criteria and the metrics associated with the criteria. Depending on the size of the project and stakeholders involved, several workshops can be held using a facilitated discussion to refine and finalize the criteria and metrics. In continuing with the same example, the criteria for utility electricity, solar, or geothermal systems under the three main categories (environmental, social, and economic) could be as categorized in Table 2.1.

   Subcriteria can be developed under these criteria for further detailed analysis.
3. Apply metrics to each criterion. Metrics that are numerically measurable are ideal, as this information simplifies the development of comparative scores between the alternatives being analyzed. The overall analysis can be perceived as being more defendable when subjective metrics are avoided. Some criteria lend themselves well to quantification such as capital costs ($), operational costs ($), carbon footprint (t CO_2e), and areal footprint (m^2). For our power supply example, the metrics under the preceding criteria would be calculated for each alternative. Each criterion can have more than one quantifiable metric.
4. Work with stakeholders in a facilitated discussion to develop initial relative weightings-of-importance for the various TBL criteria for each alterative. These weightings need to reflect stakeholder values. A voting system may be implemented to achieve consensus on the weightings before moving forward.

   The total weightings can have a sum of 10, 50, or 100, for instance. In the preceding example, the weightings for environmental, social, and economic factors rated by the decision makers could be 30, 30, and 40 with an overall score of 100. The decision maker may then apply weightings to each metric, as shown in Table 2.2.

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