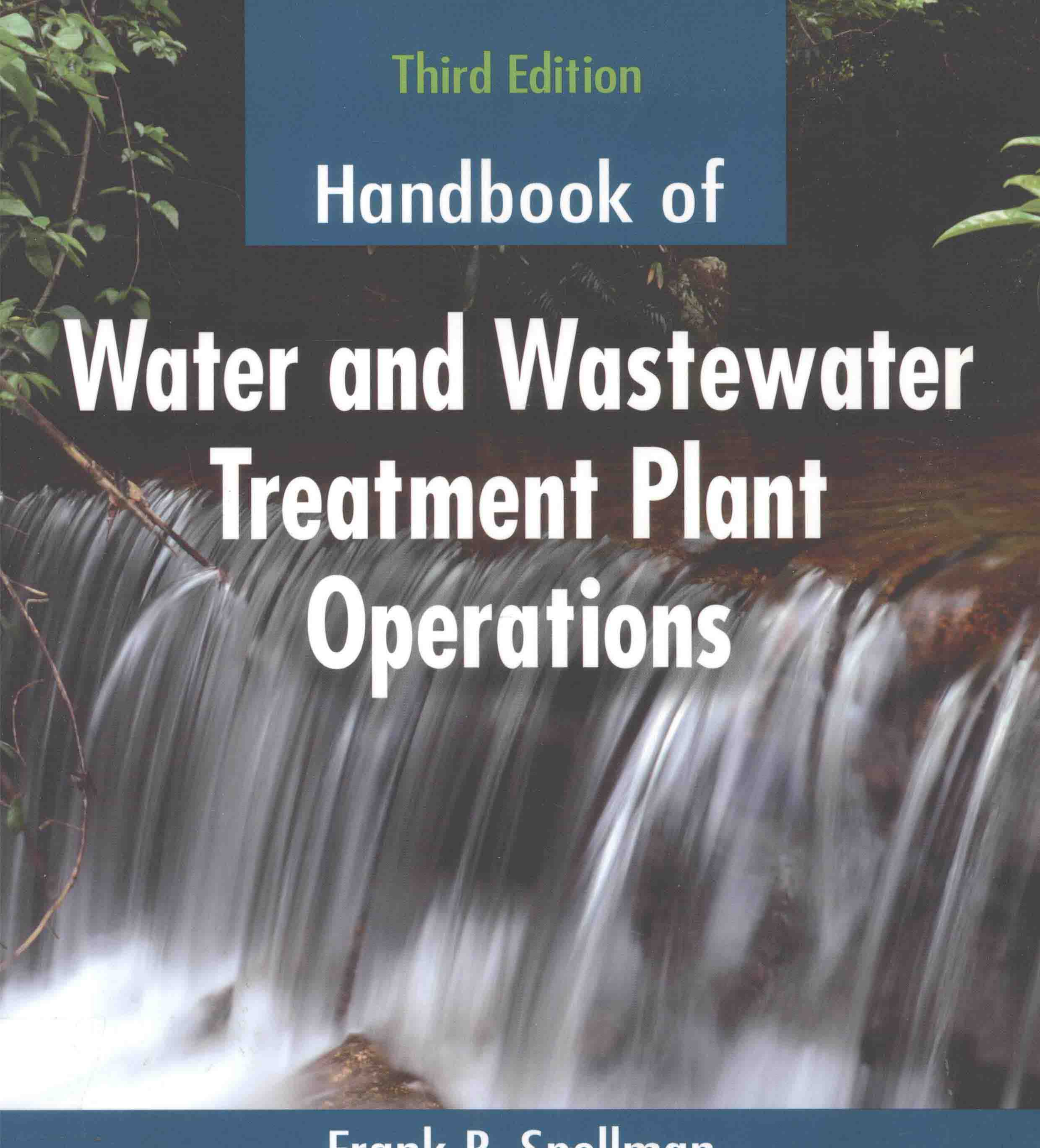

Third Edition

Handbook of Water and Wastewater Treatment Plant Operations

Frank R. Spellman

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Taylor & Francis Group

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Foreword

> It is very difficult to make an accurate prediction, especially about the future.
>
> **Niels Bohr**

A rational person would have difficulty arguing against Bohr's view concerning the difficulty of making accurate predictions about the future. It must be said, however, that rational people are also capable of recognizing that in a few instances there are exceptions to every rule. More specifically, as the result of certain actions that occur, knowledgeable and observant individuals can make fairly accurate predictions about the potential future consequences of such actions. As a case in point, consider the actions of humans that pollute the air we breathe, the water we drink, and the land we live on and gain our sustenance from. It is probably safe to predict that when contamination and destruction of our life-sustaining environment occur on a daily basis, certain fairly accurate predictions can be made about the future consequences. Awareness and observance of these actions have resulted in a sense of foreboding concerning the dire consequences of the impact of humans on their environment that motivated a group of concerned and enlightened individuals to organize the first Earth Day celebration in 1970.

The organizers of the first Earth Day celebration were concerned about these destructive actions of humans. To a degree, the organizers' concern was driven by obvious predictors of a quality of life anticipated for the future that was not that promising. Some of these organizers and other concerned individuals made dire predictions based on what they had observed, on what they had read, or on what they had heard. For example, they might have observed or learned about certain rivers within the United States that were so oil soaked that they actually burned. Moreover, others had observed or heard or read about skies above great metropolitan areas that were red with soot. Others had breathed air that they could actually see. And still others had observed lakes choked with algae, lakes that were dying. Then there were those unusual mountains that they had heard about. These were mountains unlike the Alps or Rocky Mountains, however. Instead, these mountains were made of trash, garbage, refuse, discarded materials, and other waste products. As with all things that disgust humans, these mountains of waste and filth became unbearable to live with and were torn down. The entire unsightly, stinking mess was deposited into rivers, lakes, streams, oceans, or landfills. Sometimes these mountains of unwanted wastes were torn down and piled up again on barges that were towed from port to port to port with no place to land; no one wanted these floating mountains of waste, a case of "not in my backyard" (NIMBY). All these observations, of course, were indicators of what was occurring environmentally in the here and now; moreover, they were actions portending what was in store for the inhabitants of Earth and for future generations to come. Thus, these present indicators of environmental problems became reliable predictors of greater environmental problems ahead in the future.

Along with the organizers and participants of that first Earth Day celebration in 1970 there were other citizens who were concerned about their futures and the futures of their loved ones. And although Niels Bohr was correct in his statement about the difficulty in making accurate predictions, especially those about the future, in 1970 it was clear to many concerned individuals that if corrective actions were not taken quickly to protect and preserve the Earth's environment then there would be no need to worry about making future predictions; that is, there would be no future to predict.

To say that we face huge environmental challenges today, as was the case in 1970, is to make an accurate statement. Since that first Earth Day celebration in 1970, progress has been made in restoring the Earth's environment, but there is still a long way to go before predictors or indicators of the future consequences of the ongoing damage to Earth's environment become more promising. It should come as no surprise to anyone that it can be said with a great deal of accuracy that the quality of life here on Earth is directly connected to our actions.

It should be pointed out that not all of the news concerning manmade waste and its disposal is of the doom and gloom variety. For example, it is noteworthy to take into account the steps that have been taken in recent years to clean up our air and our lakes and to properly dispose of waste using Earth-friendly disposal techniques. One such clean-up step, cleaning up the water we drink and dispose of, is described in this text.

Preface to Third Edition

The growing interest in water and wastewater treatment plant operations and their main products (potable water and cleaned used water), ongoing advancements in treatment techniques and innovations such as energy conservation measures, and the unprecedented reception of the first and second editions of this book have called for a new edition. After publication of the previous editions, many reviewers sent me their comments. I am grateful for their constructive criticism and valuable suggestions and have incorporated them in this new edition. For example, this edition includes the addition of

- Updates on current issues facing the water and wastewater treatment industries
- 200 additional math operations with solutions
- A new chapter on package units
- Expanded discussion of oxidation ditches
- Expanded discussion of biological nutrient removal processes
- Discussion of water quality reports
- New chapter on energy conservation measures with applicable case studies
- Discussion of membrane bioreactors
- Discussion of variable frequency controls
- Discussion of PID control systems
- Expanded discussion of ultraviolet disinfection

In addition to assisting utility administrators, managers, and directors; water and wastewater plant managers; plant operators; and maintenance operators manage or operate their treatment works in a successful and compliant manner, this new edition (as was the purpose of the other editions) is designed to aid and assist all personnel preparing for all levels of operator licensure.

Preface to First and Second Editions

> Water is the new oil.
>
> Water is a carrier of things it picks up as it passes through—it carries the good and the bad.

When I wrote the first edition to this text and it was published, I had no idea it would be so well received and become an instant bestseller. Hailed on its first publication as a real-world practical handbook for general readers, students, and water/wastewater practitioners, the *Handbook of Water and Wastewater Treatment Plant Operations* continues to make the same basic point in its second edition: Water and wastewater operators must be Jacks or Jills of many trades; that is, they must have basic skill sets best described as being all encompassing in nature. In light of the need for practitioners in the field who are well rounded in the sciences, cyber operations, math, mechanics, and technical aspects of water treatment, the second edition picks up where the original left off.

Based on constructive criticism of the first edition, the second edition has been upgraded and expanded from beginning to end. Many reviewers appreciated the candid portrayal of regulatory, privatization, management, and other ongoing current issues within the water/wastewater industry. With regard to privatization, this books recognizes that critics of privatization insist that water/wastewater operations are too important to be left to the mercies of private enterprise. It is my premise, however, that water/wastewater operations are too important *not* to be subject to market forces. In my opinion, the debate should not be about taking the supply, treatment, reuse, and distribution of water/wastewater away from perhaps dysfunctional public service agencies and implementing pricing, property rights, and private, competent enterprise instead, but over how best to do so. Based on actual personal experience in water/wastewater public sector operations, one thing seems certain to me: I have found that engineers, biologist, chemists, environmental scientists, hydrologists, and other public-service technical officials generally know little, and usually care even less, about markets and ratepayers. In a nutshell, even though the original edition took a hard-line, no-nonsense look at problems engendered by current management and various dysfunctional management styles unique to the industry, the second edition takes an even more penetrating look at these problems. This is especially the case with regard to management problems within the public sector entities involved in water and wastewater operations. Simply, it is the author's view, based on personal experience, that when it comes to water and wastewater public service managers, relevance and common sense are rare commodities.

In addition to a no-holds-barred look at current management issues, the second edition includes the latest security information pertinent to protecting public assets from the indiscriminate and destructive hand of terrorism. As a result of the events of September 11, 2001, things have changed for all freedom-loving people everywhere. How many of us thought security was a big deal prior to 9/11? Some of us did, but some of us didn't give it any thought at all. Today, we must adjust or fall behind. In the current climate, falling behind on keeping our potable water supplies secure is not an option. We must aggressively protect our precious water sources and those ancillaries that are critical to maintaining and protecting water quality. Because water and wastewater operations are listed by the Department of Homeland Security as one of this nation's 13 critical infrastructures, water and wastewater practitioners must realize and understand that the threat of terrorism is real. Accordingly, extensive coverage of security needs is provided in this edition.

In addition to more in-depth coverage of management aspects and security, the second edition includes a new chapter covering the basics of blueprint reading. This is a critical area of expertise that is important for maintenance operators and others. Also, the chapter on water and wastewater mathematics has been tripled in size and now contains an additional 200 example problems and 350 math system operational problems with solutions. These examples and operational math problems are typical of those seen on water and wastewater licensure examinations used throughout the United States. Every chapter has been upgraded to include emerging technologies pertinent to the content presented. Practical hands-on information necessary for proper plant operation is provided that will also help readers obtain passing scores on licensure examinations.

The text of this handbook follows a pattern that is nontraditional; that is, the paradigm (i.e., model or prototype) used here is based on real-world experience and proven parameters—not on theoretical gobbledygook. Clearly written and user friendly, this timely revision of the handbook builds on the remarkable success of the first edition. Still intended to serve as an information source, this text is not limited in its potential for other uses. This work can be utilized by water/wastewater practitioners to gain valuable insight into the substance they work so hard to collect, treat, supply, reuse, or discharge for its intended purpose, but it can just as easily provide important information for policymakers who may be tasked with making decisions concerning water or wastewater resource utilization. Consequently, this book serves a varied audience: students, lay personnel, regulators, technical experts, attorneys, business leaders, and concerned citizens.

This text is not about the planning, designing, or construction of water and wastewater treatment facilities. Although these tasks are of paramount importance during the conception and construction of facilities and infrastructures, many excellent texts are already available that address these topics. This text is not about engineering at all. Instead, this handbook is about operations and is designed for the plant manager and plant operator. We often forget the old axiom: "Someone must build it, but once built, someone must operate it." It is the operation of *it* that concerns us here.

With regard to plant managers and operators, most texts ignore, avoid, or pay cursory attention to such important areas as the multiple-barrier concept, maintaining infrastructure, benchmarking, plant security, operator roles, water hydraulics, microbiology, water ecology, math operations, basic electrical principles, pumping, conveyance, flow measurement, basic water chemistry, water quality issues, biomonitoring, sampling and testing, water sources, and watershed protection. All of these important topics are thoroughly discussed in the second edition of the *Handbook of Water and Wastewater Treatment Plant Operations*.

To maximize the usefulness of the material contained in the text, it has been presented in plain English in a simplified and concise format. Many tables have been developed, using a variety of sources. Moreover, to ensure its relevance to modern practice and design, illustrative problems are presented in terms of commonly used operational parameters.

Each chapter ends with chapter review questions to help evaluate the reader's mastery of the concepts presented. Before going on to the next chapter, work through the questions, compare your answers to the key provided in Appendix A, and review the pertinent information for any problems you missed. If you miss many items, review the whole chapter.

This text is accessible to those who have no experience with water or wastewater operations. If you work through the text systematically, an understanding of and skill in water/wastewater operations can be acquired—adding a critical component to your professional knowledge.

To the Reader

While reading this text, you are going to spend some time following water on its travels.

Even after being held in bondage, sometimes for eons, eventually water moves.

Do you have any idea where this water has been?

Where this water is going?

What changes has it undergone, during all the long ages that the water has lain on and under the face of the Earth?

Sometimes we can look at this water … analyze this water … test this water to find out where it has been.

Water, because it is the universal solvent, has a tendency to pick up materials through which it flows.

When this happens, we must sometimes treat the water before we consume it.

Whether this is the case or not, water continues its endless cycle.

And for us this is the best of news.

So, again, do you have any idea where water has been?

More importantly, where is the water going?

If we could first know where we are and wither we are tending, we could better judge what we do and how to do it."

Abraham Lincoln

Author

Frank R. Spellman, Ph.D., is a retired U.S. Naval Officer with 26 years of active duty, a retired environmental safety and health manager for a large wastewater sanitation district in Virginia, and a retired assistant professor of environmental health at Old Dominion University, Norfolk, Virginia. The author/co-author of 79 books, Dr. Spellman consults on environmental matters with the U.S. Department of Justice and various law firms and environmental entities throughout the globe. He holds a BA in public administration, a BS in business management, and an MBA and MS/PhD in environmental engineering. Recently he traced and documented the ancient water distribution system at Machu Pichu, Peru, and surveyed several drinking water resources in Coco and Amazonia, Ecuador. Dr. Spellman also studied and surveyed two separate potable water supplies in the Galapagos Islands.

Water: The New Oil?

Even though over 70% of the Earth is covered with water, only 3% is fit for human consumption, of which two thirds is comprised of frozen and largely uninhabited ice caps and glaciers, leaving 1% available for consumption. The remaining 97% is saltwater, which cannot be used for agriculture or drinking. If all of the Earth's water fit in a quart jug, available fresh water would not equal a teaspoon; thus, some (including the author) would consider water the new oil. Let's take a moment to make a few important points about water, the new oil.

Unless you are thirsty, in real need of refreshment, when you look at a glass of water you might wonder what could be more boring. The curious might want to know what physical and chemical properties of water make the water in the glass so unique and necessary for living things. Again, when you look at a glass of water, when you taste it and smell it, well, what could be more boring? Pure water is virtually colorless and has no taste or smell, but the hidden qualities of water make it a most interesting subject.

When the uninitiated becomes initiated to the wonders of water, one of the first surprises is learning that the total quantity of water on Earth is much the same now as it was more than 3 or 4 billion years ago, when the 320+ million cubic miles of it were first formed—there is no more freshwater on Earth today than there was millions of years ago. The water reservoir has gone round and round, building up, breaking down, cooling, and then warming. Water is very durable but remains difficult to explain, because it has never been isolated in a completely undefiled state.

Have you ever wondered about the nutritive value of water? Well, the fact is that water has no nutritive value. It has none; yet, it is the major ingredient of all living things. Consider yourself, for example. Think about what you need to survive—just to survive. Food? Air? PS3? MTV? Water? Naturally, the focus of this text is on water. Water is of major importance to all living things; in some organisms, up to 90% of their body weight comes from water. In humans, up to 60% of their body weight is water, the brain is composed of 70% water, the lungs are nearly 90% water, and about 83% of our blood is water. Water also helps us digest our food, transport waste, and control body temperature. Each day, humans must replace 2.4 liters of water, some through drinking and the remainder by the foods we eat.

There wouldn't be any you, me, or Lucy the dog without the existence of an ample liquid water supply on Earth. The unique qualities and properties of water are what make it so important and basic to life. The cells in our bodies are full of water. The excellent ability of water to dissolve so many substances allows our cells to use valuable nutrients, minerals, and chemicals in biological processes. Water's "stickiness" (from surface tension) plays a part in the body's ability to transport these materials throughout our bodies. The carbohydrates and proteins that out bodies use as food are metabolized and transported by water in the bloodstream. No less important is the ability of water to transport waste material out of our bodies.

Water facts:

- Water is used to fight forest fires; yet, we spray water on coal in a furnace to make it burn better.
- Chemically, water is basically hydrogen oxide. Upon more advanced analysis, however, it can be a mixture of more than 30 possible compounds. In addition, all of its physical constants are abnormal (strange).
- At a temperature of 2900°C, some substances that contain water cannot be forced to part with it; yet, others that do not contain water will liberate it when even slightly heated.
- When liquid, water is virtually incompressible; as it freezes, it expands by an 11th of its volume.

For all of these reasons, and for many others, we can truly say that water is special, strange, and different.

Characteristics of Water

To this point many things have been said about water; however, it has not been said (nor will it be) that water is plain. Nowhere in nature is plain water to be found. Here on Earth, with a geologic origin dating back over 3 to 5 billion years, water found in even its purest form is composed of many constituents. You probably know that the chemical description of water is H_2O—that is, one atom of oxygen bound to two atoms of hydrogen. The hydrogen atoms are attached to one side of the oxygen atom, resulting in a water molecule having a positive charge on the side where the hydrogen atoms are and a negative charge on the other side, where the oxygen atom is. Because opposite electrical charges attract, water molecules tend to attract each other, making water kind of "sticky," as the hydrogen atoms (positive charge) attract the oxygen side (negative charge) of other water molecules.

Note: All of these water molecules attracting each other mean they tend to clump together. This is why water drops are, in fact, drops! If not for some of Earth's forces, such as gravity, a drop of water would be ball shaped—a perfect sphere. Even if it does not form a perfect sphere on Earth, we should be happy that water is sticky.

Along with H_2O molecules, hydrogen (H^+), hydroxyl (OH^-), sodium, potassium, and magnesium, other ions and elements are present. Additionally, water contains dissolved compounds, including various carbonates, sulfates, silicates, and chlorides. Rainwater, often assumed to be the equivalent of distilled water, is not immune to contamination that is collected as it descends through the atmosphere. The movement of water across the face of land contributes to its contamination when the water takes up dissolved gases, such as carbon dioxide and oxygen, and a multitude of organic substances and minerals leached from the soil. Do not let that crystal-clear lake or pond fool you. These bodies of water are not filled with water alone but are composed of a complex medium of chemical ingredients far exceeding the brief list presented here; it is a special medium in which highly specialized life can occur.

How important is water to life? To answer this question all we need do is to take a look at the common biological cell, as it easily demonstrates the importance of water to life. Living cells are comprised of a number of chemicals and organelles within a liquid substance (the cytoplasm), and survival of the cell may be threatened by changes in the proportion of water in the cytoplasm. This change in proportion of water in the cytoplasm can occur through desiccation (evaporation), oversupply, or the loss of either nutrients or water to the external environment. A cell that is unable to control and maintain homeostasis (i.e., the correct equilibrium/proportion of water) in its cytoplasm may be doomed; it may not survive.

Note: As mentioned, water is called the *universal solvent* because it dissolves more substances than any other liquid. This means that wherever water goes, either through the ground or through our bodies, it takes along valuable chemicals, minerals, and nutrients.

Water Use

In the United States, rainfall averages approximately 4250 $\times 10^9$ gallons a day. About two thirds of this rainfall returns to the atmosphere through evaporation directly from the surface of rivers, streams, and lakes and transpiration from plant foliage. This leaves approximately 1250×10^9 gallons a day to flow across or through the Earth to the sea.

The U.S. Geological Survey (USGS, 2004) points out that estimates in the United States indicate that about 408 billion gallons per day (1000 million gallons per day, abbreviated Bgal/d) were withdrawn from all uses during the year 2000. This total has varied less than 3% since 1985 as withdrawals have stabilized for the two largest uses—thermoelectric power and irrigation. Fresh groundwater withdrawals (83.3 Bgal/d) during 2000 were 14% more than during 1985. Fresh surface-water withdrawals for 2000 were 262 Bgal/d, varying less than 2% since 1985.

About 195 Bgal/d, or 8% of all freshwater and saline-water withdrawals for 2000, were used for thermoelectric power. Most of this water was derived from surface water and used for once-through cooling at power plants. About 52% of fresh surface-water withdrawals and about 96% of saline-water withdrawals were for thermoelectric-power use. Withdrawals for thermoelectric power have been relatively stable since 1985.

Irrigation totaled 137 Bgal/d and represented the largest use of freshwater in the United States in 2000. Since 1950, irrigation has accounted for about 65% of total water withdrawals, excluding those for thermoelectric power. Historically, more surface water than groundwater has been used for irrigation; however, the percentage of total irrigation withdrawals from groundwater has continued to increase, from 23% in 1950 to 42% in 2000. Total irrigation withdrawals were 2% more for 2000 than for 1995, because of a 16% increase in groundwater withdrawals and a small decrease in surface-water withdrawals. Irrigated acreage more than doubled between 1950 and 1980, then remained constant before increasing nearly 7% between 1995 and 2000. The number of acres irrigated with sprinkler and microirrigation systems has continued to increase, and they now account for more than one half of the total irrigated acreage.

Public-supply withdrawals were more than 43 Bgal/d for 2000 compared to public-supply withdrawals in 1950 of 14 Bgal/d. During 2000, about 85% of the population in the United States obtained drinking water from public suppliers, compared to 62% during 1950. Surface water provided 63% of the total during 2000, whereas surface water provided 74% during 1950.

Self-supplied industrial withdrawals totaled nearly 20 Bgal/d in 2000, or 12% less than in 1995; compared to 1985, industrial self-supported withdrawals declined by 24%. Estimates of industrial water use in the United State were largest during the years from 1965 to 1980, but usage estimates for 2000 were at the lowest level since reporting began in 1950. Combined withdrawals for self-supplied domestic, livestock, aquaculture, and mining were less than 13 Bgal/d for 2000, and represented about 3% of total withdrawals. California, Texas, and Florida accounted for one fourth of all water withdrawals for 2000. States with the largest surface-water withdrawals were California, Texas, and Nebraska, all of which had large withdrawals for irrigation.

All of this factual information is interesting. Well, it is interesting to those of us who are admirers, purveyors, or students of water. Obviously, these are the folks who read and use a book like this one. However, the question is what does all of this information have to do with water being the new oil?

Water is the new oil because there is no more freshwater on Earth today than there was millions of years ago. Yet, at the present time, more than 6 billion people share it. Since the 1950s, the world population has doubled, but water use has tripled. A simple extrapolation of today's water usage compared to projected usage in the future shows that water will become a much more important commodity than it is today. Earlier it was suggested that the day is coming when a gallon of water will be comparable in value to (or even more expensive than) a gallon of gasoline. There are those who will read this and shake their heads in doubt and think: "Water is everywhere. Water belongs to no one; water belongs to everyone; no one owns the water. Water pours freely from the sky. Water has no real value. Certainly water is nowhere near as valuable as gasoline, nowhere near as valuable as gold or diamonds."

Water has no real value? Really?

With regard to water and diamonds and which of the two is more valuable, consider the following. In his epic book, *The Wealth of Nations*, Adam Smith, the 18th-century philosopher credited with laying the foundation of modern economics, described the paradox of diamonds and water. Smith asked how could it be that water, so vital to life, was so cheap, while diamonds, used only for adornment, were very costly? Smith pointed out that, when it came to value, a container full of diamonds was exponentially more valuable than an equal amount of water. In today's value system, this is still true. It is true unless you are dying of thirst. While on the verge of dying of thirst, what value would you place on that same container of diamonds? On the container of water? If you were offered one or the other, which would you choose? Which would you give up everything you own for? That is my point. Although Adam Smith used the paradox for his own pedagogical purposes, explaining the basic concepts of supply and demand and showing that prices reflect relative scarcity, today the paradox provides a troubling description of the way water is treated in our economy. Water may be critical to life itself, but we do not have a clue as to its true value. We have not reached that point yet. However, with the majority of the world's population being relatively thirsty and many dying of thirst or dying from drinking filthy, pathogen-contaminated water, the dawn of new understanding is just around the corner. Moreover, as our population continues to grow and degradation of the world's supply worsens and global climate changes accelerate, it is my view that the diamond and water paradox will flip-flop. Diamonds will lose some value when compared to safe, potable drinking water. This will occur because when it comes to sustaining life and quenching our thirst, all of the diamond-encrusted drinking glasses filled to the brim with diamond-clear water will be just what the doctor ordered, thank you very much!

Years ago, when I first stated that water will be more valuable than an equal amount of gasoline, many folks (reviewers) asked me what part of the planet Mars was I from? Well, I have not been to Mars and have not changed my opinion on the ever-increasing value of water—and this same realization will soon confront us all. By the way, with regard to that water we flush down our toilets and drains, the day is coming, in my opinion, when we will have direct pipe-to-pipe connection from wastewater treatment plants to our municipal potable water supply systems. Why? Because water is the new oil. Furthermore, have you heard about the recent discovery of the presence of water on ancient Mars? My guess is that if we do not protect our water supplies, the Mars of today may be the Earth of tomorrow. This is a thought to keep close at hand, close at heart, very close to the brain cells as a reminder of what really matters.

If you do not accept the premise that water is the new oil, maybe you are willing to accept the possibility that we can use water to make oil. I am not talking about converting hydrogen from water into fuel; instead, consider that we can turn algae into fuel. Scientists at Old Dominion University (ODU), Norfolk, Virginia, for example, are conducting successful research on growing algae in treated sewage and extracting fatty oils from the weedy slime, then converting the oils into cleaner-burning fuel. As part of the research project, the algae is grown in tanks at a wastewater treatment plant in Norfolk and then converted to biofuel at an ODU facility. It should be pointed out that this wastewater-grown-algae-to-oil-to-fuel-process has already proven itself in New Zealand (Harper, 2007).

The bottom line: The day is drawing near when water becomes new oil. This day is closer than we may be willing to readily acknowledge.

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Contents

SECTION II Water/Wastewater Operations: Math, Physics, and Technical Aspects