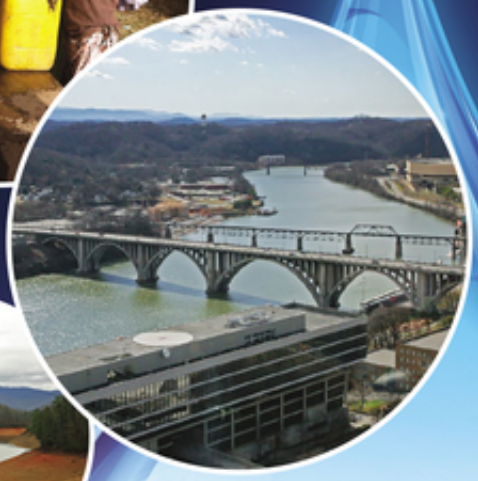
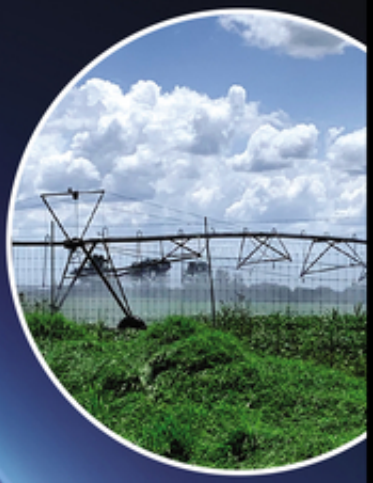
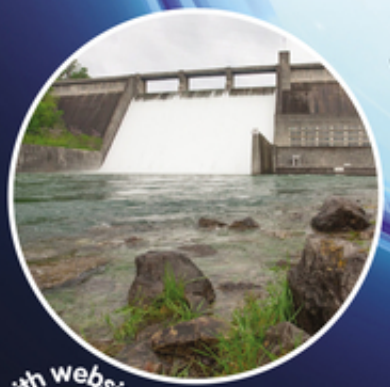




FUNDAMENTALS OF WATER SECURITY

QUANTITY, QUALITY, AND EQUITY IN A CHANGING CLIMATE

JIM F. CHAMBERLAIN
DAVID A. SABATINI



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Fundamentals of Water Security

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Quantity, Quality, and Equity in a Changing Climate

Jim F. Chamberlain
University of Oklahoma, United States of America

David A. Sabatini
University of Oklahoma, United States of America

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The authors dedicate this work to:

My students who inspire me with their passion for the world's most disadvantaged peoples, and my brother-in-law, Frank Zemanek, who paddled with me many peaceful and beautiful waters.

(Jim)

My wife - Frances Sabatini - and my children and their families - Caleb, Kirbie and Conrad Sabatini, and Peggy and Hunter McDonald - for their love, encouragement, and endearing support.

(Dave)

Contents

Preface

The world is rapidly changing. Burgeoning populations along with ever-increasing standards of living, especially for those in emerging countries, increase the *demand* and stress on our water resources. What is not increasing, however, is the *supply*, the total amount of water in earth's biosphere, water that is integral to all standards of living. This water is needed not only for human consumption and growing the food we eat but also for generating electricity, for sustaining health and healing illnesses, for maintaining ecosystem services, and for making various other products and services that comprise life's modern amenities. No less importantly, water has been, and continues to be, used for transportation, recreation, cultural well-being, and religious ceremony. Water, thus, is valuable from physical, cultural, and spiritual vantage points. While the total amount of water remains the same, the amount that is available and useful at any given time and place, for human and ecological flourishing, is transitory between its various stocks and flows.

Water security is the modern term that describes a state of having sufficient quantity and quality of water necessary to equitably meet both immediate and long-term human and ecological needs. As such, water security spans multiple environmental science and engineering disciplines, including groundwater and surface-water hydrology, geography, geology, water resources, soil science, ecology, atmospheric science, chemistry, biology, and health science, and also the disciplines of social and political science.

This volume is an introductory volume directed toward both the academic student and the practitioner. As a textbook, this volume could be used for the education of upper-level undergraduate or entry-level graduate students who already have some background in chemistry, biology, and mathematics. For the practitioner, this volume serves as an introduction to the diverse field of water security, perhaps serving as a supplement to critical hands-on training and experience.

In the **Introduction (Part I)** section, we begin by defining water security as existing at the water quantity–quality–equity nexus along with a brief overview of historical water challenges and insecurity and the manner in which affected communities adapted. The second section of the book – **The Context of Water Security (Part II)** – offers basic principles of water security under the threefold headings of water quantity, quality, and equity. Here, the student is given a basic understanding of hydrology, watershed management, aquatic chemistry and biology, and the social dynamics of water access and distribution. The final chapter in this section is devoted to climate change, which impacts all three of these principles. The third section – **Competing Uses of Water and Threats to Security (Part III)** – delves deeper into the diverse uses of water – for food, energy, industry, and ecosystems – and security threats that exist within, and at the nexus of, these uses.

The fourth section, entitled **Sustainable Responses and Solutions (Part IV)**, presents modern attempts to correct and/or mitigate the challenges of global water stress in pursuit of water security. The final section – **Resilience, Economics, and Ethics (Part V)** – invites the reader to consider various approaches to water planning as well as the fundamentals of water resource economics, critically important to water security. Finally, we propose an ethic of water for the modern pilgrim.

Case studies and examples are given throughout the text in order to both illustrate the principles and to create a sense of solidarity with sisters and brothers throughout the world. Regions in both developed and developing countries are now, or will soon be, experiencing water stress, and so we include issues and examples from a range of global contexts. We also highlight seven persons who have been working in various aspects of water security in sections called **The Practice of Water Security** following several chapters. These women and men are winners of the University of Oklahoma International Water Prize, awarded biennially from 2009 to 2022. Finally, most chapters culminate in a "Foundations" section, which provides a more quantitative probe into the science of water security. Depending on the background and orientation of the reader or student, this section may be considered optional.

The study of water security can be both sobering and optimistic. Because water is most often experienced as a local resource, there are "haves" and "have-nots" in the world of water security. But there are also signs of a brighter future – from a greater application of old and new technologies, a growing appreciation for the benefits and vulnerability of our water resources. and a desire for water cooperation and innovation among diverse entities.

Acknowledgments

This book began with material developed for two University of Oklahoma courses – an on-campus course "Introduction to Water" (taught by Chamberlain) and a new "Water Security" course (taught by Sabatini) developed as part of our online Master's program in *Hydrology and Water Security*. We would like to acknowledge those students who provided helpful input into both courses based on their particular knowledge and experience. We especially thank Christian Newkirk, Heath Orcutt and Shannon Mathers for their assistance in the tedious work of producing figures as well as gaining permission for the use of existing figures. Their contributions are felt – and seen – throughout this book. We would also like to acknowledge the School of Civil Engineering and Environmental Science (CEES), the Gallogly College of Engineering, and the University of Oklahoma administration for their support of our efforts, which are an outgrowth of the OU WaTER Center, the Hydrology and Water Security program, and the larger water enterprise on campus. Without their support, and invaluable interactions with our esteemed colleagues, this volume would not have been possible.

We want to thank the many academic colleagues from across the US that provided valuable input into the content of the above courses and the outline of this book. Their input was invaluable. We also want to thank water experts that provided detailed reviews of specific chapters – Drs Emma Colven, Randy Kolar, R. David Lamie, Mark Shafer, Aondover Tarhule, Evan Tromble, and Paul Weckler – and a very special thanks to Dr. Michael Campana, affectionately known as Aquadoc (Doctor Water), for reviewing the book draft in its entirety.

Finally, we give thanks to our generous and passionate colleagues, the Directors of the OU WaTER Center – Drs Yang Hong, Robert Knox, Robert Nairn, Jason Vogel and, especially, Randy Kolar, who continue to lead us and inspire us to do great work on behalf of the common good.

About the Companion Website

This book is accompanied by a companion website.

www.wiley.com/go/chamberlain/fundamentalsofwatersecurity

This website includes solutions to selected end-of-chapter problems.

Part I

Introduction

1

Introduction to Water Security

In this chapter, readers are introduced to the concept and importance of global water security. Many of the United Nations Sustainable Development Goals address or depend upon water security. Several water-security definitions are presented with a brief discussion on the focus and limitations of each. We then offer a network of considerations that form the context for water security – water quantity, quality, and social equity. In the context of these three components, water security is found at the nexus where water is of suitable quality for the user's purpose(s), is of sufficient quantity for the user's purpose(s), and is equitably available to users, regardless of age, gender, social, or economic status. And all of this happens in the modern setting of a changing climate. The chapter then discusses various ways in which water security is measured, using metrics that are quantifiable and useful for comparison. The analysis of water security can be at watershed, household (local), regional, or global level for bases of comparison.

Learning Objectives

Upon completion of this chapter, the student will be able to:

1. Understand the concept of global water security with its various facets and components.
2. Articulate a working definition of water security.
3. Discuss the ways in which many of the United Nations Sustainable Development Goals, either directly or indirectly, overlap with water security.
4. Quantify water security using several commonly used metrics.
5. Understand the various scales of water security – from local to global.
6. *Utilize the various units of measurements of water quantity and quality.

1.1 Introduction

What do we think of when we hear the term **"water security"**? We might immediately think of water that is needed to survive, to live. This is the water that we drink to sustain our bodily functions. Water is necessary for all biochemical processes, as reflected by the fact that our bodies are composed of 60% water (Ford 2016). But water is also needed to grow food, from

Fundamentals of Water Security: Quantity, Quality, and Equity in a Changing Climate, First Edition.
Jim F. Chamberlain and David A. Sabatini.

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cabbage to cow and everything in between. We might next think of the other ways that we use water in the home – for cooking, cleaning, bathing, and watering plants and landscape. Water security then would involve the availability of enough water to accomplish these very personal tasks upon which we all depend.

But as our horizons expand a bit, we might also realize that populations historically tended to settle near bodies of water, along rivers, lakes, seas, springs (fed by groundwater), and coastlines. This early development reflects the fact that water is necessary for sustaining agriculture, for transporting goods, for power generation, and for supplying the industrial sector that undergirds a nation's economy. Thus, water security is not only a local phenomenon but also a regional and global one. Whole populations can be affected by drought, by flooding, and by widespread contamination that threatens the quality of a large water body. Whole segments of a population may also lack access to water of sufficient quality and quantity. This lack of access may be because they cannot afford to purchase water or because they are unfairly prevented from accessing a water source. These examples foretell the inverse of water security, that is, the *in*security that comes with an imbalance of water quantity, a degradation of water quality, or water inequity that results in an inability to access the water necessary to sustain life.

These initial thoughts lead us to realize that *water security* is a consequence of scale, focus, and function. The *scale* of water security may be local (household), regional (watershed, aquifer), national, transboundary (within or between countries or other jurisdictions), or global. The *focus* of water security may be on the quantity, quality, or equitable access (equity) to water. The *function* of water security may be on basic human health and wellbeing, economic progress, ecosystems' functioning, or any combination of the above. These aspects are captured in the four editorial foci for the journal *Water Security* (Lall et al. 2017):

- Shortage (water quantity)
- Flooding (water quantity)
- Governance (water equity)
- Health and sanitation (water quality)

Likewise, a threat to water security (i.e. the threat of water *in*security) will also be faced, analyzed, and mitigated according to water quantity, quality, and equity, which are all intertwined. The lack of quality, quantity, or equity represents an uneven risk to people, the economy, and/or the environment. And so, a drought that threatens the Ethiopian teff harvest may affect rural people to a greater extent than city dwellers who have a more diversified diet. The construction of a Tennessee dam that generates hydroelectric power for local benefit may upset aquatic ecosystems downstream in neighboring states. The Bangladeshi reliance on groundwater wells to avoid cholera-impacted surface water may expose unsuspecting villagers to water tainted with arsenic. In addition, nearly all of these threats will be impacted by a climate that is warming gradually and consistently.

In this introductory chapter, we describe both the measures and usefulness of water security as a basis for study and analysis. Subsequent chapters will zoom in on various foci within the areas of water quantity, quality, equity, and climate change while looking at water security at a number of scales.

1.2 Sustainable Development Goals (SDGs)

Adopted in 2015, the United Nations **Sustainable Development Goals** (SDGs) set forth 17 targets (endpoints) designed to achieve a better and more sustainable future for all peoples (United Nations 2015) (Figure 1.1). One of these goals specifically addresses "Clean Water and Sanitation" (SDG 6). The goal of SDG 6 is to "Ensure availability and sustainable management of water and sanitation for all." This goal will be achieved by, among other things, reducing water pollution, increasing water-use efficiency, protecting ecosystems and watersheds, and strengthening proper water management (Table 1.1).

Other SDGs are also intertwined with water security (United Nations 2015). Table 1.1 illustrates the connections between water and several of the SDGs. Water is needed to grow food and put an end to hunger (SDG 2). Clean water is needed for the elimination of waterborne diseases (SDG 3). Children must be regularly healthy in order to attain a quality education (SDG 4). The need for women and girls to fetch water at long distances is a threat to their safety and ability to attend school along with the boys. Such is a deterrent to gender equity (SDG 5). Water-related disasters result in economic losses that are much harder on the poor and vulnerable in urban settings (SDG 11). Water safety entails the proper management of chemicals that might be released into the hydrosphere (SDG 12), and the cooperation of international bodies is required to protect terrestrial and inland freshwater ecosystems and their services (SDG 15). In order to meet these goals, stakeholders will need to use the basic tools of water security, including knowledge of hydrology, integrated

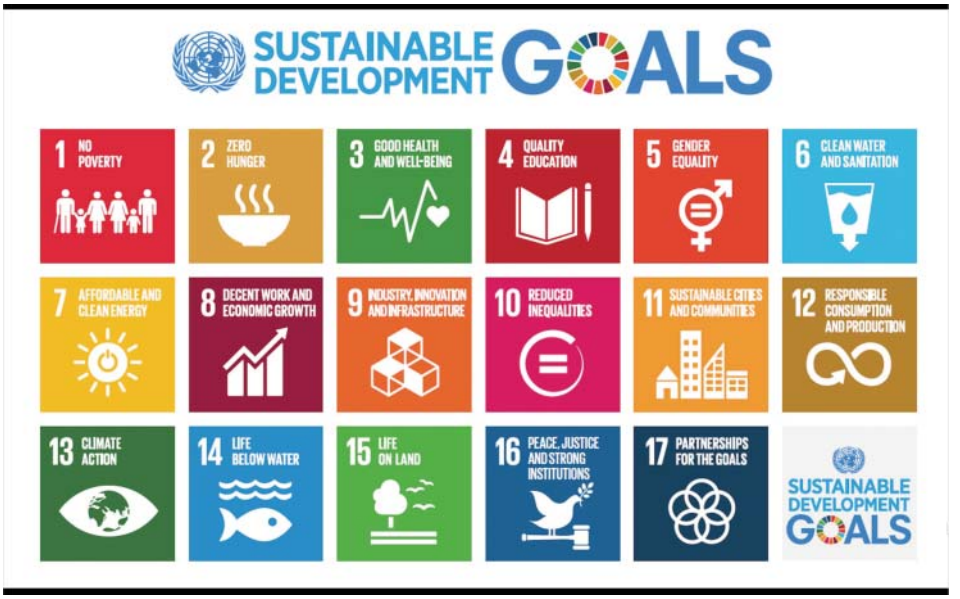

Figure 1.1 Seventeen Sustainable Development Goals (SDGs) agreed upon by member states of the United Nations, ushered in on 1 January 2016 (Martin 2015). Source: With permission from United Nations.

Table 1.1 Sustainable development goals (SDGs) and targets that are directly and indirectly relevant to water security.

SDGs DIRECTLY RELEVANT TO WATER SECURITY	
SDG 6: "Ensure availability and sustainable management of water and sanitation for all" **6.1** Achieve universal and equitable access to safe and affordable drinking water for all. **6.2** Achieve access to adequate and equitable sanitation and hygiene for all. **6.3** Improve water quality by reducing pollution. **6.4** Increase water-use efficiency across all sectors and reduce the number of people suffering from water scarcity. **6.5** Implement integrated water resources management at all levels. **6.6** Protect and restore water-related ecosystems. **6.A** Expand international cooperation and capacity-building support to developing countries. **6.B** Strengthen the participation of local communities for improving water and sanitation management.	
SDGs INDIRECTLY RELEVANT TO WATER SECURITY	
SDG 2: "End hunger, achieve food security and improved nutrition and promote sustainable agriculture." 2.1 End hunger and ensure access by all people, in particular the poor and people in vulnerable situations … to safe, nutritious and sufficient food all year round. 2.2 End all forms of malnutrition … and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons. 2.3 Double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers.	SDG 3: "Ensure healthy lives and promote well-being for all at all ages" 3.3 End the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases. 3.9 Substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination.
SDG 4: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all." 4.5 Eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations.	SDG 5: "Achieve gender equality and empower all women and girls." 5.2 Eliminate all forms of violence against all women and girls in the public and private spheres.
SDG 11: "Make cities and human settlements inclusive, safe, resilient and sustainable." 11.5 Significantly reduce the number of deaths and the number of people affected … decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.	SDG 12: "Ensure sustainable consumption and production patterns." 12.4 Achieve environmentally sound management of chemicals and all wastes throughout their life cycle … and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment.

Table 1.1 (Continued)

SDGs INDIRECTLY RELEVANT TO WATER SECURITY	
SDG 15: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." 15.1 Ensure conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements; 15.8 significantly reduce the impact of invasive alien species on land and water ecosystems, and control or eradicate the priority species.	

Source: United Nations (2015).

water management, and the food–energy–water nexus, to achieve the future envisioned by the SDGs.

1.3 Definitions of Water Security

The above discussion refers to water security without yet providing a definition of water security. The Global Water Partnership (GWP) has offered a very straightforward goal of water security, in which "every person has access to enough safe water at an affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced" (Lankford et al. 2013). Water quantity ("enough") and quality ("safe") are explicit in this definition while equity is implicit, using affordability as a surrogate.

Another practical definition is similar: "Water security is a condition in which there is a sufficient quantity of water, at a fair price, and at a quality necessary to meet short and long term human needs to protect their health, safety, welfare, and productive capacity at the local, regional, state, and national levels." (Kaplowitz and Witter 2002; Lankford et al. 2013). This definition reminds us that there are various levels to be considered, from local to national, and even international.

The United Nations gives an even more comprehensive definition of water security – "The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water related disasters, and for preserving ecosystems in a climate of peace (equity) and political stability." (United Nations 2013). This definition is robust because it encompasses water quantity, quality, and equity while also acknowledging the threats that water brings in the form of pollution and disasters, such as flooding. It also presents several of water security's outcomes, including human well-being, socioeconomic development, ecosystem preservation, and peace and political stability.

Figure 1.2 is a word cloud made from nine definitions of "water security" found in the literature. This word cloud highlights several key themes – quality, access, availability, acceptability, and ecosystem. Based on the above, and for the purposes of this text, we generate an operative definition of water security that is a slight modification to one given by Grey and Sadoff (Grey and Sadoff 2007).

Figure 1.2 Word cloud made from nine definitions of water security. Source: Author original (using Appelgren 1997; GWP 2000; Kaplowitz and Witter 2002; WHO 2003; Xia et al. 2006; Grey and Sadoff 2007; Calow et al. 2010; ADB 2011; Norman et al. 2011).

Water security is the equitable availability
of a suitable quantity and quality of water for health and well-being,
with an acceptable level of water-related risks
to people, environment, and economies.

This definition encompasses scale, focus, and function while also acknowledging the reality that water itself brings risk to communities and the environment in which we live. The quality needed will depend upon the use of the water, and equity includes both access and affordability, which varies across nations and peoples.

1.4 Water Security at the Nexus of Quantity, Quality, and Equity

As is now becoming evident, water security develops at the nexus of the appropriate balance of water quantity, quality, and equity (Figure 1.3). This balance includes the minimization of unacceptable risks due to an overabundance (flooding) or lack (drought) of water, natural or manmade water pollution, and physical, societal, or political limitations to water access.

With regard to water, equity can be defined as the just and appropriate accessibility to sufficient water resources across gender, socioeconomic, spatial, and generational differences. For example, water resources are *not* equitable when:

- Women bear an inordinate burden of household water management, thereby limiting their education and development, when such a burden can be corrected