M50

# Water Resources Planning

Third Edition

American Water Works
Association

# Contents

# Preface

This publication is the third edition of the American Water Works Association (AWWA) Manual M50, *Water Resources Planning*, originally published in 2001, with a second edition released in 2007. The manual presents information on how to develop a plan for new water supplies to accommodate projected future water demands and provides an effective framework for water resources planning for the 21st century.

Water resources planning for potable water supplies is a very broad topic. Issues range from estimating future water demand to evaluating possible new sources of water, protecting water sources, and addressing expanding environmental regulations. One method for preparing a water resources plan is integrated resource planning (IRP). Developed in the 1990s, IRP is a way to bring together myriad issues, interests, and stakeholders through a planning process that can result in a reason-based, cost-effective, and environmentally sound plan the public can support.

This third edition significantly enhances the basis of water resources planning provided in prior editions. Additions and improvements include the following:

- Organization of the manual around the planning process
- Inclusion of stakeholder involvement at various steps throughout the process
- Inclusion of reclaimed water and other source water alternatives in the portfolio of solutions, recognizing the Total Water Solutions planning perspective
- References to AWWA standards and manuals of water supply practices for more details on specific topics
- Expanded emphasis on the evaluation of alternatives
- A new, award-winning case study that illustrates the concepts presented in the manual
- Inclusion of the AWWA policy statement on water resources planning

This manual was prepared by AWWA's Water Resources Planning and Management Committee and associated volunteer authors to help water resources planners meet the challenge of accommodating a growing demand for water, while complying with myriad regulations that govern the development and use of new water supplies.

No two water resources plans are alike, and planning is an ever-changing process. The issues discussed in this manual should allow the planner to develop and implement a comprehensive work plan that responds to technical and institutional questions that must be addressed before deciding how to develop new water supplies.

The AWWA Water Resources Planning and Management Committee welcomes your input and comments on the content and usefulness of this manual.

# Acknowledgments

The AWWA Technical and Educational Council, the Water Resource Sustainability Division, and the Water Resources Planning and Management Committee gratefully acknowledge the contributions made by those volunteers who drafted, edited, and provided the significant and critical commentary essential to updating AWWA Manual M50. The Technical Review Board members dedicated countless hours in the final stages of preparation of this edition to ensure the overall technical quality, consistency, and accuracy of the manual.

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# Chapter 1

# Introduction to Water Resources Planning

A number of years ago, archeologist Bryan Fagan addressed attendees at the American Water Works Association's (AWWA's) Sustainable Water Sources Conference. Dr. Fagan has traveled all over the world to study ancient ruins. He likened his career to "50 years of studying drainage ditches," and explained that through studying drainage ditches he could provide the audience with an understanding of the rise and fall of civilizations through history. His book *Elixir* outlines a number of these civilizations: Egypt, Babylonia, Southeast Asia, and even the American West (Fagan 2012). He found that a civilization could develop to the extent that infrastructure could be constructed to allow water to flow to where it was needed for agricultural purposes, whether that was Alexandria or Ur. If the water stopped flowing, there was trouble.

As a result, later civilizations expanded and developed as technology allowed water to flow farther to protect themselves from drought or other outages. Rome demonstrated that water could be moved with more than ditches, which would have been a severe limitation. The Romans constructed extensive tunnels and aqueducts to supply Rome with water from mountains to the east and north, some of which are still in operation. Some people have estimated that we know perhaps only about 20 percent of the Roman tunnel system in that we keep discovering more of it each year—the location of many of the tunnels in the system were lost in the Dark Ages after the fall of Rome.

Dr. Fagan demonstrated that it was access to water that allowed human civilizations to develop and evolve. It is why a number of engineering organizations like Water For People and Engineers Without Borders focus their efforts on providing access to clean water to people in Third World countries. It is critical for people to remain healthy enough to be productive in the modern world. Other infrastructure (roads, major buildings, etc.) also depends in part on people having access to adequate clean water supplies, allowing our communities and economies to thrive.

Water availability, however, can be a limiting factor. Although 70 percent of the earth's surface is covered by water (mostly in oceans), only about 3 percent of all water on earth is freshwater (USGS 2015). Because much of this freshwater is locked up in ice caps and glaciers, only about 1 percent of all freshwater is reasonably accessible for use.

Far less than 1 percent of the world's total supply of water is considered easily accessible for human use.

While supplies of freshwater are finite, its uses are not. Now estimated at more than 7 billion, the world's population is increasing by some 70 to 80 million people per year. By 2025, the number will exceed 8 billion. Hundreds of millions of people around the world already face critical water shortages. Some areas of the United States also face shortages, and other areas are at risk of future shortages. That is where water resource management and the concept of sustainability come into play. The concept of sustainability reflects water consumption at a rate that can be maintained in perpetuity, while maintaining water quality.

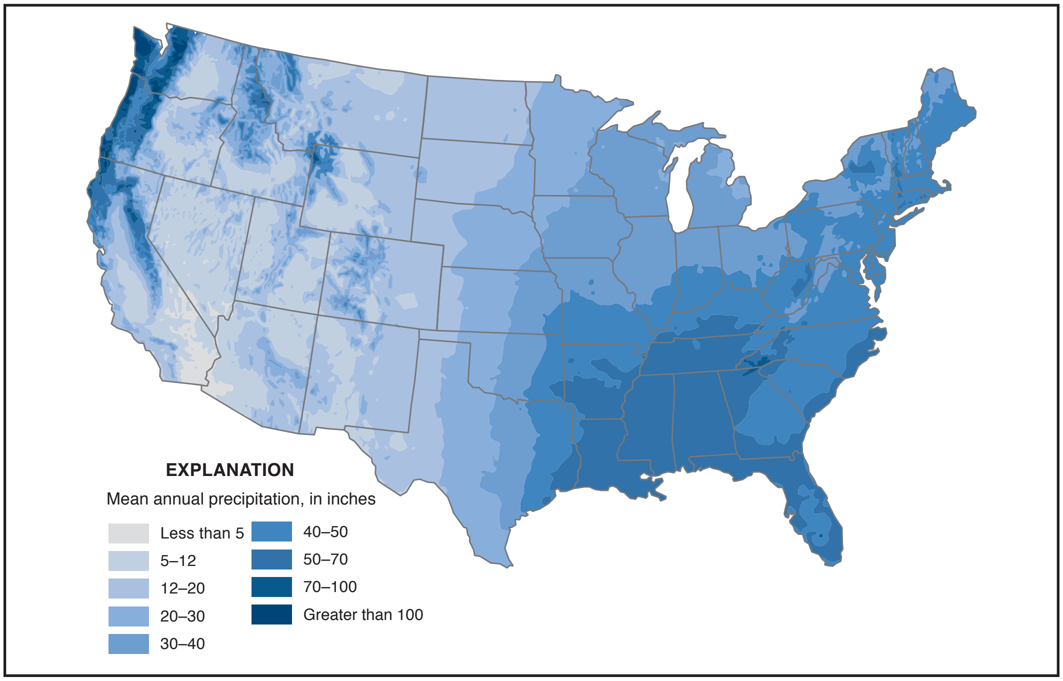
But the concept is not that simple, and buy-in to the concept of "sustainable water" depends on the profession or perspective of the person defining it (Bloetscher 2010). A sustainable world is not a rigid one where population or productivity is constant. Instead, the concept of sustainability must adapt to constant change. The concept of sustainability requires rules, laws, and social constraints that are recognized and adhered to by all (Meadows, Randers, and Meadows 2004). From a hydrologic perspective, the term "sustainable yield" is the amount of water that can be withdrawn from a source at rates that are less than their recharge potential and that do not deteriorate the source or basin. While many areas attempt to develop and use water sustainably, not all do. Even within regionally sustainable situations, unsustainable use can occur locally.

A key component of water resource management is planning the utilization of water supplies, which requires some means to determine how the hydrologic cycle provides water to the area (e.g., recharge basin), in what quantities, and with what reliability. Ultimately, reliability is a risk issue—precipitation can be consistent or can have significant fluctuations that disrupt ongoing basin development (Molak 1997). In any given basin, there are typically a variety of uses competing for water resources, and each basin has unique characteristics (Bloetscher and Muniz 2008). Major uses of water can include

- agriculture,
- ecosystems,
- recreation,
- urban and domestic use, and
- industrial and power generation use.

All these users depend on—and in many cases can compete for—reliable water supplies. From a practical perspective, sustainable development of a region depends on the appropriate management of water resources. Managing water resources requires decision-making that addresses the environmental, economic, and social concerns of the community, which may extend far beyond the community borders. The result is that researchers can define the concept of sustainability, but practitioners emphasize feasibility and limitation to sustainability of the ecosystem (Starkl and Brunner 2004).

Water quantity and quality issues have significant fiscal effect on the potential users in the basin, while there are unrealized costs and benefits that are often ignored in the current water management framework (Bloetscher and Muniz 2008). There are two categories of water supplies: surface systems and underground systems, which are described in the following sections.




Source: *Reilly et al. 2009*

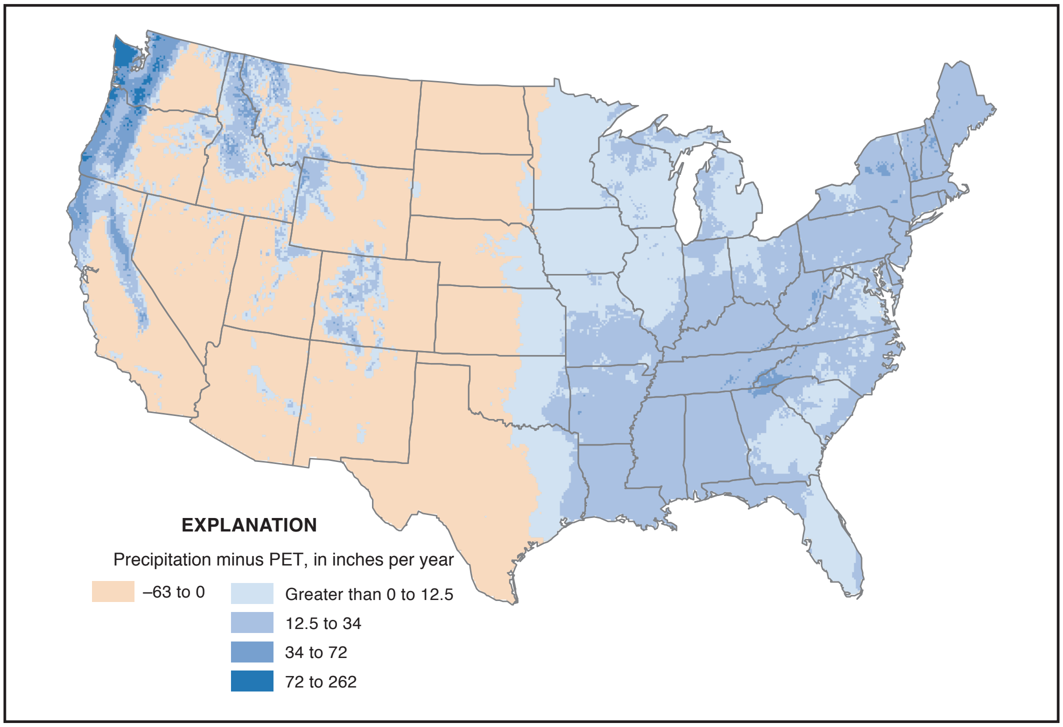
**Figure 1-1 Average annual precipitation (inches) in the United States (1961–1990)**

## SURFACE WATER

Surface water is precipitation that runs off the land, reaching streams, rivers, or lakes, or groundwater that discharges into these water bodies. Surface water bodies that mix with saltwater bodies along the coast are called estuaries (e.g., where a river meets the ocean in a delta). Surface water flow is controlled by topography because water on the surface flows downward by gravity, which means it generally flows toward the oceans. Figure 1-1 outlines precipitation throughout the continental United States. Annual rainfall is generally much higher in the eastern United States than in the west, except in the Pacific Northwest region.

Figure 1-2 shows the difference between precipitation and potential evapotranspiration (PET). The tan areas illustrate where the PET rate is higher than precipitation, meaning net water availability (precipitation minus PET) for crops and other purposes is negative. In these areas, high levels of crop irrigation may not be sustainable, depending on local conditions and sources of supply. In many of these areas, streamflows are variable and limited, so surface water storage and groundwater are often used to ensure adequate water supplies for crops and people.

Surface waters are recharged by precipitation and sometimes by groundwater. When there is limited rain, surface waters can diminish significantly and leave users at risk. The construction of reservoirs can reduce the potential for this risk, but prolonged droughts may have severe effects on supplies in surface storage (e.g., shortages experienced in and around Atlanta in 2008). Surface water quality can also be affected by adjacent or upstream land-use activities. As a result, source water protection measures are often employed to avoid detrimental surface water quality effects from point and nonpoint sources.




Source: *Reilly et al. 2009*

**Figure 1-2 Difference between average annual precipitation and PET rates**

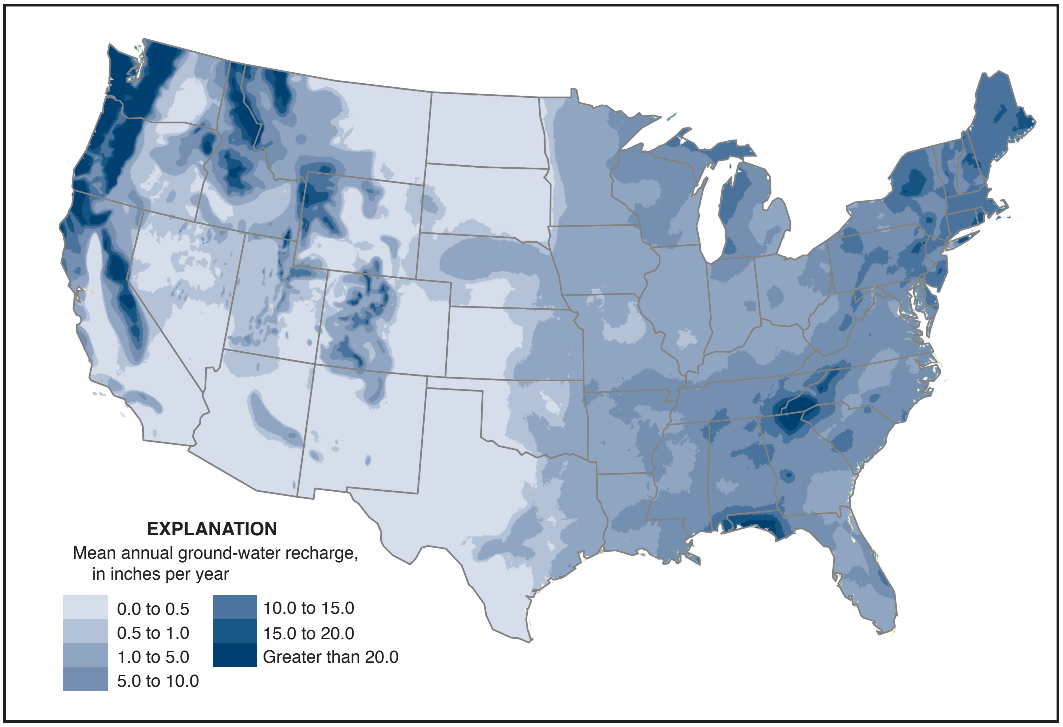
## GROUNDWATER

Groundwater is stored and flows beneath the land surface. Groundwater may be recharged by infiltration of rain and melting snow, surface waters (including streams, rivers, and lakes), and other groundwater flows. Formations that transmit groundwater are termed "aquifers." Deeper aquifers are generally recharged at slower rates relative to shallow aquifers, which are more likely to be in direct hydrologic "communication" with surface water supplies. As a result, withdrawals from deep aquifers may be more likely to be unsustainable (i.e., when withdrawals exceed recharge rates), depending on local hydrogeology, recharge rates, and patterns of use.

Ideally, planning and design of well fields should assume the wells could be pumped continuously at a rate that allows the wells to fully recharge locally. The more common practice is to pump wells that have a significant drawdown seasonally or for only a few hours each day, allowing time for the aquifer to recover. Even this is difficult, however, because the long-term capacity of an aquifer is usually determined by short-term tests and study of the geology of the area. Ultimately, using groundwater unsustainably reduces the water in aquifer storage, lowers the water table, and requires drilling and pumping from lower levels, which in turn increases capital and operating costs.

In many areas, deeper groundwater tends to have worse water quality (e.g., high total dissolved solids) as a result of having been in contact with the geologic formation longer and dissolving minerals into the water. Therefore, while some deep aquifers may be prolific, the quality of water obtained from a well may not be desirable or even usable for drinking water without substantial treatment. In addition, many deep aquifers are confined and local recharge is therefore limited. The result is the potential for aquifer drawdown that is accompanied by aquifer mining—and in extreme situations, land subsidence.

Figure 1-3 shows that the rate of groundwater recharge is very limited in much of the United States. Figure 1-4 illustrates where groundwater levels declined over the




Source: *Reilly et al. 2009*

**Figure 1-3 Mean annual groundwater recharge**

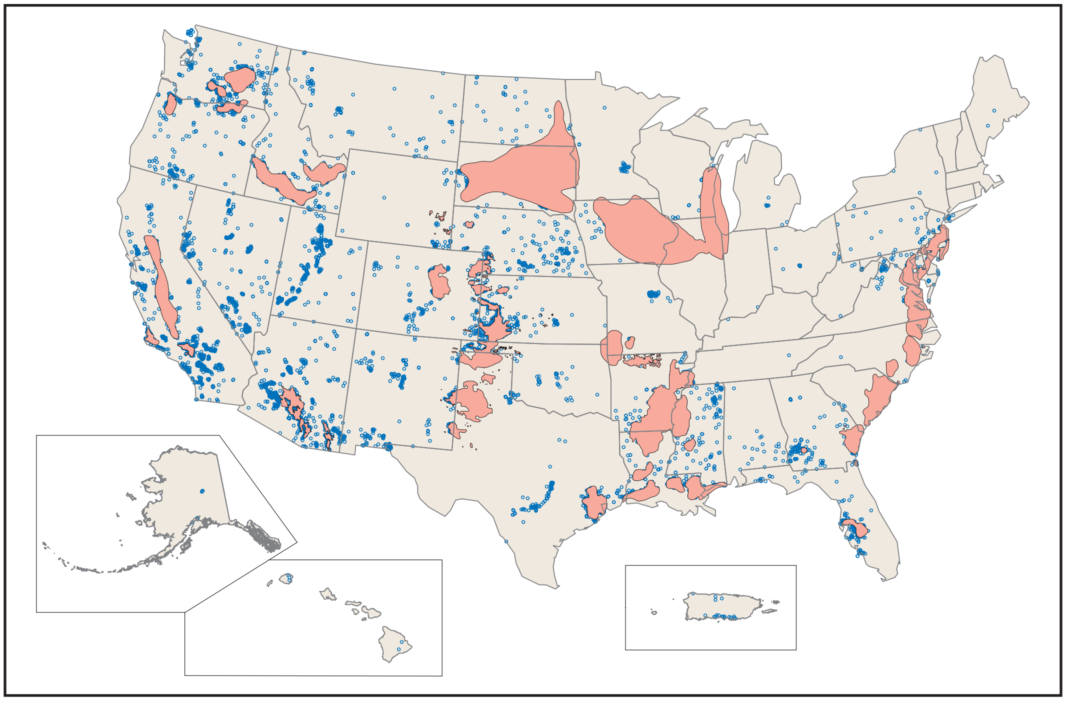
last 40 years throughout the United States. Eastern coastal areas, the Lower Mississippi Basin states, the Great Plains states, Texas, and the West are particularly affected. Red regions indicate areas in excess of 500 mi$^2$ (1,295 km$^2$) that have water-level decline in excess of 40 ft (12 m) in at least one confined aquifer since predevelopment, or in excess of 25 ft (7.6 m) of decline in unconfined aquifers since predevelopment. Blue dots are wells in the US Geological Survey National Water Information System database where the measured water-level difference over time is equal to or greater than 40 ft (12 m). The confined aquifers recharge at very low rates, meaning that in most cases, these aquifers are being mined (overdrafted).

## THE WATER RESOURCES PLANNING PROCESS

The issues discussed in this manual should allow the planner to develop and implement a comprehensive work plan that responds to technical and institutional questions that must be addressed before deciding how to develop new water supplies. However, planners are expected to use the parts of the manual that apply to their situations. Regulations and planning requirements discussed in this manual are for the United States. Specific regulations and reporting requirements of other countries should be adhered to, and the planning concepts presented in this manual adjusted accordingly.

Each chapter deals with different issues. Chapter 2 starts with the impetus for preparing a water resources plan, which can involve a variety of issues including the following:

- Changes in demand
- Changes in supply
- Raw and treated water quality
- Aging water supply infrastructure



Source: *Reilly et al. 2009*

**Figure 1-4 Groundwater level declines**

- Implementation of conservation and reuse programs
- Instream flow and water quality requirements
- Operational changes
- Capital improvement planning

A preliminary assessment is often needed to identify issues, validate the need for the plan or a new supply, and prepare a work plan. Often, a white paper or scoping paper is needed to define the issues surrounding planning for a new source. Nearly every plan is a significant undertaking and requires approval from appointed or elected officials. The process should be thought through in advance, so decision makers have timely information to guide the process along the way and the information for selecting the best plan.

Water resources planning is ultimately a local exercise that has regional effects. The decisions associated with the planning process are critically important to the community and the community's unique local conditions because the characteristics of supply and demand are unique to each locale. The goals, values, and priorities of the end users of the water can only be coordinated through local planning processes; but because local planning is likely to have effects beyond the borders of the utility, it is important to involve other stakeholders that may affect or be affected by the plan. Active engagement by local planners in regional, watershed, and statewide planning processes is key to the success of those efforts in terms of coordinating water supply planning and heading off conflicts between competing uses of shared resources. As a result, there should be a strong and beneficial linkage between local, regional, and state planning efforts.

Chapter 2 provides an understanding of public participation techniques and the important role it can play in water resources planning. It covers the process of setting goals and developing work plans to involve the public in the water resources planning process. It also describes the key elements of plan implementation that include chartering the project team, and monitoring and managing change in the process.

Chapter 3 discusses the role of water rights in water resource management. Two distinct systems of water rights are defined and described: riparian rights, used primarily in the eastern United States; and prior appropriation doctrine, predominantly used in the western United States. Water rights systems for groundwater include absolute ownership, reasonable use, correlative rights, and appropriation permit systems. Federal and Tribal rights also are described, including federal reserved rights, water rights for water not reserved, rights of navigable water, and federal contract rights. A discussion of the water quality effects of all of these water rights doctrines is also included because this is an emerging area of interest.

Chapter 4 identifies alternatives for developing, expanding, or maximizing a water resource portfolio, including

- surface water, including source identification, screening, and site selection for direct river withdrawals, onstream reservoirs, and pumped-storage reservoirs;
- groundwater, including confined and unconfined aquifers; and
- conjunctive use of surface water and groundwater.

Chapter 4 also describes other water resources alternatives that might be available to a given community, including

- reclaimed water,
- desalination,
- demand management,
- water marketing and transfers, and
- nontraditional sources.

Chapter 4 does not necessarily present a comprehensive list of options, nor does it require evaluation of all options. Local conditions will govern the options available to the water utilities. The key is to identify feasible new sources that, individually or combined, make up the identified supply deficit for an estimated future time period.

Chapter 5 begins by summarizing common water demand forecasting methods ranging from simple per capita models to more complex statistical forecasting methods. It then describes types of data normally used for forecasting, including water billing data, weather data, demographic and economic data, and other explanatory variables, and provides examples of forecasting with per capita coefficients, land-use water factors, and regression analysis of disaggregated demand data. Uncertainty analyses and probability methods conclude the chapter.

Chapter 6 explains water quality interactions and the hydrologic cycle, including physical, chemical, and biological components. This chapter defines various measures of water quality and describes the relationships between water uses and water quality. In addition, effects of natural influences, point sources, and nonpoint sources on water quality are defined, as are the major factors affecting quality of various types of surface water. Similarly, the major factors affecting groundwater quality include common contaminants and transport considerations.

Chapter 7 addresses source water protection. Source water protection has long been promoted and used by water systems, local governments, and states as a part of a multiple-barrier approach to ensure that drinking water for public water systems is high quality and meets drinking water standards for public health protection. Source protection essentially makes treatment easier by minimizing the contaminants that must be removed. Chapter 7 includes sections on

- source water protection programs,
- groundwater protection, and
- surface water source protection.

The above protections include the following elements:

- Identification of potential contaminant sources
- Assessing vulnerability and determining susceptibility
- Making source water assessments available to the public
- Development of a source water protection plan and program

AWWA's Utility Management Standards program (also known as the G Series) is designed to cover the principal activities of a typical water and/or wastewater system. It provides a means to assess service quality and management efficiency based on recognized standards for best available practices. American National Standards Institute (ANSI)/AWWA Standard G300-14 (AWWA 2014) and the associated operational guidebook (Sham et al. 2010) are valuable resources that complement the content of chapter 7.

Chapters 8 and 9 are intrinsically linked. Chapter 8 describes water supply assessments and is designed to help the reader identify the fatally flawed options and the most likely portfolio of solutions. The solutions are compared to a baseline of performance, while risks and benefits are assessed. Infrastructure, water quality and treatment of supplies, water source reliability, environmental impacts, implementation considerations, and costs should be taken into account. The evaluation criteria should be defined in conjunction with the goals of the utility.

Chapter 9 identifies the means for assessing the evaluation criteria and utility goals through a rigorous evaluation process, reflecting the nature of the new alternative sources identified. All relevant issues regarding alternative analysis should be addressed, including

- water quality of new sources,
- protection of current and new sources,
- regulations,
- water rights and policies,
- yield of new sources and effects on other sources (assessed through modeling)
- environmental impact assessments,
- economic feasibility and financing considerations, and
- long-term viability (design life).

These evaluations are intended to identify a preferred plan that balances conflicting factors. Criteria will generally include

- cost-effectiveness,
- financial feasibility,
- public acceptability, and
- environmental issues.

Chapter 10 ties all prior chapters together by outlining the planning process and planning tools. Examples are provided to illustrate the planning process and strategies. What is not discussed in detail in chapter 10, because of constantly changing rules, are regulatory requirements. Water resource projects are subject to varying degrees of regulatory approval. Developing new sources or expanding withdrawals may require permits. Examples of such permits are a state water allocation permit or a federal Section 404 permit, often requiring a long and involved approval process.

Planners should address permit requirements in the water resources plan through consultation with state and federal regulatory officials so that likely permits are identified, and the considerations required or implied are included in the alternatives analyses. However, detailed aspects of the permit approval, such as detailed environmental impact analyses, will occur after the plan is approved. Each state or locale has its own framework for assessing the environmental impacts of water resource projects. The state's water allocation agency can identify the lead permitting agency and help identify the types of environmental work that will likely need to be performed. Detailed environmental assessments or impact statements are not usually undertaken until after the preferred alternative source is identified. However, the planning process leading to that selection should include preliminary consideration of all issues likely to require detailed assessment.

Preliminary environmental screening needs to be integrated with the alternative assessment process. This will help justify the alternative selection and reduce the time required to complete environmental assessments or an environmental impact analysis for the recommended project and needed permits due to "false starts" and missing the obvious.

## SELECTING THE PROJECT TEAM

One of the most important issues a water resources planner faces is who should be involved in the planning process. Those involved are called "stakeholders" because they have a vested interest in how the process turns out and which alternative is selected. No longer are plans prepared in a vacuum, released for approval after all the technical work is completed, and the alternatives evaluated. Planners have found that this closed-door approach necessitates starting over when opposition to the proposed project surfaces, possibly more than once. An open approach requires a slower, more deliberate process. Although involving all stakeholders may slow down the technical work, the final decision and project approval are invariably reached sooner and more amicably. This critical element is discussed in more detail in chapter 2.

## REFERENCES

AWWA (American Water Works Association). 2014. ANSI/AWWA Standard G300. *Source Water Protection*. Denver, Colo.: AWWA.

Bloetscher, F. 2010. The impact of unsustainable ground water. In *Florida Water Resource Conference Proceedings, May 16–19, 2010, Orlando, Fla*. Kissimmee, Fla.: FWRC.

Bloetscher, F., and A. Muniz. 2008. Water supply in South Florida—The new limitations. In *Sustainable Water Sources (Reno) Conference Proceedings*. Denver, Colo.: AWWA.

Fagan, B. 2012. *Elixir*. New York: Bloomsbury Press.

Meadows, D., J. Randers, and D. Meadows. 2004. *Limits to Growth: The 30-Year Update*. White River Junction, Vt.: Chelsea Green Publishing.

Molak, V. 1997. *Fundamentals of Risk Analysis and Management*. Boca Raton, Fla.: Lewis Publishers.

Reilly, T.E., K.F. Dennehy, W.M. Alley, and W.L. Cunningham. 2009. *Ground-Water Availability in the United States*. USGS Circular 1323. Reston, Va.: US Geological Survey.

Sham, C.H, R.W. Gullick, S.C. Long, and P. Kenel. 2010. *Operational Guide to AWWA Standard G300, Source Water Protection*. Denver, Colo.: AWWA.

Starkl, M., and N. Brunner. 2004. Feasibility versus sustainability in urban water management. *Journal of Environmental Management*, 71:245–260.

USGS (United States Geological Survey). 2015. How Much Water Is There on, in, and Above the Earth? https://water.usgs.gov/edu/earthhowmuch.html (accessed May 15, 2015).