The Importance of Water to the U.S. Economy
Part 1: Background Report

Public Review Draft

Office of Water
U.S. Environmental Protection Agency
September 2012

PROJECT SUMMARY

OVERVIEW

Water is vital to a productive and growing economy in the United States, directly and indirectly affecting the production of goods and services in many sectors. Current economic literature provides some insights into the importance of water to various sectors, including agriculture, tourism, fishing, manufacturing, and energy production, but this information is dispersed and, in many cases, incomplete.

EPA is conducting a study on the importance of water to the U.S. economy to:

- Summarize existing knowledge on the topic;
- Provide information that supports private and public sector decision-making, and
- Identify areas where additional research would be useful.

The study focuses on the relationship between water and the market economy – the water-related economic activity that is captured in national economic accounts. Though water provides non-market services that are important to the welfare of the nation, this aspect of water is not a primary focus of this study. EPA and others are conducting research on the non-market services provided by water and other aspects of the environment, and anticipate that in the future, in response to the needs of private and public sector decision-makers, these lines of research will naturally merge.

This study does not constitute a new EPA regulation, guidance or policy, nor does it change any existing regulation, guidance or policy. Rather, EPA hopes that the study will serve as a starting point for improving our understanding of water's importance to the economy, and provide a foundation for analysis and discussion focused on improving the information available to support efficient and effective decisions related to water.

STUDY COMPONENTS

PART 1 – BACKGROUND REPORT (THIS DOCUMENT)

The background report is a literature review and general analysis of U.S. economic and water resource statistics. The purpose of the report is to provide a consistent set of conceptual and statistical information on key sectors of the U.S. economy, and to provide a foundation for evaluating cross-cutting themes. It also helped to inform Part 2 of the study, identifying broad focal areas for the solicitation of proposals for further research. A public review draft is available on the project website (see link below).

PART 2 – EXPERT PAPERS

Seven papers were funded as part of this study to examine various aspects of water use in the U.S. economy. The purpose of these papers is to go beyond the literature referenced in the background report to support current economic research on the use and economic value of water across various sectors and regions. The papers will be posted to the project website in September 2012.

PART 3 - TECHNICAL WORKSHOP

EPA is hosting a one-day technical workshop in September 2012 in Washington, DC. The purpose of the workshop is to present the findings from the background report and expert papers, and to engage a diverse mix of analysts and decision-makers from different regions and sectors of the economy in a technical discussion on:

- Challenges private and public sector decision-makers face in managing and using water resources;
- Methods and tools analysts use to generate information to support decision-making; and
- Gaps in information needed to improve management and use of water resources.

The agenda for the workshop will be posted on the project website in September 2012. A summary of the proceedings is expected to be posted to the website by the end of November 2012.

PART 4 - SYNTHESIS REPORT

The synthesis report will summarize and integrate key findings from the background report, expert papers, and technical workshop, and offer suggestions for meeting future needs, including filling research and information gaps. A public review draft is expected to be posted to the project website by the end of November 2012.

PART 5 - PUBLIC SYMPOSIUM

EPA and American University are co-hosting a half-day symposium on December 4, 2012 in Washington, DC. The goals of the symposium are:

- To provide a forum for sharing information on the role and importance of water to different sectors of the U.S. economy;
- To initiate a dialogue with public and private sector leaders on the types of information used to guide business' decisions related to water management; and
- To explore ways to fill information gaps and prepare for future water needs.

Registration through the project website is expected to open in October 2012. The agenda is expected to be posted to the project website by the end of November 2012. A summary of the symposium is expected to be posted to the website by the end of January 2013.

ACKNOWLEDGEMENTS

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ADDITIONAL INFORMATION

For additional information, go to the project website:

http://water.epa.gov/action/importanceofwater/index.cfm.

FEEDBACK

To provide feedback on this report or any other aspect of EPA's study, please send your comments by e-mail to *ImportanceOfWater@epa.gov*.

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CHAPTER 1 | INTRODUCTION

PURPOSE

Water is vital to a productive and growing economy in the United States, directly and indirectly affecting the production of goods and services in many sectors. Current economic literature provides some insights into the importance of water to various sectors, including agriculture, tourism, fishing, manufacturing, and energy production, but this information is dispersed and, in many cases, incomplete.

EPA is conducting a study on the importance of water to the U.S. economy to:

- Summarize existing knowledge on the topic;
- Provide information that supports private and public sector decision-making, and
- Identify areas where additional research would be useful.

The study focuses on the relationship between water and the market economy – the water-related economic activity that is captured in national economic accounts. Though water provides non-market services that are important to the welfare of the nation, this aspect of water is not a primary focus of this study. EPA and others are conducting research on the non-market services provided by water and other aspects of the environment, and anticipate that in the future, in response to the needs of private and public sector decision-makers, these lines of research will naturally merge.

This Background Report provides information and insights on a range of factors, including:

- The ways in which the nation uses its water resources;
- The sensitivity of various uses of water to changes in supply, quality, or other key resource characteristics;
- The impact of water resources on a variety of economic factors, such as regional economic development and U.S. competitiveness in the global economy; and
- The potential impact of factors like population growth, urbanization, and climate change on the challenges future generations may face concerning management and use of the nation's water resources.

Though governance and institutions can have an important impact on the value of water and other resources, this report approaches these topics from the standpoint of an observer rather than an advocate, and takes existing governance and institutional structures as a given. It does not attempt to estimate the total value of water to the U.S. economy, nor does it attempt to evaluate, either retrospectively or prospectively, the costs

and benefits of particular regulations, statutes, or resource management decisions. Rather, it is designed to serve as a starting point: to provide a baseline understanding of the data and methods available to analyze the value of water; to provide a foundation for analysis and discussion of this issue; and to act as a stimulus to further investment in improving the economic information available to support both public and private decisions concerning the management and use of the nation's water resources.

CONTEXT AND CONCEPTUAL FRAMEWORK

Decision-makers in both the public and private sectors regularly make choices concerning the use of scarce resources. Ideally, from an economic perspective, these choices are guided by information that leads to a socially efficient use of those resources; i.e., a mix of uses that produces the greatest net benefit to society as a whole. This outcome depends on a number of factors, including reliable information on the scarcity of the resource, the competing options for its use, and the value people place on these alternative uses. When this information is lacking, an inefficient use of resources is more likely.

In the area of natural resource management, public agencies like EPA conduct a wide range of analyses to provide the information needed to develop programs, policies, and regulations that are effective, fair, and economically efficient. The scope of these analyses is often broad and rigorous. Even the most rigorous of these analyses, however, are limited in their ability to capture and reflect the complexities of dynamic and interrelated economic, environmental, and social systems. These limitations can become particularly acute when basic information about the use and value of key resources is lacking. The absence of this information prohibits the development of the integrated, systems-based analytic methods and models that ideally would be available to support and inform resource management decisions.

With respect to water, the lack of systematic data on both use and value is evident, and increasingly problematic. In part, the lack of data reflects the historic abundance of water in many parts of the United States, where a plentiful supply has helped to minimize competition over the use of water resources. Even in these areas, however, population growth and other factors are placing increasing pressure on both surface and groundwater supplies. Clearly, decision-makers in both the public and private sectors could make better informed and more sustainable decisions if more extensive data on the use and economic importance of water were available. With the development of this report and related research, EPA is helping to bridge this gap, with the ultimate goal of gaining a systems-level understanding of:

- Water's role in the economy;
- Competition and interdependencies between and among various uses of water; and
- Ways in which the nation can improve management of its water resources to promote environmentally sustainable economic growth while maximizing the economic value derived from water's use.

ECONOMIC PERSPECTIVES FOR EVALUATING THE VALUE OF WATER

This report examines the value of water to the U.S. economy from a number of perspectives. Among the most important of these are the following:

- *Microeconomic efficiency* – The value of water is related to its relative scarcity, its alternative uses, and the opportunity costs of those uses. To maximize social welfare, scarce resources must be used in ways that provide the greatest value. Markets can produce this economically efficient use of resources, provided that they are competitive and well-informed. When they are not – for example, when trade is restricted, when prices are distorted by taxes or subsidies, or when the cost to the consumer fails to incorporate externalities like environmental impacts – an inefficient use of resources is likely to occur.
- *Sustainability* – The value of water must be considered within the context of dynamic and integrated environmental, economic, and social systems. Within an integrated system, the value of a resource is a function of both the direct and indirect impacts associated with its use. The impacts of interest include not only those that are reflected in markets, but also those that affect the production and/or consumption of non-market goods and services. This includes both immediate effects and those that may not be realized until well into the future.

FOCUS AND ORGANIZATION OF REPORT

As EPA's initial step in attempting to address these issues, this report draws on available data to provide an overview of the nexus between the nation's economy and its water resources. Within this context, it considers both "off-stream" water use – i.e., the use of water that is withdrawn or diverted from its source – and "in-stream" uses of water, to the extent that those uses are directly or indirectly reflected in market activity. Because both the use of water and the value of that use can vary significantly across different sectors of the economy, the report is organized by economic sector. This approach facilitates the presentation of economic data that are typically structured in a similar fashion, and may also increase the utility of the report in shaping subsequent research and analysis. At the same time, the report recognizes that the distribution of water resources across the United States is far from uniform, that regional differences have an enormous effect on the ways in which water is used, and that these differences have important implications for the value of water in particular areas. The report attempts to address these issues on a sector-by-sector basis. It is organized as follows.

- *Chapter 2: Economic Concepts* – explains the concept of value from a microeconomic perspective and notes some key issues in evaluating the value of water. This chapter also addresses the importance of water in a macroeconomic context, noting how the flow of goods and services between different sectors of the economy links the use of water in one sector to economic productivity in others.
- *Chapter 3: Trends in Water Use and Availability* – describes the distribution of U.S. water withdrawals by source and use, discussing both current estimates and recent trends. The chapter also examines the evidence of existing stress on

regional water supplies, as well as projections, in some areas, of heightened scarcity in the future.

- *Chapter 4: Public Supply and Domestic Self-Supply* – provides information on domestic water demands and the nation's public water supply, treatment, and distribution infrastructure.
- *Chapter 5: Agriculture* – discusses the use of water in the nation's agricultural sector, including its use in irrigation, raising livestock, and commercial aquaculture.
- *Chapter 6: Manufacturing* – describes the use of water in the U.S. manufacturing sector, focusing on the five industries that account for more than 90 percent of industrial water use.
- *Chapter 7: Mining and Energy Resource Extraction* – provides information on U.S. use of water in mining and energy resource extraction, including the production of coal, crude oil, and natural gas.
- *Chapter 8: Electric Power Generation* – discusses the use of water in generating electricity, including its use as a coolant in producing thermoelectric power and its direct use in the production of hydropower.
- *Chapter 9: Commercial Fishing* – presents information on the nation's commercial fishing industry and the impact of water resource management issues on the sector's productivity.
- *Chapter 10: Commercial Navigation* – discusses the importance of water as a medium for commercial navigation.
- *Chapter 11: Recreation and Tourism* – provides an overview of water-based recreation and tourism in the U.S., and describes the link between the state of the nation's water resources, demand for recreation, and expenditures in the market economy.
- *Chapter 12: Summary* – summarizes the major themes that emerge from the report, including the importance of water from a macroeconomic perspective; available data on the marginal value of water in different uses; trends in water use; regional perspectives on the sustainability of those trends; and the need for better information to allow decision-makers in the public and private sectors to manage and use water resources in a more efficient and sustainable manner.

CHAPTER 2 | ECONOMIC CONCEPTS

INTRODUCTION

From an economist's perspective, the value of water can be analyzed through both a microeconomic and a macroeconomic lens. Microeconomics provides a framework for examining the value of water to an individual household, firm, or industry. In contrast, macroeconomics provides a multi-sector framework for understanding how water resources contribute to economic activity at a regional or national level, as measured by such indicators as employment and gross domestic product. As discussed below, macroeconomic analysis also offers a means of understanding the complex interrelationships between the use of water in one sector of the economy and economic activity in others.

CHAPTER OVERVIEW

This chapter discusses concepts and relationships that are critical to understanding the economic importance of water, including:

- The concept of value, and the ways in which value can be measured;
- Why the economic value of water is not always equivalent to its price;
- The many factors that may influence the value of water in a particular use; and
- How the flow of goods and services between sectors of the economy links the use of water in one to economic productivity in another.

It is designed to provide a framework for understanding later chapters of the report, which focus on the use of water in the economy and the values associated with that use.

MICROECONOMIC CONCEPTS

The question of water's value has been the subject of inquiry since the first formulation of modern economic theory. In the *Wealth of Nations*, Adam Smith described the paradox of water and diamonds:

> Nothing is more useful than water: but it will purchase scarce anything; scarce anything can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it (Smith, 1776).

Smith attempted to resolve this seeming paradox by differentiating between a good's *value in use* – what we might call its *utility* – and its *value in exchange* – in other words, its *price*. While later economists abandoned this distinction in favor of a more elegant resolution, Smith was simply articulating a common thought: that the market price of a good does not necessarily reflect its true value. This is particularly obvious in the case of a good like water, which is essential to human life. Indeed, nothing is more

useful than water, yet it is bought and sold every day, often at a very low price. What does this tell us about the value of water, and how are we to use this and other economic data in making choices about the use and management of such an essential resource?

The discussion that follows attempts to address this question, explaining several concepts that are essential to understanding what economists mean when they refer to the value of water. It is written primarily for those with a background in water resource management but little or no formal training in economics. It is neither original nor exhaustive, but is designed to provide the reader with a solid grasp of the economic concepts that shape the discussion of water's value throughout the remainder of this report. Those who wish to explore these concepts in greater detail are encouraged to consult the references at the end of the chapter. Several of these works, particularly Michael Hanemann's essay on the economic conception of water (Hanemann, 2005), are essential reading.

WATER'S PRICE, COST, VALUE, AND ESSENTIAL NATURE

Let us briefly return to Smith's paradox. Why is the price of diamonds high, and the price of water low? The key insight, arrived at by later economists, is that a commodity's price is related not to its total value in use, but rather to the usefulness of the last unit consumed. More specifically, price is determined by the simultaneous interaction of two market forces, supply and demand, which reflect, respectively, the *cost* of producing the commodity and the *benefit* derived from its use. When water is abundant, as it was in Smith's native Britain, both the cost of supplying another gallon of water and the benefit derived from consuming that gallon are low; thus, water's price is low. Conversely, the scarcity of diamonds relative to consumer demand gives them a high price. If the situation were reversed – if, for example, consumers awoke to find themselves in a sparkling desert in which water was scarce but diamonds were plentiful – the relative prices of the two commodities would quickly be reversed (Nicholson, 1978).

As noted above, the price of a commodity is determined by the interaction of supply and demand. In contrast, the concept of *value* reflects the net difference between the gross benefit received from the use of that commodity and the cost of that use. In this sense, the value of a commodity is determined largely by the nature of demand for it, as measured by the amount of money that prospective purchasers of the commodity would be willing to pay to acquire a specific amount. In turn, *willingness to pay* is determined by the marginal benefit that these purchasers would derive from each increment of consumption. In the case of water, these prospective purchasers include:

- Households and similar users, for whom water serves as a final good; and
- Farmers, utilities, manufacturers, and others, for whom water serves as an input to production.

From the perspective of either group, the *total economic value* of water may be quite high, if not infinite, while its *marginal value* at current levels of supply may be quite low. Hanemann makes this point clearly in discussing the essential nature of water:

> Water is essential for all life – human, animal, or plant. In economics, there is a concept…that formalizes this notion. The concept can be

> applied either to something that is an input to production or to something that is directly enjoyed by people as a consumption commodity. In the case of an input, if an item has the property that *no* production is possible when this input is lacking, the item is said to be an essential input. In the case of a final good, if it has the property that *no* amount of any *other* final good can compensate for having a zero level of consumption of this commodity, then it is said to be an essential commodity. Water obviously fits the definition of an essential final good: human life is not possible without access to 5 or 10 liters of water per person per day. Water fits the definition of an essential input in agriculture, and also in several manufacturing industries….
>
> However, essentialness conveys no information about the productivity or value of water *outside the vicinity of the threshold.* It implies nothing about the marginal value associated with, say, applying 30 versus 35 inches of water to irrigate cotton in the Central Valley of California. It says nothing about the marginal value of residential water use at the levels currently experienced in Western Europe or the United States – the latter averages…more than two orders of magnitude larger than the minimum quantity that is needed for human survival (Hanemann, 2005).

Thus, in discussing the value of water, it is important to be clear about terms and to focus on the appropriate dimensions of value. As Hanemann notes, most people have access to *some* water, and most policy interventions involve changing the quantity and/or quality of access, rather than transforming the situation from no access to some access. In most public policy applications within the United States, the relevant consideration is the impact of a decision on the marginal use of water, and the change in net benefits associated with that change in use. These are the values upon which this report focuses.

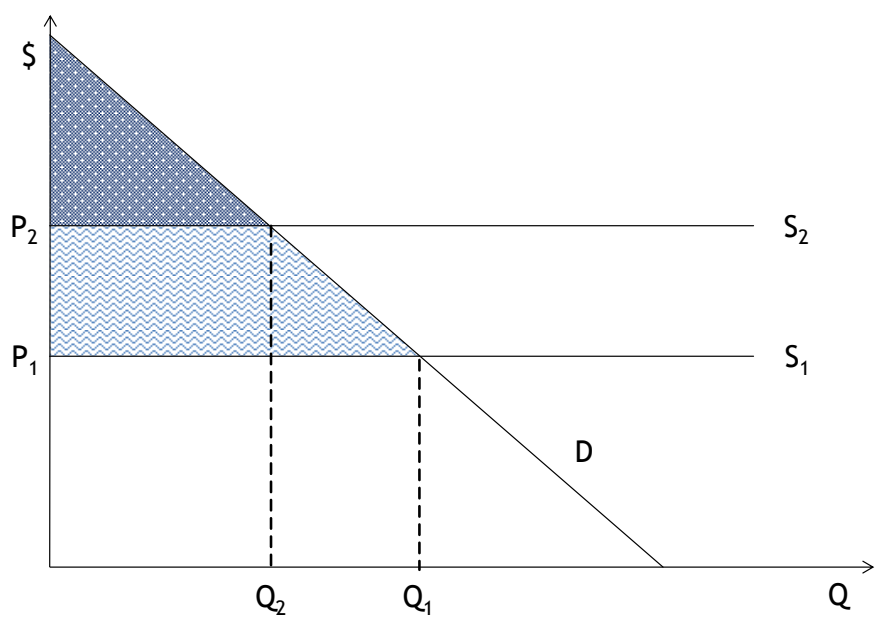
AVERAGE, MARGINAL, AND TOTAL ECONOMIC VALUES

The simplified linear supply and demand curves presented in Exhibit 2-1 help to illustrate the relationship between marginal and total economic values in the supply of water. Consider, in this case, a group of farmers served by an irrigation district. The downward sloping demand curve (D) indicates the farmers' willingness to pay for each incremental unit of water, which declines as the amount of water supplied increases; this reflects the declining marginal benefit of using additional quantities of water for irrigation purposes. The two horizontal supply curves indicate the unit cost to the irrigation district of supplying water under two scenarios: normal weather conditions, which allow the district to draw water from a nearby river (S_1), and drought conditions, which force it to draw and transport water from a more distant and expensive source (S_2). As the figure indicates, farmers will consume more water (Q_1) under normal conditions, when the irrigation district can supply water at a lower price (P_1). In this case, the marginal value realized from the use of water will equal its price (P_1), while the total economic value realized is represented by the total area under the demand curve, from the origin to Q_1. In contrast, farmers will consume less water (Q_2) if drought conditions force the irrigation district to

raise its price (P_2) to cover the added cost of drawing water from its secondary source. In this case, the marginal value realized from the farmers' use of irrigation water (P_2) will be higher, since farmers will restrict their use of water to applications in which the marginal return is equal to or greater than P_2; however, the total economic value derived from the use of water will be reduced to the area beneath the demand curve from the origin to Q_2, reflecting the elimination of uses with a marginal return between P_1 and P_2.

The example presented above assumes that farmers will consume water up to the point at which the marginal benefit (or marginal value) of consumption equals its price. It is important to emphasize, however, that the total economic value derived from the use of water exceeds the group's total expenditures on it. Under the first supply scenario, the farmers' total expenditures on water are represented by the rectangle bounded by Q_1, S_1, and the X and Y axes. The total economic value realized, however, also includes both the dark blue and light blue areas that together form a triangle above P_1. Similarly, under the second supply scenario, the farmers' total expenditures on water are represented by the rectangle bounded by the two axes, Q_2, and S_2; the total economic value includes this rectangle, as well as the dark blue triangle above P_2. In both cases, the total economic value exceeds the farmers' expenditures because, as the demand curve indicates, they would be willing to pay more than they actually pay for all but the last unit of water they consume. This difference, which economists call *consumer surplus*, represents the net benefit associated with the consumption of water.

EXHIBIT 2-1. ILLUSTRATION OF WATER'S ECONOMIC VALUE UNDER TWO SUPPLY SCENARIOS



The example presented above also helps to illustrate the relationship between the marginal value of water and its average value; i.e., the total economic value derived from the use of water divided by the quantity employed. Under drought conditions, for example, the average value of water can be determined by dividing the total value derived

from its use by the total volume used (Q_2). Consistent with the downward sloping demand function, the average value of water in this application will exceed its marginal value (P_2), reflecting the diminishing marginal returns realized from its use.

The relationship between the marginal value of water and its average value may seem academic, but can be quite important in a decision-making context. In many cases, available estimates of the value of water reflect average values, in large part because they are relatively simple to estimate. In contrast, estimates of marginal values are more difficult to derive, particularly in the absence of price data; as Hanemann notes, estimation of marginal values in such cases requires a formal or informal model of how water generates value in the production of a particular good. Reliance on average values, however, can significantly overestimate the marginal value of water as an input to production, and can lead to decisions that appropriate consideration of marginal values would not support.

WHY WATER PRICES MAY FAIL TO ENCOURAGE EFFICIENT USE[1]

A central tenet of economics is that competitive and well-informed markets will produce an optimal use of resources, reaching an equilibrium at which the market price of a good is equal to both the marginal cost of supplying it and its marginal value to consumers. In most cases, however, the price at which water is sold in the United States is not a product of market forces that will yield this optimal use. In part, this is because the prices charged for water do not, in most instances, reflect the full *opportunity cost* of its use – i.e., the cost of forgoing the use of the water for its best alternative purpose. As Hanemann notes,

> It is important to emphasize that the prices which most users pay for water reflect, at best, its physical supply cost and *not its scarcity value*. Users pay for the capital and operating costs of the water supply infrastructure but…there is no charge for the water *per se*. Water is owned by the state, and the right to use it is given away for free. Water is thus treated differently than…minerals for which the…government requires payment of a royalty to extract the resource (Hanemann, 2005).

The opportunity cost of water may be negligible when its supply is abundant, but significant when water is scarce. Beyond this limitation, the prices charged for water may not even reflect full supply costs. In some cases, this is the result of explicit government subsidies, as is the case with some Federal irrigation projects. In others, this may be the result of the common practice of establishing prices to recover the historic costs of public water supply systems, rather than their long-run future replacement costs. Again, Hanemann provides a helpful explanation:

> There is typically a large gap between these two costs because of the extreme…longevity of surface water supply infrastructure. The capital

[1] The discussion that follows notes that current prices may not fully reflect the long-run marginal cost of water or externalities associated with its use. The purpose of the discussion is not to resolve these issues, but rather to explain why prevailing prices may lead to economic inefficiencies in the use of water.

> intensity of the infrastructure exacerbates the problem because, after a major surface water project is completed…supply capacity so far exceeds current demand [that] there is a strong economic incentive to set price to cover just the short-run marginal cost (essentially, the operating cost), which is typically minuscule. As demand eventually grows and the capacity becomes more fully utilized, it is economically optimal to switch to long-run (i.e., replacement) marginal cost, but by then water agencies are often politically locked into a regime of low water prices focused narrowly on the recovery of the historical cost of construction (Hanemann, 2005).

Thus, we cannot assume in all cases that the prices currently charged for water reflect its true (long-run) marginal cost, or that the resulting use of water resources is economically efficient. To the extent that water is underpriced, it will be used in quantities that exceed the economically efficient amount, and in applications in which its marginal value is less than its true opportunity cost.

In addition to the issues discussed above, it is important to note other factors that may lead markets to fail to account for the full cost of water's use. Chief among these are *externalities*: costs imposed on third parties that are not reflected in market prices. One clear example of an externality is the impact of water use on the quality of water available for other purposes; e.g., the impact of pollutants contained in irrigation return flows on the quality of water available downstream. These pollutants may affect the costs that downstream municipalities incur to treat and supply drinking water to their residents; the costs of other market uses of water may also be affected. Such externalities may also affect the provision of non-market services, such as recreational fishing opportunities. To the extent that this occurs, the failure of the market to reflect true costs will lead to inefficiencies in the use of water resources.

THE VALUE OF THE MARGINAL PRODUCT OF WATER

A further challenge in assessing the value of water is the fact that for many economic purposes – in manufacturing, in agriculture, in mining, or in generating electricity – water is not purchased from an external provider, but is instead self-supplied. As a result, no market information on the user's willingness to pay for water is available. Even in the absence of market data, however, it is possible to draw inferences about a producer's willingness to pay for water, based on its value as an input to production. Specifically, the marginal value of water to the producer is equal to the associated gain in the value of the producer's output: the *value of the marginal product of water*. All else equal, a profit-maximizing producer would be expected to use water up to the point at which the value of water's marginal product is equal to its marginal cost. Thus, when combined with information on product prices, information on the impact of water on a producer's output – for example, the impact of various levels of irrigation on crop yields – can provide a meaningful indicator of the marginal value of water in particular applications.

It is important to note that the value of the marginal product of water in a given application is likely to depend on multiple factors, including the overall mix of inputs

used in the production process. In agriculture, for example, the value of the marginal product of water may depend in part on fertilizer or pesticide application rates. The value of water may also be affected by the *marginal rate of technical substitution* between inputs: the extent to which the use of one input, such as water, may be substituted for another, such as labor, while maintaining the same level of production. Within a given industry, different producers may employ different suites of inputs; thus, the value of the marginal product of water may vary from case to case. This is particularly true in the case of agriculture, where regional differences in climate, soils, or other factors may dictate significant variation in the mix of inputs employed and contribute to marked disparities in the value of the marginal product of water.

LONG-RUN VS. SHORT-RUN VALUES

In addition to the variation described above, the value of water as an input to production depends upon the temporal perspective employed. In the short run – i.e., when certain inputs, such as equipment and other capital stock, are fixed – the total economic value derived from the use of water may be constrained. In the long-run, however, when such constraints are eliminated, the total economic value derived from the use of water may increase. This might be the case for a manufacturer who, in the short-run, must purchase water from a municipal utility at a set price but, in the long-run, can reduce the marginal cost of the water it requires by drilling a well. As Exhibit 2-2 illustrates, the reduction in the marginal cost of water results in an increase in the manufacturer's demand for water and an increase in the total economic value derived from water's use.

HETEROGENEITY OF THE VALUE OF WATER IN A GIVEN USE

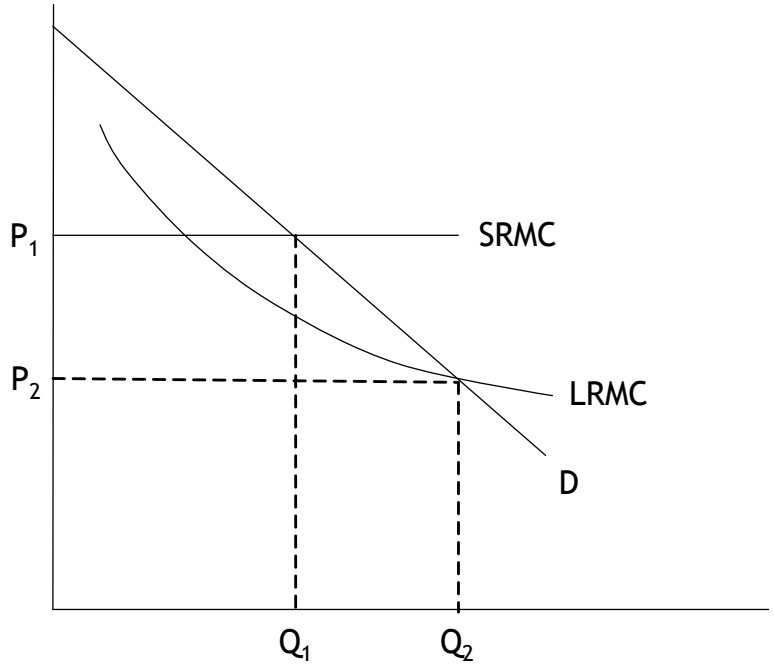
Finally, it is important to note that the value of water in a particular application is likely to depend not only on the *volume* of water supplied, but also on *where* the water is supplied, *when* it is supplied, whether the supply is *reliable*, and whether the *quality* of the water meets the requirements of the intended use. For example, the willingness of consumers to pay for drinking water will depend on whether it is reliably and continuously available at the tap, free of contaminants, and free of offensive tastes and odors. The same, to varying degrees, is likely to be true of other users. In this sense, water is a heterogeneous commodity, and empirical data on a user's willingness to pay for it will reflect the extent to which the supply in question meets the requirements of that user's needs.

DIMENSIONS OF WATER THAT INFLUENCE ITS VALUE

Water is not a one-dimensional commodity. A user's willingness to pay for water from a particular source may depend upon:

- *Quantity* - The total volume of water the source can supply;
- *Time* - When the water will be supplied;
- *Space* - The location at which the water will be supplied;
- *Reliability* – The likelihood that the supply will not be interrupted; and
- *Quality* – The extent to which the water is free of contaminants and otherwise suitable for the intended use.

EXHIBIT 2-2. SHORT-RUN VS. LONG RUN MARGINAL COSTS



MACROECONOMIC CONCEPTS

To fully appreciate water's role in the U.S. economy, we must consider not only microeconomic principles, but also the use of water in a macroeconomic context. Our dependence on a clean, reliable supply of water becomes evident when we consider the sectors that use water directly and their relationship to the economy at large. The discussion that follows presents a wide-angle view of the structure of the U.S. economy, noting not just where water use is concentrated, but also how the flow of goods and services between sectors links the use of water in one sector to economic productivity in others.

SECTOR VIEW OF THE ECONOMY

Economists have long sought to characterize the diverse and complex elements of economic systems by grouping activity into major economic sectors. Some of the earliest distinctions were established in ancient Greece and recognized agriculture, household management, and trade. Later systems classified manufacturing activity by industry and expanded to recognize other forms of activity, such as education and public administration. In the 20th century, economists such as Zoltan Kenessey arrived at the following designations, which are still commonly used today:

- Primary sectors, including agriculture, forestry, fishing, and mining;
- Secondary sectors, including utilities, manufacturing, and construction;
- Tertiary sectors, including transportation, wholesale trade, and retail trade; and
- Quaternary sectors, including finance, insurance, real estate, and public administration.

Kenessey (1987, p. 367) notes that these sector groupings or "mega-sectors" are "anchored to the four major elements of the work process: *extraction*, *processing*, *delivery*, and *information*." As described below, this logical outline of the work process provides a useful framework for illustrating how the direct use of water – which occurs predominantly in the primary and secondary sectors of the economy – ultimately affects the production of goods and services in sectors in which water is not a direct input. It also provides a basis for evaluating how shocks in the availability or quality of water may affect the structure and performance (e.g., efficiency) of the economy as a whole.

WATER USE IN MAJOR ECONOMIC SECTORS

The U.S. Department of Commerce (DOC) instituted formal use a of sector-based industrial classification system in the 1930s. DOC's Standard Industrial Classification (SIC) system categorized commercial establishments by predominant economic activity. Over several decades, government economists revised the SIC system to accommodate the changing composition of the U.S. economy. The last update to the SIC system occurred in 1987.

In 1997, DOC adopted a new scheme: the North American Industry Classification System (NAICS). The NAICS corrected methodological weaknesses in the SIC system and established a consistent classification structure for the U.S., Canada, and Mexico, the partners under the North American Free Trade Agreement (Census Bureau, 2012). Exhibit 2-3 summarizes the major NAICS sectors (at the two-digit level). The correspondence of the NAICS codes to Kenessey's view of the economy is evident. Primary activities, such as agriculture and mining, are assigned the lowest-numbered codes. Secondary activities, such as manufacturing, construction, and the provision of water and electricity, constitute the next tier.[2] The highest-numbered sectors represent tertiary and quaternary activities, such as transportation, trade, the provision of business or personal services, and public administration.

Central to this report is the understanding that direct use of water is heavily concentrated in the lower-numbered, primary and secondary tiers of the economy. The final column of Exhibit 2-3 identifies the water use sectors corresponding to the NAICS industries, as defined by the U.S. Geological Survey (USGS, 2009). Subsequent chapters provide a more detailed analysis of water use by sector and characterize specific water applications in key economic activities. Here, we simply note that agriculture (including the use of

[2] In reporting business census data, establishments that are engaged in multiple activities are assigned a NAICS code based on the activity that accounts for the largest share of their revenues. This can lead to imprecision in classifying economic activity, particularly when classifying activity at a mega-sector level. Most notably, establishments that extract large quantities of water (e.g., a manufacturer that uses water in its production process) is unlikely to be identified as part of the primary (i.e., extractive) mega-sector. Instead, establishments of this type will be classified according to the predominant activity in which they are engaged, which will likely lead to their inclusion in other mega-sectors (e.g., in the case of manufacturing establishments, the secondary mega-sector). Similarly, although integrated water utilities are likely to engage in primary and tertiary activities (e.g., the extraction of raw water and the delivery of finished water), they are generally considered part of the secondary (processing) mega-sector, presumably because their principal activity is to treat raw water prior to distribution. In light of this imprecision, the classification schemes discussed here offer only an approximate characterization of economic activity.

water for livestock and aquaculture) and mining (including the use of water for oil and gas extraction) together account for approximately 35 percent of all water withdrawals in the U.S.; these are primary sectors at the top of the NAICS listings. Manufacturing and electric utilities, generally considered secondary sectors, account for another 53 percent of total withdrawals. In 2010, these four sectors together generated approximately 16 percent of the nation's gross domestic product (BEA, 2012).[3]

EXHIBIT 2-3. MAJOR SECTORS IN NORTH AMERICAN INDUSTRY CLASSIFICATION SYSTEM

MEGA-SECTOR	NAICS CODE	SECTOR	USGS WATER USE CATEGORIES
Primary	11	Agriculture, forestry, fishing, and hunting	Irrigation, Livestock, Aquaculture
	21	Mining	Mining
Secondary	22	Utilities	Public Water Supply, Thermoelectric Power
	23	Construction	NA
	31, 32, 33	Manufacturing	Industrial (e.g., paper, petroleum, metals, chemicals)
Tertiary	42	Wholesale trade	NA
	44, 45	Retail trade	NA
	48, 49	Transportation and warehousing	NA
Quaternary	51	Information	NA
	52, 53	Finance, insurance, real estate, rental, and leasing	NA
	54, 55, 56	Professional and business services	NA
	60	Educational services, health care, and social assistance	NA
	70	Arts, entertainment, recreation, accommodation, and food services	NA
	81	Other services, except government	NA
	92	Government	NA

Sources: U.S. Department of Commerce, Bureau of Economic Analysis, Input-Output Accounts Data, Table A: Industries and Commodities in the Industry Accounts, accessed online at http://www.bea.gov/industry/io_annual.htm.

WATER USE AND SECTOR INTERACTIONS

Economic theorists such as Piero Sraffa and Wassily Leontief studied the interaction of major economic sectors. Leontief earned a Nobel Prize for his work in the field of input-output analysis, modeling the process by which one industry supplies inputs to others. Much of Sraffa's work stressed the role of "basic commodities" in the overall economy,

[3] Public supply (11 percent) and domestic self-supply (1 percent) account for the remaining withdrawals. As noted in greater detail in Chapters 3 and 4, public water supply systems (a part of the secondary mega-sector) serve customers in the manufacturing sector, as well as those in the commercial, institutional, and residential sectors. Thus, data on water withdrawals by sector likely understate the use of water in manufacturing.

and the ways in which the loss of basic commodities could undermine the functioning of a closed economic system (Kenessey, 1987).

The fundamental concepts in Sraffa and Leontief's work are reflected in current input-output data for the U.S. economy. The U.S. Bureau of Economic Analysis (BEA) publishes Industry Economic Accounts that trace the flow of goods and services between economic sectors. These include a "Use Table" that shows the commodities consumed by each industry and the source of those commodities. Exhibit 2-4 presents the 2010 use table at the level of two-digit NAICS codes. The commodities produced by the industries listed at the left of the table are consumed by other sectors of the economy in the amounts indicated in each row. For instance, sales from the mining sector to the manufacturing sector totaled approximately $427.6 billion in 2010 (see dark green highlighting). Distinct from the sale of intermediate goods, the table also shows the value of commodities sold directly to personal consumption and other final uses (see the column at the far right of the exhibit).

While the use table is complex, one simple observation is that industries in the secondary sector, such as manufacturing, rely heavily on inputs from industries in the primary sector. Exhibit 2-5 helps to clarify this point, consolidating the flow of intermediate products to the mega-sector level. As it indicates, the output of the primary sector flows predominantly to the secondary sector (see red shading); in turn, the output of the secondary sector supports both higher-level manufacturing (green shading) as well as activity in the tertiary and quaternary sectors of the economy (purple shading).

A second observation is that the sectors of the economy that make the greatest direct use of water – i.e., agriculture, mining, utilities, and manufacturing – are located at its base, in its primary and secondary tiers. The goods and services these sectors produce are used extensively by the intermediate sectors, which in turn sell their output to the rest of the economy. *As such, the economy as a whole is indirectly dependent upon the output of industries for which water is a critical input.*

The role of water-intensive sectors in supporting the economy becomes evident when we consider how a major water supply shortage could affect the broader economy. For instance, a major water shortage affecting U.S. agricultural output would result in a shortage of inputs for a variety of industries, with the greatest impact on certain categories of manufacturing. A more detailed version of the use table presented above shows food and beverage manufacturers purchase about $194 billion in inputs from U.S. farms. To the extent that food and beverage manufacturers curtailed production, an array of other sectors would be affected. For example, the food and beverage makers would purchase less packaging from the paper and plastics industries; transporters of food and beverage products (primarily rail and truck) would haul less freight; wholesalers would sell fewer food products; and so on.

EXHIBIT 2-4. BEA STANDARD "USE" TABLE, 2010 ($ MILLIONS)

Mega-Sector	NAICS Code	Sources of Purchased Commodities	INDUSTRIES PURCHASING INTERMEDIATE COMMODITIES																
			Ag, Forestry, Fishing	Mining	Utilities	Con-struction	Manu-facturing	Wholesale Trade	Retail Trade	Transpor-tation and Ware-housing	Infor-mation	Finance, Insur-ance, etc.	Profes-sional and Business Services	Educa-tional Services, Health Care	Arts, Enter-tainment, Recrea-tion, etc.	Other Services	Govern-ment	Total Interme-diate Purchases	Personal Consump-tion and Other Final Uses
Pri-mary	11	Agriculture, forestry, fishing, and hunting	64,636	-	1	1,186	220,039	475	3,430	30	3	334	1,095	422	7,610	65	2,249	301,575	72,877
	21	Mining	816	33,655	62,057	8,901	427,580	321	244	2,171	943	2,333	1,187	924	1,017	373	21,146	563,668	(161,729)
Secondary	22	Utilities	5,642	8,435	193	3,419	73,548	6,664	12,653	2,400	4,547	15,049	7,954	21,373	17,840	3,183	27,833	210,736	259,942
	23	Construction	1,747	10,821	5,714	875	17,495	2,218	5,043	6,786	8,117	43,926	8,026	5,304	5,183	4,033	74,185	199,475	846,689
	31,32, 33	Manufacturing	80,294	50,315	4,107	246,347	1,531,048	74,274	88,617	140,718	67,890	72,552	102,257	147,580	124,500	25,991	330,481	3,086,970	1,693,692
Tertiary	42	Wholesale trade	20,092	6,334	573	25,774	220,880	45,147	23,142	11,561	14,441	16,843	12,214	22,641	25,673	3,980	51,306	500,601	722,117
	44,45	Retail trade	796	767	38	36,296	7,570	760	2,363	4,200	158	10,903	1,055	1,869	4,028	2,317	187	73,308	1,141,158
	48,49	Transportation and warehousing	7,486	9,615	14,625	14,011	108,001	41,648	42,844	69,462	15,420	19,762	27,503	14,587	10,002	5,169	54,793	454,929	337,951
Quaternary	51	Information	248	905	510	6,427	20,439	11,148	14,193	4,458	157,415	56,627	51,959	25,896	17,155	7,941	78,943	454,263	549,388
	52,53	Finance, insurance, real estate, rental, and leasing	27,369	20,145	4,079	31,524	115,949	67,088	110,973	45,447	72,197	1,147,398	181,609	231,708	70,038	85,992	107,816	2,319,332	2,589,605
	54,55, 56	Professional and bus. svcs.	2,746	40,775	7,537	83,861	322,228	147,935	116,762	48,489	176,619	351,352	322,359	187,362	105,656	38,828	412,196	2,364,705	546,678
	60	Educational services, health care, etc.	621	1	39	26	83	654	2,814	74	786	188	716	35,002	935	2,150	30,040	74,128	2,175,423
	70	Arts, entertainment, recreation, etc.	252	601	1,763	2,983	16,220	7,381	7,671	7,001	34,113	43,616	52,333	18,795	30,656	5,813	35,800	264,999	822,208
	81	Other svcs. (except gov.)	732	779	302	15,066	16,085	10,633	9,287	4,262	10,011	43,243	25,081	19,653	10,779	10,788	26,566	203,269	485,340
	92	Government	45	22	90	35	2,503	9,676	9,561	9,037	4,332	6,428	7,152	8,629	9,106	2,149	11,832	80,596	2,567,807
	NA	Scrap and used goods	487	102	6	387	7,222	2	601	707	10	(661)	1,080	1,803	124	697	(2)	12,564	(4,164)
	NA	Noncomp. imports and rest-of-the-world adjust.	91	988	173	191	23,715	8,560	465	16,555	15,224	23,376	6,217	15	354	58	23,737	119,719	(118,436)
		Total intermediate purchases by industry	214,099	184,260	101,807	477,307	3,130,605	434,585	450,663	373,358	582,227	1,853,270	809,798	743,562	440,656	199,529	1,289,111	11,284,836	

Source: U.S. Bureau of Economic Analysis, Industry Economic Accounts, Annual I-O Data, 1998-2010 Summary Use Annual I-O Table before redefinitions, accessed online at http://www.bea.gov/industry/io_annual.htm.

EXHIBIT 2-5. FLOW OF INTERMEDIATE INPUTS BETWEEN MEGA-SECTORS ($ MILLIONS)

SOURCE OF COMMODITIES PURCHASED	MEGA-SECTORS PURCHASING INTERMEDIATE COMMODITIES			
	PRIMARY	SECONDARY	TERTIARY	QUATERNARY
Primary	$99,107	$719,764	$6,671	$16,306
Secondary	$157,254	$1,882,746	$339,373	$1,117,804
Tertiary	$45,090	$427,768	$241,127	$314,851
Quaternary	$95,241	$647,749	$644,544	$4,373,758

Source: U.S. Bureau of Economic Analysis, Industry Economic Accounts, Annual I-O Data, 1998-2010 Summary Use Annual I-O Table before redefinitions, accessed online at http://www.bea.gov/industry/io_annual.htm.

The economic repercussions of water shortages are not hypothetical; they can be readily observed in current events. From 2009 to 2011, large parts of west Texas and neighboring states experienced their worst drought on record. The drought depleted storage reservoirs and severely limited water availability for cotton, wheat, and peanut cultivation, beef cattle operations, and other agricultural activity. Immediate effects in the regional agricultural sector included failed crops and a sell-off of cattle (Galbraith, 2011). In the longer run, economists anticipate additional impacts, both domestically and internationally. Domestically, winter wheat shortages are expected to produce price spikes and affect producers and consumers of bread and other wheat-based products. Likewise, once the short-run glut of beef cattle passes, reduced activity at domestic slaughterhouses and increases in domestic beef prices are likely. In addition, much of the cotton crop from the region is exported to textile mills in China, Mexico, and Southeast Asia. These buyers are likely to seek other sources of cotton, endangering the long-term viability of U.S. cotton operations (Hylton, 2011).

WATER USE IN AN OPEN ECONOMY

While attempts to describe the structure of a nation's economy may, for simplicity, depict a closed system, it is unquestionably clear today that globalization has increased interdependencies between the U.S. economy and the economies of other nations. As such, domestic water shortages can have far-reaching international repercussions (as illustrated in the case of the Texas drought described above). Likewise, water supply shocks in other nations could affect the availability and prices of imported goods purchased by U.S. consumers. *Because water is an essential input into the economic system, major water shortages have the potential to affect not only the balance of trade, but also the structure and composition of different nations' economies, including the U.S. economy*. While disruptions in water supply have yet to play a key role in the mix of goods and services produced in the U.S., such outcomes are conceivable in certain scenarios. If the U.S. were to become an importer of water or water-intensive products, U.S. economic security could be affected. This highlights the importance of efficient and

sustainable management of domestic water resources, as well as the importance of global cooperation in water resource management.

SUMMARY

Exhibit 2-6 integrates the key concepts surrounding water use and macroeconomic interactions. Water and other natural resources serve as essential inputs to activity in the primary (i.e., extractive) and secondary (i.e., processing) mega-sectors of the economy.[4] All four levels of the economy interact, exchanging goods and services and delivering final goods to consumers; at a fundamental level, however, the extraction and use of natural resources lies at the base of much economic activity. Moreover, economic activity in all four sectors has an iterative effect on the abundance and quality of natural resources. This is most readily observed in the environmental impacts of resource extraction and industrial pollution. A less obvious recursive impact concerns the positive effect that the information sector can have on the environment, supporting decisions that will ensure the sustainability of natural resources and ecosystems.

CONCLUSION

The first section of this chapter provided a brief overview of key microeconomic concepts as applied to the value of water. Much of the discussion highlighted the importance of clarity in terminology, particularly in distinguishing between and among marginal, average, and total economic values. It also noted how the lack of conventional markets for water undermines understanding of its value, and how the value of water in a particular application is likely to vary not only with the relative scarcity of the resource, but also with other considerations, such as the reliability of the supply and whether the quality of the water meets the requirements of the intended use.

The macroeconomic section of this chapter noted that the use of water in the U.S. economy is concentrated in primary industries, such as agriculture and mining, and in secondary industries, such as utilities and manufacturing. It also illustrated the connection between these sectors and activity in other sectors of the economy, and discussed the potential impact of a shortage in water supply for the economy as a whole.

The concepts presented above provide important background for the water use and value information discussed in subsequent chapters of this report. The purpose of these chapters is not to arrive at a single estimate of the total value of water to the U.S. economy, nor is it to prescribe a more optimal allocation of the nation's water resources. Instead, these chapters summarize our current understanding of the use of water in the economy and the values associated with that use, both from a microeconomic and a macroeconomic perspective. The discussion also notes gaps in our understanding of these values, gaps which exacerbate the difficulty of managing water resources in an economically efficient and environmentally sustainable fashion. *As such, the chapters that follow represent an attempt both to describe water's economic importance and to identify additional information that may be needed, in the long-run, to derive the maximum sustainable value from management and use of the nation's water resources.*

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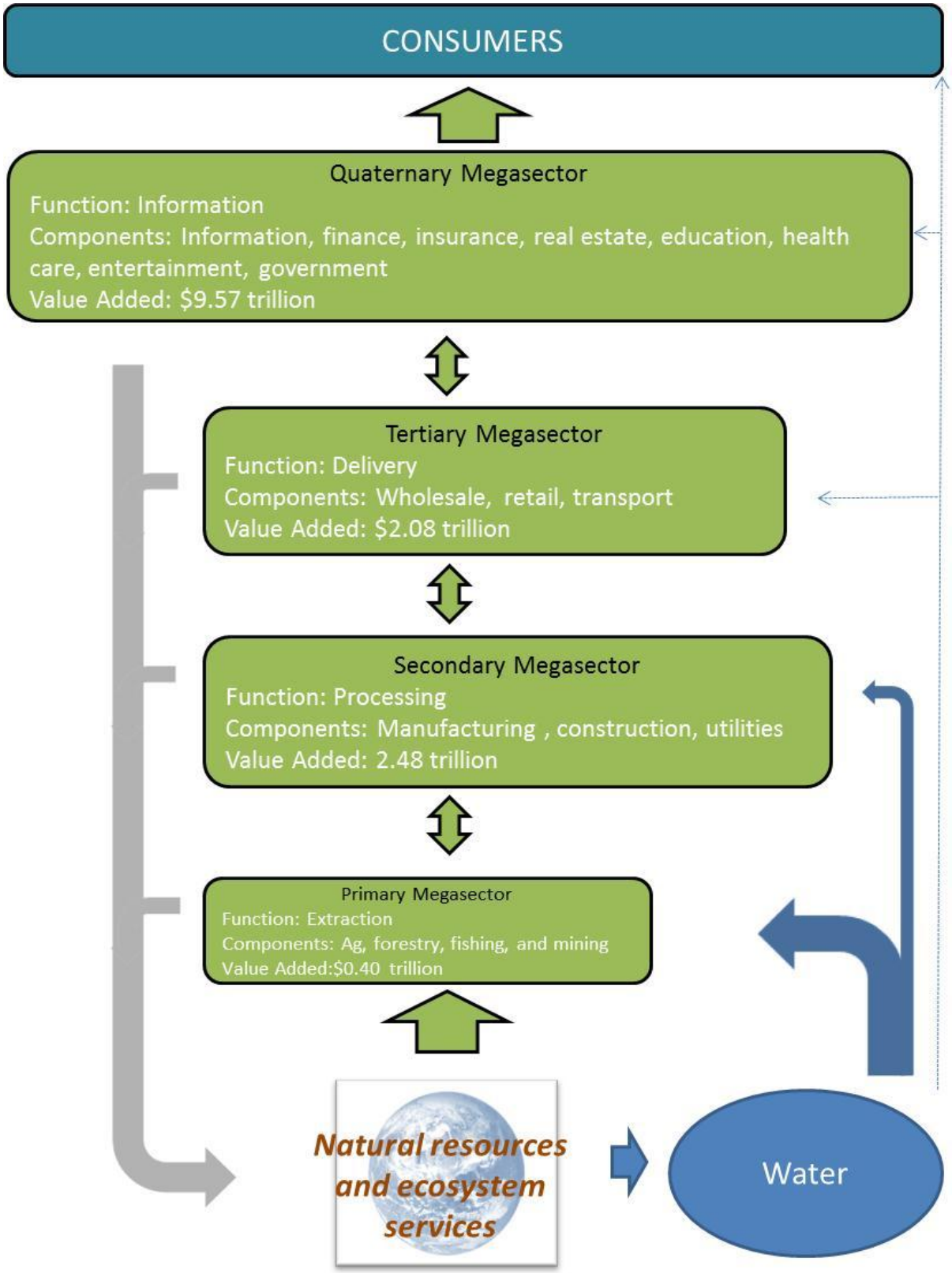
[4] Note that this characterization of natural resource use is not unique to water resources; other resources such as timber or minerals could be considered in the same framework.

EXHIBIT 2-6. INTERACTION OF MACROECONOMY, WATER USE, AND THE ENVIRONMENT



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CHAPTER 3 | TRENDS IN WATER USE AND AVAILABILITY

INTRODUCTION

Water is vital to American households, farms, and businesses. Major off-stream uses of water (i.e., uses for which water is withdrawn or diverted from its source) range from domestic consumption to the use of water in agriculture, mining, energy resource extraction, manufacturing, and the production of thermoelectric power. Major in-stream uses are similarly diverse, ranging from the generation of hydroelectric power to commercial fishing, commercial navigation, swimming, boating, and other forms of recreation. These uses draw on the nation's natural endowment in water resources and on private and public investment in the infrastructure needed to employ and manage those resources.

CHAPTER OVERVIEW

This chapter describes:

- The major water-using sectors of the U.S. economy;
- Overall trends in water use;
- State-by-state variation in water use;
- The sources of water upon which the U.S. relies; and
- Evidence of existing or potential future stress on regional water supplies.

The nation's water resources have played an important role in its economic development. Nationwide, the withdrawal of water for off-stream use grew steadily until the 1980s, when gains in efficiency and other factors led off-stream use to stabilize. Withdrawals have continued to grow, however, in certain regions, particularly in the south and west, where economic expansion and population growth have increased demand for water and raised concerns about the long-run sustainability of current levels of use. The potential for increased competition in the future points to the need for greater efficiency in the use of water, as well as for improvements in water resource management.

These developments highlight the central focus of this report. As with any resource, the scarcity of water in some regions of the country raises the opportunity costs associated with its use. In the past, supplies in many areas were generally sufficient to satisfy demand; where supplies were insufficient, public works initiatives moved water to where it was needed. The abundance of water in these cases – whether natural or engineered – precluded the development of markets or the attachment of a marginal price to water. Going forward, however, a better understanding of opportunity costs will be needed to address what could be potentially significant tradeoffs between or among competing uses. In some cases markets may emerge, providing a mechanism to use water more efficiently; such markets have already begun to develop in some western states. In other cases, where public officials may be asked to help manage scarce water resources, an understanding of the value of water in alternative uses will

help to inform decisions and yield more efficient outcomes. Likewise, when public officials evaluate investments in development and maintenance of water infrastructure, information on the value of water will help to support decisions that maximize social welfare.

The discussion that follows presents a foundation for understanding these issues. It begins with a summary of water use in the United States, examining both current use and changes in use since 1950. This portion of the chapter draws extensively upon information presented in a 2009 United States Geological Survey (USGS) report, *Estimated Water Use in the United States in 2005*. The discussion then shifts to an examination of water scarcity issues, both at the national and regional levels. It describes the evidence of existing stress on the nation's water supplies and considers forecasts of scarcity in the future, based on projected economic and population growth and potential changes in climate.

WATER USE IN THE UNITED STATES

As discussed in Chapter 2, water is a key resource for several sectors of the U.S. economy. A general understanding of the demand for water in these sectors, including recent trends in water use, is essential to understanding the importance of water to the economy as a whole. To provide this context, the discussion below characterizes U.S. water use from the following perspectives:

- First, it summarizes off-stream use by economic sector, noting both current use and recent trends. This discussion also provides a geographic perspective on off-stream uses of water, and summarizes overall trends in use over time.
- Second, it identifies areas of economic activity that make direct or indirect use of water in-stream, including hydropower, commercial fishing, commercial navigation, and recreation and tourism.

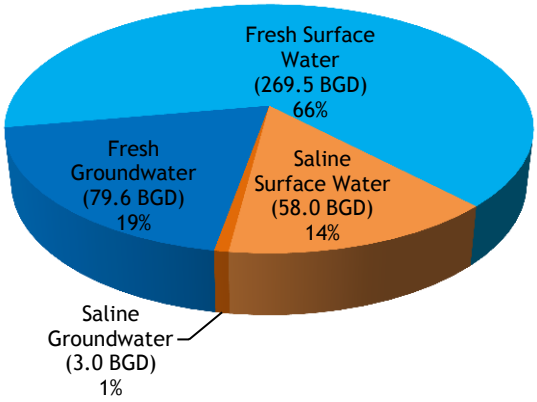
OFF-STREAM USE

In 2005, off-stream water use in the United States totaled an estimated 410 billion gallons per day (BGD). Approximately 80 percent of this water (327.5 BGD) was drawn from lakes, rivers, oceans, and other surface water sources. The remaining 20 percent (82.6 BGD) was groundwater. More than 85 percent of the water used in 2005 was fresh; 15 percent was saline. Exhibit 3-1 illustrates the distribution of withdrawals by source.

The USGS separates water withdrawals into eight water use categories, or sectors: public supply; domestic self-supply; irrigation; livestock; aquaculture; industrial; mining; and thermoelectric power. Exhibit 3-2 shows the distribution of withdrawals in 2005 by sector. Note that all sectors draw from both surface water and groundwater sources. Most sectors, however, rely exclusively on fresh water. Only the industrial, mining, and thermoelectric power sectors make use of saline water.[5]

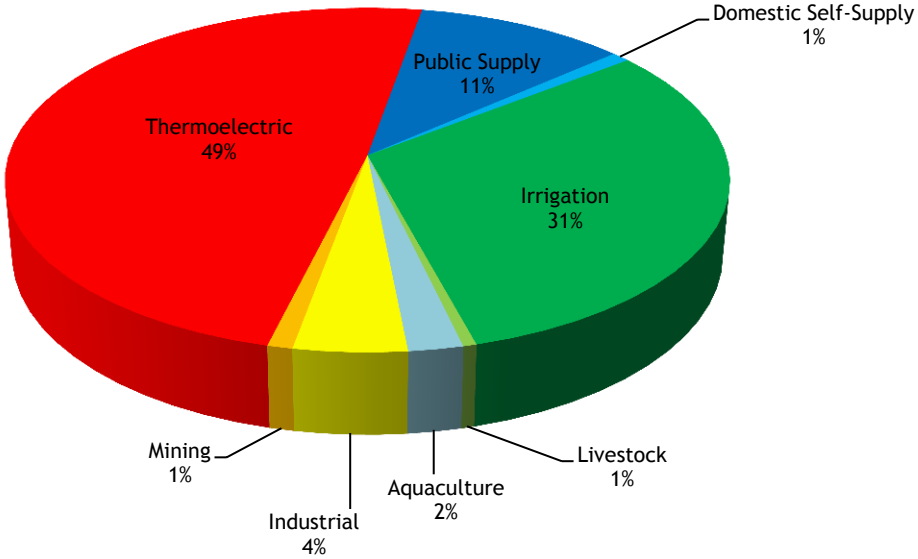
[5] It is important to note that USGS provides information on water *withdrawals* by sector, rather than water *use*. In most instances, it is reasonable to assume that water withdrawn by a sector is used in that sector. This is not the case, however, with public water supply systems, which serve residential, industrial, commercial, and institutional consumers. Additional information on the use of water withdrawn by public water supply systems is provided below and in Chapter 4.

EXHIBIT 3-1. DISTRIBUTION OF 2005 WATER WITHDRAWALS BY SOURCE



Source: Data from USGS, *Estimated Water Use in the United States in 2005*, p. 6. Hereafter *2005 Water Use*.

EXHIBIT 3-2. DISTRIBUTION OF 2005 U.S. WATER WITHDRAWALS BY SECTOR



Source: *2005 Water Use*, p. 5.

Public Supply

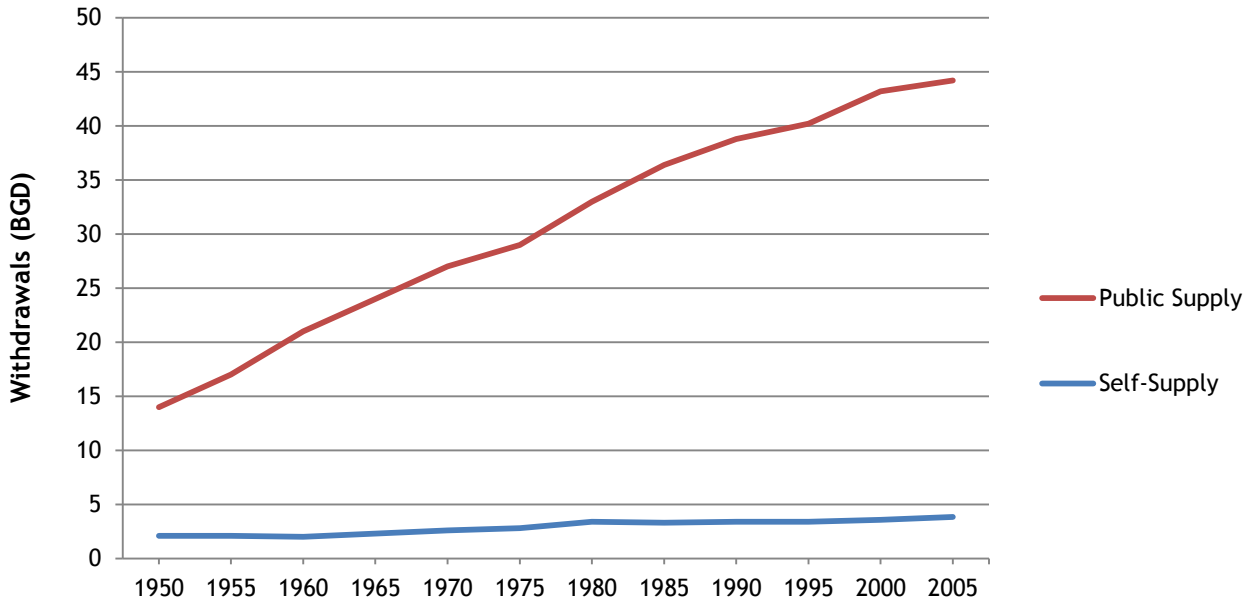
Public supply includes any water withdrawn by public or private suppliers and delivered to end users, whether for domestic (i.e., household) use or other purposes. Public supply accounts for 11 percent of total water use in the United States – approximately 44.2 BGD – of which 67 percent is drawn from surface water sources and 33 percent from groundwater. Approximately 58 percent of public supply withdrawals are delivered for

domestic use, serving an estimated 86 percent of the population. The per capita use of those served by public supply is approximately 99 gallons per day. The remaining 42 percent of public supply withdrawals go towards commercial, industrial, and other uses.

Since 1950, when the USGS began to collect and report estimates of water use, the percentage of the population served by public supply has risen considerably. In 1950, roughly 62 percent of the population was served by public supply; by 2005 that figure had risen to 86 percent. The amount of water withdrawn for public supply has increased accordingly. As shown in Exhibit 3-3, public supply accounted for withdrawals of 14.0 BGD in 1950; by 2005 the total had more than tripled, to 44.2 BGD.

Further information about the use of water in the public supply sector can be found in Chapter 4.

EXHIBIT 3-3. TOTAL PUBLIC SUPPLY AND SELF-SUPPLY WITHDRAWALS, 1950 TO 2005



Source: *2005 Water Use*, p. 43.

Domestic Self-Supply

Domestic water use includes the use of water in or around the home, either as drinking water or for bathing, household sanitation, cooking, watering lawns and gardens, and other household purposes. Approximately 14 percent of the population lives in households that are self-supplied; i.e., supplied by water from private sources, such as in-ground wells or cisterns that collect rainwater. Self-supply represents approximately 1 percent of total U.S. water use. Ninety-eight percent of all self-supplied withdrawals

come from fresh groundwater, accounting for 5 percent of total U.S. groundwater withdrawals.

Since the USGS began to compile and report estimates of water use, the population served by self-supply has diminished. In 1950, 57.5 million people supplied their own water; by 2005 only 42.9 million did. In contrast, the total volume of self-supply withdrawals increased during this period, from approximately 2.1 BGD in 1950 to 3.8 BGD in 2005. This represents an increase of 148 percent in water use per capita, from approximately 36 gallons per day to 89 gallons per day. Exhibit 3-3 shows the growth in self-supply withdrawals from 1950 to 2005.

Chapter 4 provides additional information on the domestic self-supply sector.

Irrigation

Irrigation withdrawals include all water used to sustain plant growth in agricultural and horticultural practices, including water used for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching salts from the root zone, and water lost in conveyance. Irrigation accounts for 31 percent of total U.S. water use and 37 percent of total freshwater use. Forty-two percent of all irrigation withdrawals – a total of 53.5 BGD – come from groundwater. This accounts for 65 percent of U.S. groundwater use.

From 1950 through 1980, the amount of water withdrawn for irrigation increased in every five-year reporting period, peaking in 1980 at 150 BGD. Since then, however, withdrawals for irrigation have fallen in every five-year reporting period except 2000, when, due to a dry season, the withdrawal rate rose to 139 BGD. In 2005, however, the downward trend resumed, with the withdrawal rate falling to 128 BGD.

The reduction in the quantity of water withdrawn for irrigation reflects the increased use of more efficient irrigation methods, rather than a reduction in the amount of land irrigated. In 1950 the average application rate was 3.55 acre-feet per acre served; by 2005 this figure had fallen to 2.35 acre-feet per acre served. This can be attributed to an increase in the use of sprinkler irrigation systems and a reduction in the use of flood systems, which lose water in conveyance. Between 1985 and 2005, the amount of land irrigated by sprinkler systems increased from 22 million to more than 30 million acres. In that same period, the amount of land irrigated by flood systems fell from 35.0 million to 26.6 million acres.

Chapter 5, which covers water use in the agricultural sector, provides additional information on the use of water for irrigation purposes.

Livestock

Livestock withdrawals include any water used to feed and care for livestock or used in feedlots, dairy operations, cooling of the facilities for animals and animal products, dairy sanitation and wash-down of facilities, animal waste disposal systems, and incidental water loss. Livestock, as defined by the USGS, includes dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses, and poultry. Livestock

withdrawals account for less than 1 percent of total U.S. water use. All livestock withdrawals are from freshwater sources and considered self-supplied. In 2005 approximately 2.1 BGD were withdrawn for livestock; 60 percent of this total was groundwater.

The total volume of livestock withdrawals has changed little since 1950. The 2005 figure was 3 percent lower than the figure for 1980, the peak year of U.S. water use, and 10 percent lower than the figure for 2000, the peak year of livestock water use.

Chapter 5 provides additional information on livestock withdrawals.

Aquaculture

The aquaculture category includes withdrawals of water used to raise aquatic organisms for food, restoration, conservation, or sport. Production occurs in several types of enclosures, primarily flow-through raceways and ponds, but to a lesser extent net pens, cages, and closed recirculation tanks. Aquaculture withdrawals make up an estimated 2 percent of total U.S. water use. The majority of water withdrawn for aquaculture (78 percent) comes from surface water.

The USGS first reported aquaculture withdrawals as a separate category in 2000. Estimates of withdrawals by this sector in 2005 indicate a 52 percent increase since 2000, from 5.77 BGD to 8.78 BGD. This increase reflects the rapid growth of the aquaculture industry.

Chapter 5 provides additional information on the use of water in aquaculture.

Industrial

Industrial water use refers to the use of water in a manufacturing capacity, such as cooling, diluting, fabricating, processing, washing, or transporting a product, as well as incorporating water into a product or using water for sanitation needs within a manufacturing facility. Self-supplied industrial water withdrawals make up an estimated 4 percent of total water use in the U.S.[6] Both fresh and saline water are used for industrial purposes. Of the water withdrawn for industrial use, 77 percent was fresh surface water, 17 percent was fresh groundwater, 6 percent was saline surface water, and less than 1 percent was saline groundwater.

As Exhibit 3-4 indicates, industrial water withdrawals have declined 30 percent – from an estimated 25.9 BGD to 18.2 BGD – since 1985. The reason for this decline varies from industry to industry. In some sectors, the decline may reflect a reduction in total manufacturing output. In others, it may reflect a shift towards technologies that use less water, as well as increased reliance on public water supply systems.

Chapter 6 provides additional information on the use of water in the manufacturing sector.

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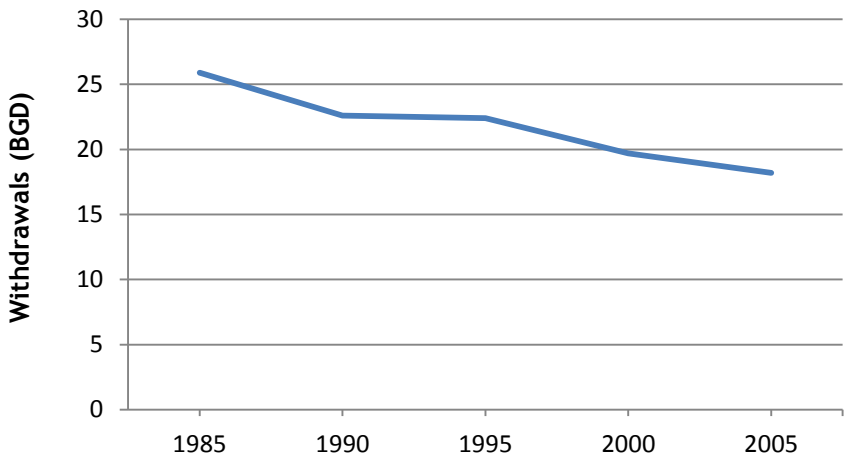
[6] Water used for industrial purposes can be self-supplied or delivered by a public supplier. The USGS did not report public-supply deliveries to industrial users in *2005 Water Use*.

EXHIBIT 3-4. INDUSTRIAL WITHDRAWALS, 1985 TO 2005



Source: *2005 Water Use*, p. 43.

Mining

The mining sector withdraws water for the purpose of extracting minerals that are solid (such as coal, iron, sand and gravel), liquid (such as crude petroleum), or gas (such as natural gas). In some instances, the withdrawal of water is simply a byproduct of the resource extraction process. In others, water is used for such processes as quarrying or milling (crushing, screening, washing, and floatation of mined materials), or is injected to assist with resource recovery. Mining withdrawals account for 1 percent of total water use in the United States. Of the water withdrawn for mining, 38 percent is saline groundwater, 32 percent is fresh surface water, 25 percent is fresh groundwater, and 5 percent is saline surface water.

The USGS began to report mining withdrawals as a separate category in 1985. Since then, withdrawal amounts have changed relatively little, increasing just 17 percent from 1985 to 2005. In 2005, estimated withdrawals were 11 percent lower than they were in 2000, falling from 4.5 BGD to 4.0 BGD.

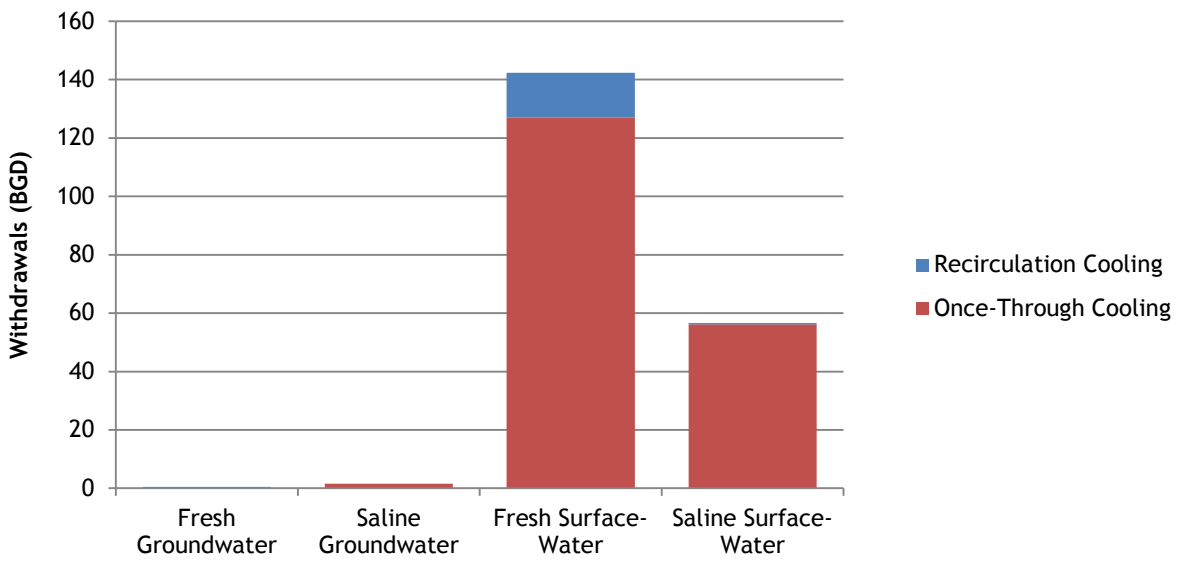
Chapter 7 provides additional detail on the use of water in mining and energy resource extraction.

Thermoelectric Power

The thermoelectric power sector is the single largest user of water in the United States, accounting for 49 percent of total withdrawals in 2005. Water withdrawn by this sector is used primarily as cooling water in generating electricity with steam-driven turbine generators. Of the water withdrawn by this sector in 2005, 71 percent was fresh surface water, 28 percent was saline surface water, about 1 percent was saline groundwater, and less than 1 percent was fresh groundwater.

The USGS separates water use in the thermoelectric power sector into two categories, based on cooling method: once-through cooling, in which water is withdrawn from the source, circulated through heat exchangers, then returned to a surface body of water; and recirculation cooling, in which water is withdrawn from a source, circulated through heat exchangers, cooled using ponds or towers, and then re-circulated. Approximately 92 percent of the water withdrawn by this sector in 2005 was used in once-through cooling. Recirculating cooling accounted for approximately 8 percent of withdrawals. Exhibit 3-5 illustrates the full distribution of use by source and cooling method.

EXHIBIT 3-5. 2005 THERMOELECTRIC POWER WITHDRAWALS BY SOURCE AND COOLING METHOD



Source: *2005 Water Use*, p. 41.

The thermoelectric power sector has been the largest user of water in the United States since 1965. Use of water for thermoelectric power peaked in 1980, when withdrawals reached approximately 210 BGD. From 1980 to 1985 there was an 11 percent decrease in thermoelectric power withdrawals. Since then, however, use by this sector has risen in every five-year period, reaching a rate of 201 BGD in 2005.

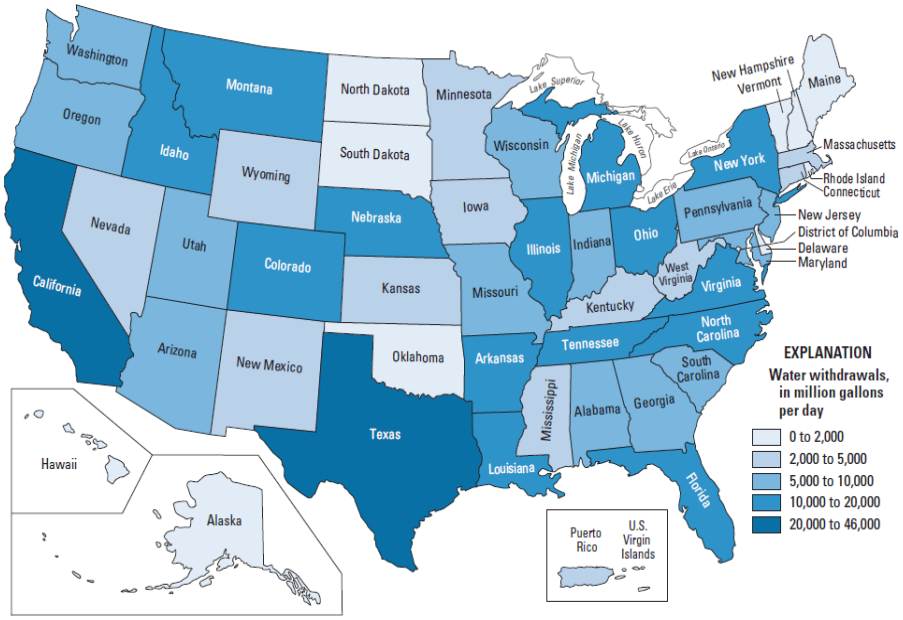
Chapter 8 provides further information on the use of water in electric power generation.

Off-Stream Water Use by State

The volume of off-stream water use varies significantly from state to state, as does the source (surface water or groundwater) and type (fresh or saline) of water that is withdrawn. Exhibit 3-6 presents the distribution of total water withdrawals by state in 2005, while Exhibit 3-7 provides a state-by-state summary of withdrawals, including a detailed breakdown by source (surface water or groundwater) and type (fresh water or saline water). As these exhibits indicate, the five states that reported the greatest volume of water withdrawals were, in order, California, Texas, Idaho, Florida, and Illinois.

Collectively, these five states accounted for more than 30 percent of total water withdrawals in the United States.

EXHIBIT 3-6. TOTAL WATER WITHDRAWALS IN THE UNITED STATES, 2005



Source: *2005 Water Use*, p. 13.

EXHIBIT 3-7. ESTIMATED WITHDRAWALS OF WATER IN THE UNITED STATES, 2005

STATE	POPULATION (THOUSANDS)	WITHDRAWALS (MILLION GALLONS PER DAY)								
		GROUNDWATER			SURFACE WATER			TOTAL		
		FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL
AL	4,560	491	0	491	9,470	0	9,470	9,960	0	9,960
AK	664	482	114	597	393	65	458	876	180	1,060
AZ	5,940	3,040	2.61	3,050	3,200	0	3,200	6,240	2.61	6,240
AR	2,780	7,510	0	7,510	3,920	0	3,920	11,400	0	11,400
CA	36,100	10,700	255	11,000	22,200	12,600	34,800	32,900	12,900	45,700
CO	4,670	2,510	14.6	2,520	11,100	0.39	11,100	13,600	15	13,600
CT	3,510	154	0	154	700	2,900	3,600	854	2,900	3,760
DE	844	127	0	127	507	383	890	635	383	1,020
DC	582	0	0	0	9.7	0	9.7	9.7	0	9.7
FL	17,900	4,200	3.26	4,200	2,620	11,500	14,100	6,820	11,500	18,300
GA	9,070	1,160	0	1,160	4,220	59.5	4,280	5,380	59.5	5,440
HI	1,280	357	1,450	1,800	90	0	90	447	1,450	1,890
ID	1,430	4,360	0	4,360	15,200	0	15,200	19,500	0	19,500
IL	12,800	1,180	25.5	1,210	14,000	0	14,000	15,200	25.5	15,200
IN	6,270	707	0	707	8,630	0	8,630	9,340	0	9,340
IA	2,970	683	0	683	2,680	0	2,680	3,370	0	3,370
KS	2,740	2,950	0	2,950	840	0	840	3,790	0	3,790
KY	4,170	157	0	157	4,170	0	4,170	4,330	0	4,330
LA	4,520	1,620	151	1,780	9,820	0	9,820	11,400	151	11,600
ME	1,320	99.2	0	99.2	366	139	505	466	139	605
MD	5,600	242	0	242	1,110	6,140	7,250	1,350	6,140	7,490
MA	6,400	318	0	318	937	2,340	3,270	1,260	2,340	3,590
MI	10,100	836	0.94	837	10,800	0	10,800	11,700	0.94	11,700
MN	5,130	863	0	863	3,180	0	3,180	4,040	0	4,040
MS	2,920	2,190	0	2,190	654	82.6	736	2,850	82.6	2,930
MO	5,800	1,750	0	1,750	7,050	0	7,050	8,790	0	8,790
MT	936	283	5.12	288	9,830	0	9,830	10,100	5.12	10,100
NE	1,760	7,710	0.09	7,710	4,890	0	4,890	12,600	0.09	12,600
NV	2,410	981	0	981	1,400	0	1,400	2,380	0	2,380
NH	1,310	93.8	0	93.8	345	885	1,230	439	885	1,320
NJ	8,720	592	0.01	592	1,340	5,460	6,800	1,930	5,460	7,390
NM	1,930	1,680	0	1,680	1,650	0	1,650	3,330	0	3,330
NY	19,300	867	0.42	867	9,420	4,890	14,300	10,300	4,890	15,200
NC	8,680	700	0	700	10,600	1,550	12,200	11,300	1,550	12,900
ND	637	142	0	142	1,200	0	1,200	1,340	0	1,340
OH	11,500	946	0	946	10,500	0	10,500	11,500	0	11,500

STATE	POPULATION (THOUSANDS)	WITHDRAWALS (MILLION GALLONS PER DAY)								
		GROUNDWATER			SURFACE WATER			TOTAL		
		FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL
OK	3,540	565	190	755	973	0	973	1,540	190	1,730
OR	3,640	2,140	0	2,140	5,080	0	5,080	7,220	0	7,220
PA	12,400	591	0	591	8,880	0.75	8,880	9,470	0.75	9,470
RI	1,080	29.4	0	29.4	111	264	376	141	264	405
SC	4,260	378	0	378	7,470	0.01	7,470	7,850	0.01	7,850
SD	776	271	0	271	230	0	230	500	0	500
TN	5,960	489	0	489	10,300	0	10,300	10,800	0	10,800
TX	22,900	8,020	548	8,570	15,600	2,580	18,200	23,600	3,130	26,700
UT	2,550	882	73	955	3,940	221	4,160	4,820	293	5,120
VT	623	42.3	0	42.3	480	0	480	523	0	523
VA	7,570	339	10.6	349	6,740	3,530	10,300	7,080	3,540	10,600
WA	6,290	1,410	0	1,410	4,190	33.2	4,230	5,600	33.2	5,640
WV	1,820	141	0.51	141	4,670	0	4,670	4,810	0.51	4,810
WI	5,540	975	0	975	7,620	0	7,620	8,600	0	8,600
WY	509	531	177	708	3,880	0	3,880	4,410	177	4,590
PR	3,910	147	0.34	147	576	2,290	2,860	722	2,290	3,010
U.S.V.I.	109	1.18	0	1.18	10.2	129	139	11.4	129	140
TOTAL	**301,000**	**79,600**	**3,020**	**82,600**	**270,000**	**58,000**	**328,000**	**349,000**	**61,000**	**410,000**

Source: *2005 Water Use*, p. 6.

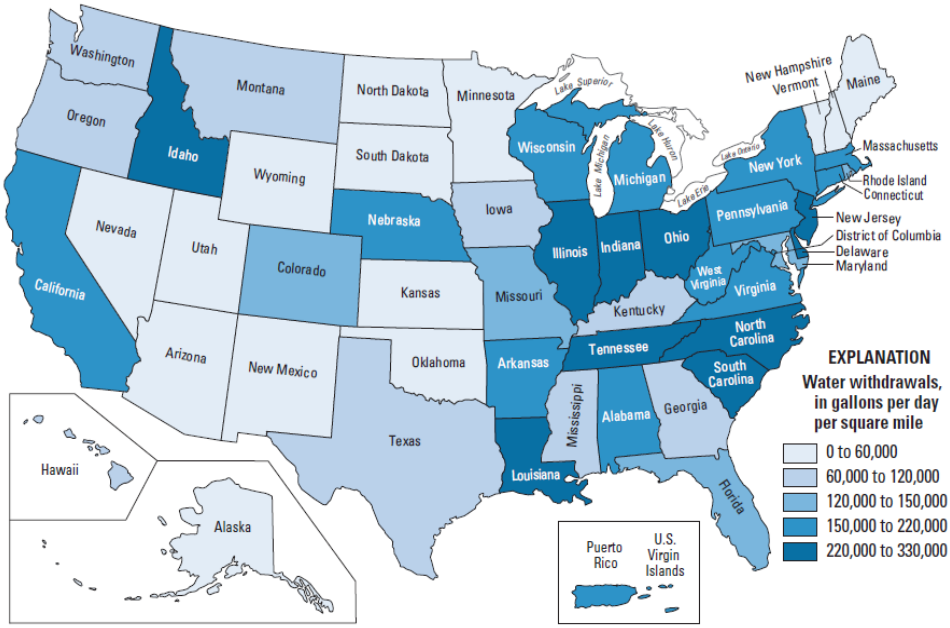
The quantity of water withdrawn for off-stream use is a function of many state-specific factors, such as its population, its economic base, its climate, and the water resources available. While it is difficult to depict the simultaneous influence of all of these factors geographically, it is useful to normalize state water use by three key determinants: geographic area, population, and gross state product (GSP).

- Exhibit 3-8 presents a map of freshwater withdrawals by state in 2005, normalized by total area. As this map indicates, the ten states with the highest ratio of freshwater withdrawals to land area include four states along the Atlantic coast (New Jersey, Delaware, North Carolina and South Carolina) and three states in the Great Lakes region (Ohio, Indiana, and Illinois), as well as Tennessee, Louisiana, and Idaho. Not surprisingly, the intensity of freshwater withdrawals per unit of area is generally greater east of the Mississippi River, where freshwater resources are more plentiful and where population density is higher.
- Exhibit 3-9 shows freshwater use per capita in each state, while Exhibit 3-10 shows freshwater use per thousand dollars of gross state product. The maps show

similar patterns, reflecting the correlation between a state's population and the size of its economy. As the exhibits indicate, relative water use is especially high in several states, including Idaho, Montana, Wyoming, Nebraska, and Arkansas. While no single factor explains this pattern, these states tend to have several features in common: they are not densely populated and have relatively small economies, but those economies include at least one water-intensive economic activity that disproportionately increases their water use. For instance, Wyoming has few residents and a small economy, but has livestock operations that use water in large volumes. Similarly, Idaho's aquaculture industry withdraws large volumes of water to maintain the raceways used in raising trout, while water use in Nebraska and Arkansas is driven primarily by irrigation. All of these agricultural uses – livestock, aquaculture, and irrigation – contribute to the relatively high withdrawals of water reported in Montana.

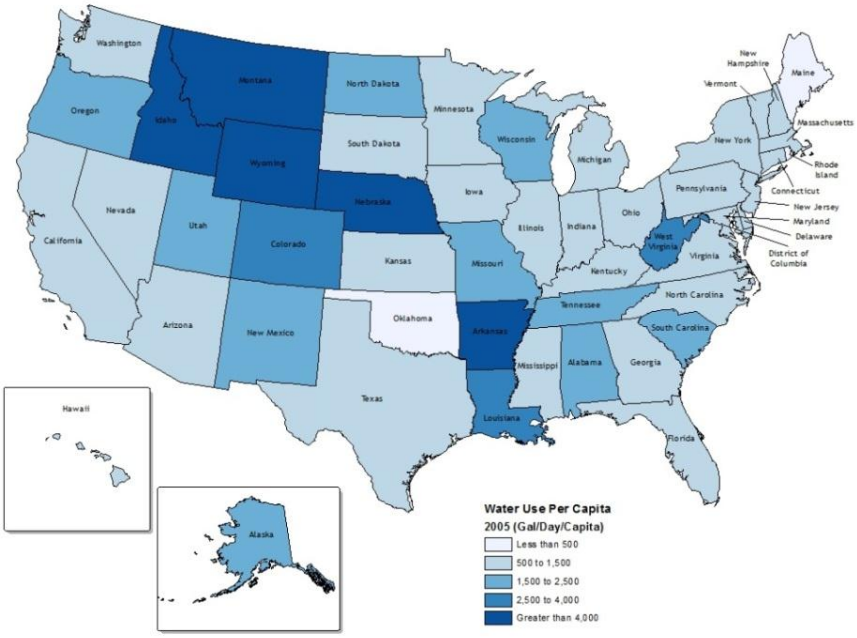
It is tempting to infer from Exhibit 3-10 that the economies of states that use a relatively large volume of water are vulnerable to disruptions in water supply. It is important to recognize, however, that activities that use large volumes of water – for example, Idaho's trout hatcheries – do not necessarily account for large shares of each state's economy. Moreover, water supplies in these states may be plentiful and relatively unsusceptible to long-term disruptions. A more detailed analysis would be needed to reach conclusions about the vulnerability of any state's economy to disruptions in water supplies.

EXHIBIT 3-8. FRESHWATER WITHDRAWALS RELATIVE TO LAND AREA, 2005



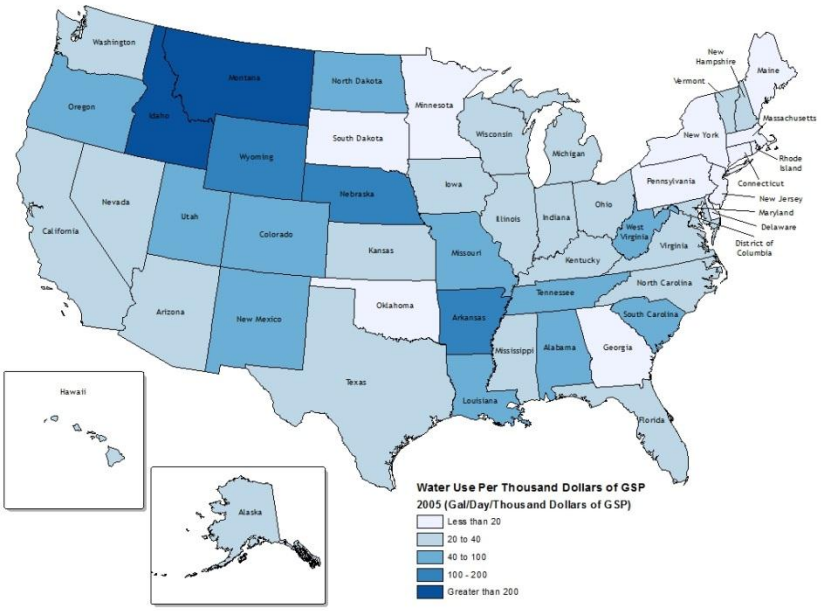
Source: *2005 Water Use*, p. 15.

EXHIBIT 3-9. FRESHWATER WITHDRAWALS PER CAPITA, 2005



Source: Analysis of data from *2005 Water Use* and U.S. Census.

EXHIBIT 3-10. FRESHWATER WITHDRAWALS RELATIVE TO GROSS STATE PRODUCT, 2005



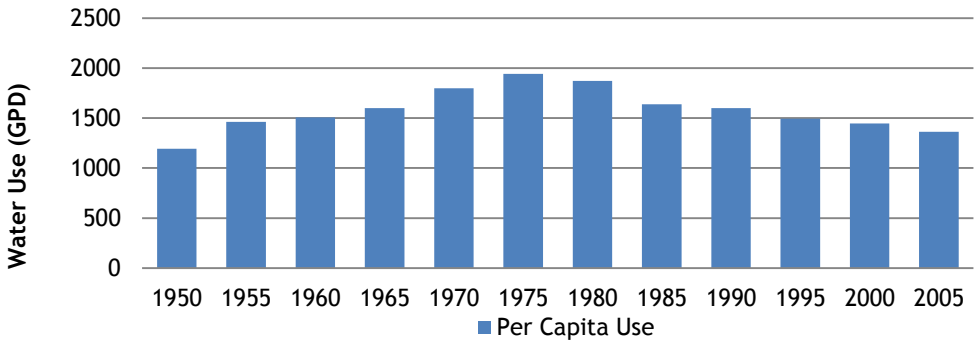
Source: Analysis of data from *2005 Water Use* and U.S Bureau of Economic Analysis.

Overall Trends in Off-Stream Water Use

The USGS estimate of total off-stream water use in 2005 is more than double the agency's estimate for 1950. As Exhibit 3-11 shows, however, per capita water use in the United States has steadily declined since 1975. By 2005 per capita use had fallen to 1,363 gallons per day, only slightly higher than the per capita rate of 55 years before. Exhibit 3-12 further illustrates this trend. As the exhibit indicates, U.S. water use reached an historic peak in 1980; since then, total withdrawals have declined slightly, while the population has continued to rise.

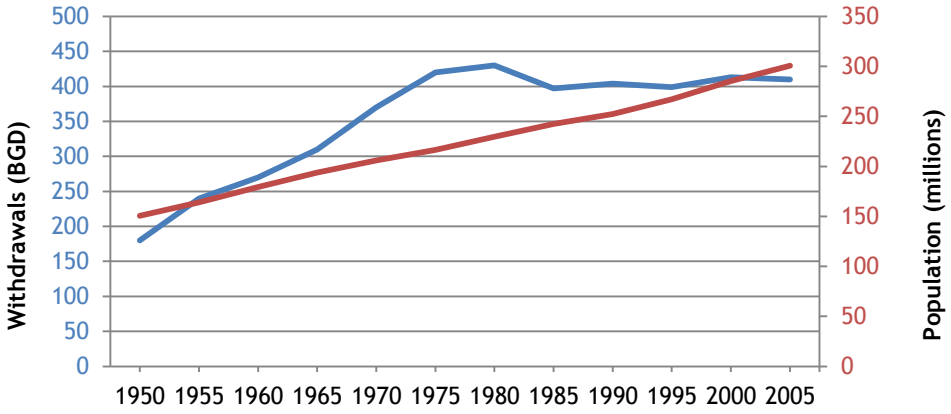
As the discussion above suggests, the decline in per capita water use since 1975 is due primarily to reductions in withdrawals by the thermoelectric power, irrigation, and industrial sectors (see Exhibit 3-13). These reductions have been offset to some extent by an increase in withdrawals for domestic use. As of 2005, both public supply withdrawals – which primarily serve domestic users – and domestic self-supplied withdrawals were at the highest levels yet reported.

EXHIBIT 3-11. PER CAPITA WATER USE IN THE UNITED STATES, 1950 TO 2005



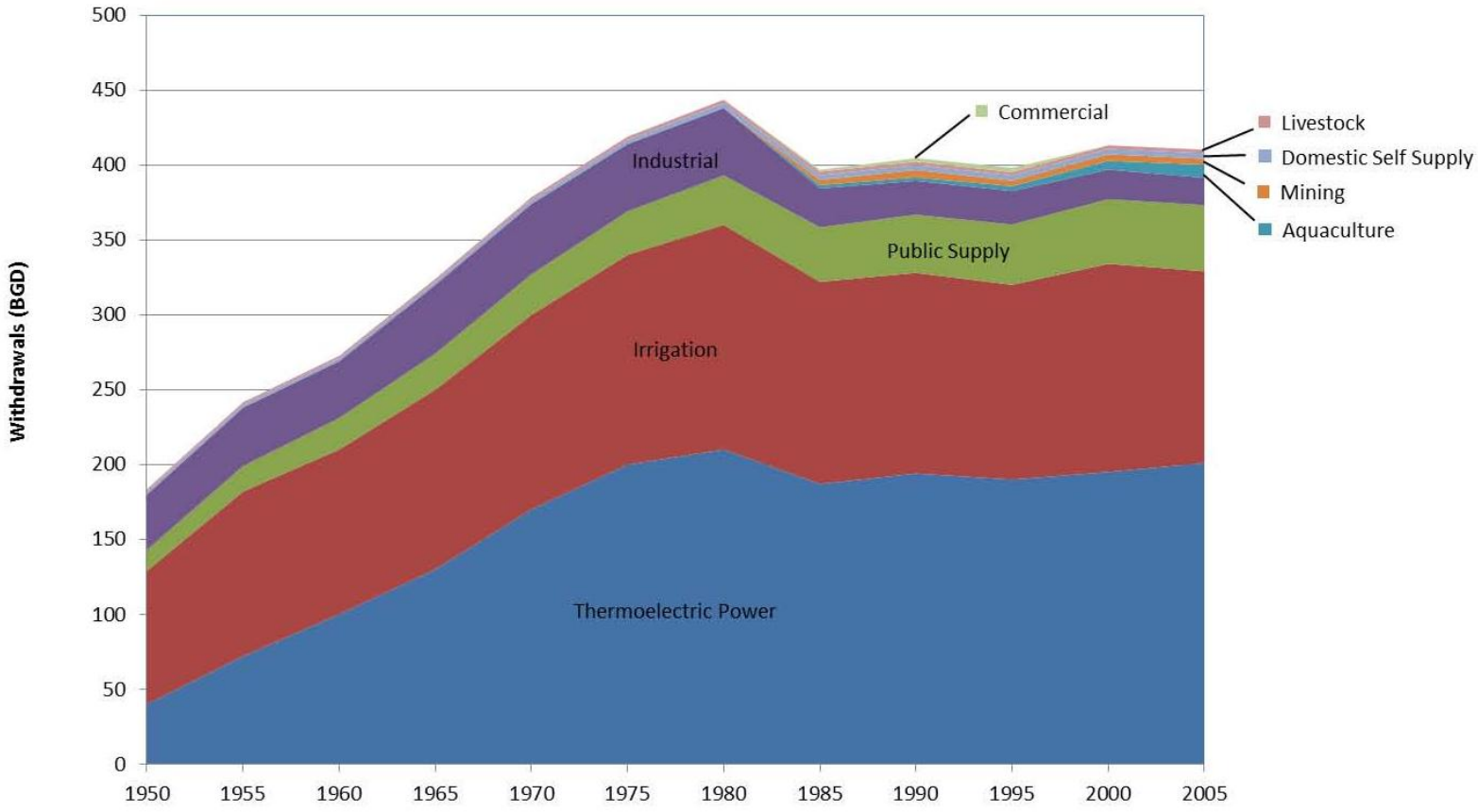
Source: *2005 Water Use*, p. 43.

EXHIBIT 3-12. TOTAL U.S. WITHDRAWALS VS. U.S. POPULATION, 1950 TO 2005



Source: *2005 Water Use*, p. 43.

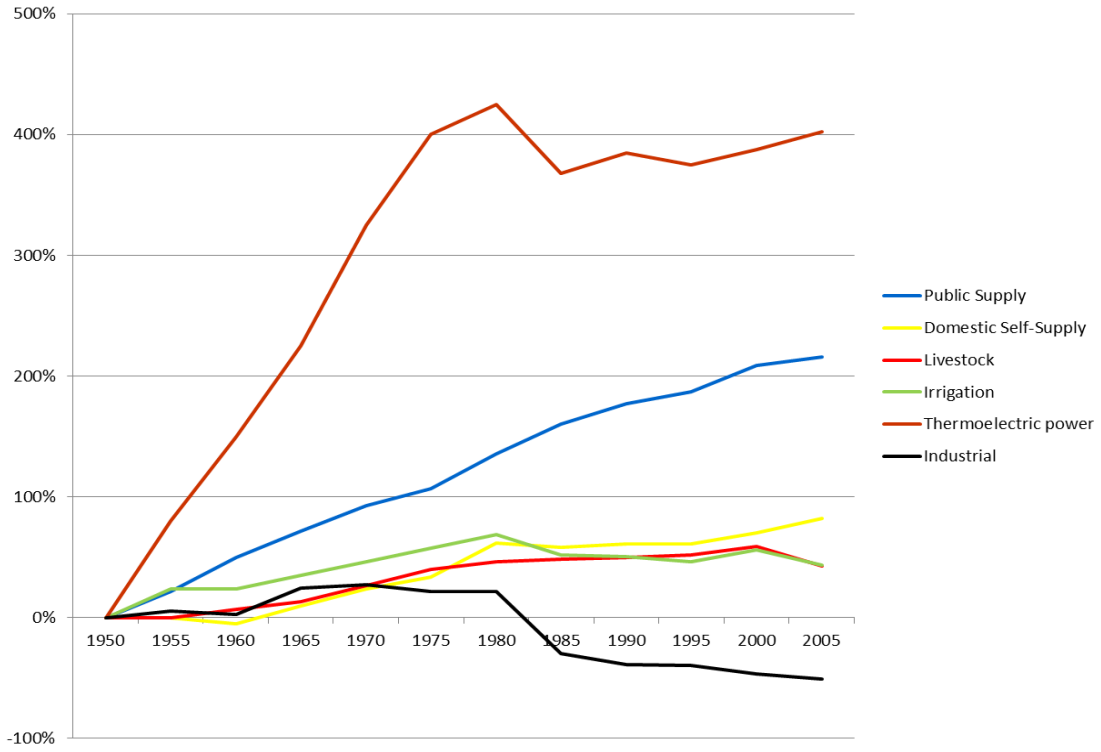
EXHIBIT 3-13. DISTRIBUTION OF U.S. WATER WITHDRAWALS BY CATEGORY, 1950 TO 2005



Source: *2005 Water Use*, p. 43. Prior to 1985 the Commercial, Mining, and Aquaculture categories were included within the industrial sector. The USGS discontinued reporting commercial withdrawals as a separate category in 2000.

Exhibit 3-14 provides an alternative depiction of trends in water use by sector, showing the percent change in water use since 1950. As shown, the use of water by thermoelectric plants grew rapidly between 1950 and 1980, but has remained relatively steady since. Water withdrawals for public supply have grown steadily with U.S. population. Only industrial water use has decreased, the result of increased efficiency, reductions in manufacturing activity, and changes in USGS' water use reporting.[7]

EXHIBIT 3-14. PERCENT CHANGE IN WATER WITHDRAWALS BY CATEGORY, 1950 TO 2005



Source: Analysis of *2005 Water Use*.

[7] The exhibit is limited to those sectors for which water use has been reported continuously since 1950. The decrease in industrial water use is partly attributable to the fact that mining and aquaculture were included in the industrial sector until 1985, at which point USGS broke them out as separate sectors. Likewise, USGS reported commercial water use and industrial water use as separate categories from 1985 through 1995. These changes account for a small share of the observed reduction in industrial water use; other factors are more influential.

IN-STREAM USE

In addition to the off-stream uses of water discussed above, there are several economic activities that use water without withdrawing it from its source. The use of water in these sectors – which include hydropower, commercial fishing, commercial navigation, and recreation and tourism – is not easily measured and is not addressed in the 2005 USGS report. In part, the difficulty in quantification stems from the fact that in-stream use of water for one purpose does not necessarily preclude its use for other purposes; many bodies of water simultaneously support multiple in-stream uses, and are managed to accommodate multiple in-stream and off-stream demands. This is not to say, however, that there is no opportunity cost associated with in-stream use. In some cases, the demands of an in-stream use, such as the management of a river's flow to maintain sufficient depths for commercial navigation, may compete with off-stream demand, such as the use of water for irrigation. Similarly, the demands of one in-stream use, such as the production of hydropower, may compete with the demands of other in-stream uses, such as management of a river to promote commercial or recreational fishing. In addition, the in-stream use of water for non-market purposes – e.g., the maintenance of minimum flows to preserve critical habitat for endangered species – can restrict the withdrawal of water for off-stream use, or the use of water for other in-stream purposes. Thus, understanding the opportunity costs associated with in-stream use is an important part of the discussion of how to optimally use scarce water supplies.

Hydropower

Hydropower accounted for approximately six percent of the electricity generated in the U.S. in 2010; it is a particularly significant source of the electric power produced in Washington, California, Oregon, and New York.

Although water generally is not withdrawn from rivers to generate hydroelectric power, the change in flow regimes associated with hydroelectric development can limit the availability of water for other uses. The reservoirs created by hydroelectric dams can also affect the availability of water by increasing evaporation rates. These reservoirs, however, often serve multiple purposes, including recreation, flood control, and providing a reliable water supply for agricultural and domestic uses. Thus, it is inappropriate to ascribe the increase in evaporative losses solely to hydropower. Chapter 8 provides additional information on the use of water in this sector.[8]

Commercial Fishing

The U.S. commercial fishing industry reported domestic ex-vessel revenues of approximately $4.5 billion in 2010. Marine fisheries account for all but a small percentage of U.S. commercial fishing revenues. Nonetheless, riverine and coastal ecosystems play a vital role in supporting sustainable fish stocks, providing spawning grounds, nurseries, and feeding areas for many commercially important species. The

[8] The 2005 USGS report does not estimate water used for hydropower generation; in 1995, the last time such data were included, USGS estimated that a total of 3,160 BGD were used. This figure, which exceeds average annual runoff in the U.S. by a factor of 2.6, is misleading because it over-counts water that is used several times as it passes through multiple hydroelectric dams on a single river.

health of these ecosystems is threatened by pollution from point sources (including manufacturing facilities or sewage treatment plants) and non-point sources (including urban stormwater and agricultural runoff). Fish species that migrate upstream to spawn also face threats from hydropower dams. Although the precise relationship between habitat quality and fish populations is complex, uses of water that harm water quality or impede fish passage may adversely affect this in-stream use of water.

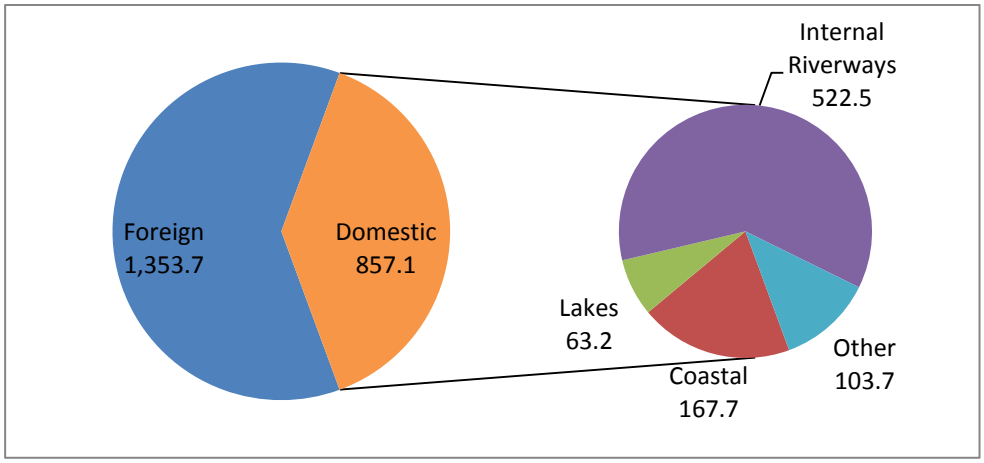
Chapter 9 provides additional information on the commercial fishing sector and the implications of changes in water or habitat quality for that sector.

Commercial Navigation

Commercial navigation encompasses the movement of cargo and passengers by water. Transport of cargo by water is generally less expensive than alternate modes of transportation (e.g., trucking, rail, air) on a cost per ton-mile basis, making it particularly important for industries that rely on bulk shipment of goods.

As Exhibit 3-15 shows, U.S. waterborne shipments of freight in 2009 totaled approximately 2.2 billion tons. International trade accounts for the majority of commercial shipping activity at U.S. ports. As the exhibit also indicates, domestic shipping occurs primarily along internal riverways, and to a lesser extent along the Pacific, Atlantic, and Gulf coasts or the Great Lakes.

EXHIBIT 3-15. U.S. WATERBORNE TRAFFIC, 2009 (MILLIONS OF TONS)



Source: USACE, Navigation Data Center, *The U.S. Waterway System*, November 2010. Note: Other includes intra-port and intra-territory traffic.

Although commercial shipping is generally unaffected by water quality, the viability of shipping routes depends on maintaining sufficient depth at ports, rivers, locks, and channels. Chapter 10 provides additional information on commercial navigation and the infrastructure required to maintain the navigability of the nation's waterways.

Recreation and Tourism

Tens of millions of Americans participate in some form of water-based recreation every year, ranging from boating, swimming, and enjoyment of beaches to hiking, hunting, and wildlife viewing in close proximity to water. Those who participate in these activities, along with travelers from abroad, help to support the nation's multi-billion dollar recreation and tourism industry.

Water quality is a critical dimension of the ability of a water resource to support recreational activity. Activities like swimming, fishing, hunting, and wildlife viewing depend on adequate water quality, either to protect human health or to support native habitats. As with the commercial fishing sector, water uses that impair water quality or aquatic habitats may jeopardize water-based recreation and tourism. Chapter 11 discusses the importance of water quality for this sector.

WATER SUPPLY AND SCARCITY

When considered in a global context, the U.S. enjoys relatively reliable supplies of water. Nonetheless, growth in water demand over time has produced shortages in certain areas, and climate change threatens to exacerbate those shortages. An understanding of these trends underlies concerns over sustainable use of the nation's water resources, the desire for better information on the value of competing uses, and the perception that, in the long run, both the public and the economy would benefit from greater attention to the ways in which the nation manages and uses its water resources.

Building on the information presented above, the discussion that follows provides an overview of the water resources upon which the U.S. relies. It then focuses on several key regions to examine how the intersection of water demand and available supply can create regional shortages. The final section places U.S. water availability in a global context, highlighting our relative position internationally with respect to water supply and sustainability.

NATIONAL PERSPECTIVE

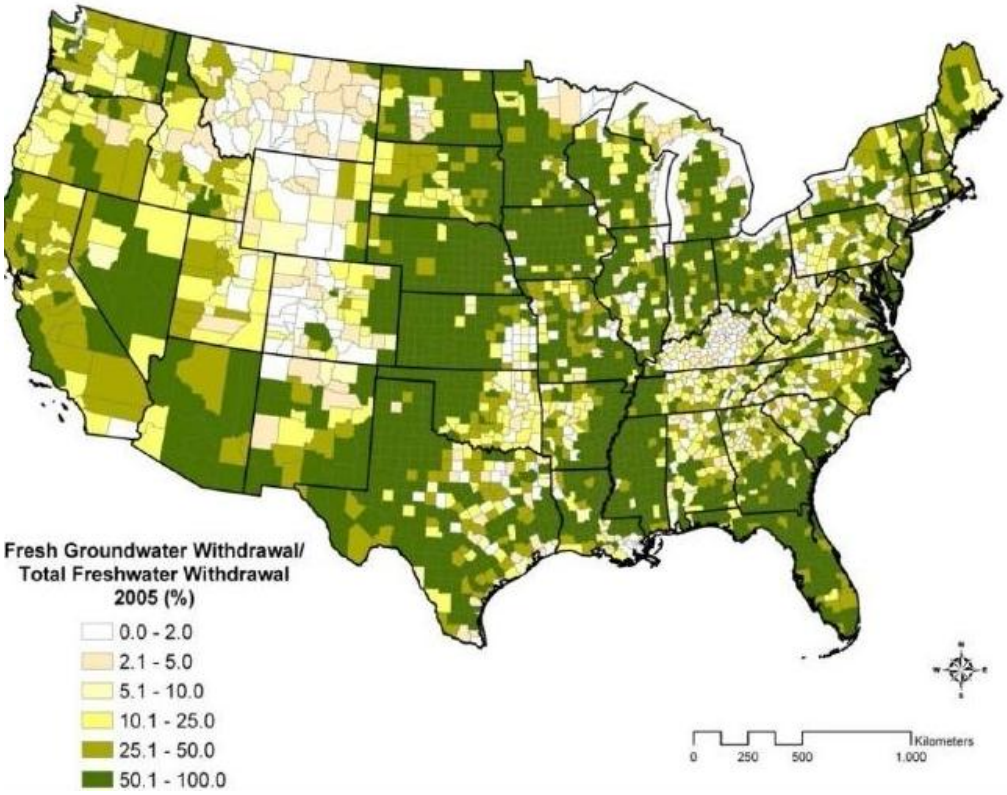
Taken as a whole, the U.S. has relatively good access to water. According to the Pacific Institute, the national boundaries of the U.S. contain about six percent of the world's renewable freshwater supply. Only Russia, Brazil, and Canada control more abundant supplies of freshwater (Pacific Institute, 2011).

As noted above, both ground and surface water sources supply the freshwater needs of key economic sectors. On the one hand, the USGS data indicate that surface water serves as the source of about 80 percent of all water withdrawn for off-stream use, and about 77 percent of all freshwater withdrawals. However, non-consumptive use of water for cooling power plants represents a large share of surface water use. When this particular application is removed from consideration and the focus shifts to uses that are generally more consumptive in nature, groundwater assumes a more prominent role, accounting for roughly 40 percent of freshwater use in 2005 (USGS, 2009). Furthermore, reliance on groundwater has been growing in recent decades, the result of improved pumping technologies, surface water depletion, and surface water quality problems. For instance, in 1950, only 26 percent of public water supplies and 23 percent of irrigation supplies

were drawn from groundwater sources (USGS, 2008); in 2005, those figures stood at 33 and 42 percent, respectively (USGS, 2009).

Exhibit 3-16 shows, by county, the percentage of freshwater withdrawals accounted for by groundwater; where this percentage is low, surface water is the dominant source. As the exhibit suggests, reliance on surface water is most common in areas of the U.S. that receive reliable rainfall or snowmelt, have a moderate climate, and, in some cases, border large lakes (e.g., the northeast, the Rocky Mountains, or the Great Lakes region). In contrast, groundwater use predominates in some areas of the south and in drier areas with less reliable precipitation (e.g., the Great Plains and the southwest).

EXHIBIT 3-16. PERCENT OF FRESHWATER USE FROM GROUNDWATER (2005)

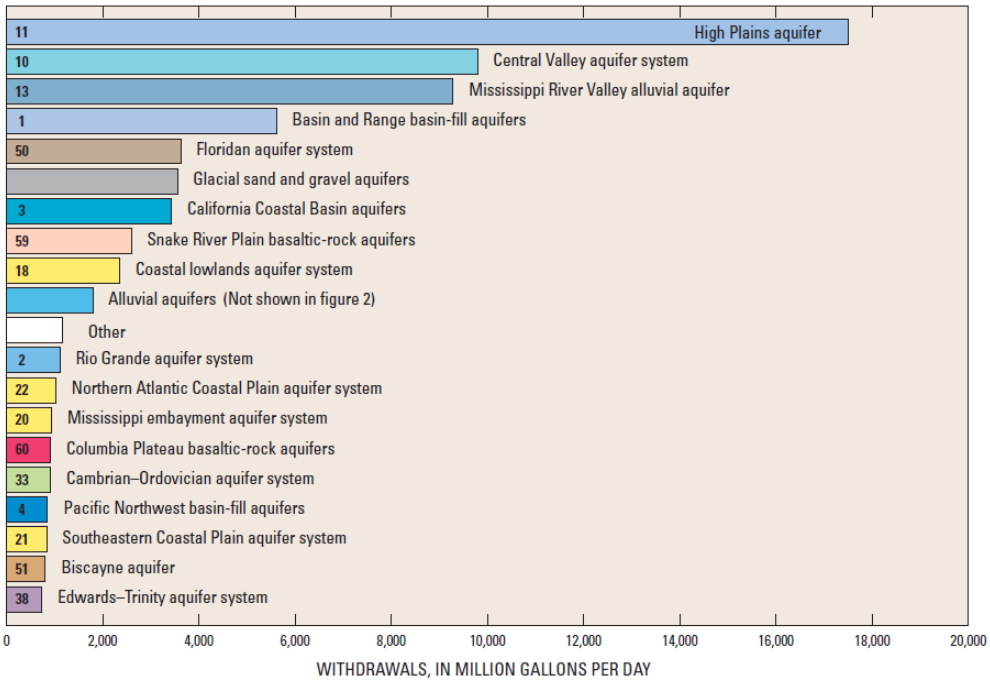


Source: EPRI, 2011, p. 5-3.

Exhibit 3-17 provides additional information on the 20 aquifers that, according to the USGS, provide 90 percent of the groundwater used in the U.S.[9] As the exhibit indicates, the High Plains aquifer (in the Central Plains states) is the largest by far, with California's Central Valley aquifer system and the Mississippi River aquifer system also accounting for large withdrawals.

[9] These 20 aquifers represent less than a third of the nation's 66 principal aquifers.

EXHIBIT 3-17. WITHDRAWALS FROM PRINCIPAL AQUIFERS IN THE U.S. (2000)[10]



Source: USGS, 2008, p. 12.

While some regions of the country have abundant water resources, others face scarcities that stem from a multitude of factors. For example:

- Climate and precipitation vary greatly across the U.S. and play a major role in the availability of water. As discussed in greater detail below, climate change is altering certain weather and climate characteristics, exacerbating the scarcity of water in some regions.
- Demographic shifts have affected water availability. In particular, population growth in the Sunbelt has placed new pressure on municipal water supplies.
- Industrial and agricultural demands for water continue to evolve and create new water supply requirements. Agriculture in particular is a major water user and plays a key role in this shifting demand; changes in crop mix, irrigation technology, fertilizer and pesticide use, and other practices can affect where and how water is used.
- The geography of water use and abundance is also affected by efforts to transport water from its original source to places where it is needed. In the west, water supply projects constructed by the U.S. Bureau of Reclamation and others have transformed the landscape, supplying irrigation water to previously non-arable land and allowing growth of municipalities in arid regions. As competition for water intensifies, however, broad support for major new inter-basin transfer

[10] The exhibit retains the colors and identifying numbers assigned to each aquifer in the source document.

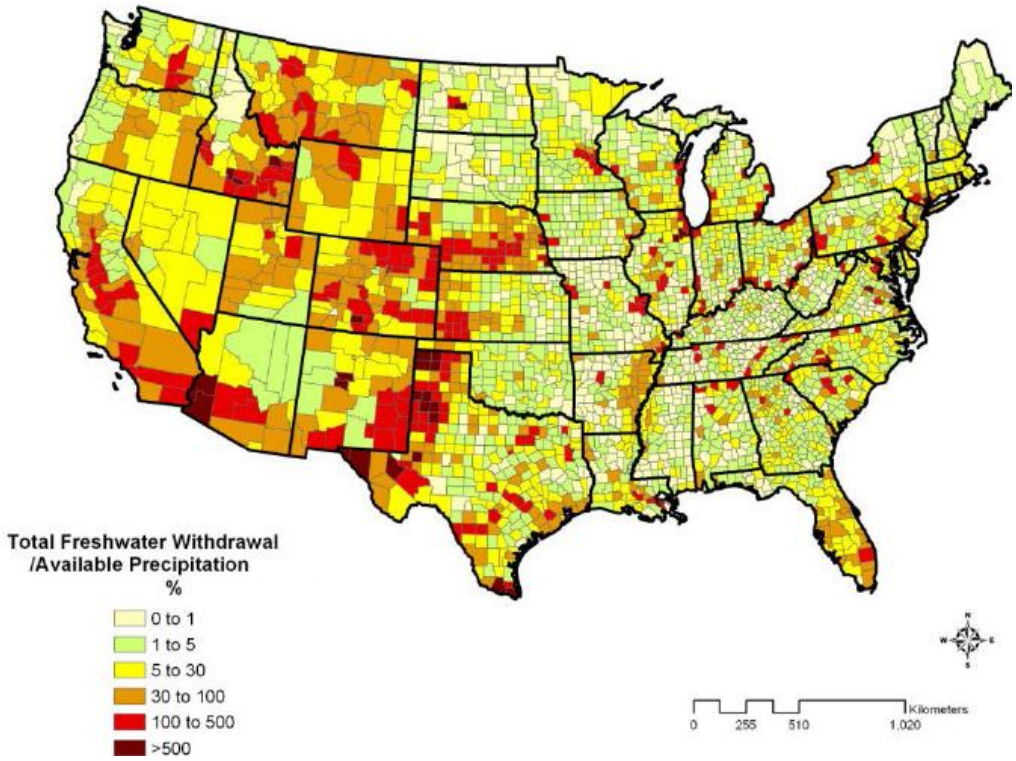
initiatives may prove increasingly difficult to obtain. The cost of developing and maintaining such projects serves as a further constraint on new initiatives.

- Institutional factors also affect water availability. Laws governing water rights, pricing, and distribution can influence which parties receive water and how efficiently that water is used.
- Water quality also influences water availability. Municipal growth, agriculture, and industrial activity have generated pollution that renders some groundwater and surface water supplies unsuitable for certain uses.

Because the balance of these factors varies greatly across the U.S., the degree of water abundance or scarcity tends to be highly regional. County-level data depict the nature and extent of this geographic variability. Exhibit 3-18 shows total freshwater withdrawals in 2005 as a percent of available precipitation. High values (red and brown) reflect greater demand relative to local precipitation; values greater than 100 indicate imports from other counties or use of stored water. Demand in excess of local precipitation is most evident in arid regions of the west. Exhibit 3-19 provides additional insight on areas that may face scarcities, focusing on depletion of groundwater resources. Specifically, the exhibit shows areas where an aquifer has experienced a significant decline in water level (defined as a 40-foot decline for confined aquifers and a 25-foot decline for unconfined aquifers). While much of the aquifer depletion occurs in arid areas, drawdown is also evident along the mid-Atlantic and southeast coast and in the Great Plains.

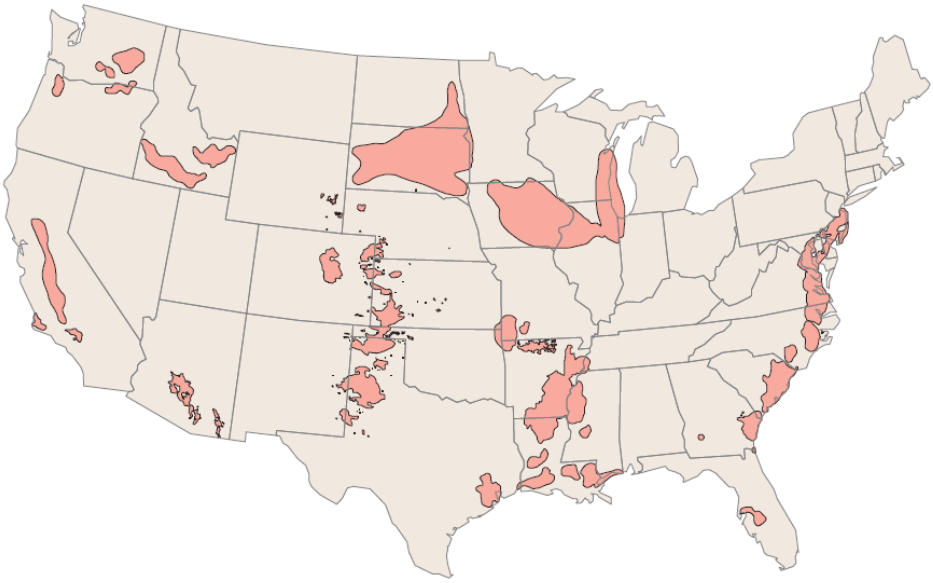
In the coming decades, water shortages are likely to intensify. The Electric Power Research Institute (EPRI) developed a study that identifies locations where water use is least sustainable. The analysis assumes that current water use trends will continue until 2030 and calculates a water sustainability risk index for each county in the U.S. The index incorporates water supply considerations such as access to renewable water supplies; susceptibility to drought; and the expected growth in water demand. As indicated in Exhibit 3-20, large portions of the southwest, Lower Mississippi Basin, and Florida appear to be on unsustainable trajectories with respect to water use.

EXHIBIT 3-18. FRESHWATER WITHDRAWALS AS A PERCENT OF AVAILABLE PRECIPITATION (2005)



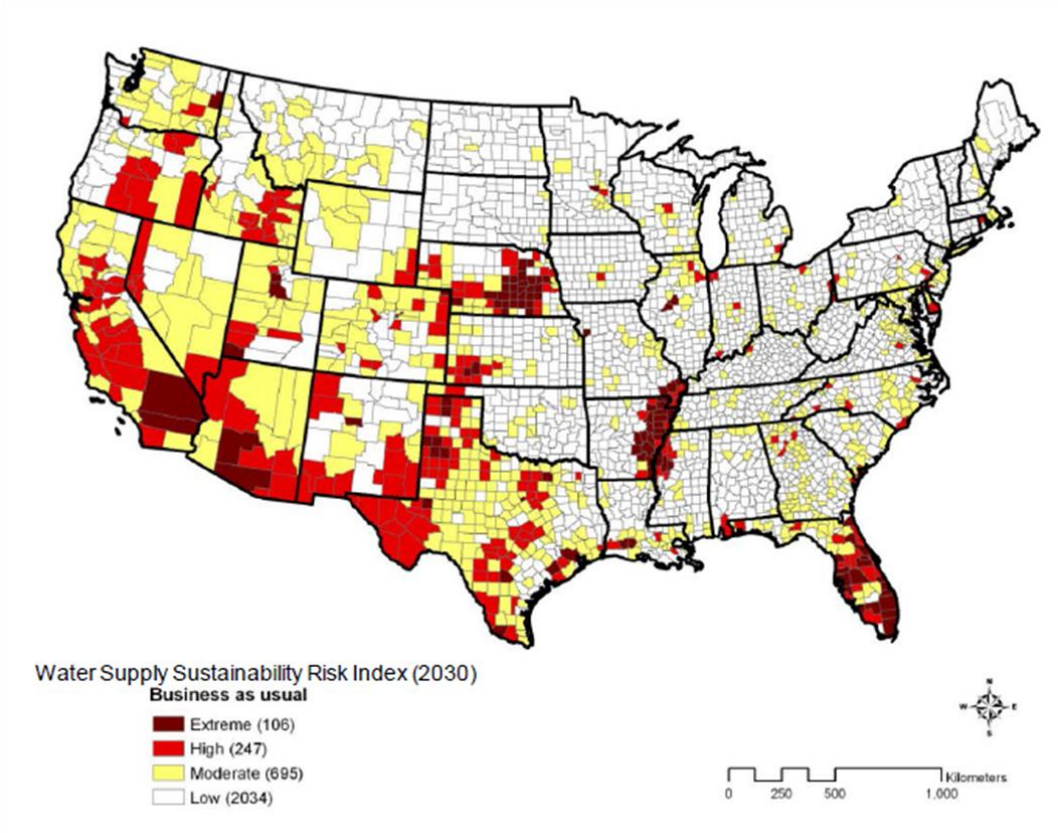
Source: EPRI, 2011, p. 5-2.

EXHIBIT 3-19. AREAS OF AQUIFER DEPLETION (2007)



Source: USGS, 2008, p. 16.

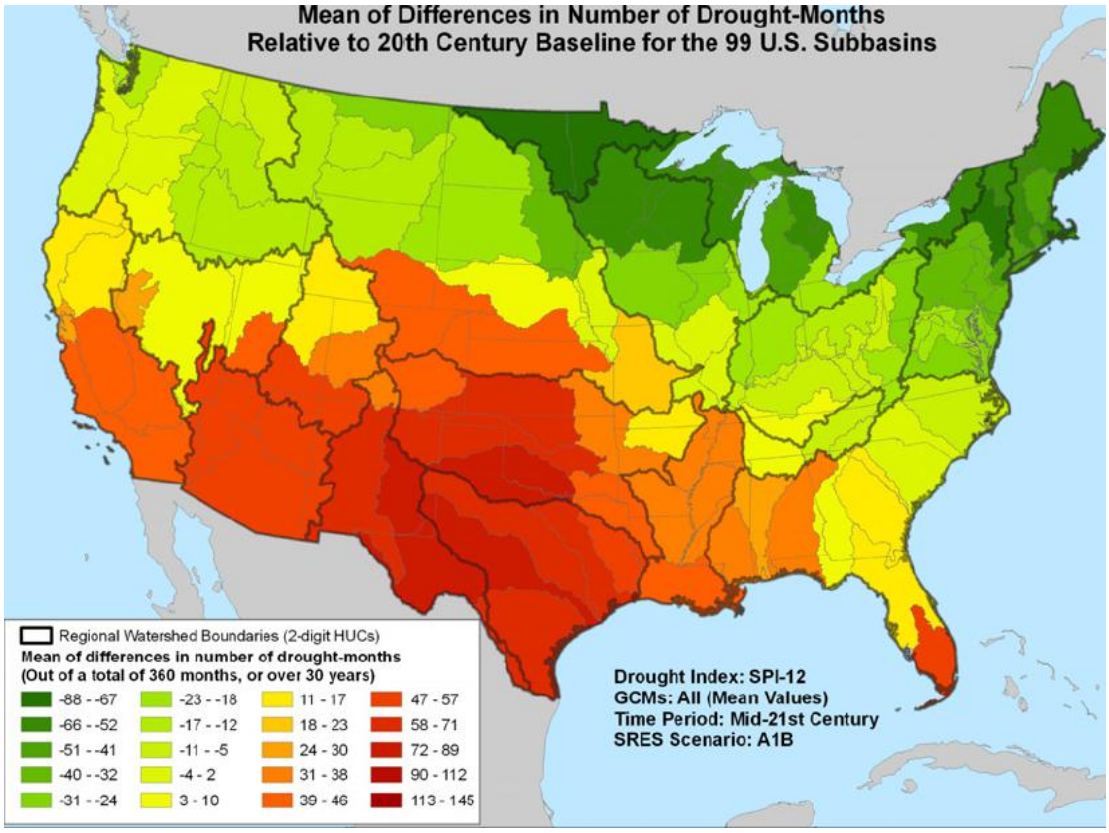
EXHIBIT 3-20. WATER SUPPLY SUSTAINABILITY RISK INDEX, 2030 PROJECTIONS



Source: EPRI, 2011, p. 5-12.

Furthermore, climate change may modify and intensify the stress on some water resources, even beyond the levels forecast by the EPRI study. Predicting the implications of climate change for water availability is highly complex, requiring advanced modeling techniques and a variety of analytic assumptions. In *National Water Program 2012 Strategy: Response to Climate Change*, EPA reviews the recent literature and concludes that "in some parts of the country, droughts, changing patterns of precipitation and snowmelt, and increased water loss due to evapotranspiration" will change the availability of water (EPA, 2012). To illustrate the geographic pattern of such changes, Exhibit 3-21 provides results from one study that modeled future changes in U.S. drought conditions as a function of greenhouse gas emissions. The map shows the change in the number of drought months, comparing a 20th century baseline to projected conditions in 2050. As shown, drought frequency is expected to increase in many watersheds in the south and west (red and orange areas) but decrease in large portions of the north and east (Strzepek, et al., 2010).

EXHIBIT 3-21. PROJECTED CHANGE IN DROUGHT FREQUENCY

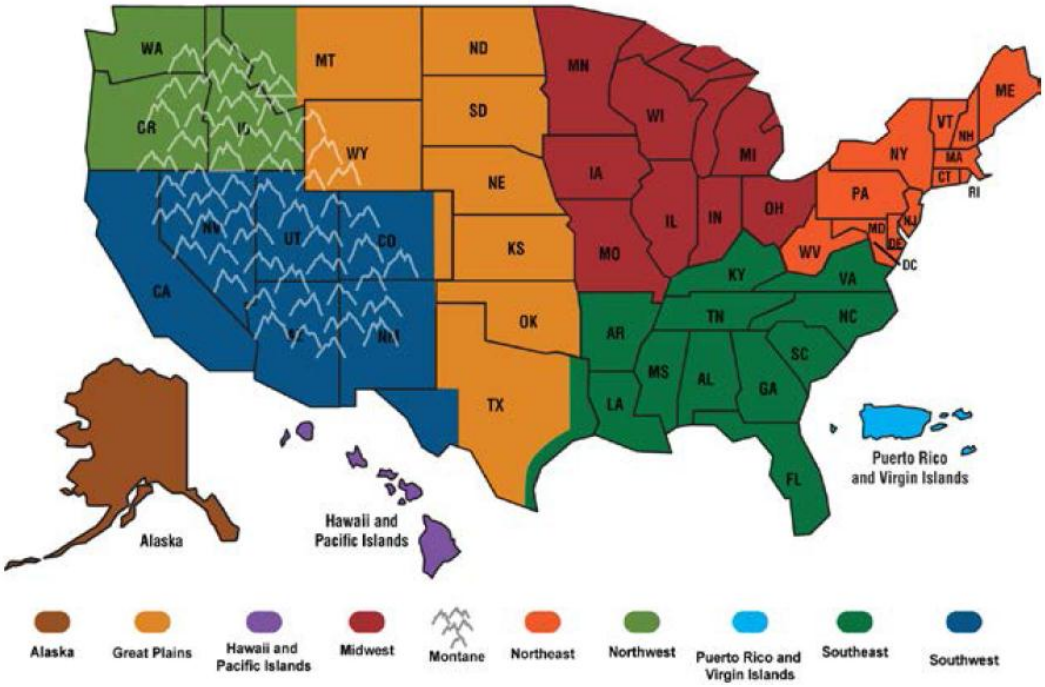


Source: Strzepek, et al., 2010.

REGIONAL PERSPECTIVES

Available data indicate that water scarcity has the potential to become acute in some regions of the U.S., but is a relatively minor concern in others. To provide a more detailed characterization of the causes and trends in water shortages, this section concentrates on several regions where water scarcity is most prevalent. We adopt the regional delineations used in EPA (2012), as depicted in Exhibit 3-22. The discussion focuses primarily on the southwest, Great Plains, and southeast regions, but also provides a brief summary of water scarcity issues in other regions.

EXHIBIT 3-22. U.S. CLIMATE REGIONS IDENTIFIED IN NWP 2012



Source: EPA, 2012.

Water Scarcity in the Southwest

Water management plays a central role in the history and future of the southwestern U.S. Unique conditions made development of the region a challenge and continue to test the limits of American ingenuity. First, much of the region has arid climate conditions that limit natural water availability as well as the ability to store and transport water. Second, beginning in the early 1900s and accelerating since the 1940s, population growth in the region has been rapid, driven by economic factors as well as an influx of immigrants and retirees. Census data indicate that the population of California, Nevada, Utah, Colorado, Arizona, and New Mexico combined grew from about 14 million in 1950 to 56 million in 2010. Much of this population growth was enabled by (and in turn, further encouraged) extraordinary investments in water infrastructure. For example, the Los Angeles Aqueduct, which was completed in 1913, brought water to the Los Angeles Basin from the Owens Valley, 250 miles distant. One historian described the project by saying that "no one had ever built anything so large, across such merciless terrain" (Reisner, 1986). Later efforts in the 1930s and 1940s diverted water to Los Angeles from the Colorado River via the Colorado River Aqueduct, further extending the area's growth.

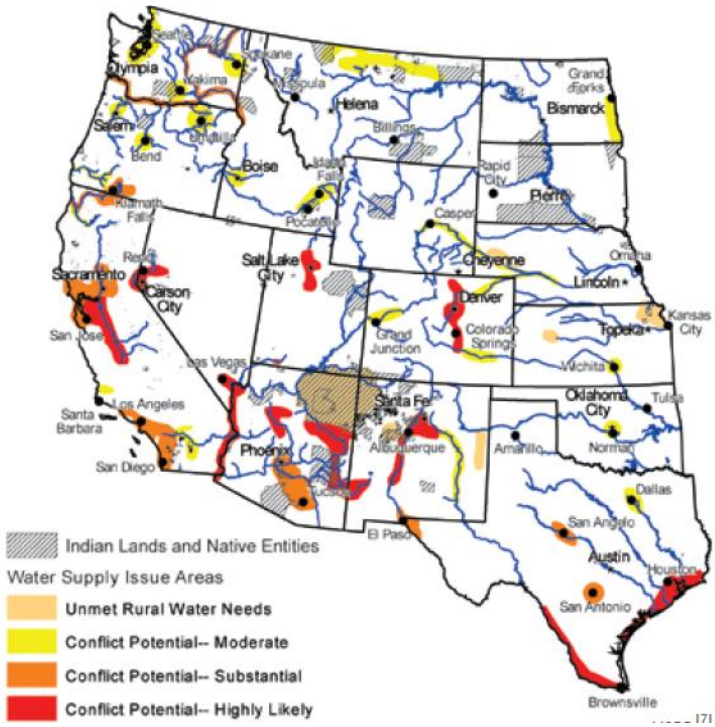
In addition to the public supply needed to support the west's growing population, other water demands have grown over time and required major public investments. Under the Reclamation Act of 1902, the Federal government took on the task of supplying irrigation water to agricultural development in the west. Numerous irrigation water supply projects resulted, with construction peaking from the 1930s through the 1950s. Today, the Bureau

of Reclamation supplies water to irrigate approximately 10 million acres of land in the western U.S., including major agricultural developments in California's Central and Imperial Valleys (BOR, 2012).

Much of the municipal and irrigation water in the southwest is diverted from the region's large rivers, including the Colorado, Sacramento-San Joaquin, and Rio Grande. Flows in these rivers have decreased, further intensifying competition for water. Hydropower operations seek to maintain flows for the purposes of power generation, while conservation interests call for management of in-stream flows to support fish and other aquatic resources.

All of these factors – climate, population growth, agricultural demand, and demand to maintain in-stream flows – have contributed to sometimes contentious competition for water in the southwest. Water managers seeking to resolve these issues by encouraging more efficient use of water are often hindered by water rights and water pricing systems that are not designed to foster efficiency (Matthews, 2003). Even in the absence of climate change, the competition for water in the southwest is expected to increase. Exhibit 3-23 shows that in 2025, the areas identified by the U.S. Global Climate Change Research Program (USGCRP) as having the greatest potential for water supply conflicts (shown in red and orange) will be heavily concentrated in the southwest.

EXHIBIT 3-23. PROJECTION OF THE POTENTIAL FOR WATER SUPPLY CONFLICTS IN 2025



Source: USGCRP, 2009.

Climate change is likely to intensify and exacerbate water shortages in the southwest, more so than in any other region. USGCRP notes that higher temperatures will reduce mountain snow packs, shifting the timing of spring runoff and constraining summer water supplies (USGCRP, 2009). Precipitation rates are projected to fall and drought frequency will likely increase in this already drought-prone region (USGCRP, 2009). River flows and groundwater recharge will likely be reduced; for instance, modeling suggests that climate change will reduce the flow of the Colorado River by five to 20 percent during the next 40 years (Zielinski, 2010).

Water Scarcity in the Great Plains

The Great Plains climate region stretches in a belt across the nation's midsection, from eastern Montana and the Dakotas through central Texas. Water use in this region is highly dependent upon the High Plains aquifer, a groundwater complex that includes the Ogallala aquifer and numerous other elements. The High Plains aquifer is the largest source of freshwater in the nation, dispensing roughly 19 billion gallons of water each day. While modest population growth has increased demand on the aquifer, most of the water (about 97 percent) is used in agriculture, irrigating 13 million acres of land (USGS, 2008; USGCRP, 2009).

Extensive use, along with increasing temperatures and other climatic changes, has depleted the High Plains aquifer. Exhibit 3-24 summarizes the extent and geographic distribution of water-level changes, comparing conditions in 2005 to conditions prior to development of irrigation infrastructure in the region (roughly 1950). The most extensive depletion (shown in red and orange) occurs in the central and southern reaches of the aquifer, where water-level declines of over 150 feet have been recorded. Across the entire aquifer, water levels have declined an average of about 13 feet (McGuire, 2007).

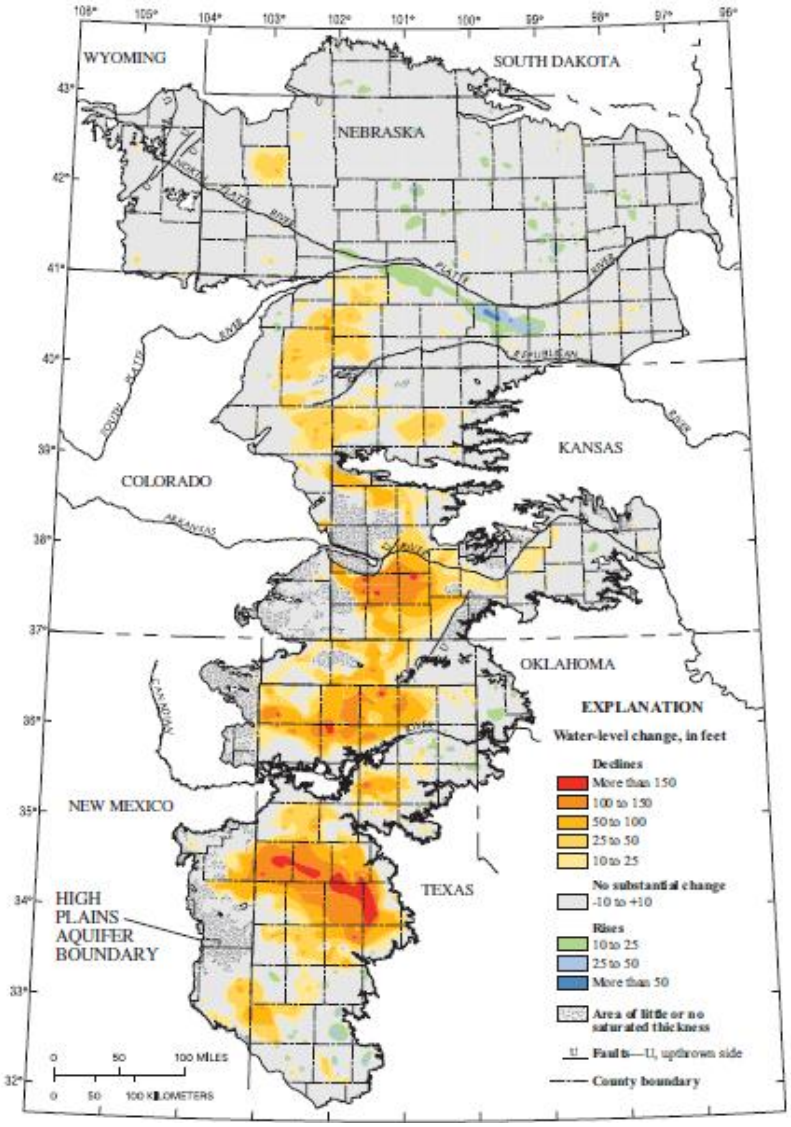
Studies suggest that while recharge in the north of the region is sufficient to support future withdrawals, pumping in the central and southern High Plains is unsustainable. One analysis estimates that at current use rates, 35 percent of the southern aquifer will be unable to support irrigation 30 years from now (Scanlon, et al., 2012). These predictions of water shortage do not factor in the effects of climate change, which are likely to hasten aquifer depletion. The USGCRP projects that the Plains will experience higher temperatures; faster evaporation rates; and more frequent and longer droughts during this century (USGCRP, 2009). In addition, increased storm intensity is expected to exacerbate non-point source runoff from agriculture, further limiting the availability of freshwater for some uses (EPA, 2012).

Water Scarcity in the Southeast

The southeast U.S. represents another water-stressed region, although pinpointing specific causes can be difficult. Rainfall in the region has historically been adequate to maintain water resources, and the region relies on a balanced mix of groundwater and surface water sources. However, various factors have contributed to growing water scarcity:

- The climate in the southeast appears to be warming and becoming increasingly prone to drought. Since 1970, the average temperature in the region has risen 1.6º F and precipitation has decreased by 7.7 percent (USGCRP, 2009).
- Agriculture, especially extensive operations in the Lower Mississippi River basin, requires large supplies of irrigation water.
- Populations, particularly in urban areas of Florida and Georgia, have grown rapidly in recent years. The population of Georgia rose from 5.4 million in 1980 to 9.8 million in 2011; the population of Florida rose from 9.7 million to 19.1 million during this same period.

EXHIBIT 3-24. WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER, PREDEVELOPMENT TO 2005

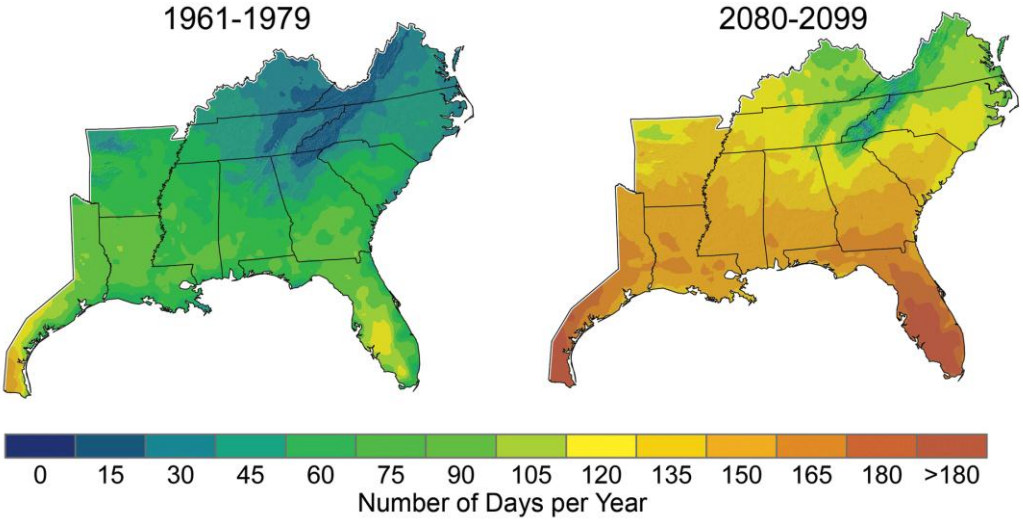


Source: McGuire, 2007.

These conditions merged to produce an acute water shortage in 2007 and 2008. Drought conditions prevailed in the region and necessitated water rationing in many cities. Attention focused on the Atlanta area, where the primary water source for the city (Lake Lanier) became dangerously depleted. Legal conflicts arose between several states, the Corps of Engineers, and the U.S. Fish and Wildlife Service (which is responsible for ensuring adequate water for endangered species). The crisis was initially attributed to what was considered an extraordinary drought; however, subsequent studies have found that the drought was of normal intensity given historical patterns. Instead, these studies demonstrate that the crisis primarily resulted from the influx of population in recent years, which placed unprecedented demands on water resources (Seager, et al., 2009).

As in other water-stressed regions, climate change will only serve to exacerbate water scarcity in the southeast. Climate models predict increasing temperatures, with average temperatures in the region expected to rise by 4.5º F by 2080 (USGCRP, 2009). As shown in Exhibit 3-25, the number of days with temperatures reaching 90º F is projected to increase throughout the region, especially in the most southern sections. The resulting evaporation, combined with less frequent rainfall (in most areas) will limit water availability. In addition, changes in the balance of runoff and recharge, combined with sea level rise, are likely to produce saltwater intrusion in shallow coastal aquifers, thereby reducing the available supply of fresh water for municipal use (EPA, 2012).

EXHIBIT 3-25. NUMBER OF DAYS PER YEAR WITH PEAK TEMPERATURES REACHING 90°F



Source: USGCRP, 2009.

Water Scarcity in Other Regions of the U.S.

Water pressures in regions other than the southwest, Great Plains, and southeast are less acute and imminent. However, climate change has important implications for the future of water resources in the following major regions of the U.S.:

- **Northeast –** In the northeast, sea level rise is projected to be greater than overall global averages, resulting in flooding and increased storm surges.

These changes may inundate coastal freshwater aquifers, producing brackish water unfit for public supply. Higher temperatures and evapotranspiration may reduce river flows in the Chesapeake Bay watershed, possibly posing a threat to drinking water supplies. While climate change presents few additional water supply issues, other water-related impacts are anticipated. Climate models project that the northeast will experience more frequent and intense precipitation events in the 21st century. This precipitation, combined with ocean storm surges, will require costly flood management and may result in property losses (USGCRP, 2009; EPA, 2012).

- **Midwest –** Climate modeling suggests that the Midwest region will see increased variability and extremity in precipitation. Such conditions can overwhelm sewer and water treatment systems, possibly affecting water quality and supply. These storms can also contribute to sewer overflows, curtailing beach use and increasing the risk of exposure to waterborne pathogens. The likelihood of drought will increase in some areas during summer. Over time, water levels in the Great Lakes may drop, affecting ecosystems, recreation, and navigation. For instance, the ability of large cargo vessels to pass through some areas may be impeded; smaller cargos may be necessitated (to reduce vessel draft), increasing overall shipping costs. Reduced streamflow and increased water temperatures are likely to reduce populations of coldwater sportfish species (USGCRP, 2009).
- **Northwest –** Much of the northwest depends heavily upon springtime snowpack to store winter precipitation. Climate change is likely to reduce the water stored as snowpack, increasing winter and spring streamflows and overwhelming the capacity of man-made water storage and delivery infrastructure in the region. Water released from reservoirs to control floods will be unavailable for use during the summer, intensifying the competition for water between municipalities, irrigators, and other interests. The change in snowmelt timing will likely increase spring streamflow, scouring streambeds and damaging salmon spawning habitat. Higher temperatures will reduce summer streamflows, further undermining salmon populations and limiting the in-stream flow available for hydropower generation (USGCRP, 2009).

WATER SCARCITY IN A GLOBAL CONTEXT

Water scarcity issues are not unique to the U.S. Indeed, many countries around the world struggle with much more dire water supply issues. While 99 percent of Americans enjoy access to safe drinking water, the figures are much lower in the world's most impoverished, arid nations; for instance, only 30 percent of the population of Somalia has access to reliable drinking water. An average of all nations shows that about 84 percent of the world has access to safe water (Pacific Institute, 2011).

More than one-third of the world's population lives in water-stressed conditions, and this figure is expected to rise to two-thirds by 2025, primarily due to population growth and

economic development (Pacific Institute, 2009). While water sustainability is a concern in the U.S., we are slightly better positioned than the world as a whole. As shown in Exhibit 3-26, water withdrawals in the U.S. represent about 8.4 percent of renewable water resources; worldwide this figure is about 8.8 percent, and is much higher in Asia and the Caribbean. As in the U.S., climate change is likely to further constrain available supplies of water, with the greatest impacts in the subtropics and mid-latitudes, where poverty is already extensive (Pacific Institute, 2009).

EXHIBIT 3-26. WATER WITHDRAWALS AS A PERCENT OF RENEWABLE RESOURCES

REGION	WITHDRAWALS AS A PERCENT OF RENEWABLE RESOURCES
Africa	5.5%
Asia	20.5%
Latin America	1.9%
Caribbean	14.0%
North America	8.4%
Oceania	1.5%
Europe	6.3%
World	**8.8%**
Source: UN, 2009.	

As noted elsewhere in this report, international water security may have implications for the U.S. Globalization has linked economies worldwide, and water shortages in other nations could create supply chain disruptions for U.S. firms and consumers. In addition, disruptions in water supplies could contribute to political instability. Recently, the U.S. State Department recognized the growing threat of international water shortages, marking World Water Day and releasing a report titled *Global Water Security* (NIC, 2012). The study concludes that:

> During the next 10 years, many countries important to the United States will experience water problems—shortages, poor water quality, or floods—that will risk instability and state failure, increase regional tensions, and distract them from working with the United States on important U.S. policy objectives. Between now and 2040, fresh water availability will not keep up with demand absent more effective management of water resources. Water problems will hinder the ability of key countries to produce food and generate energy, posing a risk to global food markets and hobbling economic growth. As a result of demographic and economic development pressures, North Africa, the Middle East, and South Asia will face major challenges coping with water problems.

In short, while the situation in the U.S. is better than that in some parts of the world, neither the nation nor its economy is insulated from the challenges others may face in managing their water resources.

THE PROSPECT OF BETTER DATA: THE USGS WATER CENSUS

This chapter relies on a variety of information sources to characterize the relative scarcity of water and the sustainability of current water use in various regions of the U.S., both now and in the future. A more comprehensive assessment would require aligning use data with detailed estimates of water reserves, water quality, climate, and usage trends. The USGS is currently developing a National Water Census designed to provide just such an assessment of water availability.[11]

Proposed as a key component of the Department of Interior's WaterSMART initiative, the National Water Census would fulfill requirements stipulated in Section 9508 of the SECURE Water Act, signed into law in 2009. This portion of the Act calls for a national program to study water quality and quantity and prepare five-year Reports to Congress that address:

- The **current availability** of water resources;
- **Significant trends** affecting water **availability**, including documented or projected impacts as a result of global climate change;
- The **withdrawal and use** of surface water and groundwater by various sectors;
- **Significant trends** relating to each **water use** sector;
- **Significant water use conflicts or shortages** that have occurred or are occurring;
- Each **factor** that has **caused**, or is causing, a conflict or shortage.

To develop such information, USGS plans to employ a water budget approach that accounts for a suite of hydrological factors, including precipitation; evapotranspiration; storage (e.g., in reservoirs); surface water flows; groundwater levels; groundwater recharge; in-stream flow requirements for wildlife; water withdrawals; return flows; and in-stream (run-of-river) uses. While all of these considerations are woven into this chapter's assessment of use and supply, the Water Census ultimately will provide more rigorously derived water budgets for individual watersheds, and a more complete assessment of water availability for the nation as a whole.

[11] http://water.usgs.gov/wsi/.

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CHAPTER 4 | PUBLIC SUPPLY AND DOMESTIC SELF-SUPPLY (OFF-STREAM USE)

INTRODUCTION

In the United States, access to clean and safe drinking water affords substantial economic and public health benefits. Most residential users receive their drinking water from public suppliers, while a smaller fraction extract their own water from private sources, primarily wells. This chapter examines residential water use, focusing on the following topics:

- The economic importance of the public water supply sector;
- Water use in the public supply and domestic self-supply sectors;
- The investment in public water supply and treatment infrastructure that is likely to be needed to meet future demands; and
- Available estimates of the value of water in domestic use, including the value of improvements in residential water quality and reliability.

OVERVIEW OF KEY FINDINGS

- Public water supply systems withdraw about 44.2 billion gallons of water per day, accounting for approximately 13 percent of all freshwater withdrawals. Most of this water - about 58 percent - is delivered to residential users. Approximately 86 percent of the U.S. population is served by a public system; the rest of the population supplies its own water, relying primarily upon private wells.
- Efficient supply of safe drinking water depends heavily upon high-quality treatment, storage, and delivery infrastructure. Analysts anticipate that an annual investment of $10 billion to $20 billion over the next 20 years is needed to maintain, upgrade and expand public water supply systems in the U.S.
- Forecasts suggest that climate change, population growth, and other factors could make current levels of domestic water use unsustainable in some parts of the U.S. In several of these areas municipal water supply needs already compete with the needs of farmers, hydropower facilities, and other users.
- Estimates of the value of water in residential use vary with the approach employed and components of value measured. Public water supply systems in the U.S. often charge rates that fall below the long-term marginal cost of supply. As a result these rates, which range anywhere from $20 to more than $120 per month for a typical household of four, are poor indicators of the efficient price for water in domestic use. Other information on residential values can be inferred from studies of demand elasticity and willingness to pay for reliable supplies, as measured by stated preference methods. Perhaps the most reliable information comes from studies of market transfers between public water supply systems and other water users; these transactions suggest that on average, municipalities will pay more than $4,500 per acre foot for water rights.

SECTOR OVERVIEW

More than 86 percent of the U.S. population receives its household water from public water supply systems, i.e., establishments involved in water extraction, water treatment, and/or water distribution (USGS, 2009). As discussed in Chapter 2, these systems are part of the secondary mega-sector of the economy. Some are owned and operated by private sector utilities, but most – especially the largest systems – are operated by municipalities or state and regional authorities (EPA, 2009a). The U.S. Census Bureau compiles data on output and employment for water utilities in the private sector, while the U.S. Census of Governments provides economic data on government-operated systems.[12]

According to the most recent census (2007), privately-held water supply and irrigation systems generated annual revenues of nearly $8 billion dollars. Approximately 92 percent of private utility revenues reflect the sale of water to customers. The remainder comprises various user charges and fees. The industry includes establishments that operate water treatment plants, pumping stations, aqueducts, and distribution mains. Exhibit 4-1 presents a basic profile of the sector. Note that these figures represent total revenue and employment for privately-held water supply and irrigation systems, including revenue derived from the sale of water to non-residential customers. More detailed data on the share of revenues or employment attributable solely to the sale of water for domestic use are not available.

EXHIBIT 4-1. ECONOMIC PROFILE OF PRIVATE SECTOR WATER SUPPLY AND IRRIGATION SYSTEMS

SECTOR CHARACTERISTIC	ESTIMATE
Total Number of Systems	24,271
Population Served	24 million
Employment	33,871
Annual Payroll	$1.6 billion
Total Revenues	$7.6 billion
Revenues from Water Sales	$7.0 billion
Sources: U.S. Census Bureau, 2007 Census data for NAICS 221310; EPA, 2009a.	

The data available from the U.S. Census of Governments on government-operated water supply systems include revenues from the sale of water to residential, industrial, and commercial customers, as well as connection, meter inspection, and late payment fees. Exhibit 4-2 provides an overview of this sector. Notably, government-operated water suppliers serve substantially more people and generate significantly more revenues than do water utilities in the private sector. In 2009, water sales by government-operated systems amounted to $45.5 billion. Taken together, privately-operated and government-operated public water supply systems employ approximately 200,725 people and generate annual revenues of more than $53 billion.

[12] Economic data on industries that provide services related to domestic self-supply is limited. Given this limitation, this section focuses solely on the public supply sector.

EXHIBIT 4-2. ECONOMIC PROFILE OF GOVERNMENT-OPERATED WATER SUPPLY SYSTEMS

SECTOR CHARACTERISTIC	ESTIMATE
Total Number of Systems	24,861
Population Served	256 million
Employment (Full-Time Equivalent)	166,854
Annual Payroll	$8.1 billion
Total Annual Expenditures[1]	$57.4 billion
Total Annual Revenues	$45.5 billion

Sources: U.S. Census of Government Employment, 2007; U.S. Census of Governments Survey of State and Local Government Finances, 2009; EPA, 2009a.

[1] Information on total annual expenditures is provided to indicate the extent to which system costs are financed by sources other than system revenues. Comparable information on annual expenditures by private sector systems is not available.

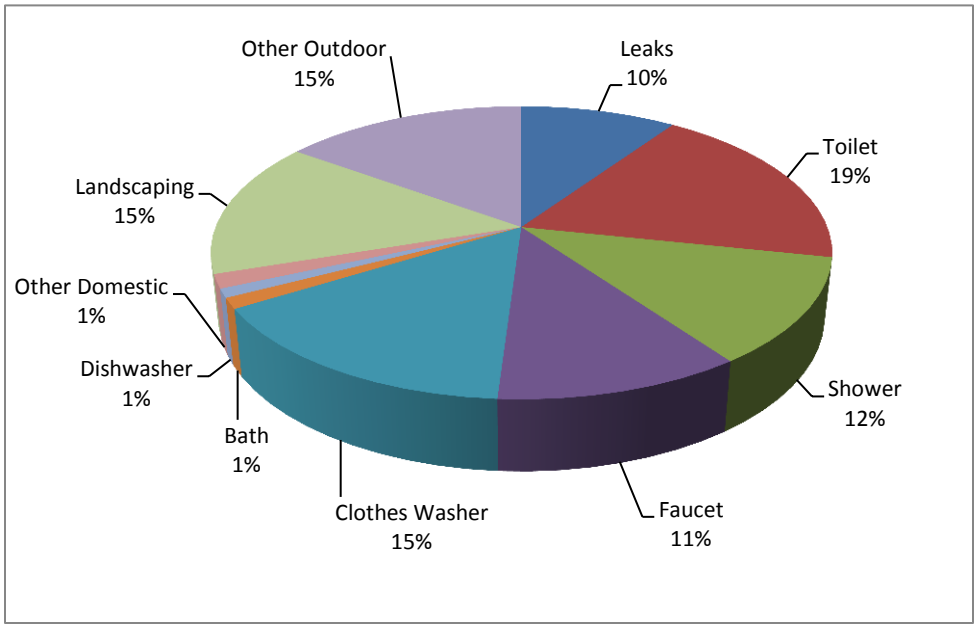
The U.S. public water supply sector has grown steadily for several decades, reflecting the combined effects of population growth, economic development, increased urbanization, and economies of scale. These forces have spurred demand for water from centralized sources. As a result, the percentage of the population served by public water supply systems has increased from 62 percent in 1950 to 86 percent in 2005 (USGS, 2009).

WATER USE

According to the USGS, a total of 49.6 million acre-feet of water were withdrawn for public supply in 2005, representing 13 percent of all freshwater withdrawals. Two-thirds of these withdrawals were from surface water sources, while the remainder was from groundwater. As noted above, public water supply systems serve residential, industrial, and commercial users. Deliveries to residential users account for approximately 58 percent of the water that public suppliers withdraw, or 28.7 million acre-feet. The remaining 20.9 million acre-feet are used in commercial, industrial, and public services (e.g., firefighting and municipal buildings), or are unaccounted for due to system losses (e.g., leaks, flushing, etc.). The discussion that follows focuses specifically on water use in the residential sector.

Residential water use pertains to any indoor and outdoor water use at households. Typical indoor uses include drinking, food preparation, washing clothes and dishes, and flushing toilets; common outdoor uses include watering lawns, maintaining swimming pools, and washing cars. In the United States, the typical four-person household consumes 400 gallons of water per day (EPA, 2008b). Approximately 70 percent of this amount is used for indoor purposes; the rest is devoted to outdoor uses (EPA, 2008b). In general, toilets account for the largest share of indoor use, while landscaping accounts for the largest share of outdoor use (EPA, 2008a; EPA, 2008b). Exhibit 4-3 provides more detailed information on residential water use.

EXHIBIT 4-3. OVERVIEW OF RESIDENTIAL WATER USE

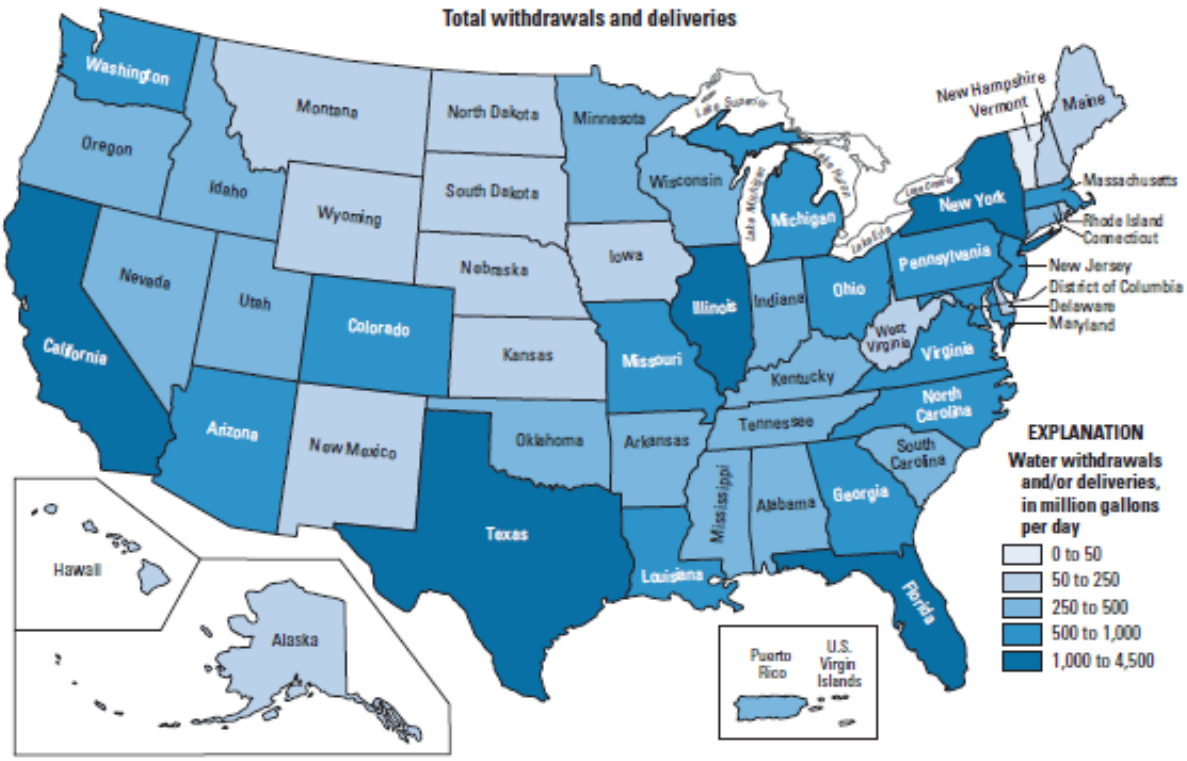


Sources: AWWA, 1999; EPA, 2008a; EPA, 2008b.

In 2005, withdrawals for domestic self-supply and residential deliveries from public supply amounted to 29.4 billion gallons per day (USGS, 2009). This implies that residential water use accounted for roughly seven percent of total withdrawals and that the average person used 98 gallons of water per day. While aggregate residential water use has increased over time, water use per capita in recent years has remained relatively constant. In 1985, the average person consumed 100 gallons per day; similarly, in 1995, the average person consumed 101 gallons per day (USGS, 2009).

Both aggregate water use and per capita water use are subject to regional variation. Exhibit 4-4 presents an overview of aggregate residential use by state. Not surprisingly, the states with the largest populations – i.e., California, Texas, New York, Florida, and Illinois – use the most water. Additional detail on residential water use by state, including data on per capita use, is provided in Exhibit 4-5. As this exhibit indicates, per capita use ranges from 54 gallons per person per day in Maine to 190 gallons per person per day in Nevada. Climate is one important determinant of per capita use, as drier regions require more water for landscaping. Other factors, like population density and household income, also play a role.

EXHIBIT 4-4. AGGREGATE RESIDENTIAL WATER USE BY STATE, 2005



Source: USGS, 2009.

EXHIBIT 4-5. TOTAL AND PER CAPITA RESIDENTIAL WATER USE BY STATE, 2005

STATE	POPULATION (THOUSANDS)	RESIDENTIAL WATER USE (MGAL/DAY)	PER CAPITA RESIDENTIAL WATER USE (GAL/DAY)
Alabama	4,560	365	80
Alaska	664	61	92
Arizona	5,940	830	140
Arkansas	2,780	272	98
California	36,700	4,470	124
Colorado	4,670	564	121
Connecticut	3,510	263	75
Delaware	844	51	61
District of Columbia	582	83	142
Florida	17,900	1,720	96
Georgia	9,070	847	93

STATE	POPULATION (THOUSANDS)	RESIDENTIAL WATER USE (MGAL/DAY)	PER CAPITA RESIDENTIAL WATER USE (GAL/DAY)
Hawaii	1,280	210	165
Idaho	1,430	267	187
Illinois	12,800	1,150	90
Indiana	6,270	477	76
Iowa	2,970	193	65
Kansas	2,740	223	81
Kentucky	4,170	278	67
Louisiana	4,520	529	117
Maine	1,320	72	54
Maryland	5,600	610	109
Massachusetts	6,400	528	83
Michigan	10,100	810	80
Minnesota	5,130	351	68
Mississippi	2,920	340	116
Missouri	5,800	512	88
Montana	936	104	111
Nebraska	1,760	237	135
Nevada	2,410	459	190
New Hampshire	1,310	98	75
New Jersey	8,720	605	69
New Mexico	1,930	207	107
New York	19,300	1,860	96
North Carolina	8,680	604	70
North Dakota	637	58	91
Ohio	11,500	792	69
Oklahoma	3,540	301	85
Oregon	3,640	441	121
Pennsylvania	12,400	704	57
Rhode Island	1,080	85	79
South Carolina	4,260	426	100
South Dakota	776	73	94
Tennessee	5,960	479	80
Texas	22,900	3,130	137
Utah	2,550	474	186
Vermont	623	40	64
Virginia	7,570	568	75
Washington	6,290	648	103
West Virginia	1,820	183	101
Wisconsin	5,540	316	57
Wyoming	509	77	152
Puerto Rico	3,910	349	89
US Virgin Islands	109	7	67
United States	**301,000**	**29,400**	**98**
Source: USGS, 2009.			

As water supplies tighten (see below), domestic water users may consider substitution and efficiency measures to limit their consumption. A variety of options exist for limiting household water use, and include installation of low-flow plumbing fixtures; use of water-efficient appliances; installation of less water-intensive landscaping; and behavioral changes (e.g., shorter showers) (EPA, 2000). Many households have instituted such practices, although data showing relatively constant water use per household suggest that further efficiency gains are possible. These observations have implications for the elasticity of demand for water in residential use. As we discuss below, short-run demand is relatively inelastic, while long-run demand is more elastic, reflecting the ability in the long run to make capital investments to improve the efficiency of household water use.

FUTURE SUPPLY

The reliability of future supplies of water for residential use is dependent on producers' ability to meet quality standards in the face of increasing demand. Satisfying future demand will largely hinge on improvements to the public water supply infrastructure, most of which was constructed in the early 20th century (EPA, 2009b). Each year, more than 240,000 water mains break, and leaking pipes lose an estimated 7 billion gallons of clean drinking water every day (ASCE, 2009; Olmstead, 2010). From an economic perspective, repairing this failing infrastructure would reduce costs and enhance the efficiency of the public water supply system. The discussion below provides an overview of the nature and magnitude of these investment needs and discusses other factors influencing the future of residential water supply.

OVERALL INVESTMENT NEEDS

In 2009, the nation's drinking water infrastructure received a D- from the American Society of Civil Engineers, reflecting the lowest grade awarded on the organization's *Infrastructure Report Card*. The poor grade is indicative of the need to replace aging facilities and to comply with existing and future Federal water regulations. While specific estimates of the investment needed to maintain the nation's public water supply vary, the overarching message is the same – the system is currently underfunded and will require significant investment over the coming decades to prevent supply shortages and drinking water contamination. Four commonly cited estimates that characterize the range of investment include:

- A Congressional Budget Office (CBO) report, "Future Investment in Drinking Water and Wastewater Infrastructure," which estimates annual drinking water system needs at $11.6 billion to $20.1 billion from 2000 to 2019.[13]
- An EPA report, "The Clean Water and Drinking Water Infrastructure Gap Analysis," which estimates annual drinking water system needs at $7.7 billion to $22.3 billion from 2000 to 2019.[14]

[13] Reflects 2001 dollars.

[14] Reflects 2001 dollars.

- A Water Infrastructure Network (WIN) report, "Clean and Safe Water for the 21st Century – A Renewed National Commitment to Water and Wastewater Infrastructure," which estimates annual drinking water system needs at $11 billion from 2000 to 2019.
- EPA's "2007 Drinking Water Infrastructure Needs Survey and Assessment," which estimates annual drinking water system needs at $16.7 billion from 2007 to 2026.[15]

EPA reports that investment in water supply infrastructure is needed both to enhance or repair existing infrastructure and to comply with specific Safe Drinking Water Act (SDWA) regulations. While all infrastructure projects facilitate continued provision of safe drinking water, certain projects are directly attributable to SDWA regulations. According to EPA estimates, 16 percent of the investment required is directly attributable to SDWA mandates; the remaining 84 percent is associated with projects that will enable water utilities to meet expected demand (EPA, 2009). Additional detail on the nature of these requirements is provided below.

INVESTMENT NEEDS BY CATEGORY

In general, infrastructure projects can be grouped into four major categories: transmission and distribution projects; treatment projects; storage projects; and source projects. The first of these, transmission and distribution, accounts for 60 percent of projected infrastructure requirements over the next 20 years. This is not surprising. Depending on soil conditions, climate, capacity requirements, and the material of which they are constructed, the pipes employed in water transmission and distribution systems are expected to remain in service for 60 to 95 years. Given that most U.S. cities' water distribution systems were constructed in the early 20th century, many pipes have already reached or are nearing the end of their useful lives. A significant investment is needed to replace or rehabilitate these pipes in order to prevent delivery system failures and contamination.

Treatment projects account for 22 percent of the projected infrastructure investment need over the next 20 years. This category of need includes most of the projects directly attributable to SDWA mandates. Treatment projects include the construction, expansion, and rehabilitation of treatment facilities that provide filtration, disinfection, and corrosion control in order to reduce drinking water contamination.

Storage needs account for 11 percent of projected infrastructure requirements over the next 20 years. This category of need includes projects to construct, rehabilitate, or cover finished water storage tanks. These projects are necessary to ensure that systems have sufficient storage to provide the public with treated water, especially during periods of peak demand. Again, adequate storage enables systems to maintain minimum pressure that prevents intrusion of contaminants into the distribution network.

[15] Reflects 2007 dollars.

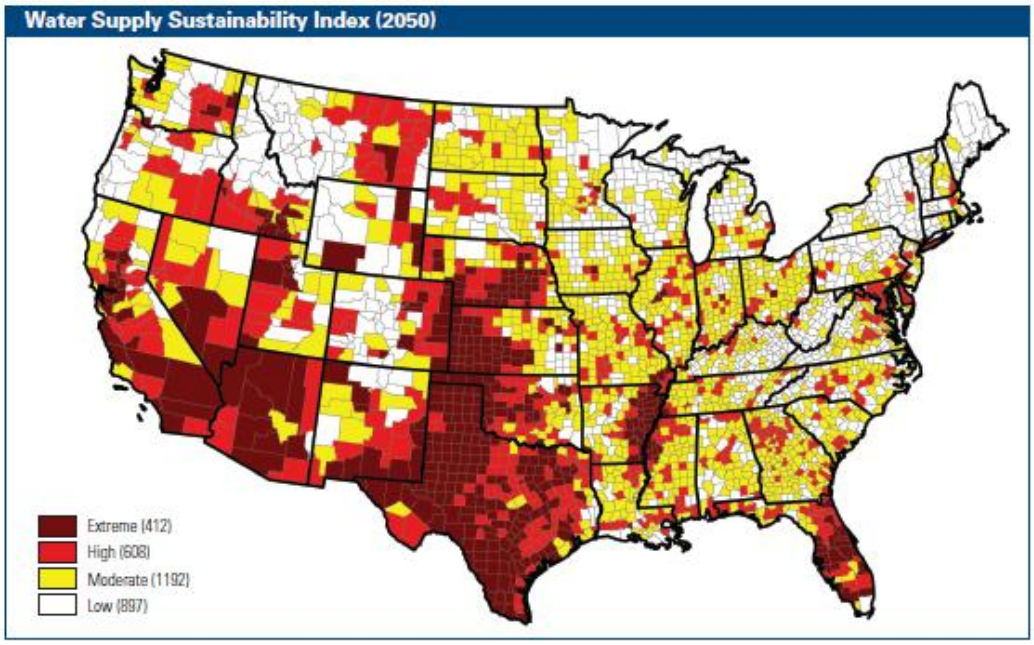
Source needs account for the remaining 6 percent of projected infrastructure requirements over the next 20 years. This category of need reflects investments in the construction or rehabilitation of surface water intake structures, drilled wells, and spring collectors. The objective of many of these projects is to obtain higher quality raw water that results in lower treatment costs to comply with SDWA standards. In addition, expanded capacity at intake structures enables systems to maintain minimum pressure that prevents intrusion of contaminants into the distribution network.

FUTURE DEMAND AND AVAILABILITY

Although the U.S. enjoys abundant water resources compared to many nations, residential water use in some parts of the country is confronting the reality of limited water supplies. Population growth in some areas has brought municipalities into direct competition with other water users such as agriculture and hydropower. For instance, the 2007-2008 drought in the southeast U.S. created legal conflicts between states, dam operators, and irrigators, as well as environmentalists seeking in-stream flows for wildlife. Atlanta's primary water source became dangerously depleted, and the condition was ultimately linked to rapid population growth and associated municipal water demands (Seager, et al., 2009). Other U.S. municipalities have encountered similar issues.

Climate change is expected to greatly increase the risk that water supplies will not be able to keep pace with withdrawals. A study of water supply vulnerability found that in the coming decades, approximately 35 percent of all U.S. counties face greater risk of water shortages as a result of climate change (Roy et al., 2012). The anticipated impact of climate change on future water supplies is driven by reduced precipitation in some regions and increases in potential evapotranspiration in most of the country. Declining precipitation is expected to be most pronounced in eastern Texas, the Lower Mississippi Basin, California's Central Valley, and the Southwestern U.S. Furthermore, sea level rise may allow saltwater intrusion into shallow coastal aquifers that serve as important municipal water supplies (EPA, 2012). Exhibit 4-6 illustrates where long-term risks to water supply sustainability are greatest.

EXHIBIT 4-6. RISKS TO SUSTAINABILITY OF WATER SUPPLIES, BY COUNTY, 2050



Source: Roy et al., 2012.

VALUE OF WATER USE

Compared to most categories of water use, there is an extensive literature on the economics of domestic water use. The available studies can be grouped into several broad categories according to the methodology used and the issues the studies are designed to assess. The first group of studies simply examines the rates that public water supply systems charge residential users; the second estimates the price elasticity of demand for domestic water; the third considers willingness to pay figures from market transfers between municipalities and other water use sectors; and the fourth uses non-market methods to determine consumer surplus associated with key features of domestic water use (quality and reliability).

WHY DOMESTIC WATER RATES MAY FAIL TO ENCOURAGE EFFICIENT USE

As noted in Chapter 2, the price at which water is sold in the United States is generally not the product of market forces that will promote an economically efficient use of the resource (i.e., the point at which the long-run marginal cost of supplying water equals its marginal value to consumers). Water prices are not determined in competitive markets and as a result do not reflect water scarcity (Olmstead, 2010). Instead, water rates are typically set by elected councils and public utility commissions. Even in times of scarcity, management officials are reluctant to raise prices. As a result, the rate paid by consumers often falls below the long-run marginal cost of water supply, its efficient price (Olmstead, 2007).

According to a cost-recovery analysis by Global Water Intelligence (GWI, 2004), water systems in industrialized nations are able to cover their operation and maintenance costs (O&M) by charging $0.40 to $1.00 for every cubic-meter of water delivered. If water systems charge more than $1.00 per cubic-meter, they are able to cover both O&M and capital costs. This amounts to approximately $45.42 per month for a four-person household that consumes 400 gallons per day. As illustrated in the discussion below, water prices fall well below these rates in many U.S. cities.

Most U.S. households served by a public water supply system face one of three water rate structures: uniform rates, increasing block rates, or decreasing block rates. With uniform pricing, consumers are charged the same price per gallon irrespective of the amount of water they consume. Increasing (or decreasing) block rate pricing means that prices per gallon increase (or decrease) with the amount of water consumed. Over the past few decades, increasing block rate price structures have become more common, with nearly a third of the population facing this type of fee schedule (Olmstead, 2007). In effect, this pricing structure means that marginal water uses (i.e., lawn watering and car washing) are charged a price that more closely equates to the efficient price; in most instances, however, first-priority uses (i.e., drinking and bathing) reflect subsidized prices (Olmstead, 2007).

The practice of subsidizing public water supply systems enables residents of many U.S. cities to purchase water at prices well below the public water supply system's long-run marginal cost. Exhibit 4-7 provides information on water rates for a number of U.S. cities, illustrating the costs that would be incurred by a typical family of four in an average month (Walton, 2010). As the exhibit shows, the average monthly bill in many cases is well below $45 per month, the general estimate cited above as necessary to cover a system's long-run costs.

Exhibit 4-7 further indicates that the variation in water rates between cities can be substantial – ranging from a low of $19.64 per month for a four-person household that consumes 400 gallons per month in San Antonio to a high of $121.42 per month for a similar household in Santa Fe. This is due in part to underlying variation in a number of factors that affect unit costs to suppliers, including the energy needed to pump and transport water, treatment costs, and infrastructure costs. Nonetheless, non-market factors like government subsidies are also important determinants of prices. For example, many cities in the arid Southwest enjoy cheap water because expensive infrastructure projects have been financed by government funding as opposed to the utility companies themselves (Walton, 2010). As a result, consumers in areas with high rainfall and lower rates of consumption may actually face higher water rates than those in areas with little rainfall and higher rates of consumption.

EXHIBIT 4-7. WATER RATES BY CITY, 2010

CITY	RATE TYPE	AVERAGE MONTHLY HOUSEHOLD BILL FOR FAMILY OF FOUR USING 100 GALLONS/PERSON/DAY
Milwaukee	Decreasing Block	$26.83
Detroit	Decreasing Block	$28.36
Indianapolis	Decreasing Block	$41.26
Fresno	Uniform	$21.95
Chicago	Uniform	$24.12
Memphis	Uniform	$26.50
Phoenix	Uniform	$34.29
Baltimore	Uniform	$39.50
New York	Uniform	$41.76
San Antonio	Increasing Block	$19.64
Salt Lake City	Increasing Block	$22.89
Jacksonville	Increasing Block	$30.04
Las Vegas	Increasing Block	$32.93
Denver	Increasing Block	$33.01
Tucson	Increasing Block	$33.04
Charlotte	Increasing Block	$35.68
Dallas	Increasing Block	$37.81
Houston	Increasing Block	$39.49
San Jose	Increasing Block	$40.93
Columbus	Increasing Block	$43.06
Fort Worth	Increasing Block	$43.48
Austin	Increasing Block	$47.17
Philadelphia	Increasing Block	$49.03
San Francisco	Increasing Block	$58.47
Los Angeles	Increasing Block	$58.49
Boston	Increasing Block	$65.47
San Diego	Increasing Block	$70.95
Seattle	Increasing Block	$72.78
Atlanta	Increasing Block	$72.95
Santa Fe	Increasing Block	$121.42
Source: Walton, 2010.		

DEMAND ELASTICITY FOR DOMESTIC WATER

The price elasticity of demand for residential water captures the relationship between the quantity of water demanded and its price, providing insight into how residential users value water. Specifically, it measures the percentage change in quantity demanded for a given percentage change in price. Both economic theory and empirical evidence suggest that domestic water is inelastic at current prices, meaning that when its price increases, the quantity demanded falls but at a correspondingly lower rate than the price increase (Olmstead, 2010). This is not surprising given that there are no readily available and comparably priced substitutes for water in most residential applications. However, as the

data show, long-run demand elasticity is generally higher than short-run; i.e., if prices remain high, residential users may invest in water efficiency measures (see earlier discussion), thereby reducing their total water demand.

Importantly, price elasticities provide an indicator of how the average consumer will respond to marginal price changes (i.e., one percent) given current local prices. Thus, an estimated price elasticity that relies on data for the East coast cannot be extrapolated to a ten-fold increase in prices on the West coast. Additionally, elasticities reflect price-responsiveness to actual prices, not efficient prices. Because consumers are paying prices that fall well below their reservation price, even large rate increases may have little to no impact on the quantity consumed.[16]

A household's demand for water is a function of the price of water, household income, and household preferences. Non-household characteristics like season and weather also affect residential demand (Olmstead, 2010). Research on the demand for residential water began in the 1960s. Since then, several economists have estimated empirical price elasticities using data on domestic water use and rate schedules. A review of 124 estimates obtained from studies completed between 1963 and 1993 reveals that the average price elasticity of demand for residential water in the United States is -0.51, and that short-run estimates are more inelastic than long-run estimates (Espey, 1997). Similarly, a meta-analysis of more than 300 estimates suggests that the average price elasticity of demand for residential water in the United States is -0.41 (Dalhuisen, 2003).[17] This means that when the price of residential water increases by one percent, the quantity demanded falls by 0.41 percent. Exhibit 4-8 provides a summary of the U.S.-based studies, their results, and their methodologies.

[16] Reservation price reflects the highest price that a buyer is willing to pay for a good or service; or, the lowest price at which a seller is willing to sell a good or service.

[17] Of the 49 studies reviewed, 41 were based on U.S. data. Six of the 8 remaining studies were based on data for high-income countries in Western Europe or Australia.

EXHIBIT 4-8. ESTIMATES OF THE PRICE ELASTICITY OF RESIDENTIAL WATER DEMAND

AUTHOR	TIME PERIOD COVERED	PRICE TYPE	LOCATION	ESTIMATED PRICE ELASTICITY
Gottlieb (1963)	1952-57	Average	Kansas, US	-1.24 to -0.66
Conley (1967)	1955	Average	U.S. general	-0.35
Howe & Linaweaver (1967)	1961-66	Fixed	U.S. general	-0.23 to -0.21
Wong (1972)	1951-61	Fixed	Chicago, IL	-0.82 to -0.02
Young (1973)	1946-71	Average	Tucson, AZ	-0.65 to -0.41
Hogarty & Mackay (1975)	1971-72	Marginal	Oak Manor, Blacksburg, VA	-1.41 to +0.09
Gibbs (1978)	1973	Marginal	Miami, FL	-0.51 to -0.62
Cassuto & Ryan (1979)	1970-75	Marginal	Oakland, CA	-0.30 to -0.14
Danielson (1979)	1969-70	Average	Raleigh, NC	-0.31 to -0.27
Foster & Beattie (1979)	1960	Marginal	U.S. general	-0.76 to -0.27
Agthe & Billings (1980)	1974-77	Marginal	Tucson, AZ	-2.23 to -0.18
Billings & Agthe (1980)	1974-77	Average, Marginal	Tucson, AZ	-0.61 to -0.27
Carver & Boland (1980)	1969-73	Marginal	Washington DC	-0.70 to -0.02
Foster & Beattie (1981)	1960	Marginal	U.S. general	-0.13 to -0.12
Hansen & Narayanan (1981)	1961-77	Marginal	Salt Lake City, UT	-0.51 to -0.47
Billings (1982)	1974-77	Average	Tucson, AZ	-0.66 to -0.27
Howe (1982)	1963-65	Marginal	U.S. general	-0.57 to -0.06
Jones & Morris (1984)	1976	Marginal, Shin	Denver, CO	-0.34 to -0.07
Schefter & David (1985)	1979	Marginal	Wisconsin	-0.13 to -0.11
Williams (1985)	1970	Average, Marginal	U.S. general	-0.62 to -0.22
Agthe, et al. (1986)	1974-80	Marginal	Tucson, AZ	-0.62 to -0.27
Chicoine & Ramamurthy (1986)	1983	Marginal	Illinois	-0.47
Chicoine, et al. (1986)	1982	Marginal, Average, Shin	Illinois	-0.42 to -0.22
Williams & Suh (1986)	1976	Average, Marginal	U.S. general	-0.48 to -0.18
Moncur (1987)	1977-85	Marginal	County of Honolulu, HI	-0.68 to -0.03
Nieswiadomy & Molina (1989)	1976-85	Marginal	Denton, TX	-0.86 to +3.50
Billings (1990)	1974-80	Marginal	Tucson, AZ	-0.72 to -0.57
Griffin & Chang (1990)	1981-86	Average	Texas	-0.38 to -0.16
Martin & Kulakowski (1991)	1965-88	Fixed	Tucson, AZ	-7.47 to +7.90
Nieswiadomy & Molina (1991)	1976-85	Shin	LE Denton, TX	-0.94 to +0.78
Schneider & Whitlach (1991)	1959-77	Marginal	Columbus, OH	-0.44 to -0.11
Lyman (1992)	1983-87	Marginal	Moscow, ID	-3.33 to -0.40
Martin & Wilder (1992)	1980-81	Average	Columbia, SC	-0.70 to -0.32
Nieswiadomy (1992)	1984	Marginal	U.S. general	-0.60 to +0.02
Stevens, et al. (1992)	1988	Average	Massachusetts	-0.69 to -0.10
Hewitt (1993)	1981-85	Fixed	Denton, TX	-1.23 to -1.12
Nieswiadomy & Cobb (1993)	1984	Average, Marginal	U.S. general	-0.64 to -0.17

AUTHOR	TIME PERIOD COVERED	PRICE TYPE	LOCATION	ESTIMATED PRICE ELASTICITY
Hewitt & Hanemann (1995)	1981-85	Marginal	Denton, TX	-1.59
Renwick (1996)	1985-90	Average, Marginal	California	-0.33
Corral, et al. (1998)	1982-92	Marginal	California	-0.30 to 0.00
Renwick, & Archibald (1998)	1985-90	Marginal	California	-0.53 to -0.11

Notably, the estimates provided in Exhibit 4-8 vary widely from study to study. Differences in the specification of the demand model, characteristics of the underlying data, and econometric techniques make it challenging to compare results across regions and studies. Perhaps most importantly, the specification of demand models in these studies varies according to assumptions made about the water prices faced by the consumer. While the earliest studies on price elasticity relied on simple demand models that employed uniform average prices, more recent research suggests that incorporating information about the rate structure faced by consumers is important. In particular, the current literature focuses on estimating demand under increasing block rate prices. Analyses that allow for discontinuous prices tend to result in higher price elasticities, suggesting that consumers are more price-sensitive to water prices than indicated by the earlier literature (Dalhuisen, 2003; Olmstead, 2010). One intuitive explanation for this result is that increasing block rates make prices more salient to consumers because the price changes with the amount consumed, thereby increasing their price responsiveness (Olmstead, 2007).

VALUES FROM WATER TRANSFER PROGRAMS

The research discussed above is based on consumer behavior in response to water rates, which are generally considered a poor indicator of the true economic value of domestic water. Only recently have U.S. economists been able to observe transactions with the potential to capture the full value of water in specific applications. In areas of water competition (e.g., the arid southwest), water transfer programs allow one party to sell or lease water rights to another party. These water transfers harness the power of market pricing signals to achieve more efficient use of water.

Water transfer programs often entail the transfer of water rights from agricultural to municipal interests. Brewer, et al. (2007) compiled detailed information from western U.S. water transactions implemented between 1987 and 2005. While the price that municipalities paid in temporary lease arrangements averaged $119 per acre foot, permanent purchase of water rights entailed prices averaging over $4,500 per acre foot.

The relatively high price paid by municipal water supply entities for additional water provides an indicator of the willingness to pay for water for municipal use and suggests the potential for economic welfare gains through mechanisms that provide for the transfer of water when municipal supplies are inadequate to meet demand. However, the obstacles to water transfers limit the availability of willingness-to-pay data. Transfer

markets tend to be active only where water law, institutional flexibility, and physical infrastructure are sufficient for implementing trades. More information on water transfers is presented in Chapter 5 of this report.

METHODS FOR VALUING WATER SUPPLY RELIABILITY

Economists have also developed studies to value the reliability of domestic water supplies. These studies use either stated preference or revealed preference methods to assess consumers' willingness to pay (WTP) for greater water supply reliability. Stated preference methods use survey responses to hypothetical choices about water supply reliability, whereas revealed preference studies infer value from market data on expenditures to increase the reliability of supply. Taken together, these studies suggest that consumers are willing to pay to avoid supply shortages.

One analysis of the value of water supply reliability, a stated preference study of California residents, estimates that they would be willing to pay an additional $12 to $17 on monthly household water bills to avoid water shortages of varying degrees; statewide, this amounted to more than $1 billion in 1994 (CUWA, 1994). A similar study of Texas residents incorporates information on household characteristics to determine WTP for avoided supply shortages by demographic. Not surprisingly, the study suggests that more affluent households would be willing to pay more to avoid shortages than low income households. In particular, a low income household would pay $17.19 to avoid a three-week shortfall with a 20 percent chance of occurring, whereas a high income household would pay $44 (Griffin, 2000). Similarly, a study of Colorado residents estimated the effect of the length of a shortage and its probability of occurrence on WTP. The authors found that residents would pay a base of $18.41 to avoid any shortage; this payment would increase with the anticipated length of the shortage and its chance of occurrence (Howe, 1994).

WTP studies are subject to a number of criticisms related to their validity and reliability (Venkatachalam, 2004). With respect to residential water supply, two criticisms are particularly relevant. First, the results of WTP studies may be biased if consumers have imperfect information about the good in question. Second, they may be biased if respondents do not have experience valuing the good in question. Imperfect information is problematic because most consumers are not fully cognizant of their monthly water usage and bills. Water bills do not garner much attention because they represent a small share of monthly household spending and are often bundled with charges for other utilities, like electricity and natural gas. If consumers do not understand how usage affects expenditures, it is hard to imagine that they will accurately gauge how much they would spend to prevent a shortage. Additionally, most consumers have never actually had to pay to avoid a water shortage. With no prior experience, consumers' responses may not reflect their true WTP.

METHODS FOR VALUING DOMESTIC WATER QUALITY

The quality of the water supplied for domestic use can have a significant effect on its value. The EPA regulates drinking water quality according to standards developed under SDWA (CBO, 2002). As a result of these regulations and additional state and local standards, the quality of water provided by public water supply systems in the United States is generally very good. Isolated instances of contamination, however, illustrate the potentially catastrophic implications of deterioration in the quality of domestic water supplies. The largest recorded waterborne disease outbreak in the United States took place in Milwaukee, Wisconsin in 1993. Cryptosporidium oocysts – transported by runoff from cattle pastures – passed through the filtration systems at one of the city's treatment plants, resulting in more than 403,000 cases of illness (25 percent of the population) and 104 deaths in just two weeks (Corso, 2003). According to an analysis by the Center for Disease Control, the total cost associated with the outbreak was $96.2 million, including $31.7 million in medical costs and $64.6 million in productivity losses (Corso, 2003). Note that these estimates likely reflect a lower bound on the true economic cost of the outbreak, since they do not consider willingness to pay to avoid the deaths and illnesses the outbreak caused.

As the example above indicates, protecting the quality of public water supplies provides substantial economic benefits, including reduced morbidity and mortality, avoided worker and school absences, and lower medical expenditures. While the literature on these benefits is sparse for the United States, many economists have considered the impacts of improved water supplies in developing countries. In particular, expanded access to high quality water supplies is strongly correlated with improved health outcomes that subsequently reduce costs associated with death, malnutrition, stunting, and productivity losses (Listorti, 1996; Esrey, et al., 1991; Galiani, et al., 2005). High-quality water also confers educational benefits by reducing barriers to school attendance (Komives, 2005).

Premiums paid for bottled water also provide an indication of individuals' willingness to pay for perceived higher-quality water. According to research by the Natural Resources Defense Council, more than half of the U.S. population consumes bottled water and more than one-third of Americans drink it regularly (Olson, 1999). In 2007, U.S. bottled water sales reached 8.8 billion gallons, worth $11.7 billion (Gies, 2008). Per gallon, bottled water costs 240 to over 10,000 times as much as tap water (Olson, 1999).

SUMMARY

The majority of the U.S. population receives its household water from public suppliers. The public system is large and complex, encompassing an extensive network of facilities engaged in the extraction, treatment, and distribution of water. While some of these systems are privately-held, most are operated by state or local governments. In 2007, this sector generated revenues of $53 billion and employed 200,725 people.

Access to safe drinking water is a cornerstone of public health and workforce productivity in the U.S. Maintaining this access will depend in part on investments in projects aimed to improve the existing public supply infrastructure. Much of this infrastructure has been in place for decades and is due for replacement. While estimates

vary, EPA and others place the annual investment need at approximately $10 billion to $20 billion over the next 20 years.

Research into residential demand for water suggests that consumers are not particularly responsive to changes in water prices because substantial subsidies keep prices artificially low. That said, research on specific rate structures indicates that increasing block prices promote more efficient water use than uniform rates. Additionally, the research suggests that households with better access to salient price and use information are more likely to consume conservatively. The challenge for decision-makers is to gain a better understanding of efficient market prices, enabling them to structure municipal water rates that simultaneously promote water conservation and generate adequate revenues to cover suppliers' costs.

As water competition intensifies in some parts of the U.S., better information on the value of municipal water is emerging. While water rates typically aim to recover treatment and delivery costs, information from water transfers provides a more complete measure of municipalities' willingness to pay for additions to their domestic water supply. Available data on trades in the western United States suggest that municipal willingness to pay for water at the margin is quite high, averaging about $4,500 per acre foot for water obtained in a permanent sale. Such findings provide important insights to the value of water in domestic use.

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CHAPTER 5 | AGRICULTURE (OFF-STREAM USE)

INTRODUCTION

A reliable supply of clean water is vital to the success of the U.S. agricultural sector. Irrigation allows cultivation of otherwise non-arable land and increases the productivity of farms, especially in the Great Plains and West. Likewise, water is an essential element in livestock and aquaculture operations. This chapter characterizes the role of water in agriculture, focusing on the following topics:

- The economic importance of U.S. agriculture and its place in the global economy;
- The use of water in the U.S. agricultural sector;
- Supply issues affecting agricultural water use and ways in which competition for water is influencing its use;
- Water quality requirements associated with agricultural water use; and
- Available estimates of the value of water used in agriculture.

SECTOR OVERVIEW

OVERVIEW OF KEY FINDINGS

- Agricultural operations – crop irrigation, livestock watering, and aquaculture – withdraw approximately 140 billion gallons of water per day. Irrigation accounts for over 90 percent of this use and is the largest single consumptive water use in the U.S.
- While water use efficiency has improved through increased use of new irrigation technologies, room for improvement still exists. Historically, efficiency incentives were often reduced by abundant water supplies made available through large public infrastructure projects. These projects created interdependencies between agriculture and other water users, such as municipalities and power generators.
- Agricultural use is a major consideration in the competition for water, especially in western states. Increasingly, agricultural interests that hold water rights are participating in water transfer initiatives through which they sell water to municipalities and other users.
- The absence of formal markets complicates efforts to value water applied in agriculture, and studies yield vastly different estimates depending upon the methodology used. Estimates based on delivery cost and factor input methods yield relatively low estimates (generally less than $100 per acre foot). Data from water transfers suggest much higher values. Transfers between farms show values averaging about $1,800 per acre foot. Transfers from farms to municipalities show even higher average values (over $4,000 per acre foot).

Agriculture is a major component of the U.S. economy. In 2010, agriculture accounted for approximately 1.1 percent of U.S. gross domestic production (U.S. CIA, 2011).

While the relative significance of the agricultural sector has decreased over the last century, U.S. output of crops and livestock has grown steadily, the result of major productivity advances associated with new machinery, soil science, and other agricultural technology.

The discussion below briefly describes the composition of the U.S. agricultural sector in greater detail, and place the U.S. industry in the context of the global economy.

U.S. AGRICULTURAL SECTOR

The National Agricultural Statistics Service (NASS) within the U.S. Department of Agriculture conducts a periodic census of U.S. agriculture. Exhibit 5-1 draws on the most recent census (2007) to provide a basic economic profile of the U.S. agricultural sector. As shown, the total market value of all agricultural products in 2007 was approximately $297 billion, with crops and livestock making up roughly equal shares of that output.[18] This production occurred on about 2.2 million farms. Most of these farms are small, family operations, which account for a relatively small share of total production. In contrast, about 64 percent of all market value is generated by a small number of large farming operations having annual sales of $500,000 or more (USDA/NASS, 2009).

EXHIBIT 5-4. OVERVIEW OF THE U.S. AGRICULTURAL SECTOR (2007)

SECTOR CHARACTERISTIC	ESTIMATE
Total Number of Farms	2,204,792
Employment	2,903,797
Land Used in Farming (acres)	922,095,840
Irrigated Land (acres)	56,599,305
Market Value of All Agricultural Products	$297.2 billion
Market Value of Crops	$143.6 billion
Market Value of Livestock	$153.6 billion
Source: USDA/NASS, 2009; BLS, 2010.	

Neither the Bureau of Labor Statistics (BLS) nor USDA maintains comprehensive data on employment in the agriculture sector. A rough estimate can be obtained by adding the number of farm proprietors (2.15 million based on the 2007 Census of Agriculture) and the number of paid employees in crop and animal production (0.754 million based on 2010 BLS data). These figures suggest that the agriculture sector employs approximately 2.9 million individuals.

The market value of U.S. farm products has grown over time and saw particularly marked growth from 2002 to 2007 (see Exhibit 5-2). Much of this growth has come as a result of productivity increases and strong markets – both domestic and export – for key products (see below). A specific driver has been growth in U.S. corn production and increases in

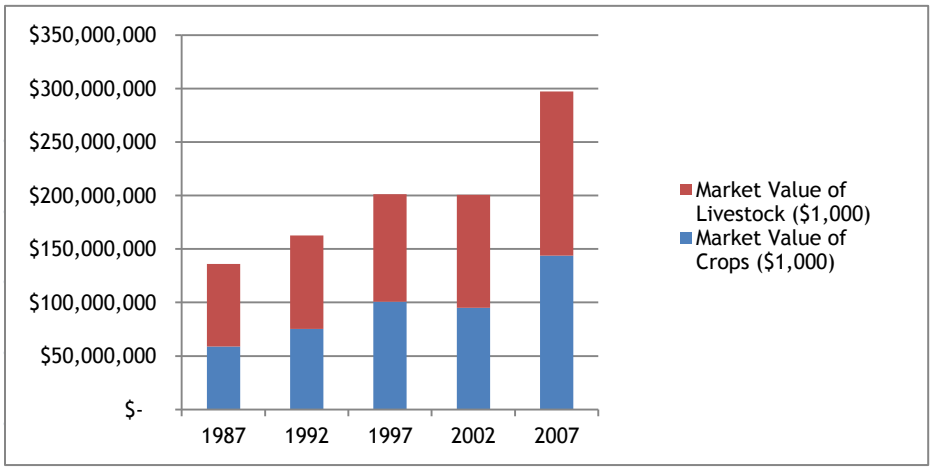
[18] In the USDA census data, aquaculture is a small component of overall livestock operations. The review of water use in aquaculture (see below) reports basic economic information for aquaculture operations to better highlight this subsector.

corn prices. Demand for corn has grown as a result of its application in new food products (e.g., sweeteners); its use as livestock feed; and its subsidized use for biofuels such as ethanol (USDA/ERS, 2008).

A diverse climate and other factors enable the U.S. agricultural sector to produce a broad array of goods. Exhibit 5-3 shows that major crops such as corn, soybeans, and wheat remain significant, but numerous other products are grown on U.S. farms. Livestock operations are dominated by cattle and dairy, but pigs and poultry play a large role as well.

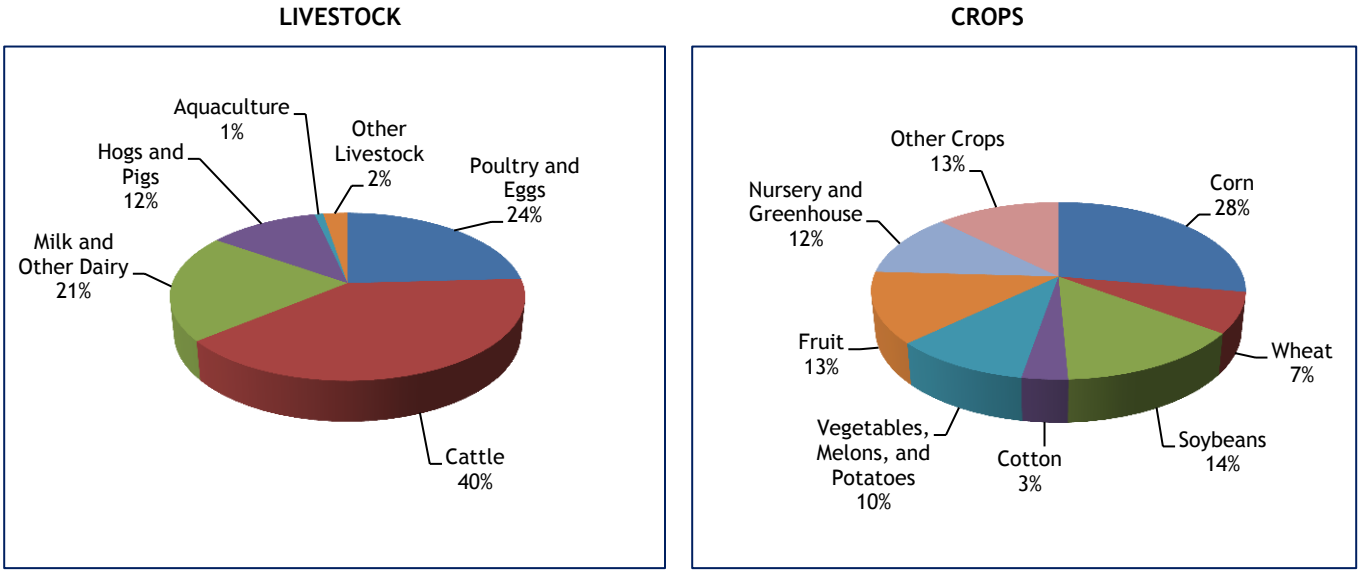
The importance of the U.S. agricultural sector should be considered in light of its linkages to other sectors of the U.S. economy. Key farming inputs from other economic sectors include energy, fertilizer, pesticides, and machinery. The USDA's Economic Research Service has estimated that each dollar of U.S. output added to agricultural exports stimulates $1.31 in activity in related economic sectors (USDA/ERS, 2009). Furthermore, as noted in Chapter 2, agriculture is a key component of the primary mega-sector of the U.S. economy. Agricultural output supports activity in other mega-sectors, especially the secondary mega-sector, which includes manufacturers that process raw agricultural inputs into final consumer goods.

EXHIBIT 5-2. MARKET VALUE OF U.S. AGRICULTURAL OUTPUT, 1987 TO 2007 ($ THOUSANDS)



Source: USDA/NASS, 2009.

EXHIBIT 5-3. DISTRIBUTION OF U.S. AGRICULTURAL PRODUCTS BY MARKET VALUE (2007)



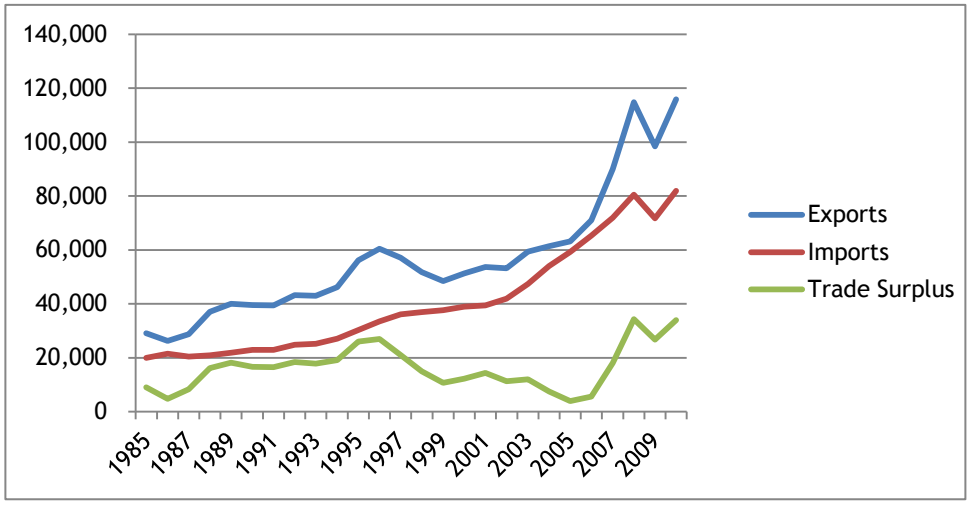
Source: USDA/NASS, 2009.

U.S. AGRICULTURE IN A GLOBAL CONTEXT

The U.S. agricultural sector is part of a complex global system of agriculture, food processing, and food marketing. Both exports and imports of agricultural products have grown over time, but growth in the export sector has been more rapid, yielding a consistently positive trade surplus in agriculture. Exhibit 5-4 shows the trade surplus (exports minus imports) over time.

Exports have undergone an important transformation in recent years. While bulk grains (e.g., corn, wheat) historically accounted for growth in U.S. exports, high-value products now play a larger role. These products include meats, poultry, fruits, and vegetables. This change is the direct result of growth in population and incomes worldwide; demand from this growth has driven U.S. exports. In addition, trade agreements have played a central role in expanding U.S. export markets. In particular, since full implementation of the North American Free Trade Agreement (NAFTA), Canada and Mexico have become the largest export destinations for U.S. agricultural products, eclipsing Japan and other traditional trading partners (USDA/ERS, *U.S. Agricultural Trade: Exports*). Overall, exports now represent roughly 30 percent of the total market value of U.S. agricultural production.

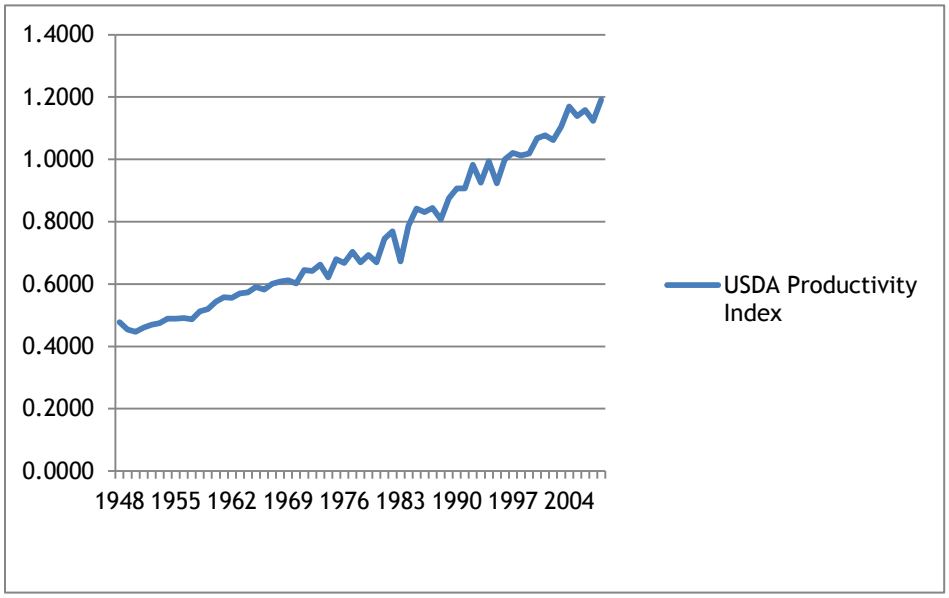
EXHIBIT 5-4. U.S. AGRICULTURAL SECTOR TRADE SURPLUS ($ MILLIONS)



Source: USDA/ERS (FATUS).

Numerous factors influence the competitiveness of the U.S. agricultural sector in the global economy. These factors include the prices of key inputs such as labor, seed, fertilizer, and machinery; the status of trade agreements with various nations; changes in subsidies and other agricultural policies; technological improvements; and access to capital. It is difficult to summarize competitiveness because the U.S. position varies greatly depending on the trading partners and the individual agricultural products under consideration; however, productivity serves as a good, stand-alone indicator of the resiliency and competitiveness of U.S. agriculture. The USDA maintains an index measuring agricultural productivity, defined as the difference between the growth in farm output and the growth of all agricultural inputs. Exhibit 5-5 shows that this measure of agricultural productivity has increased steadily over time, rising by 152 percent in the last 60 years. Through productivity gains and efficient use of inputs, the U.S. agricultural sector continues to improve its competitive position and maintain a positive balance of trade.

EXHIBIT 5-5. U.S. AGRICULTURAL PRODUCTIVITY (USDA PRODUCTIVITY INDEX)



Source: USDA/ERS, "Agricultural Productivity in the U.S."

In the context of this background report, a key question is whether a reliable supply of water influences the productivity and competitiveness of the nation's agricultural sector. Arguably, U.S. producers enjoy a comparative advantage as a result of several water-related factors, including:

- A relatively temperate climate that allows for non-irrigated production in many parts of the country;
- A relatively efficient and technologically advanced system of irrigation in areas in which it is required; and
- A reliable supply of adequate-quality groundwater and surface water for irrigation and livestock watering.

A detailed comparison of the U.S. to other nations with respect to these factors is beyond the scope of this report, but the literature suggests that few nations enjoy the advantages enjoyed by U.S. producers. First, most nations are more reliant upon irrigation for food production than is the U.S. Approximately 11 percent of all U.S. cropland is irrigated. In contrast, 19 percent of cropland worldwide is irrigated. Some major nations such as China and Pakistan irrigate over half of their cropland (*Water Encyclopedia*, no date). Another obvious indicator of U.S. competitive advantage in agriculture is our food security relative to other nations. Studies suggest that over 850 million people worldwide do not have a reliable source of food; most of these people live in the arid nations of southern Asia and sub-Saharan Africa, where water access is poor. Finally, recommendations for increasing food security emphasize the need for expanding and improving the efficiency of irrigation systems worldwide (Molden, 2007).

Studies suggest that the competitive advantage of U.S. agriculture could be reinforced by emerging climate trends. In general, climate change is anticipated to yield increased temperatures and altered precipitation patterns, intensifying competition for limited water resources in many areas. An analysis by Lobell, et al. (2011) estimates that between 1980 and 2008, global maize production declined by 3.8 percent and global wheat production declined by 5.5 percent, both as a result of climate change. The warming pattern that caused the production decreases, however, was absent in U.S. farming areas. Strzepek and Boehlert (2010) analyzed how future climate change patterns could increase competition for irrigation water. The study modeled likely changes in demand for municipal/industrial water, environmental flows (i.e., in-stream flows), and agricultural water under various climate change scenarios. The authors found that threats to agricultural water supplies are likely to intensify in Africa, Latin America, and the Caribbean. In contrast, the threat to agricultural water supplies in North America is expected to decline on net, primarily due to wetter climate conditions and a decreased need for water to maintain in-stream flows.

WATER USE

As presented in Chapter 3, agricultural applications account for approximately 34 percent of all water withdrawals. Irrigation uses represent over 90 percent of these withdrawals, while watering of livestock and supplies to aquaculture make up the balance. The discussion below provides a more detailed review of how water is used in these three agricultural applications.

IRRIGATION

Quantity and Sources of Water Used

Estimates of the total quantity of water used for irrigation on U.S. farms vary, depending on year and data source. Exhibit 5-6 shows that while USGS estimates that 144 million acre-feet were used in irrigation in 2005, the USDA estimates that only 91.2 million acre-feet were used for irrigation in 2008. The USDA survey is more recent and provides more detail on irrigation methods and patterns; therefore, the discussion below focuses on the USDA figures when possible.[19]

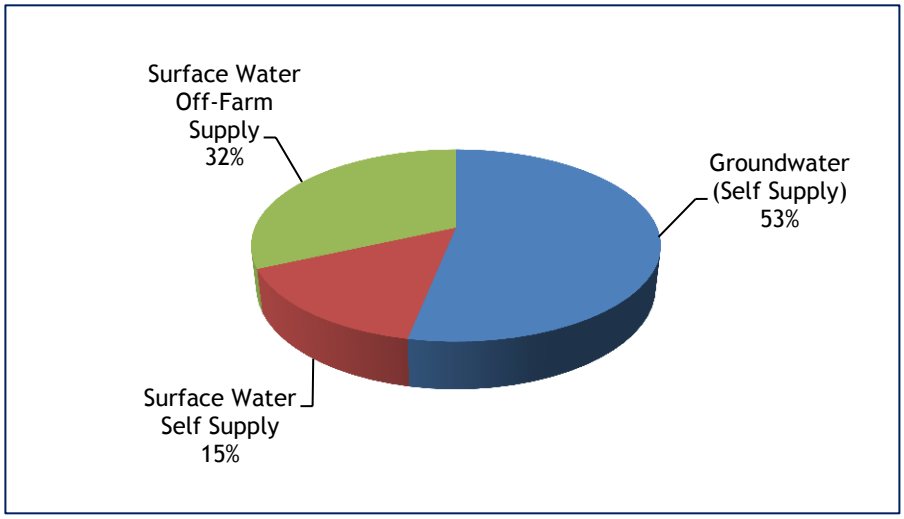
[19] As defined in the USDA 2007 Agriculture Census and 2008 Irrigation Survey, irrigation occurs exclusively on establishments in NAICS code 111 (Crop Production). The USGS irrigation figures reflect water usage in SIC codes 111 through 191 (various crop production operations), as well as SIC 4971 (Water Supply and Irrigation Systems), SIC 7992 (golf courses), and SIC 7997 (fitness, amusement, and recreational centers). This difference in scope may explain some of the disparity in estimated water use.

EXHIBIT 5-6. IRRIGATION WATER USE

SOURCE	YEAR	ACRE-FEET APPLIED	ACRES IRRIGATED	AVERAGE ACRE-FEET PER ACRE
USGS	2005	144,000,000	61,100,000	2.35
USDA Farm and Ranch Irrigation Survey	2008	91,235,036	54,929,915	1.7
Sources: USGS, 2009; and USDA/NASS, 2010.				

Exhibit 5-7 summarizes the sources of irrigation water on U.S. farms. The USDA irrigation survey suggests that just over half of all irrigation water is pumped from on-farm groundwater sources. Surface water sources are also common, with most coming from off-farm suppliers (e.g., irrigation districts). As discussed below, the source of irrigation water can play an important role in creating incentives to improve the efficiency of agricultural water use.

EXHIBIT 5-7. IRRIGATION WATER SOURCES



Source: USDA/NASS, 2010.

In all forms of irrigation, the preferred outcome is to deliver water directly to the crop. In practice, however, the ultimate disposition of irrigation water is more complex. In addition to being taken up by crops, water may leak to the ground in non-cultivated areas; evaporate during delivery or after initial application; or return overland or through drainage systems to surface water, and thus be available for reuse. Studies by USGS and USDA typically consider the "consumptive" component of irrigation water use to include the fraction that is "evaporated, transpired, incorporated into products or crops…or otherwise removed from the immediate water environment" (USGS, 2009). Based on

data from 1995, the USDA estimates that 61 percent of irrigation water is consumed, making irrigation the most dominant consumptive water use (Wiebe and Gollehon, 2006).

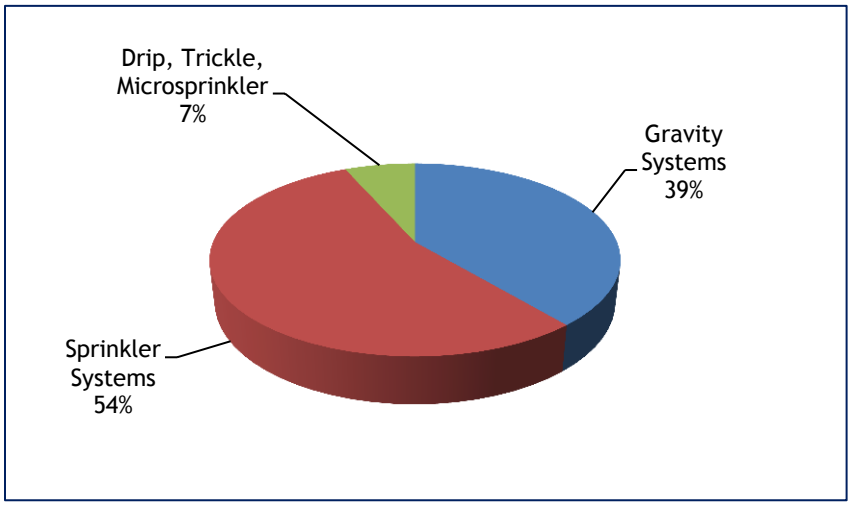
Irrigation Methods and Efficiency

U.S. farmers generally distribute irrigation water using one of three methods:

- **Gravity Systems** – Gravity-fed irrigation systems include traditional methods that deliver water to fields via ditches, furrows, or pipes. While this is a relatively low-cost approach, it is generally considered less efficient than other distribution methods.
- **Sprinkler Systems** – In a sprinkler irrigation system, water is delivered via a series of perforated pipes. Variations of sprinkler systems include rolling systems, which can be moved across fields, and rotating or pivot systems that direct water over a wide area by moving the water stream.
- **Drip/Trickle or Micro Sprinkler Systems** – Drip/trickle systems use small-diameter tubes placed on or below the soil surface, applying water frequently and slowly. Water is applied directly to the root zone of plants. Micro sprinkler systems use low-volume sprinkler heads positioned just above the soil surface. These low-flow methods are relatively high-cost but are considered highly efficient and are generally applied to high-value, perennial crops (Wiebe and Gollehon, 2006).

Exhibit 5-8 shows the mix of irrigation methods based on total acreage on which they are applied. As shown, sprinkler systems were applied on over half the irrigated acreage in 2008. Low-flow systems such as drip irrigation are used selectively and account for only about seven percent of all acreage. This mix is changing, however, as U.S. producers strive for increased irrigation efficiency (see below).

EXHIBIT 5-8. IRRIGATION METHODS



Source: USDA/NASS, 2010.

Various factors have combined to encourage improvements in the efficiency of irrigation practices. A major driver has been the increasing scarcity of water in key agricultural areas and increases in the explicit or implicit price paid for water. In addition, technological shifts and advances have allowed for greater irrigation efficiency. One technological change is simply the method of water delivery. Data show an increase in the use of sprinkler systems and a reduction in the use of flood or gravity systems (which lose water in conveyance). Between 1985 and 2005, the amount of land irrigated by sprinkler systems increased from 22 million to more than 30 million acres. In that same period, the amount of land irrigated by flood systems fell from 35.0 million to 26.6 million acres (USGS, 2009).

Irrigation water application rates further demonstrate trends in water use efficiency. USGS estimates that in 1950, the average application rate was 3.55 acre-feet per acre; by 2005 this figure had fallen to 2.35 acre-feet per acre. The 2008 USDA irrigation survey estimates per-acre application rates to be as low as 1.7 acre-feet per acre. It is important to note that increases in irrigation efficiency do not necessarily translate into decreases in water consumption. Because gravity systems deliver more water to fields than is required by crops, a significant portion of that water runs off and may be available to downstream users through irrigation return flows. By contrast, drip irrigation systems are much more precise in the amount of water delivered to crops, meaning that a much higher percentage of water used for irrigation is consumed by plants. To the extent that efficiency gains reduce losses to evaporation, they can decrease total consumptive use of water in this sector.

Despite recent increases in irrigation efficiency, significant room for improvement remains. As discussed below, distortions in the prices that some irrigators pay for water can limit the economic incentive to improve efficiency. Comparative studies suggest that the U.S. is not among the most efficient users of irrigation water. Many operations that could employ precision technologies are still using inefficient gravity systems (Gleick, 2006). Likewise, few farmers are taking advantage of scheduling and measurement technologies in irrigation. Most irrigators still rely heavily on the feel of the soil or the condition of the crop. The 2008 USDA irrigation survey suggests that only about nine percent use soil moisture sensors; likewise, only two percent use plant moisture sensors.

Contribution of Irrigation to Agricultural Output

Irrigation contributes significantly to the productivity of U.S. agriculture. First, as shown in Exhibit 5-9, over 50 percent of the market value of all crops is generated on farms where at least some irrigation is used. Farms that irrigate their entire crop account for about one-third of total crop value.

EXHIBIT 5-9. VALUE OF IRRIGATED CROPS ($ THOUSANDS)

MARKET VALUE OF ALL CROPS	FARMS WITH ANY IRRIGATED LAND		FARMS WITH ENTIRE CROP IRRIGATED	
	MARKET VALUE OF CROPS	PERCENT OF ALL CROPS	MARKET VALUE OF CROPS	PERCENT OF ALL CROPS
$143,657,928	$78,297,158	54.5%	$46,872,638	32.6%
Source: USDA/NASS, 2009.				

The importance of irrigation is also reflected in its effect on crop yields. Exhibit 5-10 lists major irrigated crops in the U.S. and the effect that irrigation has on yields of these crops. As shown, ranked by total acreage at farms where the entire crop is irrigated, major irrigated crops include corn, alfalfa, soybeans, cotton, and wheat.[20] In all cases, irrigation improves the recorded yield per acre. This improvement is most striking for alfalfa and wheat, where yields double when the entire crop is irrigated.

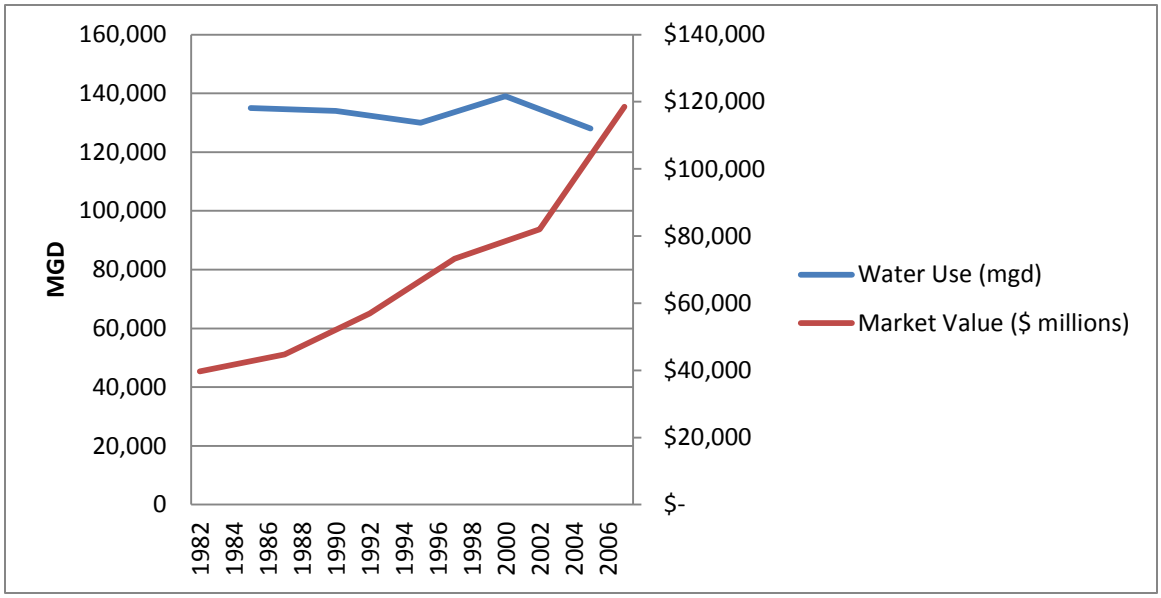
EXHIBIT 5-10. MAJOR IRRIGATED PRODUCTS AND YIELD IMPROVEMENTS ON IRRIGATED LAND

PRODUCT	ENTIRE CROP IRRIGATED		PART OF CROP IRRIGATED		NONE OF CROP IRRIGATED	
	ACRES	AVERAGE YIELD	ACRES	AVERAGE YIELD	ACRES	AVERAGE YIELD
Corn for grain (bushels)	6,103,769	180	7,053,000	150	66,656,287	144.3
Alfalfa hay (tons, dry)	5,746,037	4.9	810,615	3.3	12,846,779	2.5
Soybeans for beans (bushels)	2,175,069	45.3	3,062,006	40.8	55,282,030	40.2
Cotton (bales)	2,046,094	2.5	1,989,516	1.8	4,214,480	1.5
Wheat for grain (bushels)	1,806,902	80.3	1,557,177	42.7	43,865,291	37
Source: USDA/NASS, 2009.						

The value of irrigated crops reflects two key trends: (1) the importance of irrigation for farm productivity; and (2) increased efficiency in the use of irrigation water. Exhibit 5-11 compares irrigation water use to the value of irrigated crops over the last 20 years. The graph demonstrates that the market value of irrigated crops has steadily increased despite relatively unchanged water inputs.

[20] The list excludes several irrigated products for which yield information was not available, including forage, orchard crops, rice, and vegetables.

EXHIBIT 5-11. MARKET VALUE OF IRRIGATED CROPS AND IRRIGATION WATER USE



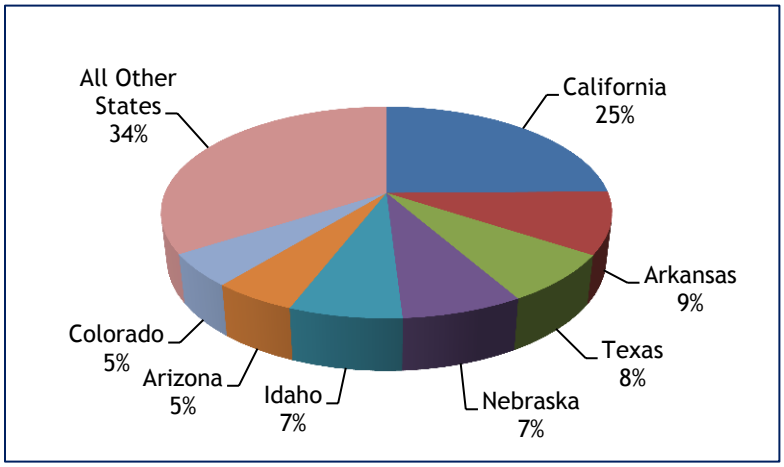
Sources: USDA/NASS, 2009; USGS, 2009.

Major Irrigation Regions

Irrigation water use is concentrated in a limited number of states. This is the result of some obvious factors, such as arid climate, as well as complex factors that include demographic patterns and institutional decisions that have enhanced the availability of water for irrigation. As shown in Exhibit 5-12, seven states account for about two-thirds of all irrigation water use: California, Arkansas, Texas, Nebraska, Idaho, Arizona, and Colorado. California is by far the largest user, accounting for about one quarter of all irrigation water.

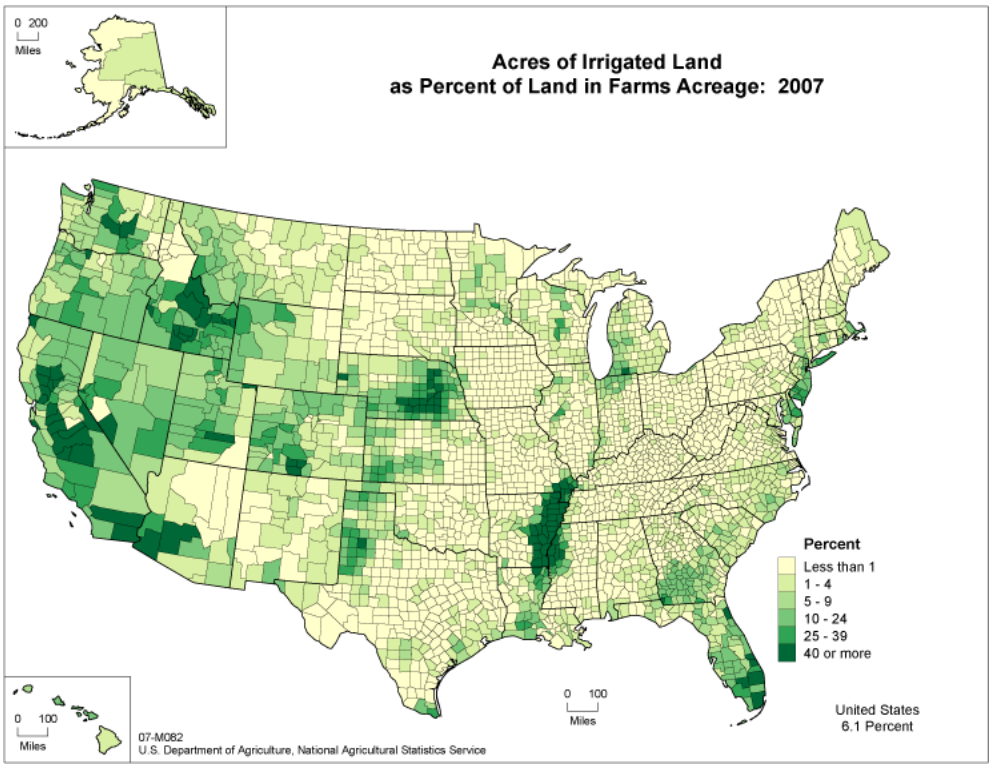
Exhibit 5-13 shows the areas where irrigation is most intensively used. The map depicts the percentage of all farmland that is irrigated, organized by county to provide a more detailed level of geographic resolution. The darkest areas are those where more than 40 percent of farmed acreage is irrigated. These areas correspond to some of the most productive agricultural regions in the U.S., including California's Central Valley and the Lower Mississippi River Basin. Farms are also intensively irrigated in southern California, southern Florida, central Idaho, eastern Nebraska, and parts of Arizona, Colorado, Utah, and Washington.

EXHIBIT 5-12. STATES' SHARE OF IRRIGATION WATER USE



Source: USDA/NASS, 2010.

EXHIBIT 5-13. ACRES OF IRRIGATED LAND AS PERCENT OF LAND FARMED (2007)



Source: USDA/NASS, 2007 Census Publications (accessed online).

LIVESTOCK

The USGS estimates that U.S. farmers and ranchers withdraw approximately 2.1 billion gallons of water per day to maintain livestock. These withdrawals accounted for less than one percent of total U.S. water withdrawals in 2005. Approximately 60 percent of this supply is drawn from groundwater sources. The vast majority of the water is consumed rather than returned to surface water or aquifers. USGS studies of water consumption estimate consumptive-use coefficients ranging from 84 percent to 100 percent, depending on the predominant animal type, geographic region, and other factors (Shaffer and Runkle, 2007).

Few states require that livestock operations report water usage. As a result, the USGS method relies on water-use coefficients to estimate livestock water withdrawals. These coefficients reflect total daily water usage for each major category of livestock; the coefficients are combined with USDA data on animal inventories to estimate water use. Where available, USGS applies water-use coefficients specific to a given state. When state-specific coefficients are not available, USGS applies the median values shown in Exhibit 5-14.

EXHIBIT 5-14. USGS LIVESTOCK WATER USE COEFFICIENTS

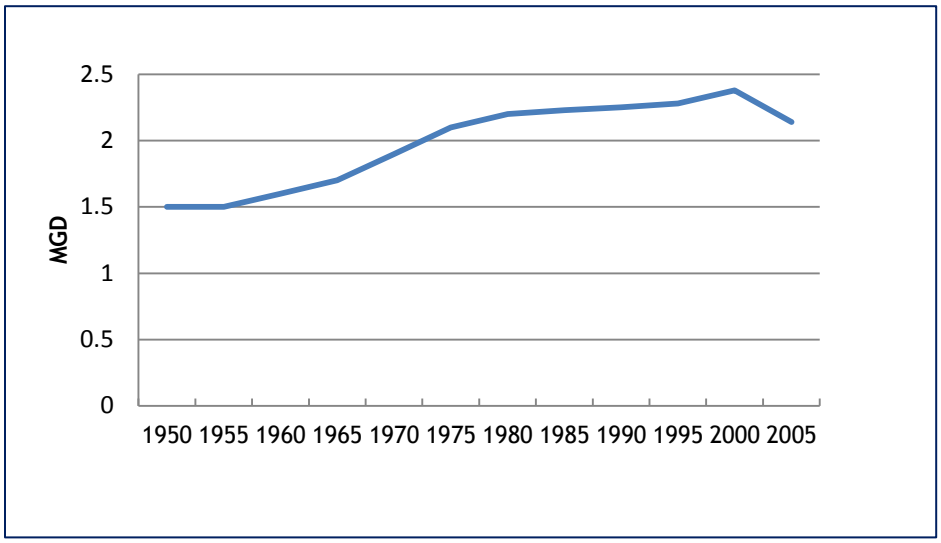
ANIMAL TYPE	WATER-USE COEFFICIENT (GAL/DAY)
Dairy Cows	35
Beef and Other Cattle	12
Hogs and Pigs	3.5
Laying Hens	0.06
Broilers and Other Chickens	0.06
Turkeys	0.1
Sheep and Lambs	2
Goats	2
Horses	12
Source: Lovelace, 2009.	

As shown, water requirements vary greatly by animal type. This is partly due to the water consumption requirements of larger versus smaller animals; it also reflects differences in the use of water for purposes other than consumption. These purposes include waste disposal, sanitation, cooling, and other needs. Water use in waste disposal can vary greatly, depending on the manure management method applied on a given farm. Dairy operations are especially water-intensive; they require water for cleaning cow udders prior to milking, sanitation of equipment, and cooling of storage tanks (Lovelace, 2009a). This intensive water use is reflected in the high water-use coefficient for dairy cows.

Although some technological changes have improved livestock water use efficiencies, these changes are minor. The drinking component of water use dominates, and animals' water requirements are obviously constant. As a result, livestock water use has varied

little over the last half century, as shown in Exhibit 5-15. The growth in water use largely reflects growth in the overall size of the U.S. livestock inventory.

EXHIBIT 5-15. LIVESTOCK WATER USE OVER TIME (MGD)



Source: USGS, 2009.

The geographic distribution of withdrawals corresponds to where livestock are raised (see Exhibit 5-16). In particular, water use is high in states with major dairy and beef cattle operations; these states include Texas, California, and Oklahoma, the top three users of livestock water in the U.S.

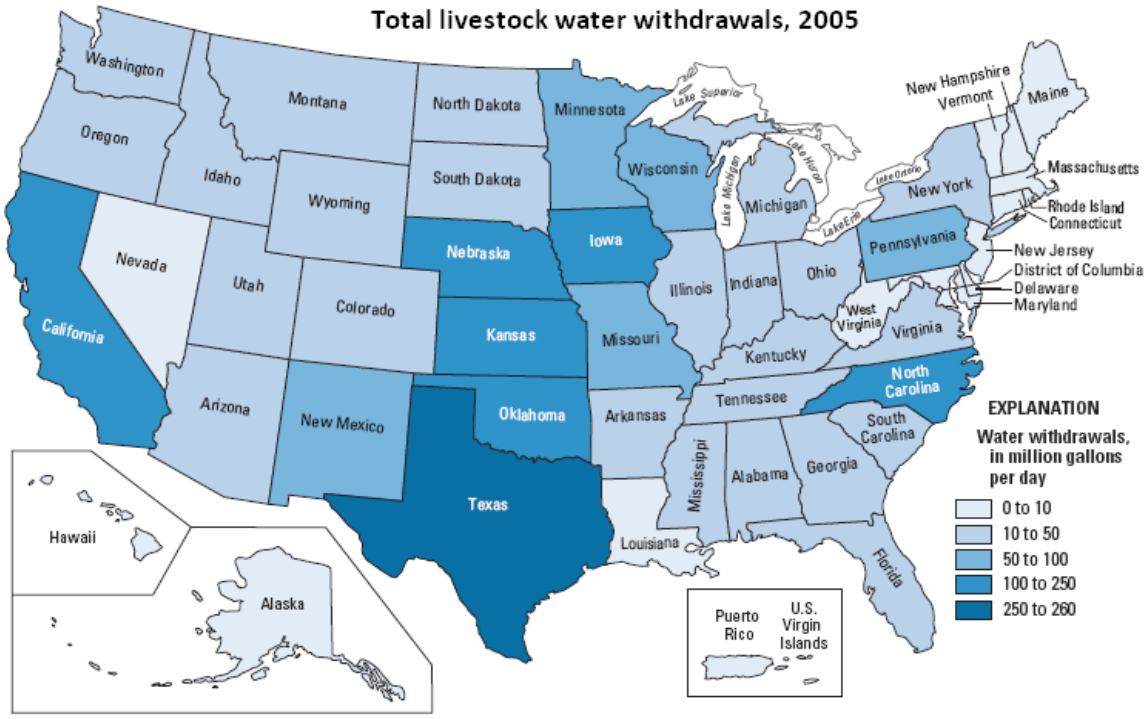
AQUACULTURE

USGS reports that aquaculture operations account for roughly two percent of all U.S. water withdrawals. USGS considers all the withdrawals to be self-supplied, with about 78 percent taken from surface water sources and the remainder from groundwater. Available data are limited but suggest that aquaculture water use is growing rapidly, as indicated by an estimated 52 percent increase in withdrawals for this purpose from 2000 to 2005.

Aquaculture water use is largely non-consumptive, but depends on the aquaculture method applied. Major methods include the following:

- **Raceways** – Some production (e.g., trout, salmon) occurs in flow-through raceways. In raceways, water is temporarily diverted from a spring or stream to maintain a flowing environment for the fish. Therefore, this growing method is a major water user, but is non-consumptive, since virtually all of the water is returned to its source. USGS reports that about 10 percent of all aquaculture operations use raceways (Lovelace, 2009b).

EXHIBIT 5-16. GEOGRAPHIC DISTRIBUTION OF LIVESTOCK WATER USE

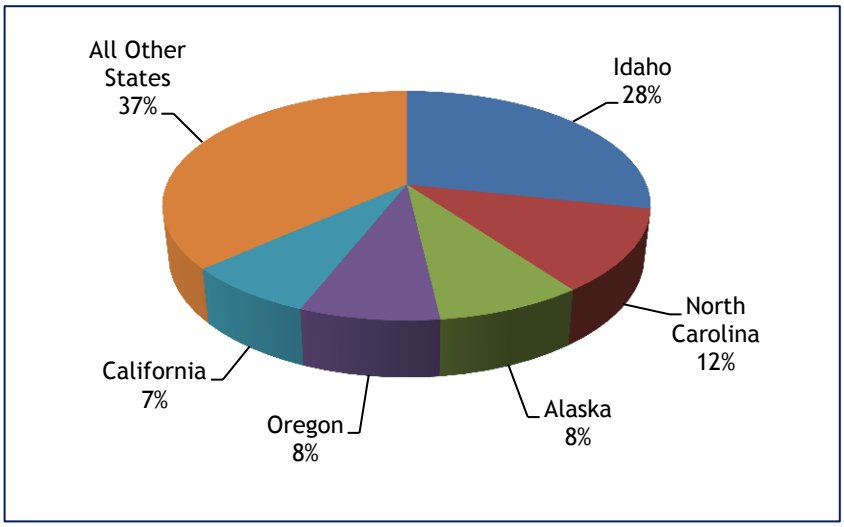


Source: USGS, 2009.

- **Ponds** – Ponds are another common aquaculture method, and are used to grow species such as catfish. The amount of water added to ponds varies greatly, depending on precipitation, evaporation, leakage, and the species grown. Therefore, ponds can represent a somewhat more consumptive water use in comparison to raceways, but generally do not require large water withdrawals. USGS reports that about 54 percent of all aquaculture operations use ponds (Lovelace, 2009b).
- **Tanks** – Tanks are used to grow a diverse array of fish species, including trout, salmon, bass, tilapia, perch, and others. Water is removed during waste management and through evaporation; however, the method generally consumes little water since many operations use recirculating filtration systems. USGS reports that about 17 percent of all aquaculture operations use tanks (Lovelace, 2009b).
- **Other Methods** – Other types of aquaculture operations include pens and cages (used for both fish and shellfish) as well as egg incubators.

Five states account for nearly two-thirds of aquaculture water use: Idaho, North Carolina, Alaska, Oregon, and California (see Exhibit 5-17). Idaho, by far the largest user, is the nation's leading producer of rainbow trout; hence, the use of raceways there is common.

EXHIBIT 5-17. GEOGRAPHIC DISTRIBUTION OF AQUACULTURE WATER USE



Source: USGS, 2009.

Aquaculture is growing rapidly in the U.S., although comprehensive data are not readily available to characterize this growth. USDA only began reporting complete aquaculture information in its 2007 Census. Exhibit 5-18 summarizes the market value of major products and the associated number of aquaculture operations. As shown, products from the aquaculture industry had a market value of approximately $1.4 billion in 2007. Catfish, trout, and mollusks were the most significant products, both with respect to market value and in terms of the number of operations. It is important to note that the species listed differ greatly in terms of aquaculture method and water use. For example, while catfish are predominantly grown in man-made ponds, trout are frequently raised in in-stream raceways that effectively consume little or no water.

EXHIBIT 5-18. MAJOR AQUACULTURE PRODUCTS (2007)

PRODUCT	NUMBER OF OPERATIONS	MARKET VALUE ($ 1,000)
Catfish	1,725	$455,378
Trout	1,124	$210,568
Other Food Fish	643	$187,711
Baitfish	358	$40,343
Crustaceans	788	$50,855
Mollusks	1,097	$243,007
Ornamental Fish	684	$61,049
Sport or Game Fish	815	$80,568
Other Aquaculture Products	341	$85,793
Total		$1,415,272
Source: USDA/NASS, 2009.		

SUPPLY AND PRICING ISSUES

In a textbook microeconomic system, scarcity and pricing combine to produce an efficient use of finite resources. The use of water in agriculture is at odds with this textbook system in a variety of ways. This section examines the economic setting for agricultural water use by first summarizing the current system of pricing and distribution. The discussion then reviews how heightened competition for scarce water supplies is encouraging stakeholders to pursue more efficient approaches to the use of water resources.

PRICING AND DISTRIBUTION OF AGRICULTURAL WATER

The ways in which farmers acquire water greatly affects the cost of water and the economic signals to which they respond. Exhibit 5-19 summarizes key information on the three major sources of irrigation water: self-supplied groundwater, self-supplied surface water, and surface water delivered from off-farm sources. Self-supplied surface water is generally the least costly water supply method, although this option is available on limited acreage, mostly in eastern areas where surface water is plentiful. Groundwater pumping costs vary greatly, depending on local conditions. Water purchases from off-farm retailers also vary in cost, depending on the prices charged by the supplier; this water acquisition approach is common in the West. As discussed below, these costs are very low when compared to both true delivery costs and to the full social cost of irrigation water use.

EXHIBIT 5-19. IRRIGATION WATER SOURCES AND COSTS

WATER SOURCE	SHARE OF IRRIGATED ACRES (2008)	AVERAGE COST ($ PER ACRE, 2003)	COST RANGE ($ PER ACRE, 2003)	COST CONSIDERATIONS
Groundwater, Self-supplied	53%	$39.50	$7 - $176	Pumping cost varies with energy prices, depth to water, and pump efficiency
Surface Water, Self-supplied	15%	$26.39	$10 - $82	Cost reflects expense for lifting or pressurizing surface water; when pumping not required, effective cost is zero
Surface Water, Off-farm supply	32%	$41.73	$5 - $86	Reflects costs charged by water supply intermediaries; most common in western U.S.
Sources: Wiebe and Gollehon, 2006; Heimlich, 2003; and USDA/NASS, 2010.				

These modes of water delivery and their associated costs are a product of numerous institutional factors that have evolved over time. First, laws governing water rights are complex. Riparian water rights (i.e., the right to divert surface water on one's own property) have long applied in areas with abundant surface water supplies. In arid regions, however, the "appropriation doctrine" has generally prevailed. Introduced during the period of western expansion, this system allows water users to stake claims to

water sources; this has allowed a complex system of seniority rights to develop (Wichelns, 2010).

Beginning with the Reclamation Act of 1902, the Federal government took a key role in supplying irrigation water. The Bureau of Reclamation (BOR) acts as a water wholesaler by developing large water supply infrastructure projects. Through 1994, BOR had built 133 projects that supply irrigation water, at a total cost of $21.8 billion. State governments have funded and developed additional water supply projects. BOR and other water developers typically make the water available to intermediate water retailers such as irrigation districts. These intermediaries are generally non-profit entities that seek to supply water at the lowest possible cost (Wiebe and Gollehon, 2006).

Over the past century, state governments have become increasingly involved in the management of water rights and resources. While state policies vary, they generally grant water-use rights to individuals, charging nothing other than minor administrative fees for these rights (Wiebe and Gollehon, 2006). These approaches also extend to the management of groundwater resources. Some states actively manage groundwater use through permit systems, while others place no limits on pumping (Wichelns, 2010).

The sum effect of all these institutional factors is that, in many cases, the cost that farmers face for the use of irrigation water has been established entirely outside of conventional economic markets. While water costs for farmers may partially reflect access and delivery costs, they have little or no relationship to: (1) total supply costs; (2) the on-farm value of irrigation water (e.g., increased yield); and (3) the potential social value of water in its highest and best use. For instance, water from Federal supply projects is often heavily subsidized by other project beneficiaries (e.g., hydropower producers), allowing farmers to obtain water at prices far below the actual cost of delivery.

These subsidies can result in a variety of economic distortions. First, studies show that increasing water scarcity has driven up the value of water in industrial and municipal applications (see below); as such, the lack of pricing mechanisms results in an economically inefficient use of water in some regions of the U.S. In addition, subsidized water may reduce incentives for water-use efficiency in irrigation and may encourage the cultivation of water-intensive crops poorly suited to natural and market conditions.

RESPONSES TO INCREASED COMPETITION FOR WATER

Agricultural interests face increased competition for water from a number of sectors, particularly in the West. The sources of this competition include:

- **Municipal Water Use** – Growth in many arid and semi-arid cities in the western U.S. has required increasing water deliveries for municipal water systems.
- **Energy Sector** – Hydropower projects may store water and make it available for agricultural use, creating interdependencies between farms and power generators. If water shortages arise, however, power generation may compete with agriculture for access to adequate supplies of water.

- **Conservation and Recreation** – Increasingly, environmental regulations require the maintenance of in-stream flows for the benefit of key wildlife species, as well as for recreational and other uses (CBO, 1997).

Data and modeling suggest that competition among these interests has increased the potential for irrigation water shortages. USDA survey data indicate that, in 2008, 33,000 farms reported diminished crop yields due to irrigation problems. Of these, over 17,000 highlighted a shortage of surface water as the specific problem encountered, the single largest cause reported. Another 3,400 farms reported a shortage of ground water (USDA/NASS, 2010).

In recent years, stakeholders have responded to the increased competition for water in a variety of ways. Some of these efforts are essentially regulatory in nature. For instance, Congress passed the Central Valley Project Improvement Act (CVPIA) in 1992. Established in 1935, the Central Valley Project (CVP) in California is the largest of BOR's water resource projects. It delivers water to the Sacramento Valley in northern California and the San Joaquin Valley in central California. About 85 percent of the CVP's water supply is used for irrigation, while 15 percent is delivered to municipal and industrial users. The CVPIA sought to address problems associated with dewatering of wetlands and rivers in the region. It mandates release of more water to supplement rivers and wetlands; habitat restoration; water temperature control; water conservation; and other steps. These actions have increased water prices for Central Valley producers and encouraged increased irrigation efficiency (Wichelns, 2010).

Other initiatives seek to harness the power of market pricing signals to achieve more efficient water use. Many of these efforts fall under the general umbrella of "water transfers" or "voluntary water marketing." In general, these arrangements introduce flexibility into traditional water rights systems, bringing regional water users together in a collaborative trading setting. Specifically, water transfers involve transactions where one party sells or leases water rights to another party. These transactions frequently entail transfer of water rights from agricultural to municipal interests. They may involve

WATER TRANSFERS IN COLORADO

Within 20 years, the population of the South Platte River basin outside Denver, Colorado is projected to grow by 1.9 million. This growth is expected to strain available water supplies, significant shares of which are currently used to irrigate alfalfa and other forage crops. Through the Lower South Platte River Irrigation and Research Demonstration Project, agriculture experts from Colorado State University are collaborating with the Parker Water and Sanitation District to address this issue. Initiated in 2007, the project is identifying and implementing irrigation efficiency techniques designed to generate surplus water that can be traded to the municipal water authority. The project also involves proceedings in Colorado's Water Court to demonstrate that agriculture-to-municipal trades will have no net impact on in-stream flows in the South Platte River.

Source: Lytle, 2008.

retirement of irrigated cropland, or may focus on improved irrigation efficiency and transfer of surplus water generated by these efficiency gains (see text box).

Research has clearly demonstrated the potential for economic welfare gains from water transfers. One comprehensive study of water transfers between 1987 and 2005 showed consistently high prices when irrigators sold to municipalities. The sample of over 1,000 agriculture-to-municipal sales showed a median sales price of over $2,600 per acre-foot (Brewer, et al., 2007). Economists have concluded that because water can command higher prices for municipal and other non-irrigation uses, there is significant economic gain to be found in agriculture-to-urban transfers (Eden, et al., 2008).

But there are many obstacles to water transfer and marketing. Markets tend to be active only where water law, institutional flexibility, and physical infrastructure combine to allow trading. Likewise, trading may generate unintended externalities for third parties (e.g., reduced groundwater supplies for farms neighboring the irrigator involved in the trading arrangement). Studies suggest that current water markets involve only one to two percent of all irrigation withdrawals (Wiebe and Gollehon, 2006).

LONG-TERM CHALLENGES

Long-term global changes are likely to intensify water competition and the need for innovative responses worldwide. Foremost among these challenges is climate change. Climate change is likely to lead to rising temperatures, shifting patterns of precipitation, and more extreme weather events. Most studies predict that agriculture in lower-latitude countries will suffer the greatest harm (Molden, 2007). These studies show that areas such as sub-Saharan Africa and parts of India and China have high vulnerability (in terms of climate and hydrological conditions) and low adaptability (e.g., in terms of water supply and storage options) (UN, 2009). As noted earlier, modeling of future climate change scenarios also supports the idea that threats to agricultural water could intensify in parts of Africa, Latin America, and the Caribbean (Strzepek and Boehlert, 2010).

Climate change poses a threat to agricultural water supplies in the U.S., but to a lesser degree relative to some other nations. As noted in Chapter 3, increased temperatures and drought risk in portions of the southwest and Great Plains may render current irrigation withdrawals unsustainable (EPA, 2012). Studies have forecast that increased drought risk in southwestern and Rocky Mountain regions may necessitate development of storage capacity to better manage variable water supplies (Strzepek, et al., 2010).

In addition to climate change, other global trends may increase water competition and affect agricultural water supplies. Population growth worldwide has the combined impact of increasing urban water demand while adding to the demand for food. As economic globalization proceeds, increased incomes in developing countries will continue to enhance the demand for meat and other foods that are resource intensive. A legitimate comparison of the water resource demands of meat versus crop production is the subject of considerable debate; however, available literature consistently demonstrates that much more water is required to produce a given quantity of meat than a calorie-equivalent quantity of virtually any crop (Peden, et al., 2007). Competition for water in U.S. agriculture could increase as producers strive to meet food demand in export markets.

Finally, the surge in production of certain crops for biofuels may place additional stress on agricultural water supplies. Worldwide, the production of bioethanol from sugarcane, corn, sugar beets, wheat, and sorghum tripled between 2000 and 2007. Along with Brazil, the U.S. is the major producer meeting this demand, primarily through corn cultivation (UN, 2009). Future trends in biofuels markets may have important consequences for U.S. agricultural water supplies.

Modeling efforts have attempted to integrate all these long-term economic and demographic factors. A study of worldwide trends in water demand determined that competition among municipal/industrial users, environmental flow requirements, and the agricultural sector would result in an 18 percent reduction in the availability of irrigation water by 2050 (Strzepek and Boehlert, 2010).

WATER QUALITY ISSUES

The adequacy of water resources for agricultural purposes depends not only upon the quantity of water supplied, but also its quality. Data suggest that water quality issues do not currently pose a major problem for U.S. producers. Of the 33,000 farms that reported interruptions in their irrigation operations in 2008, only about two percent attributed the problem to poor water quality (USDA/NASS, 2010). As competition for water grows, however, producers may seek out new water supplies of lesser quality, increasing the potential for quality-related problems.

The discussion below briefly reviews water quality requirements for irrigation, livestock, and aquaculture applications.

IRRIGATION

The United Nations Food and Agriculture Organization (FAO) has compiled a comprehensive reference document on water quality issues affecting agriculture (Ayers and Westcot, 1994). The FAO study highlights four major categories of water quality problems affecting irrigation:

- **Salinity** – Salts contained in irrigation water can accumulate in the root zone of crops. Yield reductions may result when salt levels grow so great that plants are unable to extract sufficient water from the soil. The salts that contribute to salinity problems are readily transported in irrigation water. Salinity problems may be exacerbated in the presence of a shallow water table, where salts can accumulate and remain in contact with the crop root zone.
- **Water Infiltration Rate** – The rate at which irrigation water infiltrates soil can be slowed under certain conditions, causing water to remain on the soil surface and possibly evaporate. Although soil factors affect infiltration rates, water quality plays a role as well. High sodium relative to calcium and magnesium content in the water will decrease infiltration (as will high salinity).
- **Toxicity** – Plants can absorb certain toxic constituents in irrigation water, and these contaminants can concentrate to levels that damage the plants or reduce yields. Permanent, perennial crops such as trees are most sensitive to these

effects. The constituents of greatest concern include chloride, sodium, and boron.

- **Other** – The FAO study cites additional water quality problems that may affect irrigation, but which are less common. High nitrogen concentrations can cause excessive vegetative growth and delayed crop maturity. Likewise, sprinkler water containing excessive concentrations of bicarbonate, gypsum, or iron can create unsightly deposits on fruit or leaves. Finally, excessive pH can lead to various plant abnormalities.

LIVESTOCK

Guidance documents for livestock operations emphasize the importance of safe, healthy water supplies. Ensuring the quality of the water supply can be especially challenging given the impacts that livestock operations themselves can have on nearby source waters. Available guidance highlights several categories of water quality concerns:

- **Salinity and Associated Minerals** – Salinity is the problem most commonly encountered in livestock water. Salinity is correlated with the presence of many specific compounds, including sodium, chloride, calcium, magnesium, and bicarbonate. Available guidance suggests that impacts on animals' digestive systems may begin at total salt levels of 3,000 mg/l; some animals may also refuse water with this level of salt. Concentrations above 10,000 mg/l are considered highly saline and unacceptable for use (Faries, no date).
- **Nitrogen** – Nitrogen as nitrate is digested and converted to nitrite in animals. The nitrite reduces the blood's ability to carry oxygen and can therefore poison animals. Guidance recommends against using livestock water with greater than 300 ppm nitrate (Pfost and Fulhage, no date).
- **Blue-Green Algae** – High nutrient loadings in farm runoff can result in excessive growth of blue-green algae in livestock water. When ingested by animals, the algae can be toxic and may result in muscle tremors, liver damage, and possibly death (Pfost and Fulhage, no date). Guidance recommends chlorination of livestock water to reduce algae growth (Faries, no date).
- **Suspended Solids** – Water with high levels of suspended solids may discourage animals from drinking adequately. The desired range for suspended solids is below 500 mg/l, while concentrations above 3,000 mg/l are considered problematic (Pfost and Fulhage, no date).

AQUACULTURE

Since water constitutes the environment in which fish live, water quality is of utmost importance in aquaculture. Aquaculture operations are often carefully calibrated to create the optimum setting for fish and shellfish to thrive. Although water quality requirements are highly specific to the species being cultured, key considerations include the following:

- **Temperature** – Every species has a water temperature in which it grows most readily. For instance, catfish thrive in temperatures between 70 and 85 degrees Fahrenheit; as a result, pond-based catfish farming has been highly successful in southern states (Swann, 1992).
- **Dissolved Oxygen** – To prevent stress or death, dissolved oxygen (DO) in aquaculture systems must be maintained at levels conducive to the species in question. In general, warmwater species (e.g., tilapia, carp, catfish) require DO levels above 3.0 ppm, while coldwater species (e.g., trout) require DO levels above 5.0 ppm (Buttner, et al., 1993).
- **Ammonia, Nitrates, and Nitrites** – Most fish and shellfish excrete ammonia as their primary nitrogenous waste. Fish exposed to total ammonia-nitrogen levels above 0.02 ppm may grow slower and be more susceptible to disease (Buttner, et al., 1993).
- **pH** – Fish survive and grow best in water with a pH between 6 and 9.

Exhibit 5-20 summarizes the primary water quality concerns associated with irrigation, livestock, and aquaculture.

EXHIBIT 5-20. SUMMARY OF IRRIGATION WATER QUALITY ISSUES

AGRICULTURE SECTOR	PRIMARY WATER QUALITY CONCERNS
Irrigation	• Salinity • Toxicity
Livestock	• Salinity and minerals • Nitrogen • Algae • Suspended solids
Aquaculture	• Temperature • Dissolved oxygen • Ammonia, nitrates, nitrites • pH

VALUE OF WATER USE

As discussed, a variety of factors influence the availability of water for agriculture and the economic incentives faced by farmers. These factors include irrigation technology; water rights and water use law; subsidizing of public water supply projects; competition from other users; climate change; commodity prices; and the structure and nature of global food demand. These and other factors create a system that strays far from a conventional microeconomic pricing framework for water. The result is that traditional information for assessing commodity value (e.g., consumer and producer surplus estimates) is frequently lacking.

In response to the lack of conventional microeconomic data, economists have implemented a variety of approaches that seek to establish the value of a unit of water used in the agricultural sector. Exhibit 5-21 summarizes the available estimates, placing all the values in common terms (i.e., value per acre foot expressed in 2010 dollars).[21] The wide range in values is explained by both the mix of methodologies applied and the specific aspects of water value that each method captures; as such, the values are difficult to compare directly.

One method for valuing irrigation water simply considers the cost that farmers incur in acquiring the water. Some of the lowest rates are paid by farms acquiring water from large surface water supply projects in the western U.S. For instance, farmers in California's Imperial Irrigation District paid only about $15.50 per acre foot for water in 2003 (Brewer, et al., 2007). Historically, these projects are subsidized and can offer irrigation water at low rates. Average acquisition costs nationwide are somewhat higher, as reflected in Exhibit 5-21. By multiplying published information on the per-acre cost of irrigation by the average quantity of water applied per acre, we can estimate a rough average for the cost of acquiring water through different sources.[22] The cost of self-supplied groundwater is roughly $80 to $110 per acre foot; this is also true for the nationwide average cost of surface water delivery from off-farm sources. Self-supplied surface water costs about $53 to $73 per acre foot on average.

Acquisition cost is an imperfect reflection of the true value of irrigation water. At best, acquisition cost represents a lower-bound estimate of the water's value; i.e., farmers pay the implicit or explicit price to acquire the water, so it must be worth at least that amount. Other studies have attempted to establish more reliable measures of the actual value of irrigation water. One method for doing so is the factor input method. This method incorporates the relationship between crop yield and water input. As discussed earlier, irrigation has a demonstrable positive impact on the yield of many crops, depending on the growing conditions. Under the factor input method, yield increases can be valued by commodity prices to provide an estimate of the value of water as an input to production.

[21] All figures have been adjusted to 2010 dollars using the GDP implicit price deflator.

[22] Specifically, we calculate the acquisition costs using the per-acre irrigation costs reported by Wiebe and Gollehon (2006). To obtain a lower-bound cost per acre foot, we multiply the per-acre cost by the average acre feet of water applied to irrigated land (1.7 acre feet) as reported by USDA (2008). The upper-bound estimate is based on the USGS water application estimate (2.35 acre feet per acre).

EXHIBIT 5-21. VALUES FOR IRRIGATION WATER

VALUATION METHOD	WHAT IS MEASURED	DATA SOURCE	VALUE PER ACRE FOOT OF WATER ($2010)
Acquisition Cost (Groundwater)	Average per-acre cost for groundwater pumping, multiplied by the average water application rate per acre	Wiebe and Gollehon, 2006; USGS, 2009; USDA, 2009	$79 - $109
Acquisition Cost (Surface Water)	Average per-acre cost for self-supplied surface water, multiplied by the average water application rate per acre	Wiebe and Gollehon, 2006; USGS, 2009; USDA, 2009	$53 - $73
Acquisition/Delivery Cost (Surface Water)	Average per-acre cost for surface water delivery from an off-farm supplier, multiplied by the average water application rate per acre	Wiebe and Gollehon, 2006; USGS, 2009; USDA, 2009	$84 - $116
Factor Input Method	Based on crop-water production function method; reflects increased yield associated with irrigation; average for all crops and regions	Frederick, et al., 1996; AWWA, 2007	$98
Water Transfer, Ag to Ag, Temporary Lease	Average market price associated with temporary water lease agreements between agricultural producers	Brewer, et al., 2007	$30
Water Transfer, Ag to Muni, Temporary Lease	Average market price associated with temporary water lease agreements between agricultural producers and municipal water suppliers	Brewer, et al., 2007	$119
Water Transfer, Ag to Ag, Permanent Sale	Average market price associated with permanent water rights sale agreements between agricultural producers	Brewer, et al., 2007	$1,825
Water Transfer, Ag to Muni, Permanent Sale	Average market price associated with permanent water rights sale agreements between agricultural producers and municipal water suppliers	Brewer, et al., 2007	$4,562
Hedonic Price Method	Based on sales of agricultural land with varying access to irrigation water; figures incorporate land sales in Malheur County, Oregon	Faux and Perry, 1999	$12 - $56
Hedonic Price Method	Based on sales of agricultural land with varying access to irrigation water; figures incorporate land sales in Georgia's Flint River basin	Petrie and Taylor, 2006	$39

Exhibit 5-21 shows that the factor input method provides an overall average value for an acre foot of water of approximately $98. This figure is based on research performed by Frederick, et al. (1996) and reviewed in a more recent study by the AWWA Research Foundation (2005). Frederick, et al. assembled data from over 170 individual studies of irrigation water value. The average value masks wide variation, depending upon the crop in question, the region of the country, and other factors. In the lower bound, some studies found irrigation water values of zero, while upper-bound values approached $1,000 per acre foot for some crops.

The value of water in agriculture can be further characterized by examining data from water transfers. As discussed above, water transfers involve one party selling or leasing water rights to another party. When properly structured, such trades provide the only direct, market-based evidence of the value of irrigation water. Brewer, et al. (2007) assembled data on numerous water transfer arrangements in the western U.S. As reviewed in Exhibit 5-21, water transfers yield a wide range of values, depending on the specific conditions of the transfer. When an agricultural entity leases temporary water rights to another agricultural entity, the average price per acre foot is approximately $30. The price rises to an average of over $1,800 per acre foot for the permanent sale of water rights. This differential highlights the value of securing a reliable or certain source of water, an important facet of the overall value of water.

Water transfers also occur between agricultural entities and municipal water suppliers. While lease arrangements averaged $119 per acre foot, permanent sale of water rights entailed prices averaging over $4,500 per acre foot. These transactions reveal a gap between the value of water in irrigation and its value in domestic use. In economic terms, irrigators' willingness to accept compensation in exchange for their water rights offers an indication (at the high end) of the value of water in an agricultural setting.

Finally, economists have implemented other methods for valuing irrigation water, although the literature supporting these methods is limited. Most notably, Faux and Perry (1999) tested a hedonic price approach for valuing irrigation water in Malheur County, Oregon. This study involved estimating the implicit price paid for water by studying the sale price of properties with varying access to irrigation water. The study found that property sales imply a value per acre foot of between $12 and $56. A similar hedonic analysis conducted by Petrie and Taylor (2006) estimated a comparable value of $39 per acre foot for irrigation water in Georgia's Flint River basin. Although these studies involve permanent purchase of water rights, the estimated price per acre foot is much lower than that observed in water transfers involving sales of permanent water rights. Numerous factors could account for this difference, although the relatively abundant supply of water in the hedonic study areas is likely a key contributor.

SUMMARY

In 2007, the agricultural sector produced crops and livestock valued at $297 billion. This output was due in part to the sector's reliance on water resources. Agricultural operations – crop irrigation, livestock watering, and aquaculture – withdraw approximately 140 billion gallons of water per day, and consume the largest quantity of water of any sector in the U.S. economy. Access to water is vital to agricultural productivity, particularly in

the arid and semi-arid regions of the Great Plains and the West, where irrigation projects bolster the international competitiveness of U.S. farms.

Irrigation, by far the largest component of agricultural water use, has become more efficient over time, although the traditional system of water rights and pricing provides limited efficiency incentives. As water supplies grow tighter in many areas, the competition for water among agricultural, municipal, and other water users is likely to intensify. Research suggests that the marginal value of water to municipal users in many cases is greater than its marginal value for irrigation. This highlights the opportunity to increase economic welfare by fostering mechanisms, such as trading programs, which provide incentives for more efficient water use and facilitate the voluntary transfer of water rights among different users. The challenge for decision-makers pursuing this objective will be to structure water trading and other economic incentives in a way that encourages an efficient and equitable use of resources, while at the same time maintaining the competitiveness of the U.S. agricultural sector.

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CHAPTER 6 | MANUFACTURING (OFF-STREAM USE)

INTRODUCTION

Water use in manufacturing varies greatly across industries. In industries such as chemical, paper, petroleum, primary metal, and food product manufacturing, water is vital to the production process. In some instances, these industries use water to fabricate, process, wash, dilute, cool, or transport a product; in others, they incorporate water directly into the product. Water is also used for sanitation needs within manufacturing facilities (USGS, 2009). This chapter characterizes the role of water in manufacturing, focusing on the following topics:

- The economic importance of U.S. manufacturing and its place in the global economy;
- The use of water in the U.S. manufacturing sector;
- Water quality requirements associated with the use of water in manufacturing; and
- Available estimates of the value of water used in manufacturing.

OVERVIEW OF KEY FINDINGS

- Manufacturers withdraw approximately 18.2 billion gallons of water per day, which represents four percent of total water withdrawals in the U.S. In addition to these direct withdrawals, the most recent data available suggest that approximately 12 percent of publicly-supplied water withdrawals (4.74 billion gallons of water per day in 1995) were used for manufacturing.
- Since 1985, direct withdrawals of water by the manufacturing sector have declined by 30 percent. This change is due in large part to increasing efficiency in water use, including recycling and/or reuse of water.
- The pollution control requirements introduced under the Clean Water Act are one factor that has contributed to the decline in withdrawals of water by the manufacturing sector. The cost of complying with these requirements provides a strong economic incentive to reduce effluent discharges, which in turn encourages greater efficiency in water use.
- It is difficult to develop estimates of the value of water in the manufacturing sector, largely because most water used within the sector is self-supplied. Nonetheless, the available estimates indicate that manufacturing may be among the highest value uses. This chapter presents estimates of marginal values that range between $14 and $1,527 per acre-foot. The wide range in values is explained by the mix of methodologies applied, the specific aspects of water value that each method captures, and regional variation.

SECTOR OVERVIEW

As noted in Chapter 2, manufacturing is a major component of the secondary mega-sector of the U.S. economy. In 2007, manufacturing accounted for approximately 17 percent of U.S. gross domestic production. The discussion below describes the composition of the U.S. manufacturing sector in greater detail and provides additional information on the sector in the context of the global economy.

U.S. MANUFACTURING SECTOR

The U.S. Census Bureau's Economic Census provides a detailed portrait of the United States' economy once every five years. Exhibit 6-1 draws on the most recent census (2007) to provide a basic economic profile of the U.S. manufacturing sector. As shown, the total value added by manufacturing industries in 2007 was in excess of $2.38 trillion. Approximately 288,000 firms engaged in manufacturing in 2007, employing approximately 13.4 million workers.

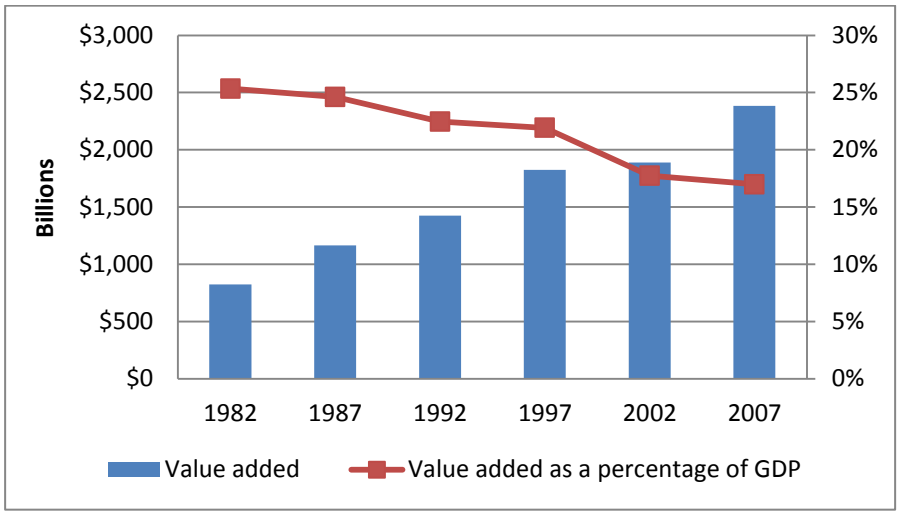
EXHIBIT 6-1. OVERVIEW OF THE U.S. MANUFACTURING SECTOR (2007)

SECTOR CHARACTERISTIC	ESTIMATE
Number of Companies	287,654
Number of Establishments	332,536
Number of Employees	13,395,670
Value Added	$2,382 billion
Total Value of Shipments	$5,319 billion
Source: U.S. Census Bureau, Economic Census, 2007.	

The value of U.S. manufacturing has grown in recent years, but the importance of manufacturing as a share of total GDP has diminished (see Exhibit 6-2). In addition, employment within the sector has declined steadily, from 17.8 million workers in 1982 to 13.3 million workers in 2007 (U.S. Census Bureau, 2007). The declines in employment can be explained by gains in productivity and increased competition from foreign producers (Brauer, 2008). The gains in productivity between 1995 and 2007 are particularly notable; during this period, productivity growth in manufacturing averaged 4.1 percent annually, up from an average of 2.7 percent from 1973 to 1995 (Brauer, 2008).

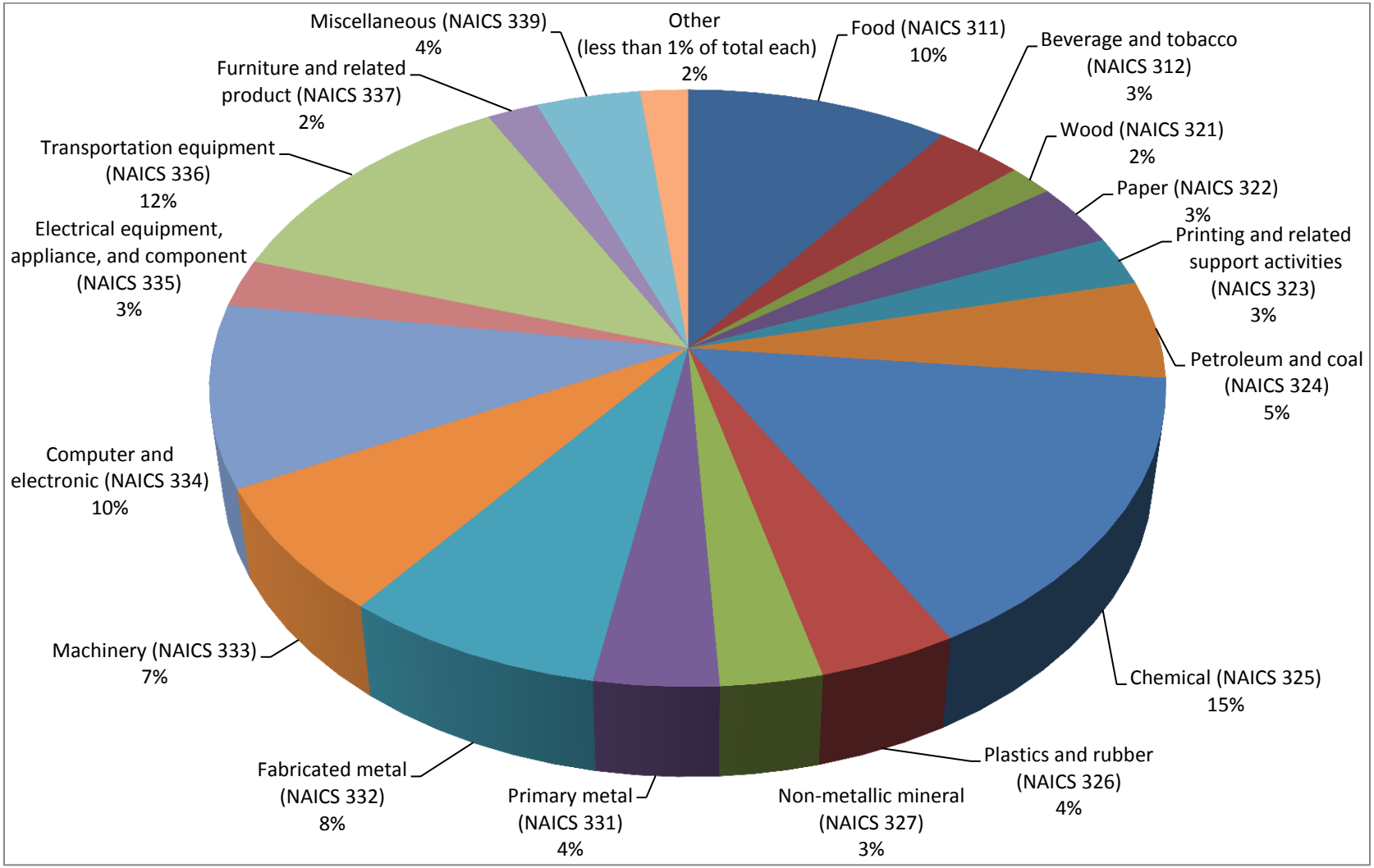
The U.S. produces a wide range of durable and non-durable goods. Exhibit 6-3 shows the distribution, by industry, of total value added in the manufacturing of these goods. As the exhibit indicates, chemical manufacturing contributes the largest share of value added to the U.S. economy, followed by transportation equipment and food products. Overall, these three industries account for approximately 38 percent of the value added by manufacturing.

EXHIBIT 6-2. VALUE ADDED BY U.S. MANUFACTURING, 1982 TO 2007



Source: U.S. Census Bureau, Economic Census, 2007; Bureau of Economic Analysis, Value Added by Industry, released December 13, 2011.

EXHIBIT 6-3. DISTRIBUTION OF VALUE ADDED IN MANUFACTURING DURABLE AND NON-DURABLE GOODS (2007)



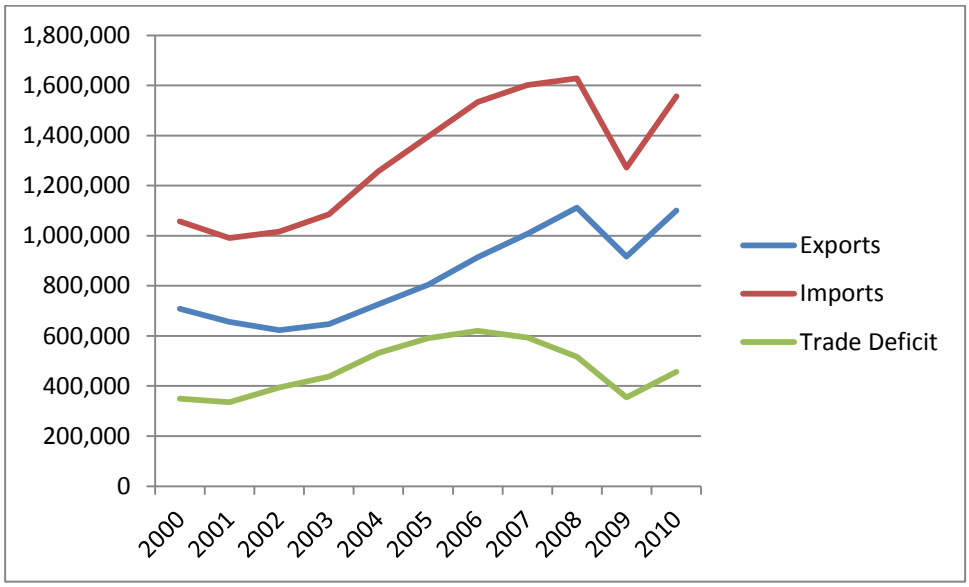
Source: U.S. Census Bureau, Economic Census, 2007.

U.S. MANUFACTURING IN A GLOBAL CONTEXT

In 2007, the U.S. led the world in manufacturing value added, followed by China and Japan (United Nations Statistics Division, 2010). U.S. manufacturing has long held this position. Between 1970 and 2000 the U.S. share of global manufacturing fluctuated little, varying from 21 percent to 29 percent (United Nations Statistics Division, 2010). Since 2000, however, the U.S. has seen a steady decline in its relative contribution to manufacturing worldwide, while China has seen a sharp increase. Between 2000 and 2007 the U.S. share of global manufacturing declined from 26 percent to 19 percent, while China's share increased from eight percent to 16 percent (United Nations Statistics Division, 2010).

In recent years, the U.S. manufacturing sector has been greatly affected by foreign competition, especially competition from emerging economies (Brauer, 2008). Between 1999 and 2007 the nominal trade deficit in manufactured goods doubled (see Exhibit 6-4). Over this period exports of manufactured goods from the U.S. rose by $334 billion (58 percent), but imports grew by $692 billion (78 percent) (Brauer, 2008). The deficit narrowed in both 2008 and 2009, reflecting reductions in both the import and export of manufactured goods, but began to increase again in 2010, as both imports and exports began to rise.

EXHIBIT 6-4. U.S. MANUFACTURING SECTOR TRADE DEFICIT ($ MILLIONS)



Source: U.S. Census Bureau, International Trade Statistics, "Value of Exports, General Imports, and Imports by Country by 3-digit NAICS."
Note: Exports calculated on F.A.S. value basis and general imports calculated on C.I.F. value basis.

Increased exposure to competition from low-wage countries, such as China, has had a negative effect on U.S. manufacturing plant survival and growth (Bernard et al., 2005). In response to competition from abroad, the U.S. has shifted manufacturing activity towards capital- and skill-intensive products (Bernard et al., 2005). Recent analysis has shown that even these high-tech industries are not immune to competition from abroad. In some high-tech industries, increased international trade has led to decreasing demand for skilled labor (Silva, 2007). Even in high-tech industries where demand for skilled labor has increased, wages have not necessarily risen in response (Silva, 2007). Competition from abroad is likely to continue to affect wages in the U.S. manufacturing sector for an extended period of time, reflecting the comparative advantage currently enjoyed by manufacturers based in low-wage countries.

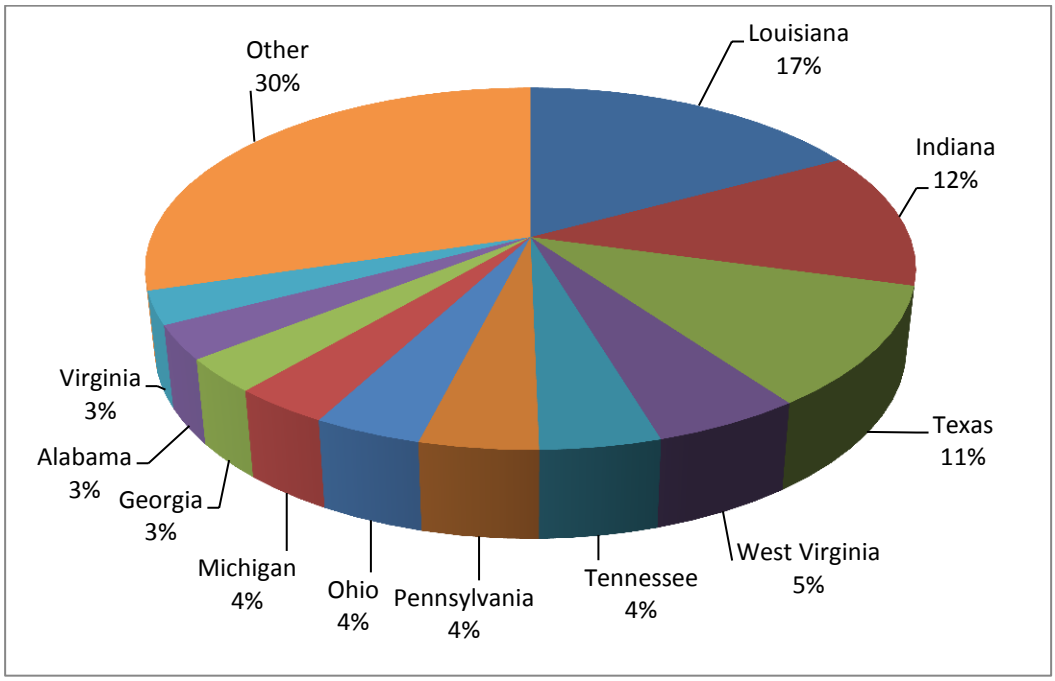
WATER USE

As noted in Chapter 3, self-supplied manufacturing water withdrawals account for approximately four percent of total water withdrawals in the U.S. (18,200 MGD). In addition, some industries use publicly-supplied water. The most recent published estimate of the use of publicly-supplied water in manufacturing dates from 1995. At that time, 12 percent of publicly-supplied water withdrawals (4,750 MGD) were used for manufacturing (USGS, 1998). This amount represented 18 percent of water use in manufacturing in 1995.

The withdrawal of water for manufacturing purposes is heavily concentrated in a limited number of states. As Exhibit 6-5 shows, 11 states account for approximately 70 percent of self-supplied manufacturing water use. Louisiana, Indiana, and Texas are the top three users; combined they account for 38 percent of self-supplied manufacturing withdrawals. Exhibit 6-6 provides a map that illustrates the distribution of self-supplied manufacturing water withdrawals by state in 2005. Not surprisingly, this map shows that the withdrawal of water for manufacturing purposes is greatest east of the Mississippi and in the Gulf Coast states.

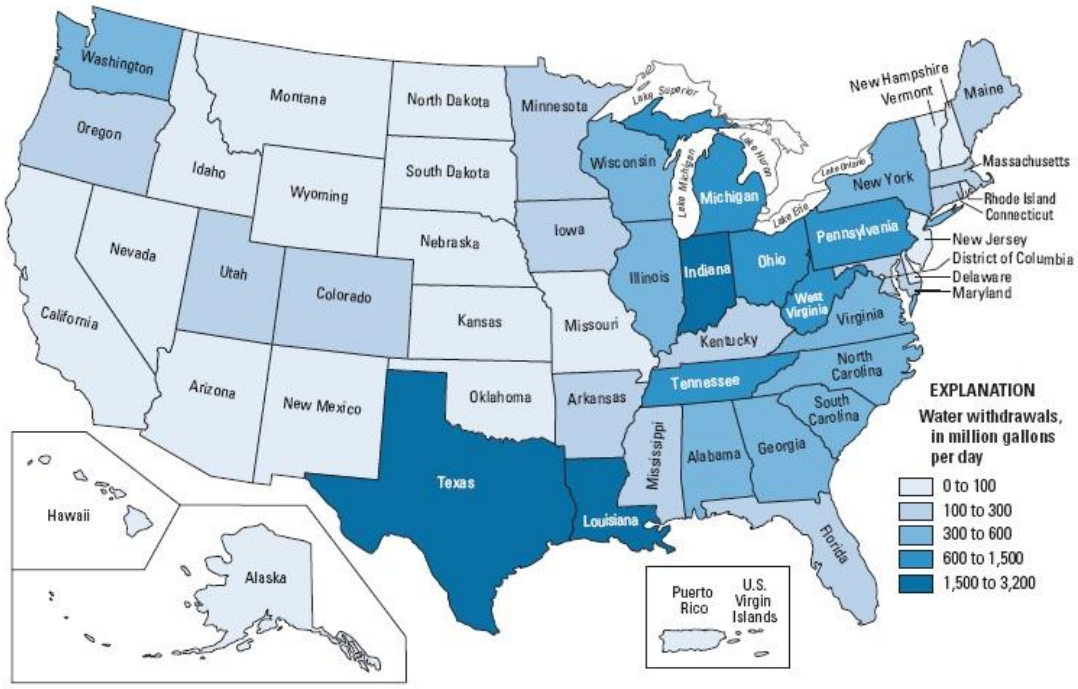
The withdrawal of water for manufacturing purposes does not necessarily correspond to state-level manufacturing output. Exhibit 6-7 provides data on manufacturing value added and self-supplied water withdrawals by state. This exhibit shows that California has the highest level of manufacturing output, but manufacturers in this state withdraw relatively little water. On the other hand, states such as Texas and Pennsylvania host a large manufacturing sector and report significant withdrawals of water for manufacturing purposes.

EXHIBIT 6-5. STATES' SHARE OF SELF-SUPPLIED MANUFACTURING WATER WITHDRAWALS, 2005



Source: U.S. Geological Survey, Estimated Water Use in the United States in 2005, 2009.

EXHIBIT 6-6. GEOGRAPHIC DISTRIBUTION OF SELF-SUPPLIED MANUFACTURING WATER WITHDRAWALS, 2005



Source: U.S. Geological Survey, Estimated Water Use in the United States in 2005, 2009.

EXHIBIT 6-7. MANUFACTURING VALUE ADDED AND SELF-SUPPLIED WATER WITHDRAWALS BY STATE

RANK	STATE	VALUE ADDED, 2007 ($ THOUSAND)	WITHDRAWALS, 2005 (ACRE-FEET)	VALUE ADDED PER ACRE-FOOT ($ THOUSAND)
1	Rhode Island	6,312,653	0.6	11,272,595
2	California	249,562,672	107.3	2,325,840
3	Nevada	9,151,409	6.6	1,384,479
4	Arizona	32,435,899	25.2	1,287,139
5	South Dakota	5,928,943	4.9	1,200,191
6	Nebraska	13,451,384	12.7	1,059,164
7	Oklahoma	23,873,547	27.0	884,205
8	Kansas	28,910,605	46.9	616,431
9	New Jersey	56,049,398	96.4	581,425
10	Missouri	52,521,827	90.7	579,072
11	Wyoming	3,871,454	6.8	571,854
12	New Mexico	7,591,119	14.8	512,913
13	Vermont	4,045,104	8.9	453,996
14	Massachusetts	48,953,028	126.0	388,516
15	Minnesota	50,575,982	155.0	326,297
16	Connecticut	34,919,720	118.8	293,937
17	Illinois	111,842,223	408.0	274,123
18	New York	89,312,490	337.0	265,022
19	North Dakota	4,158,533	16.5	252,032
20	North Carolina	106,231,884	442.0	240,344
21	New Hampshire	9,792,330	46.6	210,136
22	Kentucky	43,220,821	209.0	206,798
23	Oregon	39,557,131	193.0	204,959
24	Florida	55,686,388	273.3	203,733
25	Iowa	41,884,753	212.0	197,570
26	Delaware	9,152,569	46.4	197,254
27	Alaska	2,275,607	13.8	165,499
28	Ohio	129,183,927	788.0	163,939
29	Colorado	24,068,597	160.0	150,429
30	Wisconsin	75,761,615	528.0	143,488
31	Michigan	97,353,707	705.0	138,090
32	Idaho	9,203,793	70.9	129,814
33	Pennsylvania	109,667,091	863.0	127,077
34	Arkansas	24,805,373	200.0	124,027
35	Utah	20,239,201	182.7	110,778
36	Georgia	65,001,711	621.3	104,622
37	Mississippi	22,810,607	221.0	103,215
38	Texas	214,235,777	2,203.0	97,247
39	Washington	52,804,461	546.2	96,676
40	Hawaii	3,013,731	34.7	86,751
41	Virginia	50,108,533	600.6	83,438
42	South Carolina	38,976,952	469.0	83,107

RANK	STATE	VALUE ADDED, 2007 ($ THOUSAND)	WITHDRAWALS, 2005 (ACRE-FEET)	VALUE ADDED PER ACRE-FOOT ($ THOUSAND)
43	Maryland	21,948,385	280.9	78,136
44	Alabama	43,137,817	617.0	69,915
45	Tennessee	60,269,688	878.0	68,644
46	Montana	3,921,739	75.2	52,151
47	Indiana	105,188,368	2,470.0	42,586
48	Maine	8,676,436	210.0	41,316
49	Louisiana	59,057,861	3,480.0	16,971
50	West Virginia	9,736,591	1,080.0	9,015
51	District of Columbia	201,624	0.0	NA

Sources: U.S. Census Bureau, Economic Census, 2007; U.S. Geological Survey, Estimated Water Use in the United States in 2005, 2009.

The inconsistency in manufacturing output and water withdrawals across states can be explained in part by the varying levels of water use across industries. Exhibits 6-8 and 6-9 provide data on water use by industry group in 1983, as reported in the 1987 Statistical Abstract of the United States (the last time that the U.S. Census Bureau published manufacturing water use data at this level of disaggregation). At that time, chemical, paper, petroleum and coal, primary metal, and food manufacturing accounted for approximately 90 percent of water used for manufacturing. Other major uses included transportation equipment, which accounted for approximately three percent of water used for manufacturing; the remaining 12 industries each accounted for less than one percent. Thus, the variation in the intensity with which water is used in the manufacturing sectors of different states likely reflects underlying differences in each state's industrial base.[23]

[23] It is important to note that the composition of the nation's manufacturing sector has changed since 1983. This change in composition may have contributed, at least in part, to the approximately 30 percent reduction in direct withdrawals of water by the manufacturing sector between 1985 and 2005 (USGS, 1988; USGS, 2009). Given the available data, however, it is reasonable to assume that disparities in water use across industries persist, and that the industries which were major users of water in 1983 remain major users of water today.

EXHIBIT 6-8. WATER USE BY INDUSTRY (BIL. GAL.), 1983

NAICS	INDUSTRY	TOTAL GROSS WATER USED[1]	WATER INTAKE[2]	WATER RECYCLED[3]
311	Food and kindred products	1,406	648	759
313 + 314	Textile mill products	333	133	200
316	Leather and leather products	7	6	1
321	Lumber and wood products	218	86	132
321	Tobacco products	34	5	29
322	Paper and allied products	7,436	1,899	5,537
324	Petroleum and coal products	6,177	818	5,359
325	Chemicals and allied products	9,630	3,401	6,229
326	Rubber, misc. plastic products	328	76	252
327	Stone, clay, and glass products	337	155	182
331	Primary metal products	5,885	2,363	3,523
332	Fabricated metal products	258	65	193
333	Machinery, exc. electrical	307	120	186
335	Electric and electronic equipment	335	74	261
336	Transportation equipment	1,011	153	859
337	Furniture and fixtures	7	3	3
339	Miscellaneous manufacturing	15	4	11
N/A	Instruments and related products	112	30	82

Notes:

(1) Based on establishments reporting water intake of 20 million gallons. This represents 96 percent of the total water use estimated for manufacturing industries.

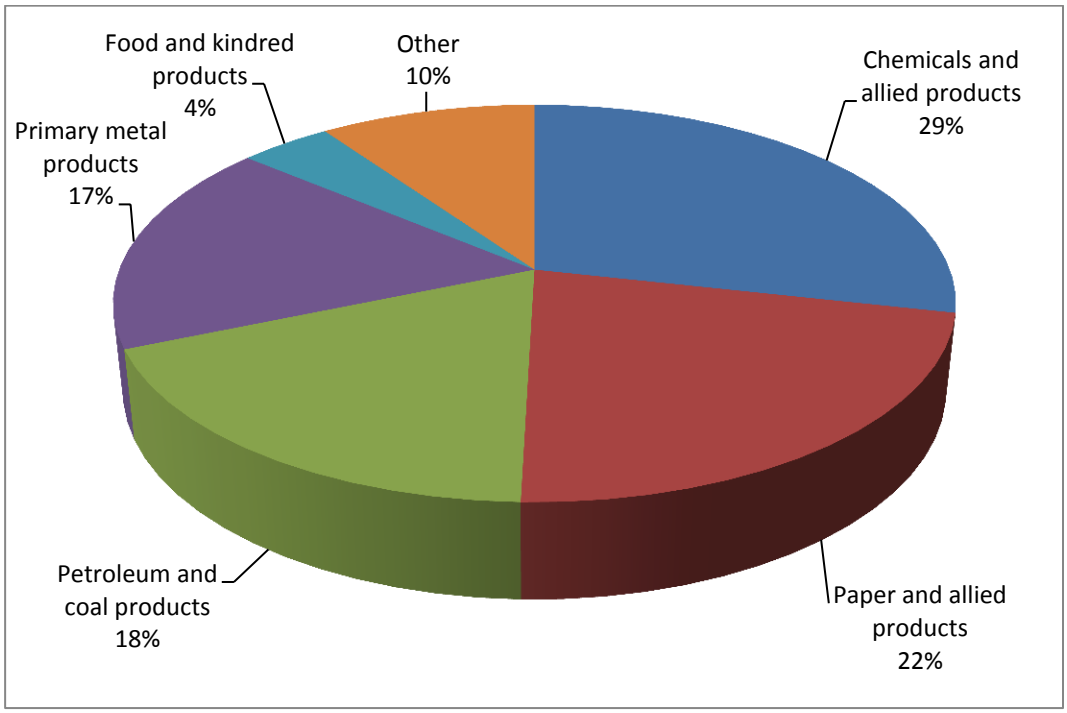
(2) Refers to water used/consumed in the production and processing operations and for sanitary services.

(3) Refers to water recirculated and water reused.

Source:

U.S. Bureau of Census, Statistical Abstract of the United States: 1987 (107th edition.) Washington, DC, 1986.

EXHIBIT 6-9. USE OF WATER IN MANUFACTURING BY INDUSTRY, 1983



Source: U.S. Bureau of Census, Statistical Abstract of the United States: 1987 (107th edition.) Washington, DC, 1986.

More recent data has been collected on water pollution abatement operating costs, which give a sense of the levels of water use across industries. The data on pollution abatement costs are presented in Exhibit 6-10. Similar to the 1983 water use data, the five industries representing the highest water pollution abatement costs are chemical, food, paper, petroleum and coal, and primary metal manufacturing (in that order). Water use in these five industries is discussed in more detail below.

As previously noted, overall withdrawals of water by the manufacturing sector declined approximately 30 percent between 1985 and 2005 (USGS, 1988; USGS, 2009). This change is due in large part to increasing efficiency in water use, including recycling and/or reuse of water. These efficiency gains have been driven by a variety of factors, including the diminishing availability of sources of raw water of sufficient quality, increasing water purchase costs, and strict environmental effluent standards (Ellis et al., 2003). Many uses of water in manufacturing (e.g., cooling and processing) do not require water of particularly high quality, allowing manufacturers to reuse water multiple times before treating and discharging it as wastewater. In addition, substitutes, such as using air for cooling instead of water, allow manufactures to decrease their water use. Sector-specific gains in water-use efficiency are described in greater detail below.

While most industries in the manufacturing sector are primarily concerned with access to adequate supplies of water, some are also concerned with the water's quality. These industries include the food and beverage sector and the electronics sector. Water used in

the processing of food and beverages must meet health and safety standards; thus, access to clean water is an important consideration when locating bottling and food processing facilities. In the electronics sector, ultrapure water is used to manufacture high-tech products such as semiconductors and microchips. In these sectors, water quality is so important that manufacturers are likely to rely on sophisticated systems to purify their source water, regardless of its initial quality (Strzepek, 2011). Nonetheless, high quality source water can, at least to some extent, reduce the costs associated with water purification and treatment.

EXHIBIT 6-10. WATER POLLUTION ABATEMENT OPERATING COSTS, 2005

NAICS	INDUSTRY	COST ($ MILLION)
311	Food manufacturing	933.1
312	Beverage & tobacco product manufacturing	152.9
313	Textile mills	77.2
314	Textile product mills	13.6
316	Leather & allied product manufacturing	33.9
321	Wood product manufacturing	47.2
322	Paper manufacturing	757.9
323	Printing & related support activities	20.1
324	Petroleum & coal products manufacturing	754.9
325	Chemical manufacturing	1,986.2
326	Plastics & rubber products manufacturing	84.6
327	Non-metallic mineral product manufacturing	76.4
331	Primary metal manufacturing	638.4
332	Fabricated metal product manufacturing	284.2
333	Machinery manufacturing	97.1
334	Computer & electronic product manufacturing	270.9
335	Electrical equipment, appliance, & component manufacturing	59.5
336	Transportation equipment manufacturing	394.6
337	Furniture & related product manufacturing	13.0
339	Miscellaneous manufacturing	28.1

Source:
U.S. Census Bureau, Pollution Abatement Costs and Expenditures: 2005, April 2008.

CHEMICAL MANUFACTURING

Chemical and allied products manufacturing is likely the leading user of water in the U.S. manufacturing sector. It accounted for 29 percent of industrial water use in 1983 (U.S. Census Bureau, 2008). The primary uses of water in chemical manufacturing are for non-contact cooling, steam applications, and product processing (U.S. EPA, 2008). Water use varies by product – silicone-based chemicals require larger quantities of water to produce, while many of the top manufactured chemicals by volume (including nitrogen, ethylene, ammonia, phosphoric acid, propylene, and polyethylene) require less water during production (U.S. EPA, 2008). Exhibit 6-11 provides data on water use by product within the chemical manufacturing industry, circa 1983.

Exhibit 6-11 shows that much of the water used for chemical manufacturing can be recycled. In fact, water use per unit of production decreased steadily from 1954 to 1973 in part due to water recycling (David, 1990). In addition, improvements in overall efficiency and the substitution of air in place of water during certain cooling processes have contributed to the reduction in water use per unit of production (David, 1990).

EXHIBIT 6-11. CHEMICAL MANUFACTURING WATER USE BY PRODUCT (MGAL/DAY), 1983

PRODUCT	TOTAL GROSS WATER USED	WATER INTAKE	WATER RECYCLED
Industrial Organic Chemicals	11,300	4,150	7,150
Industrial Inorganic Chemicals	5,930	2,420	3,510
Plastics and Synthetics	3,930	1,170	2,760
Agricultural Chemicals	3,780	836	2,944
Drugs	658	249	409
Soaps, cleaners, and toilet goods	285	178	107
Paints and allied products	11	5	6
Miscellaneous chemical products	490	301	189
Total	**26,400**	**9,310**	**17,090**

Source: David, Elizabeth L., "Trends and Associated Factors in Off-Stream Water Use: Manufacturing and Mining Water Use in the United States, 1954-83," USGS National Water Summary 1987 – Hydrologic Events and Water Supply and Use, Water-Supply Paper 2350, 1990.

The importance of water quality varies across use within the chemical manufacturing industry. Cooling accounts for approximately 88 percent of the gross water used in chemical manufacturing; 67 percent of this water is recycled (Ellis et al., 2003). In general, the quality of water used for cooling is not of great importance. On the other hand, certain processes such as rinsing parts may require high-quality water (Michigan Chamber of Commerce, 2008).

PAPER MANUFACTURING

Paper and allied products manufacturing accounted for 22 percent of industrial water use in 1983 (U.S. Census Bureau, 2008). Paper is produced from raw materials containing cellulose fibers, such as wood, recycled paper, and agricultural residues. The main steps in paper manufacturing are raw material preparation (e.g., wood debarking and chip making), pulp manufacturing, paper manufacturing, and fiber recycling (World Bank, 1998). Water is used at various points in this process. In the initial step of raw material preparation, much water is needed to clean the wood, transport wood from one place to another in the facility, cool machinery used for conveyors, debark, and chip (David, 1990). To produce pulp more water is used to steam-cook wood chips, which are then washed and screened. In the paper manufacturing step the pulp is further diluted before being drained, heat-dried, and pressed (David, 1990). The water that drains off can be reused in the paper manufacturing step (David, 1990).

Water use in paper manufacturing decreased from 26,700 gal/ton-product in 1975 to 16,000 gal/ton-product in 1996 (Ellis et al., 2003). Decreases in water use are due to

recycling of water at various points in the production process and improved technology, such as high-pressure, low-volume showers (Michigan Chamber of Commerce, 2008). Although positive from the perspective of total resource use, water use reductions can increase the concentration of contaminants in process water, leading to high rates of scale deposition and other unwanted effects (Ellis et al., 2003). This build-up of contaminants may increase production costs and decrease product quality (Ellis et al., 2003).

PETROLEUM AND COAL PRODUCTS MANUFACTURING

Petroleum and coal products manufacturing accounted for approximately 18 percent of industrial water use in 1983 (U.S. Census Bureau, 2008). Within this industry, petroleum refining accounts for between 1,000 and 2,000 million gallons of water use daily, compared to 400 million gallons per day for natural gas processing and pipeline operations (U.S. DOE, 2006). Refineries use about one to 2.5 gallons of water for processing and cooling per gallon of product (U.S. DOE, 2006). This figure has decreased more than 95 percent since 1975 (Ellis et al., 2003).

Cooling is the primary use of water in petroleum refining; a typical refinery may use 10 times as much cooling water as process water (David, 1990). However, petroleum refineries have the highest rate of water recycling of any major industry (Ellis et al., 2003). Water is used approximately 7.5 times before being discharged (David, 1990). As with chemical manufacturing, water quality is not a critical consideration in the use of water for cooling. The use of water for other purposes, however, may be more sensitive to water quality considerations.

PRIMARY METAL MANUFACTURING

Primary metal products manufacturing accounted for approximately 17 percent of industrial water use in 1983 (U.S. Census Bureau, 2008). Information on water use in primary metal manufacturing focuses largely on iron and steel manufacturing. Water is used in the steel industry for three purposes: material conditioning, air pollution control (i.e., use in wet scrubbers), and cooling (CH2M HILL, 2003). Exhibit 6-12 provides data on water use for each of these three purposes. In addition, this exhibit provides information on the percent of water recycled or reused for each process. Overall, cooling represents the primary use of water within the steel industry (approximately 75 percent). In addition, 12 percent of water is used for material conditioning and 13 percent is used for air pollution control. Cooling represents over 70 percent of the water used in most processes. The exceptions are sinter plants and pickling, where air pollution control represents the largest water use.

The intensity of water use within the steel industry has declined in recent years, principally due to recycling and reuse of water in production facilities (CH2M HILL, 2003). In addition, process changes in steel production, such as the replacement of basic oxygen furnaces with electric arc furnaces, have decreased water demand (CH2M HILL, 2003). Water use within the industry is expected to continue to decline, and facilities may reduce their use of surface and groundwater by moving towards reuse of treated municipal effluent. In addition, internal treatment and recycling of water is expected to increase (CH2M HILL, 2003).

EXHIBIT 6-12. WATER USE FOR VARIOUS UNIT OPERATIONS IN STEEL MANUFACTURING

PROCESS AREA	WATER USE UNIT	WATER USE PURPOSE			PERCENT RECYCLED/REUSED
		MATERIAL CONDITIONING	AIR POLLUTION CONTROL	COOLING	
Coke-making	gallons/ton coke	200	250-300	8,000-8,500	0 percent (newer plants may recycle cooling water)
Boilers for Converting Coke Oven Gas, Tars, and Light Oils	gallons/ton coke			40,000-120,000	Varies depending on age of boiler
Sinter Plant	gallons/ton sinter	20-30	900-1,000	200	80 percent
Blast Furnace	gallons/ton molten iron	100-200	800-1,000	2,500-3,000	90 percent
Boilers for Converting Blast Furnace Gas	gallons/ton molten iron			20,000-60,000	Varies depending on age of boiler
Basic Oxygen Furnace	gallons/ton liquid steel	100-200	800-1,000	2,500-3,000	50 percent
Direct Reduced Iron Processes	gallons/ton iron	70-80	Negligible	200-250	80 percent
Electric Arc Furnace	gallons/ton liquid steel	Negligible	Negligible	2,000-2,500	80 percent
Continuous Caster	gallons/ton cast product	Negligible	Negligible	3,000-3,500	70 percent
Plate Mill	gallons/ton plate	1,000-2,000	Negligible	7,000-8,000	30 percent
Hot Strip Mill	gallons/ton hot-rolled strip	400-600	Negligible	7,000-8,000	60 percent
Pickling	gallons/ton steel pickled	30-40	80-100	20-30	70 percent
Cold Rolling	gallons/ton cold-rolled strip	50-100	Negligible	2,500-3,000	90 percent
Coating	gallons/ton coated steel	60-70	1-10	1,200-1,800	80 percent

Source: CH2M HILL, "Water Use in Industries of the Future," Industrial Water Management: A Systems Approach, Second Edition, 2003.

FOOD AND BEVERAGE MANUFACTURING

Food and kindred products manufacturing accounted for approximately four percent of industrial water use in 1983 (U.S. Census Bureau, 2008). Although this industry accounts for a relatively small portion of overall industrial water use, water quality is particularly important in food and beverage manufacturing. Within the food and beverage industry, water is used as an ingredient in products, a mixing and seeping medium in food processing, and a medium for cleaning and sanitizing operations (U.S. EPA, 2008).

Water use varies by food product. Exhibit 6-13 provides estimates of water used for the processing of various water-intensive foods. In addition to the products listed in Exhibit 6-13, sugar refining is a large user of water within the food processing industry. Unlike

most food products, which require water primarily for processing, sugar refineries use about half of their intake water for cooling (David, 1990). Beverage manufacturers also use large quantities of water for cooling (David, 1990).

EXHIBIT 6-13. WATER USE IN PROCESSING OF FOOD PRODUCTS (GAL/TON-PRODUCT)

PRODUCT	WATER USE
Beer	2,400-3,840
Milk products	2,400-4,800
Meat packing	3,600-4,800
Bread	440-960
Whisky	14,400-19,200
Green beans (canned)	12,000-17,000
Peaches and pears (canned)	3,600-4,800
Other fruits and vegetables (canned)	960-8,400
Industry-wide average	8.6 gal/unit output*

*Example "unit output": 1 gal. of milk
Source: Ellis, Mark, et al., "Industrial Water Use and Its Energy Implications," December 2003.

Unlike the other industries discussed above, water use in the food products industry has not declined dramatically over the last several decades (David, 1990). Food processing techniques have changed little and only minimal water recycling and reuse occurs within the industry (Ellis et al., 2003). Water recycling and reuse is limited by safety concerns. The water used in food processing must meet human health and safety standards.

VALUE OF WATER USE

It is difficult to develop estimates of the value of water in the manufacturing sector largely because most water used within the sector is self-supplied (AWWA, 2005). Where industries have made purchases on water markets, estimates can be derived from price data (AWWA, 2005). Where information on the price paid for water does not exist, but analysts have access to information on the quantity of water withdrawn, methods have been developed to infer the value of water used (Renzetti and Dupont, 2002). These methods consider the relationship between the value of industry output and the quantity of water used. Where data on neither price nor quantity of water used exist, analysts have examined the marginal cost of in-plant water recycling as a proxy for the marginal value of intake water (Renzetti and Dupont, 2002).

While it is difficult to estimate the value of water to the manufacturing sector, studies have indicated that manufacturing may be among the highest value uses (Frederick et al., 1996). The discussion below reviews the available literature and suggests potential areas for further research.

AVAILABLE ESTIMATES

Exhibit 6-14 summarizes existing estimates of the value of water in manufacturing, placing all the values in common terms (i.e., value per acre-foot expressed in 2010

dollars).[24] The wide range in values is explained by both the mix of methodologies applied and the specific aspects of water value that each method captures. In addition, regional differences between study areas, such as differences in water scarcity, cause values to differ.

One method for valuing manufacturing water simply considers the cost that firms incur in acquiring the water. Since the majority of water used in manufacturing is self-supplied, the data on water purchases is limited. A 1991 survey of manufacturers in California indicates that the price paid to utilities for publicly-supplied water ranges from $219 to $1,113 per acre-foot with an average price of $736 per acre-foot (Wade et al., 1991). The cost of self-supplied groundwater ranges from $107 per acre-foot for food manufacturers to $280 for petroleum refiners, and averages approximately $206 per acre-foot (Wade et al., 1991). Regional variations in the cost of both publicly-supplied and self-supplied water are great. It is important to note that the prices presented here were collected from manufacturers in California.

As with other sectors, acquisition cost is an imperfect reflection of the true value of water in manufacturing. At best, acquisition cost represents a lower-bound estimate of the water's value; i.e., manufacturers pay the implicit or explicit price to acquire the water, so its value to them must be at least that great. Other studies have attempted to establish more reliable measures of the marginal value of water to manufacturers. One method for doing so uses information on manufacturing inputs, including the quantity of water used, and information on the value of industry output to estimate the value of water. Following this general method, studies have derived the value of manufacturing water from the production function, the cost function, and the input distance function.

Exhibit 6-14 shows that the methods that rely on the quantity of water used and output value provide a range of average values per acre-foot of water from $74 to $1,527. This wide range in values may depend in part upon the country of study. Renzetti and Dupont (2002), who examine the value of manufacturing water use in Canada, note that their estimate is much lower than found in previous American studies; they attribute the difference in part to differences between the Canadian and American regulatory environment. In addition, they note that most manufacturing water intake in Canada is self-supplied and is available at almost zero external cost; therefore it follows that the marginal value derived from the use of water would also be very low (Renzetti and Dupont, 2002). It is unclear whether it would be appropriate to transfer marginal values derived from manufacturing experience in foreign countries to the U.S. Economic conditions in the U.S. differ from conditions in other countries, especially developing nations such as China, Korea, and India. In addition, water supply and regulations governing water use may differ from country to country. All of these factors may affect the value of water.

[24] All figures have been adjusted to 2010 dollars using the GDP implicit price deflator.

EXHIBIT 6-14. ESTIMATES OF THE VALUE OF WATER IN MANUFACTURING

VALUATION METHOD	WHAT IS MEASURED	DATA SOURCE	COUNTRY	VALUE PER ACRE-FOOT OF WATER ($2010)
Acquisition Cost (public supply)	Weighted average of a sample of California industrial water rates.	Wade et al., 1991	U.S.	$736
Acquisition Cost (groundwater)	Average cost to California manufacturers of groundwater pumped from wells on-site.	Wade et al., 1992	U.S.	$206
Derived from Production Function	Average marginal value of water is estimated using a translog production function.	Wang and Lall, 2002	China	$741
Derived from Production Function	Average marginal value of water is estimated using a translog production function.	Ku and Yoo, 2012	Korea	$1,527
Derived from Cost Function	Average marginal (shadow) value of water estimated from a restricted cost function in which water is treated as a quasi-fixed input.	Renzetti and Dupont, 2002	Canada	$74
Derived from Input Distance Function	Average marginal (shadow) value of water is estimated using an input distance function.	Kumar, 2006	India	$321
Cost of Recirculation	Marginal cost of recirculation for cooling water.	Gibbons, 1986	U.S.	$14 - $23
Cost of Recirculation	Marginal cost of recirculation for process water.	Gibbons, 1986	U.S.	$37 - $174
Meta-analysis	Median of seven studies on the marginal value of water for industrial processing.	Frederick et al., 1996	U.S.*	$183
Meta-analysis	Mean of seven studies on the marginal value of water for industrial processing.	Frederick et al., 1996	U.S.*	$392

*The study areas for the seven studies considered in Frederick et al., 1996 are not explicitly stated and references are unavailable. This assumption is based on the description of the studies within the text.

The third method explored here requires data on neither price nor quantity of water used. When these data do not exist, analysts have examined the marginal cost of in-plant water recycling as a proxy for the marginal value of intake water. Following this method, Gibbons (1986) reports that the marginal cost of recirculation for cooling water is lower ($14 - $23 per acre-foot) than that used for processing ($37 - $174 per acre-foot). This finding is intuitive, as processing generally requires higher quality water and additional treatment before reuse. It should be noted that these estimates come from studies performed before recent technological advances, and therefore may no longer be applicable.

Finally, in 1996 Frederick et al. reviewed seven studies that provide a value for industrial water use and concluded that industrial processing is one of the highest value uses. Frederick et al.'s review of these studies finds an average value of $282 per acre-foot and a median value of $132 per acre-foot. The authors note that "at the national level the median values may provide a better indication of the relative values of water in various uses under relatively normal hydrologic conditions" (Frederick et al., 1996).

Water use across industries within the manufacturing sector differs greatly; clearly, the value of water also differs by industry. Exhibit 6-15 provides estimates of the value of water for the five industries discussed above. This exhibit shows a wide range of estimates, both within and across industries. Both Wang and Lall (2002) and Renzetti and Dupont (2002) report the highest value for water used in petroleum and coal products manufacturing, followed by the value of water in primary metal manufacturing. All of these values, however, are based on studies conducted outside the U.S. Their relevance to the value of water in U.S. manufacturing is unclear.

EXHIBIT 6-15. VALUES FOR MANUFACTURING WATER BY INDUSTRY

INDUSTRY	VALUE PER ACRE-FOOT OF WATER ($2010)		
	WANG AND LALL, 2002 (CHINA)	RENZETTI AND DUPONT, 2002 (CANADA)	KUMAR, 2012 (INDIA)
Chemicals	$297	$115	$141
Paper and allied products	$254	$49	$1,358
Petroleum and coal	$1,643	$460	-
Primary metal	$1,156	$171	-
Food	$778*	$27	-
Beverage	-	$61	-

*Value provided is for the food and beverage industry.

While the body of literature on the value of water in manufacturing is small, the literature that investigates the effect of water quality on the value of water in manufacturing is even smaller. One study, by Renzetti and Dupont (2002), investigates this relationship. By incorporating water treatment expenditures into their model, the authors are able to

examine the relationship between changing water treatment costs (most likely caused by changes in water quality) and firms' valuation of intake water. It is expected that decreases in water quality will increase water treatment costs, thereby decreasing the value of raw intake water. In other words, firms are willing to pay less for low-quality intake water as they will have to spend additional funds on internal treatment. The authors' study confirms this hypothesis – Canadian manufacturing firms' valuation of intake water is positively related to the quality of water.

DEMAND FOR WATER IN MANUFACTURING

The price elasticity of demand for water in manufacturing captures the relationship between the quantity of water demanded and its price – specifically, it measures the percentage change in quantity demanded for a given percentage change in price. Both economic theory and the empirical evidence suggest that the demand for water in manufacturing is inelastic at current prices, meaning that when its price increases, the quantity demanded falls but at a correspondingly lower rate. The available evidence suggests that industrial firms' water demands may be relatively more price sensitive than agricultural or domestic water demands (Renzetti, 2005). Exhibit 6-16 provides a summary of studies that have estimated price elasticity of demand for water by manufacturers. The range in elasticities presented in this exhibit reflects differences across industries and regions. Not surprisingly, estimated elasticities tend to be higher where the cost of water inputs is large relative to that of other inputs (Reynaud, 2003).

EXHIBIT 6-16. ESTIMATES OF THE PRICE ELASTICITY OF DEMAND FOR WATER IN MANUFACTURING

DATA SOURCE	METHOD	COUNTY	ESTIMATED PRICE ELASTICITY
Grebenstein and Field (1979)	Translog	USA	-0.80 to -0.33
Babin, Willis, and Allen (1982)	Translog	USA	-0.66 to +0.14
Ziegler and Bell (1984)	Cobb-Douglas	USA	-0.08
Williams and Suh (1986)	Log/Log	USA	-0.97 to -0.44
Renzetti (1988)	Cobb-Douglas	Canada	-0.54 to -0.12
Schneider and Whitlatch (1991)	Log/Log	USA	-1.16
Renzetti (1992)	Translog	Canada	-0.59 to -0.15
Wang and Lall (1999)	Translog	China	-1.03
Dupont and Renzetti (2001)	Translog	Canada	-0.77
Renzetti and Dupont (2002)	Translog	Canada	-0.86 to +0.54
Reynaud (2003)	Translog	France	-0.79 to -0.10
Feres and Reynaud (2005)	Translog	Brazil	-1.18 to -1.06

Source: Feres, Jose, and Arnaud Reynaud, "Assessing the Impact of Environmental Regulation on Industrial Water Use: Evidence from Brazil," *Land Economics*, 81(3): 396-411, 2005.

The estimates presented in Exhibit 6-16 can be compared to those presented in Exhibit 4-8 for residential water use. Two major meta-analyses of the price elasticity of residential water demand have found average elasticities of -0.51 and -0.41. These average estimates fall within the range of the elasticity values presented for manufacturing, but are not as inelastic as the low-end manufacturing values.

SUMMARY In 2007, the manufacturing sector added $2,382 billion to the U.S. economy. This contribution to GDP stems in part from the sector's reliance on water resources. Manufacturing operations withdraw approximately 18,200 million gallons of water per day, representing four percent of U.S. water withdrawals. A large share of this water is used by five industries: chemical, paper, petroleum and coal, primary metal, and food products manufacturing.

The number of studies that provide an estimate of the value of water in manufacturing are limited. There has been far more research in the areas of agricultural and residential water use, in part because these sectors represent an overall larger portion of U.S. water withdrawals. The research that has been done suggests that manufacturing may be one of the highest value uses of water.

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CHAPTER 7 | MINING AND ENERGY RESOURCE EXTRACTION (OFF-STREAM USE)

INTRODUCTION

Relative to other sectors, the mining and energy resource extraction sector uses a small amount of water: approximately 4.0 BGD, only one percent of the nation's total use (USGS, 2009). Nonetheless, water plays a crucial role in many production processes, including hydraulic-fracturing (fracking), secondary oil recovery, and the extraction and processing of oil-shale. This chapter examines the economic importance of water in mining and energy resource extraction. It includes:

- Background information on the mining and energy resource extraction industry;
- A discussion of the role of water in the production of minerals, crude oil, and natural gas; and
- Available estimates of the value of water to this sector.

OVERVIEW OF KEY FINDINGS

- In mineral extraction water is used for such processes as milling, wet-screening, and hydraulic mining, while in petroleum and natural gas extraction it is used for procedures like hydraulic fracturing, secondary oil recovery, and the extraction and processing of oil shale. In 2005, withdrawals of water by the mining and energy resource extraction sector totaled approximately 4.0 BGD. This figure, which has remained relatively constant since 1985, represents just one percent of the U.S. total.
- The use of water in mining and energy resource extraction is relatively insensitive to source water quality. For example, much of the water used in oil and gas extraction is water that is withdrawn during the drilling process. Reuse of this water, which is often unsuitable for other purposes, helps to offset the demands of water-intensive processes like secondary oil recovery.
- Scarcity of water in the west may constrain exploitation of the region's oil shale deposits, a potentially significant source of petroleum. This issue has encouraged research into less water-intensive processes.
- Water is used extensively in hydraulic fracturing, a process employed in extracting natural gas from shale formations. EPA is currently evaluating the impact of this process on groundwater quality.
- The value of water in mining and energy resource extraction is likely to vary significantly from case to case. Published information on such values is limited. A review of the literature identified one study that reported a small number of instances in which mining interests leased water from other sources. The prices associated with these leases ranged from $40 to $2,662 per acre foot (2010 $). The median of this range, $202, was more than double the value reported for transactions involving municipalities, farmers, or other interests, suggesting that, at least in some instances, the marginal value of water in mining and energy resource extraction is relatively high.

SECTOR OVERVIEW

The mining and energy resource extraction sector of the U.S. economy is part of the primary mega-sector described in Chapter 2. Most of its output flows to the manufacturing or utility sectors, with relatively little output flowing directly to other sectors of the economy.

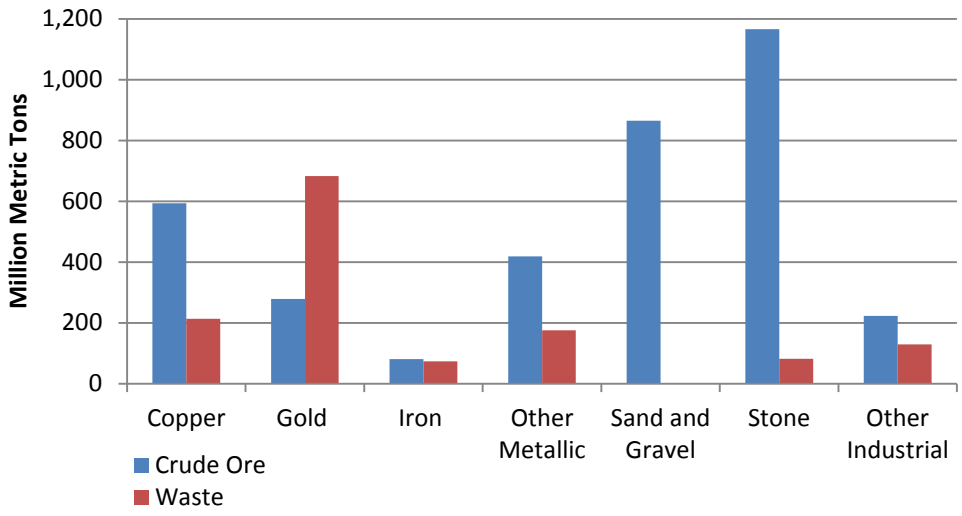
The distinction between mining and energy resource extraction is a simple one: mining refers to the extraction of any solid mineral other than coal and uranium, while energy resource extraction includes coal and uranium, as well as raw petroleum and natural gas.

MINING

Mining includes the extraction of two general categories of mineral: metals (iron, gold, copper, etc.) and industrial materials (clays, feldspar, salt, sand and gravel, etc.). In 2009, the U.S. removed approximately 5.0 billion metric tons of material in mining operations, including approximately 3.6 billion metric tons (73 percent) of crude ore and 1.4 billion metric tons (27 percent) of waste material. Of this total, 51 percent was associated with the production of metals and 49 percent was associated with the production of industrial materials (USGS, 2011). Exhibit 7-1 shows the distribution of material extracted by major product in 2009, noting both ore and waste extractions.

In 2009, the average revenue per metric ton of material extracted during mining operations was $15.42; an average of $21.51 for metals and an average of $12.90 for industrial materials. Excluding sand, gravel, and stone, the average revenue per metric ton of material extracted was $47.66. Dimension stone (i.e., stone cut to specific size and shape specifications) had the highest yield, earning $202.61 per metric ton of material extracted. This high yield reflects the minimal amount of waste material extracted during the stone-cutting process. Among metals, iron had the highest revenue per metric ton of material extracted, averaging $92.76. In comparison, the revenue derived from gold mining averaged $26.68 per metric ton of material extracted, reflecting the high ratio of material extracted (both waste and crude ore) to final product in the gold mining process (USGS 2011).

EXHIBIT 7-1. 2009 CRUDE ORE AND WASTE EXTRACTIONS BY MINERAL



Source: USGS, *2009 Minerals Yearbook*, 2011.

ENERGY RESOURCE EXTRACTION

The United States is one of the leading producers of energy resources in the world; as of 2010, the U.S. ranked third worldwide in crude oil production, second in natural gas production, and second in coal production (world statistics for uranium production were unavailable). The United States is the only nation to rank in the top three in each of these categories.

Crude Oil

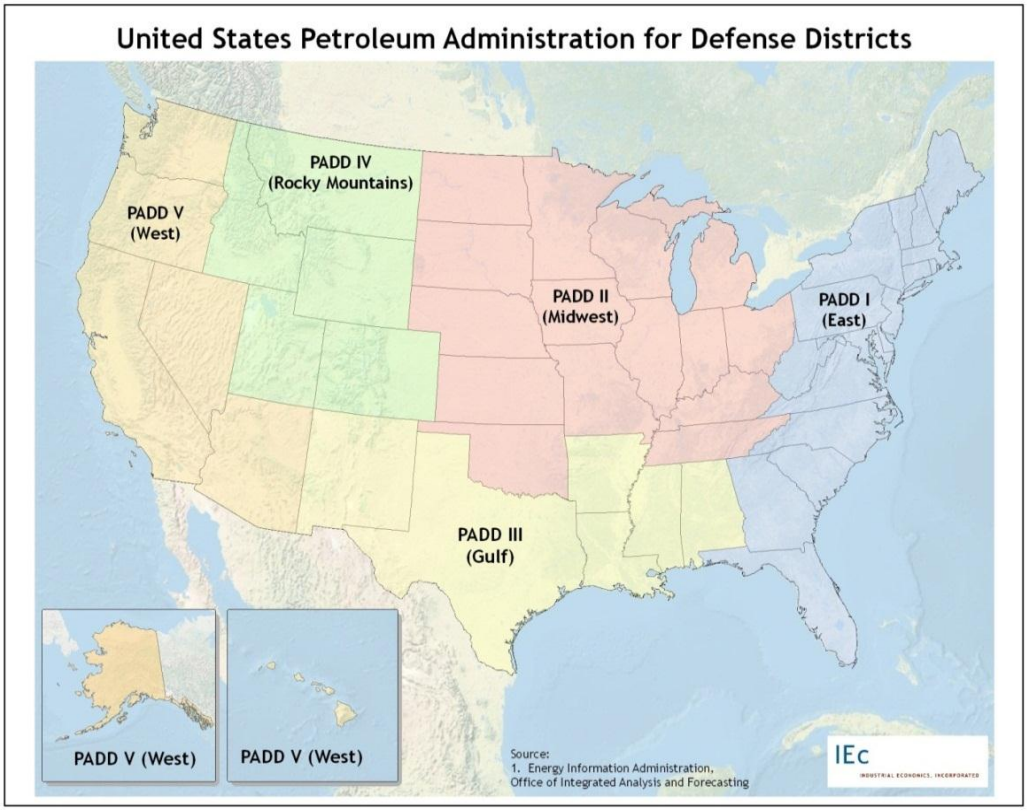
The U.S. Department of Energy (DOE) reports that the U.S. produced approximately 2.0 billion barrels of crude oil in 2010. DOE tracks this production by region, identifying each area as one of five Petroleum Administration for Defense Districts (PADD).[25] Exhibit 7-2 shows the location of these regions, while Exhibit 7-3 shows the distribution of production by region and location in 2010. As the latter exhibit indicates, the Gulf region produced the most crude oil in 2010, accounting for 58 percent (1.2 billion barrels) of total U.S. production. The West (22 percent), Midwest (13 percent), and Rocky Mountain (seven percent) regions also contributed significantly to crude oil production.

[25] The Petroleum Administration for War (PAW), established by an Executive Order during World War II, designated five geographic regions for administration of the nation's gasoline rationing program (the program also rationed other petroleum-derived fuels). PAW was dissolved after the war, but the Defense Production Act of 1950 created the Petroleum Administration for Defense (PAD), a branch of the Department of the Interior which administered policies and programs to meet military, government, industrial, and civilian requirements for petroleum and gas during the Korean War. PAD adopted PAW's regional structure, designating the regions as Petroleum Administration for Defense Districts. PAD was absorbed into DOI's Oil and Gas Division in 1954, but the Federal government has continued to refer to PADDs and employ the geographic boundaries of the PADDs in tracking the supply and movement of crude oil and petroleum products throughout the nation (http://www.eia.gov/todayinenergy/detail.cfm?id=4890).

In comparison, the production of crude oil in the East (7.7 million barrels) was minor (*Crude*, 2011).

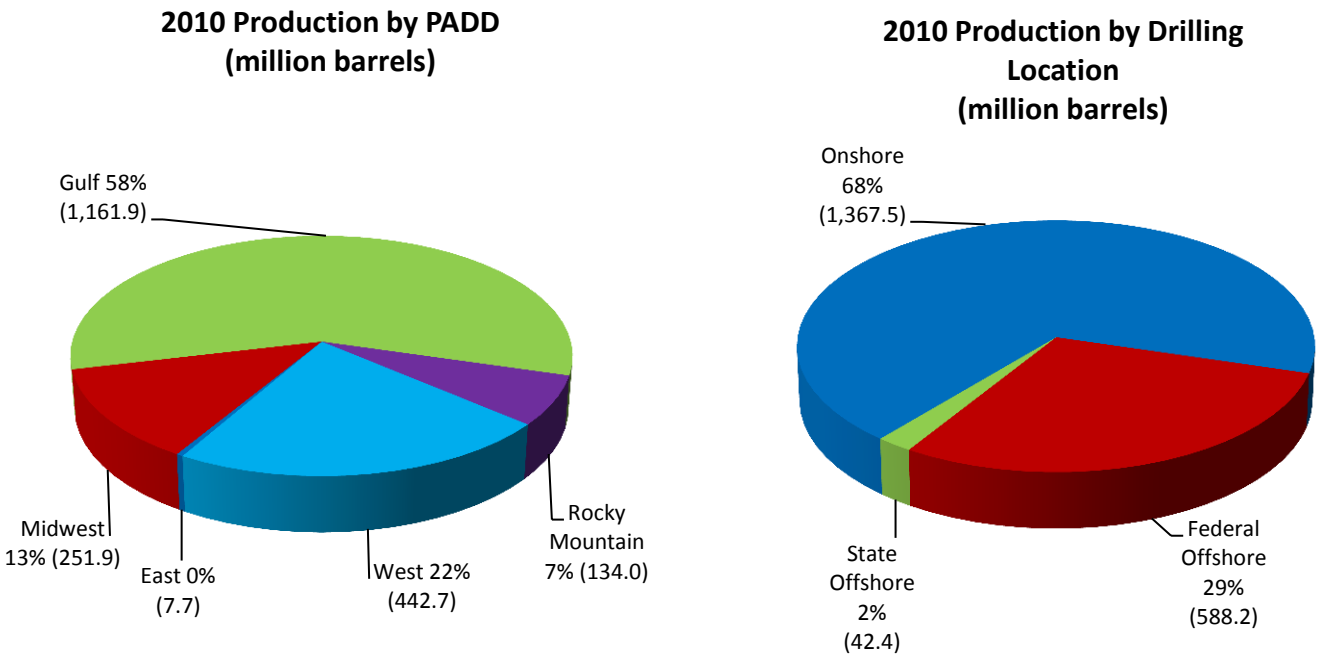
Exhibit 7-3 also shows the distribution of crude oil production in 2010 by drilling location (onshore or offshore). As the exhibit indicates, onshore wells accounted for approximately 68 percent of total production. Offshore production, 32 percent of the nation's total, was concentrated in the Gulf region. There, approximately 49 percent (573.7 million barrels) of the region's production was accounted for by offshore drilling. This represents 91 percent of U.S. offshore production.

EXHIBIT 7-2. LOCATION OF U.S. PETROLEUM ADMINISTRATION FOR DEFENSE DISTRICTS



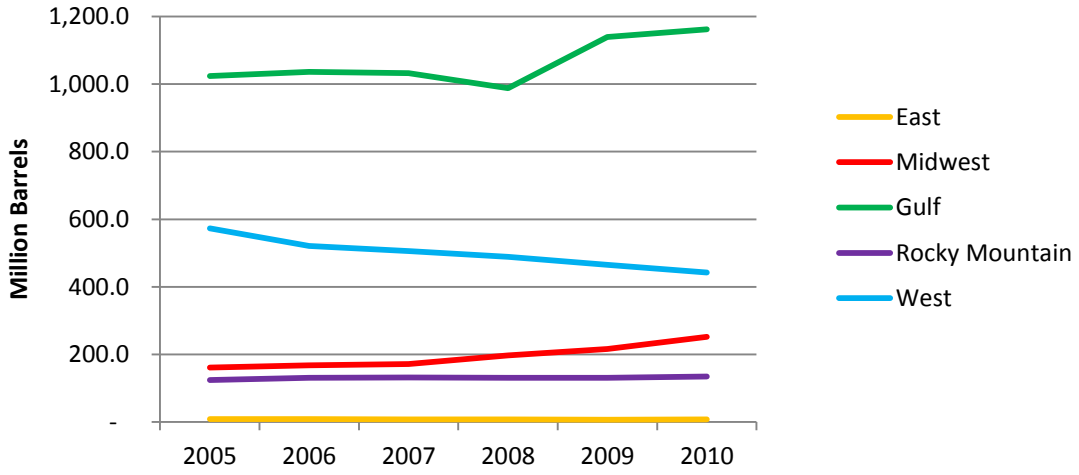
Total U.S. crude oil production was five percent higher in 2010 than in 2005, increasing from approximately 1.9 billion barrels to 2.0 billion barrels per year. As Exhibit 7-4 illustrates, the Midwest region experienced the greatest growth in that period, with production increasing 56 percent, from 161.6 million barrels to 251.9 million barrels per year. In contrast, the West experienced a 23 percent decrease in production, with output falling from 572.8 million barrels in 2005 to 442.7 million barrels in 2010. This decline can be attributed to the dramatic dip in the region's offshore production, which fell from 148.1 million barrels in 2005 to only 57.0 million barrels in 2010. In particular, production in Alaskan state waters (0-3 miles offshore) saw the greatest drop-off (a fall of 79 percent), and was the driving force behind the West's overall decline in production (*Crude*, 2011).

EXHIBIT 7-3. DISTRIBUTION OF U.S. CRUDE OIL PRODUCTION BY PADD AND DRILLING LOCATION



Source: *Crude Oil Production*, October 2011.

EXHIBIT 7-4. U.S. OIL PRODUCTION BY PADD FROM 2005-2010



Source: *Crude Oil Production*, October 2011.

Natural Gas

In 2009, the United States extracted approximately 26.0 trillion cubic feet of natural gas. Approximately 22.9 trillion cubic feet (88 percent) of this total was produced onshore, while 2.5 trillion cubic feet (10 percent) came from Federal offshore sources and 587.0 billion cubic feet (two percent) came from state offshore sources. Texas was the nation's leading producer of natural gas, accounting for 7.7 trillion cubic feet (29 percent) of the national total. Texas's production helped make the Gulf region the leading regional producer of natural gas. The region's total production in 2009 was 55 percent of the U.S. total, approximately 14.4 trillion cubic feet (*Natural*, 2011). Exhibit 7-5 shows the distribution of natural gas production by state and region in both 2005 and 2009.

EXHIBIT 7-5. NATURAL GAS PRODUCTION BY STATE AND REGION, 2005 AND 2009

STATE	2005 (MILLION CUBIC FEET)	2009 (MILLION CUBIC FEET)	PERCENT CHANGE	PERCENT OF 2009 TOTAL
EAST				
Florida	2,954	290	-90%	0%
Maryland	46	43	-7%	0%
New York	55,180	44,849	-19%	0%
Pennsylvania	168,501	273,869	63%	1%
Virginia	88,610	140,738	59%	1%
West Virginia	221,108	264,436	20%	1%
Total	536,399	724,225	35%	3%
GULF				
Alabama	317,206	255,965	-19%	1%
Arkansas	190,774	680,613	257%	3%
Federal Offshore Gulf of Mexico	3,150,818	2,444,102	-22%	9%
Louisiana	1,309,913	1,558,638	19%	6%
Mississippi	189,371	352,888	86%	1%
New Mexico	1,656,850	1,425,222	-14%	5%
Texas	6,006,837	7,653,647	27%	29%
Total	12,821,769	14,371,075	12%	55%
MIDWEST				
Illinois	166	1,443	769%	0%
Indiana	3,135	4,927	57%	0%
Kansas	378,250	355,394	-6%	1%
Kentucky	92,795	113,300	22%	0%
Michigan	266,776	159,400	-40%	1%
Nebraska	1,201	2,916	143%	0%
North Dakota	55,904	92,489	65%	0%
Oklahoma	1,639,310	1,857,777	13%	7%
Ohio	83,523	88,824	6%	0%
South Dakota	11,349	12,927	14%	0%
Tennessee	2,200	5,478	149%	0%
Total	2,534,609	2,694,875	6%	10%

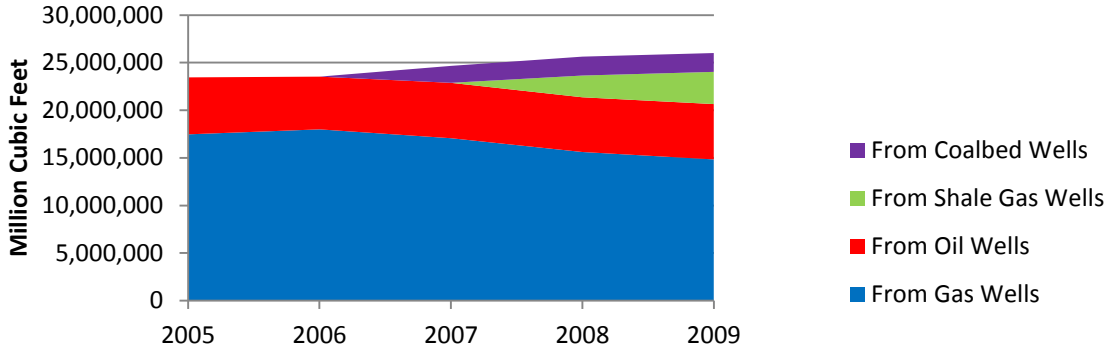
STATE	2005 (MILLION CUBIC FEET)	2009 (MILLION CUBIC FEET)	PERCENT CHANGE	PERCENT OF 2009 TOTAL
ROCKY MOUNTAIN				
Colorado	1,143,985	1,511,654	32%	6%
Montana	108,555	105,251	-3%	0%
Utah	311,994	449,511	44%	2%
Wyoming	2,003,826	2,536,336	27%	10%
Total	3,568,360	4,602,752	29%	18%
WEST				
Alaska	3,642,948	3,312,386	-9%	13%
Arizona	233	712	206%	0%
California	352,044	306,263	-13%	1%
Nevada	5	4	-20%	0%
Oregon	454	821	81%	0%
Total	3,995,684	3,620,186	-9%	14%
U.S. Total	23,456,822	26,013,115	11%	100%
Source: Natural Gas Gross Withdrawals and Production, October 2011.				

As Exhibit 7-5 shows, U.S production of natural gas rose 11 percent from 2005 to 2009, from 23.5 trillion cubic feet to 26.0 trillion cubic feet. During this period, the only region that did not see overall growth was the West, which experienced a nine percent decrease in natural gas production. Much of the growth in natural gas production can be attributed to the increased extraction of shale-gas and of gas from coal-beds. As Exhibit 7-6 shows, prior to 2007 no production of gas from coal-beds was reported, and prior to 2008 no production of shale-gas was reported. By 2009, however, shale-gas and coal-bed extractions added a combined 5.4 trillion cubic feet to U.S. production. Conversely, the extraction of gas from conventional wells fell 15 percent, from 17.5 trillion cubic feet to 14.8 trillion cubic feet (*Natural*, 2011).

Coal

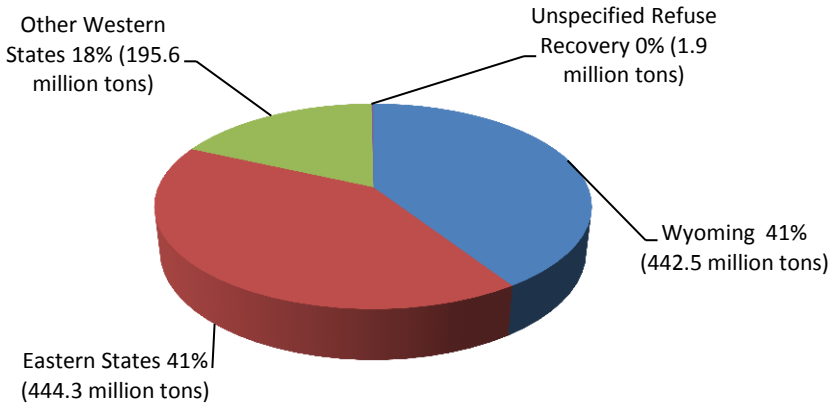
In 2010, the United States produced approximately 1.1 billion tons of coal; surface mines accounted for approximately 68 percent (745.4 million tons) of this total. Ninety-three percent (1,175) of the nation's coal mines are located east of the Mississippi River; however, eastern mines produced only 41 percent (444.3 million tons) of the nation's coal. In contrast, Wyoming, with only 19 mines, alone accounted for 41 percent (442.5 million tons) of the nation's coal production (see Exhibit 7-7). Next to Wyoming, West Virginia produced the most coal, generating approximately 12 percent (135.2 million tons) of the national total (*Coal*, 2011).

EXHIBIT 7-6. NATURAL GAS EXTRACTIONS BY SOURCE, 2005-2009



Source: *Natural Gas Gross Withdrawals and Production*, October 2011.

EXHIBIT 7-7. DISTRIBUTION OF 2010 COAL PRODUCTION BY LOCATION



Source: *U.S. Coal Production*, July 2011.

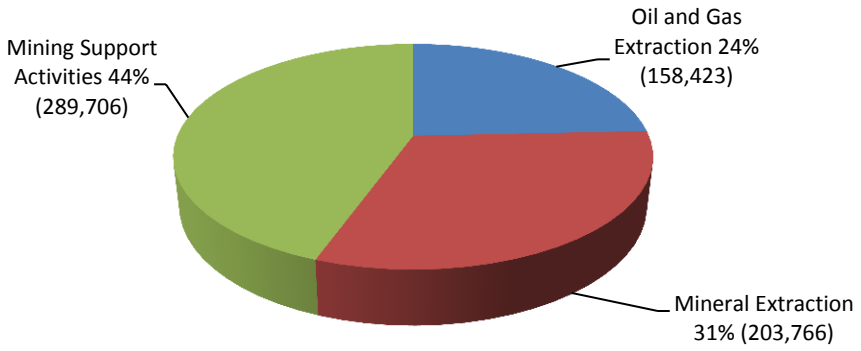
U.S. coal production has declined slightly in recent years. Production totaled 1,131.5 million tons in 2005; by 2010 it had fallen to 1,084.3 million tons, a four percent reduction.

SECTOR EMPLOYMENT

Exhibit 7-8 shows the distribution of employment in mining and energy resource extraction by industry subsector. As the exhibit indicates, aggregate sector employment in 2010 was approximately 652,000, with 24 percent employed in oil and gas extraction, 31 percent employed in mining (which includes coal mining), and 44 percent employed in mining support activities (which includes the drilling of oil and gas wells). The state with the greatest aggregate employment was Texas, which accounts for approximately 31 percent of the national total. Other states that account for a substantial share of

employment in the sector include Louisiana (eight percent) and Oklahoma (seven percent). Exhibit 7-9 shows the full breakdown of employment in the mining and energy resource extraction sector by state, region, and subsector (QCEW, 2011).

EXHIBIT 7-8. DISTRIBUTION OF MINING SECTOR EMPLOYMENT BY INDUSTRY SUBSECTOR IN 2010



Source: BLS, *QCEW*, 2011.

EXHIBIT 7-9. DISTRIBUTION OF MINING INDUSTRY EMPLOYMENT BY STATE IN 2010

	OIL AND GAS EXTRACTION	MINERAL EXTRACTION	MINING SUPPORT SERVICES	TOTAL	PERCENT OF U.S. TOTAL
EAST					
Connecticut	ND	547	ND	571	0%
Delaware	ND	ND	ND	ND	ND
Florida	73	3,021	538	3,632	1%
Georgia	ND	4,605	ND	4,929	1%
Maine	ND	ND	ND	179	0%
Maryland	ND	980	ND	1,477	0%
Massachusetts	ND	970	ND	1,050	0%
New Hampshire	ND	ND	ND	491	0%
New Jersey	31	1,175	162	1,368	0%
New York	448	3,549	627	4,624	1%
North Carolina	23	2,845	141	3,008	0%
Pennsylvania	3,807	12,831	9,365	26,004	4%
Rhode Island	ND	172	ND	ND	ND
South Carolina	ND	1,183	ND	1,245	0%
Vermont	ND	ND	ND	595	0%
Virginia	446	6,695	1,465	8,605	1%
West Virginia	2,244	21,312	5,751	29,307	4%
Total	7,072	59,885	18,049	87,085	13%
GULF					
Alabama	779	6,157	841	7,776	1%
Arkansas	968	2,080	5,310	8,358	1%
Louisiana	8,533	1,176	39,507	49,217	8%
Mississippi	1,005	774	3,984	5,763	1%
New Mexico	4,503	4,077	9,843	18,423	3%
Texas	81,762	9,483	113,326	204,570	31%

	OIL AND GAS EXTRACTION	MINERAL EXTRACTION	MINING SUPPORT SERVICES	TOTAL	PERCENT OF U.S. TOTAL
Total	97,550	23,747	172,811	294,107	45%
MIDWEST					
Illinois	864	6,332	1,869	9,065	1%
Indiana	189	5,827	253	6,269	1%
Iowa	ND	2,099	34	2,133	0%
Kansas	2,303	1,146	4,902	8,352	1%
Kentucky	883	18,059	2,894	21,836	3%
Michigan	605	3,422	1,588	5,615	1%
Minnesota	N	5,084	ND	5,219	1%
Missouri	30	3,831	233	4,093	1%
Nebraska	68	702	144	913	0%
North Dakota	844	1,698	8,118	10,660	2%
Ohio	2,759	5,609	2,566	10,934	2%
Oklahoma	18,677	1,958	22,859	43,494	7%
South Dakota	32	758	28	818	0%
Tennessee	48	2,791	722	3,561	1%
Wisconsin	ND	2,207	ND	2,221	0%
Total	27,302	61,523	46,210	135,183	21%
ROCKY MOUNTAIN					
Colorado	7,830	5,026	11,376	24,232	4%
Idaho	28	1,987	276	2,290	0%
Montana	650	4,235	1,977	6,862	1%
Utah	1,406	4,749	4,286	10,442	2%
Wyoming	4,197	9,636	11,262	25,098	4%
Total	14,111	25,633	29,177	68,924	11%
West					
Alaska	3,551	2,249	9,355	15,155	2%
Arizona	20	9,899	631	10,550	2%
California	8,755	5,134	10,555	24,445	4%
Hawaii	ND	336	ND	338	0%
Nevada	25	10,709	1,480	12,214	2%
Oregon	4	1,478	94	1,576	0%
Washington	ND	1,983	ND	2,146	0%
Total	12,355	31,788	22,115	66,424	10%
U.S. Total	158,423	203,766	289,706	651,981	100%

Source: BLS, *QCEW*, 2011.

VALUE ADDED

Exhibit 7-10 presents information from the 2007 Economic Census on value added for the mining, quarrying, and oil and gas extraction sector (NAICS code 21). As the exhibit indicates, value added for the industry as a whole totaled approximately $417.8 billion. Oil and gas extraction accounted for approximately 66 percent of this total. Mining accounted for an additional 17 percent, as did mining support activities. Of the $72.8 billion in value added generated from mining, $27.6 billion was attributable to coal production, $26.6 billion was attributable to the mining and quarrying of non-metallic minerals, and $18.6 billion was attributable to the mining of metal ores. The state with

the highest value added for the industry was Texas, which, at $111.6 billion, represented 27 percent of the national total.

EXHIBIT 7-10. VALUE ADDED IN THE MINING, QUARRYING, AND OIL AND GAS EXTRACTION INDUSTRY (NAICS CODE 21), 2007

SECTOR	VALUE ADDED	PERCENT OF TOTAL
Oil and Gas Extraction	$275,736,571,000	66.0%
Mining	$72,753,826,000	17.4%
Mining Support Activities	$69,357,339,000	16.6%
U.S. Total	$417,847,736,000	100.0%
Source: *2007 Economic Census*.		

SECTOR IN A GLOBAL CONTEXT

As stated previously, the United States is one of the leading producers of energy resources in the world, ranking third in 2010 in world production of petroleum, second in world production of natural gas, and second in world production of coal. The U.S., however, is also the world's leading consumer of energy resources. In 2010, the U.S. ranked first in natural gas consumption, utilizing approximately 24.1 trillion cubic feet; second in coal consumption, utilizing 1.0 billion tons; and first in petroleum consumption, utilizing 19.1 million barrels per day (no other country consumed more than 10.0 million barrels per day). Exhibit 7-11 shows the distribution of U.S. energy resource imports and exports by type and country in 2010. As the exhibit indicates, U.S. petroleum imports (3.4 billion barrels) far outstripped exports (15.2 million barrels). The source of U.S. petroleum imports was almost evenly split between OPEC and non-OPEC countries. The U.S. was also a net importer of natural gas in 2010, importing approximately 3.7 trillion cubic feet (primarily from Canada) and exporting approximately 1.1 trillion cubic feet (primarily to Canada). In contrast, the U.S. has a favorable balance of trade in coal, importing only 9.9 million tons in 2010 and exporting approximately 39.8 million tons. South America was the leading source of U.S. coal imports (7.5 million tons), while Europe was the top destination for U.S. coal exports (19.4 million tons).

WATER USE

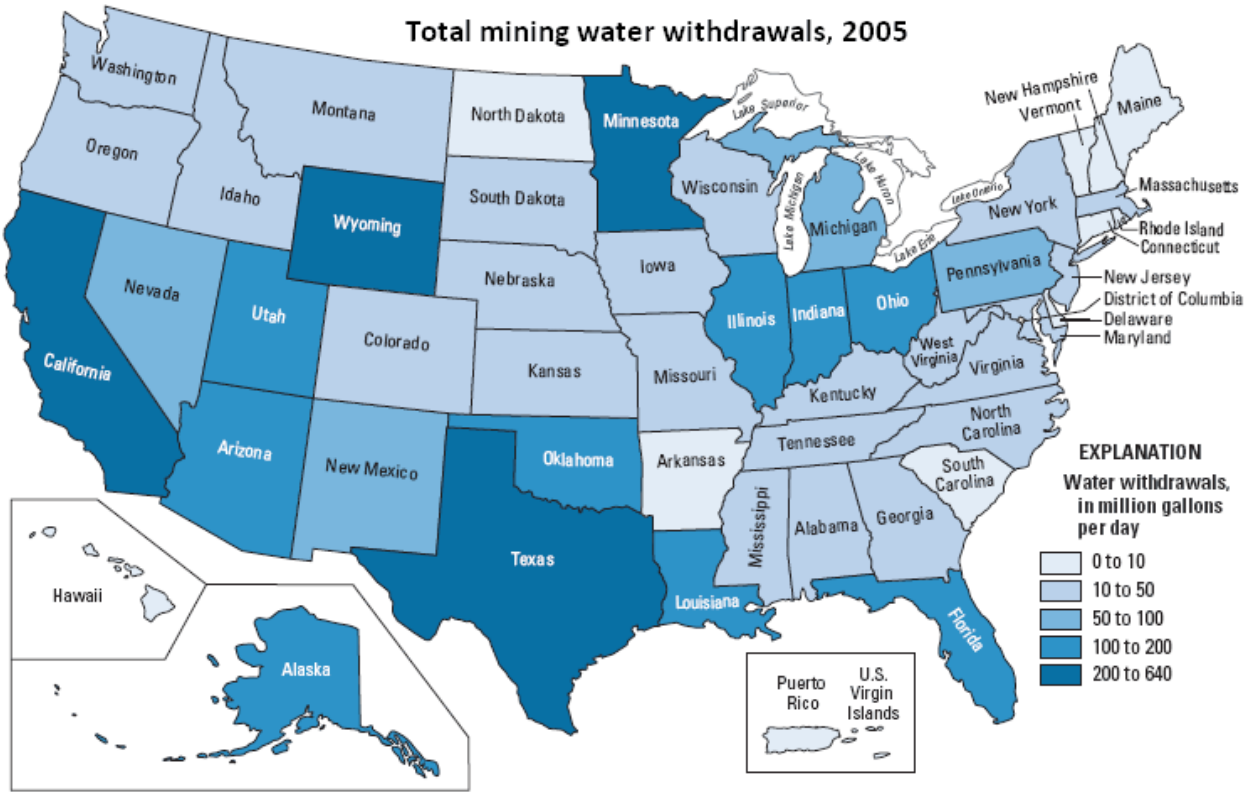
Water is used in mining and energy resource extraction for a variety of purposes: in mineral extraction it is used for such processes as milling, wet-screening, and hydraulic mining, while in petroleum and natural gas extraction it is used for procedures like hydraulic fracturing, secondary oil recovery, and the extraction and processing of oil shale. In 2005, withdrawals of water by the mining and energy resource extraction sector were estimated at approximately 4.0 BGD, representing one percent of total U.S. withdrawals. The 2005 figure is consistent with estimates since 1985, when USGS first reported withdrawals for the mining sector as a separate category. Since then estimated withdrawals have ranged from 3.4 BGD to 4.9 BGD, with a mean of 4.1 BGD (USGS, 2009).

EXHIBIT 7-11. U.S. IMPORTS AND EXPORTS OF CRUDE OIL, NATURAL GAS, AND COAL IN 2010

	IMPORTS	EXPORTS
PETROLEUM (THOUSAND BARRELS)		
All Countries	3,362,856	15,198
OPEC	1,661,727	-
Nigeria	358,924	-
Saudi Arabia	394,967	-
Venezuela	332,926	-
Other	574,910	-
Non-OPEC	1,701,129	15,198
Canada	719,175	15,198
Colombia	123,525	-
Mexico	420,567	-
Other	437,862	-
NATURAL GAS (MILLION CUBIC FEET)		
Total	3,740,757	1,136,789
Pipeline Gas	3,309,747	1,071,997
Canada	3,279,752	738,745
Mexico	29,995	333,251
Liquid Natural Gas	31,010	64,793
Egypt	72,990	-
Japan	-	32,922 -
Qatar	45,583	-
South Korea	-	1,809
Trinidad	189,748	-
United Kingdom	-	9,584
Other	122,689	10,478
COAL (SHORT TONS)		
Total	9,861,277	39,771,564
North America	748,707	4,868,452
South America	7,467,725	4,910,392
Europe	20,675	19,434,074
Asia	1,531,674	9,540,195
Australia and Oceania	92,054	1,383
Africa	442	1,017,068
Source: *EIA*, 2011.		

Exhibit 7-12 provides a map that illustrates the distribution of mining water withdrawals by state in 2005. Exhibit 7-13 presents more detailed information on this distribution, noting both the source (surface water or groundwater) and type (freshwater or saline water) of water used for mining purposes. According to the USGS, oil and gas operations in Texas, California, Oklahoma, Wyoming, and Louisiana were responsible for the large volume of saline groundwater withdrawals in these states; these withdrawals are a byproduct of the resource extraction process. In contrast, sand and gravel operations in Indiana and iron ore mining in Michigan and Minnesota accounted for the largest volume of withdrawals from fresh surface water sources. Mineral salt extraction from the Great Salt Lake in Utah accounted for the largest volume of saline surface water withdrawals for mining purposes, while withdrawals of fresh groundwater for mining purposes were highest in Florida, Ohio, Nevada, Arizona, and Pennsylvania (USGS, 2009).

EXHIBIT 7-12. GEOGRAPHIC DISTRIBUTION OF MINING WATER WITHDRAWALS, 2005



Source: USGS, *Estimated Use of Water in the United States in 2005*, 2009.

EXHIBIT 7-13. DISTRIBUTION OF DAILY MINING WITHDRAWALS BY STATE, SOURCE, AND TYPE, 2005

STATE	GROUNDWATER (MGD)			SURFACE WATER (MGD)			ALL SOURCES (MGD)		
	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL
Alabama	19.6	0	19.6	8.26	0	8.26	27.8	0	27.8
Alaska	0	114	114	22.2	60.9	83.1	22.2	175	198
Arizona	91.6	2.61	94.2	9.05	0	9.05	101	2.61	103
Arkansas	0.24	0	0.24	1.05	0	1.05	1.29	0	1.29
California	34.5	255	289	18.6	0.29	18.9	53.1	255	308
Colorado	5.2	14.6	19.8	1.24	0.39	1.63	6.44	15	21.4
Connecticut	0.67	0	0.67	2.73	0	2.73	3.4	0	3.4
Delaware	0.8	0	0.8	0.75	0.01	0.76	1.55	0.01	1.56
Florida	138	0	138	56.9	0	56.9	195	0	195
Georgia	48.9	0	48.9	0.47	0	0.47	49.4	0	49.4
Hawaii	1.42	0	1.42	0.44	0	0.44	1.86	0	1.86
Idaho	2.16	0	2.16	22	0	22	24.2	0	24.2
Illinois	15.5	25.5	41	71.2	0	71.2	86.7	25.5	112
Indiana	4.7	0	4.7	95.5	0	95.5	100	0	100
Iowa	3.23	0	3.23	44.2	0	44.2	47.4	0	47.4
Kansas	10.1	0	10.1	4.64	0	4.64	14.8	0	14.8
Kentucky	7.89	0	7.89	28.7	0	28.7	36.6	0	36.6
Louisiana	6.11	151	157	20.8	0	20.8	26.9	151	178
Maine	1.5	0	1.5	5.26	0	5.26	6.76	0	6.76
Maryland	9.05	0	9.05	4.17	0	4.17	13.2	0	13.2
Massachusetts	2.96	0	2.96	7.77	0	7.77	10.7	0	10.7
Michigan	13.2	0.94	14.1	81.4	0	81.4	94.6	0.94	95.5
Minnesota	8.05	0	8.05	418	0	418	426	0	426
Mississippi	11.3	0	11.3	0.61	0	0.61	11.9	0	11.9
Missouri	22.9	0	22.9	11.8	0	11.8	34.7	0	34.7
Montana	1.2	5.12	6.32	34.2	0	34.2	35.4	5.12	40.5
Nebraska	0.08	0.09	0.17	10.2	0	10.2	10.3	0.09	10.4
Nevada	99.1	0	99.1	0	0	0	99.1	0	99.1
New Hampshire	0.02	0	0.02	3.74	0	3.74	3.76	0	3.76
New Jersey	0.91	0	0.91	37.4	0	37.4	38.3	0	38.3
New Mexico	57.4	0	57.4	1.29	0	1.29	58.7	0	58.7
New York	6.94	0.42	7.36	25.9	0.42	26.4	32.9	0.84	33.7
North Carolina	35	0	35	11	0	11	46.1	0	46.1
North Dakota	5.26	0	5.26	0.4	0	0.4	5.66	0	5.66
Ohio	112	0	112	61.7	0	61.7	174	0	174
Oklahoma	1.01	190	191	1.67	0	1.67	2.68	190	193
Oregon	13.9	0	13.9	2.09	0	2.09	16	0	16
Pennsylvania	84.9	0	84.9	10.8	0	10.8	95.7	0	95.7
Rhode Island	0.59	0	0.59	1.12	0	1.12	1.71	0	1.71
South Carolina	8.56	0	8.56	0.5	0	0.5	9.06	0	9.06
South Dakota	4.55	0	4.55	5.93	0	5.93	10.5	0	10.5
Tennessee	10.4	0	10.4	11.4	0	11.4	21.7	0	21.7

STATE	GROUNDWATER (MGD)			SURFACE WATER (MGD)			ALL SOURCES (MGD)		
	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL
Texas	26.8	548	575	64.2	0	64.2	91	548	639
Utah	3.73	33.7	37.4	1.41	128	130	5.14	162	167
Vermont	0.24	0	0.24	3.55	0	3.55	3.79	0	3.79
Virginia	2.47	0	2.47	27.3	0	27.3	29.8	0	29.8
Washington	22.4	0	22.4	4.14	0	4.14	26.6	0	26.6
West Virginia	4.71	0.51	5.22	9.44	0	9.44	14.2	0.51	14.7
Wisconsin	17.6	0	17.6	14.9	0	14.9	32.5	0	32.5
Wyoming	38.3	177	216	13.5	0	13.5	51.8	177	229
Puerto Rico	1.76	0.34	2.1	0.22	0	0.22	1.98	0.34	2.32
U.S. Virgin Islands	0	0	0	0	0.02	0.02	0	0.02	0.02
TOTAL	1,020	1,520	2,540	1,300	190	1,490	2,310	1,710	4,020

Source: USGS, *Estimated Use of Water in the United States in 2005*, 2009.

COAL AND OTHER MINERAL EXTRACTION

Extracting minerals such as coal, hard rock, sand and gravel, and metal ores from the earth can involve a number of procedures that are water-intensive, particularly those which involve reducing the size of the extracted material. Wet screening, for instance, in which the mined material is filtered by water through a series of screens, can use anywhere from 30 to 250 gallons of water per ton of mined material. Milling (or grinding), in which the mined material is broken down into smaller particles, also uses a large amount of water: anywhere from 125 to 300 gallons per ton of mined material. Water is also used in drilling for minerals; however, usage is highly variable, depending on the diameter of the hole, depth, orientation, etc. In general, water use ranges from two to five gallons per meter drilled (Mavis, 2003).

The use of water in mineral extraction is greatest when processing softer minerals, such as kaolin (a type of clay) and silica sand. Kaolin clay, a material used primarily in paper-making, goes through several processing procedures, such as suspension and dispersion, screening, grit removal, brightening, and flocculation, all of which are water intensive. While the exact amount varies from facility to facility, roughly 2,000 gallons of water are used to process a ton of kaolin. Kaolin is also shipped via slurry pipelines in a mixture of 70 percent kaolin and 30 percent water (Mavis, 2003).

In coal mining, water is used for several purposes, mainly for the cooling of machinery, dust suppression, and safety (i.e., dousing fires). The majority of water used in mining is for dust control, which utilizes approximately 5.2 gallons per ton of coal produced. Water use statistics for other coal mining processes are not readily available (Mavis, 2003).

Water quality is of little concern in most mining operations; much of the water that is utilized is later reused for the same process. Some procedures, particularly in increasing mineral concentration, are sensitive to water quality, yet these are so rare as to be inconsequential (Mavis, 2003).

CRUDE OIL

In petroleum extraction, water is used in many of the same ways that it is for mineral extraction: dust suppression, cooling of machinery, etc. Much of the water used in oil extraction (and in gas extraction) is produced water, or water that is generated during the drilling process. This water is generally saline but can range from fresh to hyper-saline. In 1995, the American Petroleum Institute estimated that oil and gas operations produced roughly 49 million gallons of water per day, much of which was reused in oil and gas production. Only some of this water was sent off-site for treatment (*Energy Demands*, 2006).

Water is a primary input to the process known as secondary oil recovery, which is used to maintain production at wells that would otherwise be abandoned. Water (or steam) is injected into the wells in order to extract additional oil. The amount of water used in secondary oil recovery varies greatly, as anywhere from 2 to 350 gallons of water can be used per gallon of oil extracted. While this process can be extremely water intensive, much of the water used is produced water, and otherwise unusable (*Energy Demands*, 2006).

In addition to conventional crude oil reserves, the U.S. holds one of the largest deposits of oil shale in the world. These reserves are not heavily utilized at present but could have a significant impact on the nation's future oil output. DOE's Energy Information Administration (EIA) estimates that, by 2035, shale oil could account for two percent of total U.S. oil production (*Energy Outlook*, 2011). A potential impediment to that production, however, is the resource-intensive process for turning mined oil shale into useable crude oil. The process, retorting, requires 2 to 5 gallons of water per gallon of refinery-ready oil.[26] Moreover, the majority of oil shale deposits are located in areas of the west in which water is scarce. The scarcity of water increases the costs of retorting and may, in some cases, render it economically infeasible. To address this issue, the industry is attempting to develop in-situ retorting processes that are less water-intensive. These processes could dramatically reduce reliance on water for oil shale production (*Energy Demands*, 2006).

NATURAL GAS

As with mineral extraction and oil extraction, natural gas extraction utilizes water in a variety of ways, such as the cooling of machinery and dust suppression. Water is also used extensively in the mining of unconventional natural gas sources, such as tight gas (gas that is trapped beneath sandstone formations), coal bed gas (gas that is generated by coal, then stored within its seams), and shale-gas (gas stored within low-porosity shale, which also acts as a source). The extraction of gas from these unconventional sources often (almost always in the case of shale-gas) requires a water-intensive process known as hydraulic fracturing (Ground Water Protection Council, 2009).

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[26] Retorting is a heating process that separates the oil fractions of oil shale from the mineral fractions. For additional information, see http://ostseis.anl.gov/guide/oilshale/index.cfm.

Hydraulic fracturing involves high-pressure injection of a solution – typically made up of 98 percent water and sand and two percent chemical additives – into the shale where the gas is trapped. This creates cracks or fractures in the shale, allowing for easier extraction of the gas. This process allows for access to gas that is otherwise unreachable, greatly increasing natural gas production (Ground Water Protection Council, 2009). While shale-gas accounted for only 16 percent of U.S. natural gas production in 2009, the EIA estimates that by 2035 its share of total production may increase to roughly 43 percent (*Energy Outlook*, 2011).

Much of the projected increase in shale-gas production is contingent on the use of hydraulic fracturing, a process that is under scrutiny due to environmental concerns, mainly the potential contamination of groundwater resources. The greatest concern is that fracturing may allow gas and other contaminants, such as those in the fracturing fluid, to seep into underground sources of drinking water. The EPA is now investigating these issues, conducting a study that is not expected to be completed until 2014; however, the agency recently released a draft report detailing tests done at hydraulic fracturing sites in Wyoming's Pavillion gas field. In this report, the EPA noted that domestic groundwater sources located near hydraulic fracturing sites had a high number of organic and inorganic contaminants associated with hydraulic fracturing (DiGulio et al., 2011). While these findings are not definitive and the Agency has reached no conclusions about the safety of hydraulic fracturing, the results suggest that environmental externalities associated with the production of shale gas may, at least in some cases, affect the use of groundwater for other purposes.

VALUE OF WATER USE

As stated previously, much of the water used in mining and energy resource extraction is produced water, i.e., water that is generated during the mining process. In these cases water is not purchased by an external provider, and no market information on the user's willingness to pay for water is available. In some cases, however, produced water is unavailable, and mining operators must obtain it from other sources, including the purchase of water in water markets. A study by the U.S. Forest Service (USFS) of more than 2,000 water market transactions that occurred between 1990 and 2003 identified 28 transactions that involved the lease of water for the purpose of mining; 25 of the 28 leases were entered into by mining interests in Texas's Rio Grande basin. The amount of water purchased through these arrangements totaled 3,241 acre-feet per year.

Exhibit 7-14 summarizes the data on purchases of water by mining operations, which provide some insight to the value of water in the mining sector. All values are reported in 2010 dollars. As the exhibit indicates, prices ranged from $40 per acre-foot per year to nearly $2,700 per acre-foot per year, with a median value of approximately $202 and a mean value of $482. The median price paid for water by mining concerns was more than double the median price paid by any other group considered in the USFS study, including municipalities, environmental interests, farmers, water districts, public agencies, power plants, developers, and others. The small number of transactions involved makes it difficult to draw definitive conclusions from these findings, particularly given the concentration of purchases in a relatively small geographic area. Nonetheless, this price

information provides an indication that at least in some circumstances the marginal value of water to mining interests is relatively high. Presumably, this reflects:

- The relatively high value of the marginal product of water;
- Limited ability to substitute other inputs (such as labor) for water; and
- A relatively inelastic demand for water, at least in the quantities acquired.

EXHIBIT 7-14. WESTERN WATER MARKET TRANSACTIONS, 1990 TO 2003: PURCHASES FOR MINING PURPOSES (2010 DOLLARS; N = 28)

PARAMETER	$/ACRE-FOOT/YEAR
Mean Price	$482.24
Median Price	$201.62
Minimum Price	$40.09
Maximum Price	$2,662.35
Source: Brown, *The Marginal Economic Value of Streamflow From National Forests*, 2004.	

The literature reviewed provides no empirical information on any of these presumptions. Nonetheless, it is reasonable to infer that under circumstances similar to those surrounding this particular suite of transactions, the marginal value of water for mining purposes may be extremely high.

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CHAPTER 8 | ELECTRIC POWER GENERATION (OFF-STREAM AND IN-STREAM USE)

INTRODUCTION

Water plays a vital role in the U.S. electric power sector, both as a coolant for thermoelectric power generation and as an energy source for the generation of hydroelectricity. The direct use of water as a power source at hydroelectric facilities is generally considered a non-consumptive, in-stream use. In contrast, the use of water as a coolant in thermoelectric power generation is considered an off-stream use, one which accounted for 49 percent of total water withdrawals in 2005 (USGS, 2009). The vast majority of water used by the electric power sector is not consumed; instead, it is either returned to its source or retained by the power generator for future use.

OVERVIEW OF KEY FINDINGS

- Thermoelectric power plants withdraw over 200 billion gallons of water per day, more than that withdrawn by any other sector. Thermoelectric plants use most of this water for cooling; those with once-through cooling systems return most of what they use to its source, while those with recirculating systems retain the water for future use. The power sector also makes significant use of in-stream water, employing it to generate electricity at hydroelectric plants.
- The withdrawal of water for thermoelectric power generation peaked in 1980 and has remained relatively constant since that time, despite a significant increase in power production. The heightened efficiency in the use of water is largely due to a shift away from once-through cooling systems to recirculating cooling systems, a change that was triggered by Clean Water Act restrictions on cooling water discharge. Recirculating systems withdraw less water than do once-through systems; however, their use of evaporative cooling increases overall water consumption.
- As the largest off-stream user of water, thermoelectric power generation competes with other major water users, particularly agriculture and public supply. In contrast, the development of a hydropower project can act as a complement to other uses of water, as reservoirs created for large storage dams improve the availability of water for other purposes, including agriculture, public supply, and recreation. In some cases, however, concern about the environmental impact of hydropower, particularly the impact of dams on fish and other wildlife, have restricted project development or constrained operations.
- Estimating the value of water in the electric power generation sector is complicated by several factors, including the nature of the electricity market (where prices are affected by regulation and constantly changing demand) and the nature of water use in this sector (where the majority of water withdrawals are not consumed and are available for further use downstream). Estimates based on comparing the cost of electricity generation with and without the use of water have generally found the value of water to be less than $100 per acre-foot.

The discussion that follows provides additional information on the use of water in electric power generation. It includes:

- An overview of the electric power generation sector;
- A summary of the sector's use of water;
- A description of the potential effects of water resource constraints on the sector's current and future operations; and
- Available estimates of the value of water used in electric power generation.

SECTOR OVERVIEW

Electricity is vital to the economy of the United States, which produces (and consumes) more electricity than any other country. The discussion that follows presents an overview of the electric power generation sector, which is part of the U.S. economy's secondary mega-sector. It focuses in particular on thermoelectric power and hydropower generation. The discussion draws primarily on data published by the Department of Energy (DOE)'s Energy Information Administration (EIA), including the 2010 Electric Power Annual and the 2011 Annual Energy Outlook.

OVERVIEW OF ELECTRIC POWER GENERATION

Electricity is generated at facilities that convert energy from a variety of sources into electrical energy that can be distributed and used in the residential, commercial, and industrial sectors. The sources of power used to generate electricity include fossil fuels (primarily coal and natural gas) and nuclear fission, as well as renewable energy sources like hydropower, wind, solar radiation, biomass (e.g., forest residues and municipal solid waste), and geothermal energy (i.e., heat from within the Earth).

Generating Capacity and Generation

In 2010, the generating capacity of the U.S. electric power sector totaled 1.1 million megawatts (MW), while net generation of electricity totaled 4,125 million megawatt hours (MWh). Exhibits 8-1 and 8-2 present more detailed information on generating capacity and net generation, including the distribution of net generation by power source.

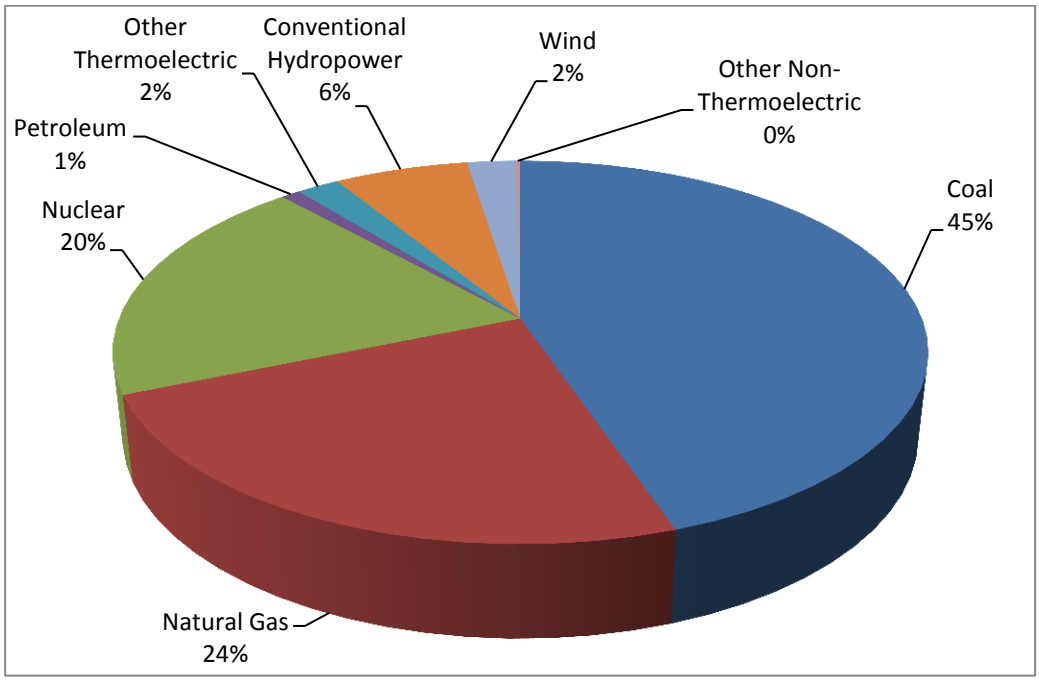
EXHIBIT 8-1. GENERATING CAPACITY AND NET GENERATION BY POWER SOURCE, 2010

POWER SOURCE	GENERATING CAPACITY (MW)	NET GENERATION (MILLION MWH)
Coal	342,296	1,847
Petroleum	62,504	37
Natural Gas	467,214	988
Other Gases	3,130	11
Nuclear	106,731	807
Hydroelectric Conventional	78,204	260
Wind	39,516	95
Solar Thermal and Photovoltaic	912	1
Wood and Wood Derived Fuels	7,949	37
Geothermal	3,498	15
Other Biomass	5,043	19
Pumped Storage	20,538	-6
Other	1,027	13
Total	1,138,563	4,125

Source: EIA, 2010.
Note: Other includes non-biogenic municipal solid waste, batteries, chemicals, hydrogen, and other sources. Pumped storage refers to hydroelectric facilities that use electricity during periods of low electricity demand to store energy by pumping water into reservoirs for later use during high-demand periods.

Within the electric power generation sector, the two primary water users, thermoelectric power generation and hydropower generation, together accounted for the vast majority of net generation in 2010. Thermoelectric power generation, which encompasses all power generated from combustion of fossil fuels (e.g., coal, natural gas, petroleum), nuclear power, and some renewable power sources like biomass and geothermal, produced more than 90 percent of net power generated in 2010; hydropower accounted for an additional six percent.

EXHIBIT 8-2. DISTRIBUTION OF NET ELECTRIC POWER GENERATION BY POWER SOURCE, 2010



Source: EIA, 2010. Note: Hydropower includes conventional hydropower (6.3 percent) and pumped storage (-0.1 percent). Other thermoelectric includes other gases (0.3 percent), wood and wood derived fuels (0.9 percent), geothermal (0.4 percent), and other biomass (0.5 percent). Other non-thermoelectric includes solar thermal and photovoltaic (<1 percent), and other (0.3 percent).

Distribution of Generation by State

Electric power is generated throughout the U.S., but the quantity of power produced and the methods of power production vary widely by region. Factors such as proximity to fuel sources, construction costs, and Federal and state regulations have played a role in how the electric power generation sector has developed in each state. Exhibit 8-3 lists net thermoelectric power and hydropower generation for each state in 2010.

As the exhibit shows, electric power generation varies widely by state. Texas, Florida, Pennsylvania, Illinois, and California were the largest generators of thermoelectric power in 2010, while Washington, California, Oregon, New York, and Montana were the largest producers of hydropower.

EXHIBIT 8-3. NET THERMOELECTRIC POWER AND HYDROPOWER GENERATION BY STATE, 2010

STATE	2010 NET GENERATION (THOUSAND MWH)	
	THERMOELECTRIC POWER[1]	HYDROPOWER[2]
Alabama	143,079,814	8,704,254
Alaska	5,313,828	1,433,141
Arizona	104,754,355	6,831,190
Arkansas	57,313,323	3,658,441
California	163,178,980	33,259,605
Colorado	45,699,230	1,457,472
Connecticut	32,232,903	400,159
Delaware	5,625,089	0
Florida	226,004,462	177,474
Georgia	134,515,657	3,043,748
Hawaii	10,138,843	70,423
Idaho	2,350,848	9,154,244
Illinois	196,465,455	118,543
Indiana	121,412,963	453,712
Iowa	47,390,216	948,168
Kansas	44,505,483	13,214
Kentucky	95,621,955	2,580,246
Louisiana	101,216,954	1,108,794
Maine	12,386,185	3,810,381
Maryland	41,668,388	1,667,396
Massachusetts	41,351,929	659,270
Michigan	110,631,360	227,994
Minnesota	47,780,408	840,410
Mississippi	54,478,564	0
Missouri	88,928,119	2,427,033
Montana	19,165,072	9,414,662
Nebraska	34,894,505	1,313,856
Nevada	32,772,035	2,157,296
New Hampshire	20,585,745	1,477,583
New Jersey	65,249,155	-175,653
New Mexico	34,193,420	217,010
New York	108,591,216	24,942,433
North Carolina	123,503,154	4,756,549

STATE	2010 NET GENERATION (THOUSAND MWH)	
	THERMOELECTRIC POWER[1]	HYDROPOWER[2]
North Dakota	28,564,536	2,042,118
Ohio	143,131,859	429,024
Oklahoma	65,786,780	2,655,870
Oregon	20,617,904	30,542,260
Pennsylvania	225,421,335	1,624,422
Rhode Island	7,731,889	3,706
South Carolina	102,650,226	1,441,743
South Dakota	3,439,085	5,238,801
Tennessee	74,889,146	7,416,323
Texas	383,834,579	1,261,832
Utah	40,932,525	695,512
Vermont	5,259,211	1,346,887
Virginia	72,542,755	9,580
Washington	30,324,080	68,341,711
Washington, DC	199,858	0
West Virginia	78,481,796	1,367,361
Wisconsin	61,050,297	2,111,852
Wyoming	43,780,717	1,023,887
Total	3,761,638,191	254,701,937

Source: EIA, 2010.

Notes:
1. Thermoelectric power includes coal, petroleum, natural gas, nuclear, other gases, wood and wood derived fuels, geothermal, and other biomass.
2. Hydropower includes conventional hydroelectric and pumped storage.

ECONOMIC IMPORTANCE OF THE ELECTRIC POWER GENERATION SECTOR

Electrical power in the U.S. is generated both at private sector and government-operated facilities.[27] This complicates the compilation of data on economic activity related to power generation. The 2007 Economic Census provides economic data for electric power generation, but only for private sector facilities. The U.S. Census of Governments reports economic data for government-operated electric utilities, but this includes electric power transmission and distribution, in addition to generation. Exhibit 8-4 summarizes

[27] Government-operated facilities range from small municipal power stations to complex Federal installations, such as the 31 hydroelectric dams in the Columbia River basin that generate power for much of the Pacific Northwest. Power from these dams is marketed by the U.S. Department of Energy's Bonneville Power Administration.

Economic Census data on the number of privately owned establishments in each subsector within the electric power generation sector, the total employment at such establishments, total payroll, and annual revenue. The exhibit also summarizes economic data for government-operated electric utilities, including total employment, payroll, and revenues.

EXHIBIT 8-4. ECONOMIC PROFILE OF THE U.S. ELECTRIC POWER GENERATION SECTOR (2007)

SUBSECTOR	NUMBER OF ESTABLISHMENTS	EMPLOYMENT	ANNUAL PAYROLL ($BILLION)	ANNUAL REVENUE ($BILLION)
Private Hydroelectric	295	4,086	$0.3	$2.2
Private Fossil Fuel	1,248	74,860	$6.4	$85.4
Private Nuclear	79	37,972	$4.1	$29.0
Private Other[1]	312	5,875	$0.5	$4.4
Total Private	1,934	122,793	$11.3	$121.0
Total Public[2]	Not available	79,697	$5.1	$76.0
Total	>1,934	202,490	$16.4	$197.0

Source: Data for private facilities come from U.S. Census Bureau, *2007 Economic Census*, 2007. Data were summarized for NAICS Codes 21111, 21112, 21113, and 21119. Data for public facilities come from U.S. Census of Government Employment, 2007 and U.S. Census of Governments Survey of State and Local Government Finances, 2009.

[1] Includes solar, wind, tidal, and geothermal power generation.
[2] Includes employment, payroll, and revenue associated with electric power transmission and distribution, as well as generation.

Thermoelectric Power

As noted in Exhibit 8-2, thermoelectric power plants produce more than 90 percent of the electricity generated in the U.S. Large thermoelectric power plants—particularly coal-fired and nuclear plants—require long startup times and operate at highest efficiency at relatively constant levels of output. Accordingly, most thermoelectric power generation is used to meet "base load" demand, or the minimal amount of electricity that must be available at all times. By contrast, "peak load" demand, or the electricity required to meet the highest daily, weekly, and yearly demand, depends on power plants that can come online rapidly, in response to sudden increases in demand. Smaller thermoelectric plants, such as gas-turbine plants, are often used to meet peak demand.

Hydropower

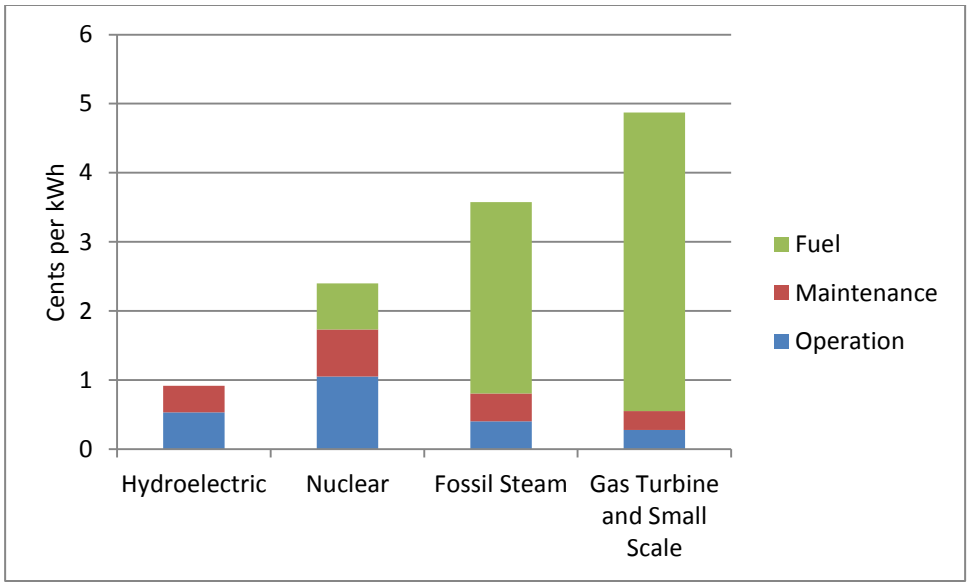
Although hydropower accounts for only six percent of national electric power generation, it has a much larger share of total generation in some states, particularly in the western U.S. In Washington, Oregon, Idaho, and South Dakota, more than 50 percent of total generation comes from conventional hydropower. In addition, hydropower generation plays an important role in ensuring the reliability of electricity supply, both by meeting peak load demand and by storing excess electricity during low-demand periods. Because

hydroelectric generators can be activated or deactivated very rapidly, hydropower is well suited for meeting peak demand (Gillilan and Brown, 1997).

The three primary types of hydropower facilities are storage, run-of-the-river, and pumped-storage. A storage facility uses a dam to create a reservoir in a water body, creating a "head," or difference in elevation between the reservoir and the water body beneath the dam (U.S. Bureau of Reclamation, 2005). Run-of-the-river plants do not rely on reservoirs and do not substantially interfere with the flow of the rivers in which they are located. Pumped-storage facilities use electricity to pump water into a storage reservoir when electricity demand is low and release the stored water to generate power when demand is high, essentially serving as batteries for the electric power grid. Storage and pumped-storage facilities can control the timing of electricity production and are therefore used to meet peak demand. Because run-of-the-river facilities are subject to seasonal variation in river flows, they are primarily used to meet base demand.

Hydropower is a relatively inexpensive source of electricity, primarily because hydroelectric plants incur no costs for fuel. Exhibit 8-5 compares the average cost of electricity generation at different types of power plants in 2010, showing the variation in fuel, maintenance, and operation costs.

EXHIBIT 8-5. AVERAGE POWER PLANT OPERATING EXPENSES, 2010



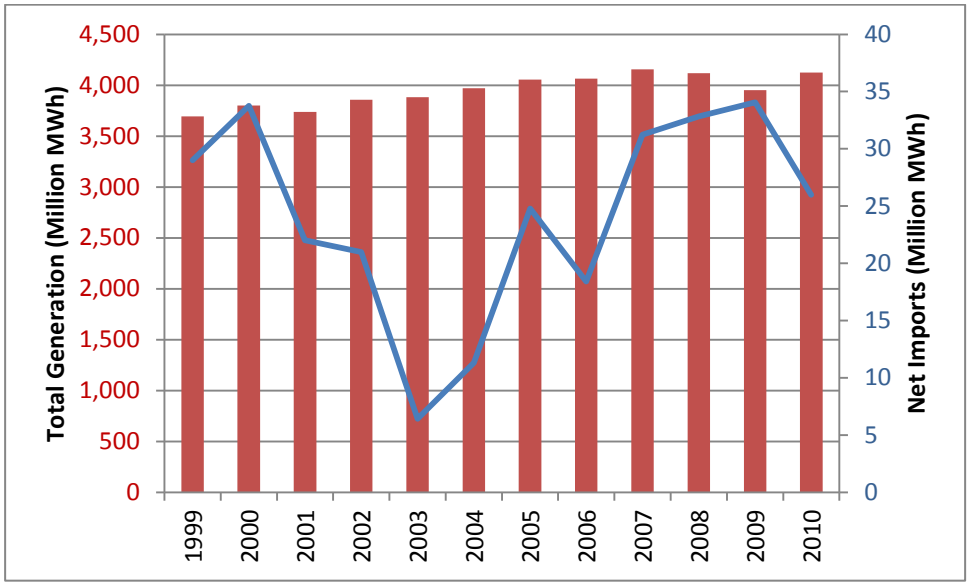
Source: EIA, 2010. Note: Hydroelectric includes both conventional hydroelectric and pumped storage; gas turbine and small scale includes gas turbine, internal combustion, photovoltaic, and wind plants.

International Trade

The U.S. is the world's largest electricity consumer, but also the largest electricity producer (Enerdata, 2011). International trade in electricity is generally limited to countries with shared borders, and the U.S. is no exception, trading electricity only with

Canada and—to a lesser extent—Mexico. As Exhibit 8-6 shows, the U.S. in recent years has been a net importer of electricity, with net imports ranging between 34 million MWh in 2000 and 2009 and 6 million MWh in 2003. The trade deficit is small, however, relative to total domestic production. In 2010, U.S. net imports of electricity from Mexico and Canada were about 26 million MWh, less than one percent of the 4,125 million MWh produced in the U.S. that year.

EXHIBIT 8-6. U.S. ELECTRICITY PRODUCTION AND NET IMPORTS, 1999-2010 (MILLION MWH)

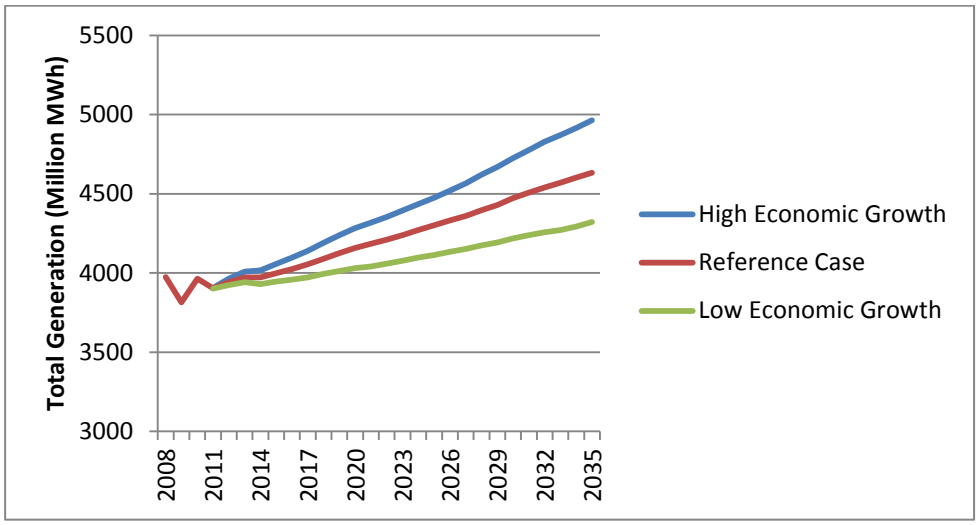


Source: EIA, 2010.

PROJECTED FUTURE GENERATION

Each year, the EIA's Annual Energy Outlook (AEO) projects energy production and consumption for the next 25 years, providing forecasts linked to alternative economic growth scenarios. In the 2011 AEO, the EIA projected that electric power generation will increase steadily between 2011 and 2035, ranging from a 10.7 percent increase in its "low economic growth" scenario to a 27.2 percent increase in its "high economic growth" scenario. To meet increased demand for electricity in the future, the EIA expects that increased generation will come primarily from increased utilization of existing capacity at coal-fired plants, as well as increased reliance on plants powered by natural gas or renewable sources (EIA, 2011). Exhibit 8-7 presents the 2011 AEO's high economic growth, reference case, and low economic growth projections of total electric power generation through 2035.

EXHIBIT 8-7. PROJECTED ELECTRIC POWER GENERATION THROUGH 2035 (MILLION MWH)



Source: EIA, 2011.

WATER USE

As noted in Chapter 3, thermoelectric power generation is the largest off-stream water user, accounting for approximately 49 percent of all water withdrawals, though a much smaller share of total water consumption. In addition, hydropower is a significant user of in-stream water, particularly in the western U.S. The discussion below provides a more detailed review of how water is used in the generation of electricity.

WATER USE IN COOLING FOR THERMOELECTRIC POWER GENERATION

In all thermoelectric power plants, heat sources are used to generate steam, which turns a turbine to generate electricity. Cooling is then required to condense the steam back into boiler feed water before it can be used again; most plants have "wet cooling" systems, which use water as a cooling agent, though a small number of plants use "dry cooling" systems, which do not.

Although thermoelectric cooling is the largest user of water, the vast majority of water used in this way is not consumed, but is instead returned to its source or retained for future use. Although the USGS study of water use in 2005 did not track water consumption, the 1995 edition of the study found that only 2.5 percent of fresh water withdrawn for thermoelectric cooling was consumed (Solley et al., 1998). Total water consumption by thermoelectric cooling was just 3.3 percent of total water consumption in 1995 (see Exhibit 8-8), representing a much smaller share than the water consumed in the domestic, industrial, and agricultural sectors. More recently, the DOE's National Energy Technology Laboratory (NETL) estimated water withdrawal and consumption factors for several types of thermoelectric power plants and found that consumptive water use in this sector totaled 3,600 MGD in 2005 (NETL, 2009a), which again was about 2.5 percent of total water withdrawals for thermoelectric cooling in that year (USGS, 2009).

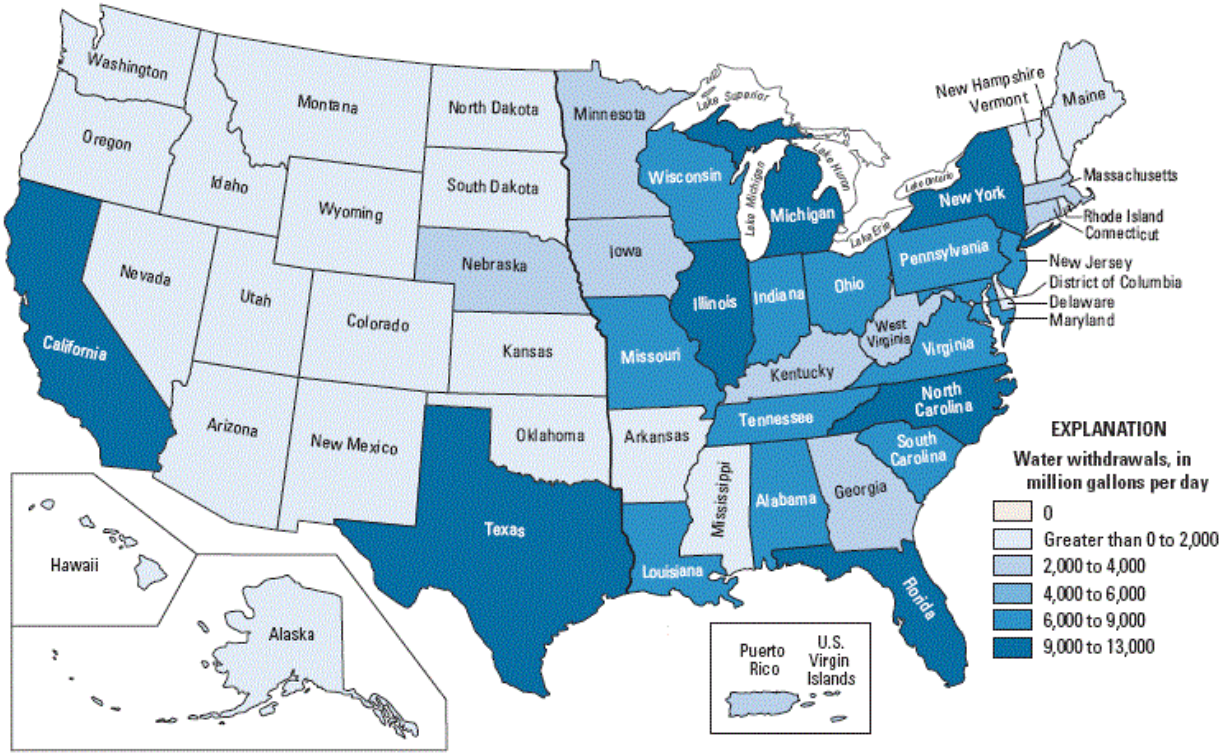
EXHIBIT 8-8. THERMOELECTRIC WATER WITHDRAWALS AND CONSUMPTION, 1995

WATER USE	TOTAL WITHDRAWALS (MGD)		CONSUMPTIVE FRESHWATER (MGD)
	SALINE	FRESH	
Thermoelectric Power	57,900	132,000	3,310
Total	60,800	341,000	100,000
Source: Solley et al., 1998.			

Geographic Distribution of Water Use

Just as thermoelectric power generation varies by state, so does the use of water for thermoelectric cooling. Exhibit 8-9 maps total water withdrawals for thermoelectric cooling in 2005, while Exhibit 8-10 presents a more detailed breakdown of thermoelectric water withdrawals by state, showing the distribution of water withdrawals by water type (fresh vs. saline) and source type (groundwater vs. surface water).

EXHIBIT 8-9. GEOGRAPHIC DISTRIBUTION OF WATER WITHDRAWALS FOR THERMOELECTRIC POWER, 2005



Source: USGS, 2009.

EXHIBIT 8-10. WATER WITHDRAWALS FOR THERMOELECTRIC POWER GENERATION BY WATER SOURCE AND STATE, 2005

STATE	TOTAL WATER WITHDRAWALS (MGD)								
	GROUNDWATER			SURFACE WATER			ALL SOURCES		
	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL
Alabama	0.22	0	0.22	8,270	0	8,270	8,270	0	8,270
Alaska	2.15	0	2.15	31.4	0	31.4	33.6	0	33.6
Arizona	50.5	0	50.5	39.4	0	39.4	89.9	0	89.9
Arkansas	0.93	0	0.93	2,000	0	2,000	2,000	0	2,000
California	9.84	0	9.84	39.7	12,600	12,600	49.6	12,600	12,600
Colorado	6.5	0	6.5	117	0	117	123	0	123
Connecticut	0.08	0	0.08	207	2,870	3,070	207	2,870	3,070
Delaware	0.32	0	0.32	422	383	804	422	383	805
Florida	16.9	3.26	20.2	541	11,500	12,000	558	11,500	12,000
Georgia	3.76	0	3.76	2,680	36.9	2,720	2,680	36.9	2,720
Hawaii	37.8	1,450	1,480	0	0	0	37.8	1,450	1,480
Idaho	1.1	0	1.1	0	0	0	1.1	0	1.1
Illinois	7.2	0	7.2	12,300	0	12,300	12,400	0	12,400
Indiana	12.6	0	12.6	6,040	0	6,040	6,050	0	6,050
Iowa	25.5	0	25.5	2,510	0	2,510	2,530	0	2,530
Kansas	13.4	0	13.4	445	0	445	459	0	459
Kentucky	5.14	0	5.14	3,420	0	3,420	3,430	0	3,430
Louisiana	97.4	0	97.4	6,180	0	6,180	6,280	0	6,280
Maine	0.53	0	0.53	99	121	220	99.5	121	221
Maryland	1.77	0	1.77	436	5,950	6,390	438	5,950	6,390
Massachusetts	0	0	0	107	2,340	2,440	107	2,340	2,440
Michigan	4.07	0	4.07	9,140	0	9,140	9,150	0	9,150
Minnesota	2.41	0	2.41	2,440	0	2,440	2,450	0	2,450
Mississippi	37.3	0	37.3	317	82.6	400	355	82.6	437
Missouri	21	0	21	6,160	0	6,160	6,180	0	6,180
Montana	0.25	0	0.25	89.6	0	89.6	89.9	0	89.9
Nebraska	7.86	0	7.86	3,540	0	3,540	3,550	0	3,550
Nevada	15.9	0	15.9	21	0	21	36.8	0	36.8
New Hampshire	0.99	0	0.99	228	885	1,110	229	885	1,110
New Jersey	1.59	0.01	1.6	662	5,460	6,120	663	5,460	6,120
New Mexico	10.4	0	10.4	45.5	0	45.5	55.9	0	55.9
New York	0	0	0	7,140	4,880	12,000	7,140	4,880	12,000
North Carolina	0.14	0	0.14	8,340	1,550	9,890	8,350	1,550	9,890
North Dakota	0	0	0	1,060	0	1,060	1,060	0	1,060
Ohio	22.5	0	22.5	8,910	0	8,910	8,930	0	8,930
Oklahoma	1.25	0	1.25	163	0	163	164	0	164
Oregon	0.88	0	0.88	7.57	0	7.57	8.45	0	8.45
Pennsylvania	4.39	0	4.39	6,420	0.75	6,420	6,430	0.75	6,430
Rhode Island	0	0	0	1.44	264	266	1.44	264	266

STATE	TOTAL WATER WITHDRAWALS (MGD)								
	GROUNDWATER			SURFACE WATER			ALL SOURCES		
	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL	FRESH	SALINE	TOTAL
South Carolina	5.58	0	5.58	6,530	0	6,530	6,540	0	6,540
South Dakota	0.72	0	0.72	3.97	0	3.97	4.69	0	4.69
Tennessee	0	0	0	8,940	0	8,940	8,940	0	8,940
Texas	55.8	0	55.8	9,620	1,860	11,500	9,680	1,860	11,500
Utah	13.4	4.18	17.6	44.6	0	44.6	58	4.18	62.2
Vermont	0.26	0	0.26	421	0	421	421	0	421
Virginia	3.07	0	3.07	4,910	3,510	8,420	4,920	3,510	8,420
Washington	0	0	0	456	0	456	456	0	456
West Virginia	0.2	0	0.2	3,550	0	3,550	3,550	0	3,550
Wisconsin	3.37	0	3.37	6,890	0	6,890	6,900	0	6,900
Wyoming	1.32	0	1.32	221	0	221	223	0	223
Washington, DC	0	0	0	9.7	0	9.7	9.7	0	9.7
Puerto Rico	1.39	0	1.39	1.42	2,290	2,290	2.81	2,290	2,290
U.S. Virgin Islands	0	0	0	0.18	129	129	0.18	129	129
Total	510	1,450	1,960	142,000	56,700	199,000	143,000	58,100	201,000
Source: USGS, 2009.									

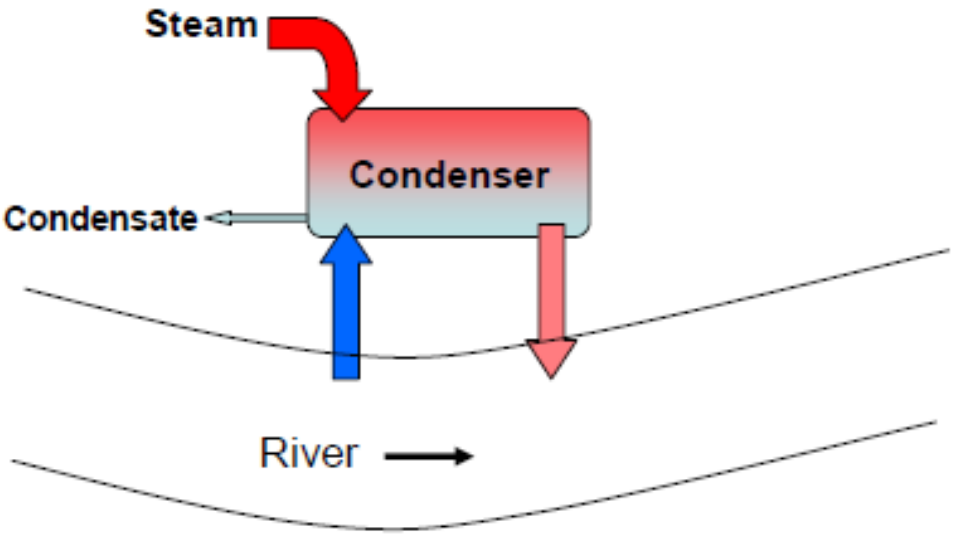
Unsurprisingly, the states generating the largest amount of electricity from thermoelectric power plants—California, Florida, Illinois, New York, and Texas—are the largest users of water for thermoelectric cooling. However, as Exhibit 8-10 indicates, several coastal states, including California, Florida, Maryland, and New Jersey, use saline water for the majority of their thermoelectric cooling needs. Looking just at freshwater withdrawals, Illinois and Texas remain among the largest users, joined by Michigan, Tennessee, and Ohio.

Types of Cooling Systems

Thermoelectric power plants use two types of wet cooling systems: once-through cooling and recirculating, or closed-cycle cooling. In once-through cooling, water is withdrawn from a water body, passed through heat exchangers (also called condensers) to cool the boiler steam used to power the generator, and then returned to a water body, usually at a temperature about 10-20 degrees higher than the receiving water. In recirculating cooling, water is withdrawn from a water body, passed through heat exchangers, cooled using ponds or towers, and then recirculated within the system. A small number of thermoelectric plants in the U.S. use dry cooling systems, in which an air-cooled condenser uses ambient air to dissipate steam heat without the use of water.

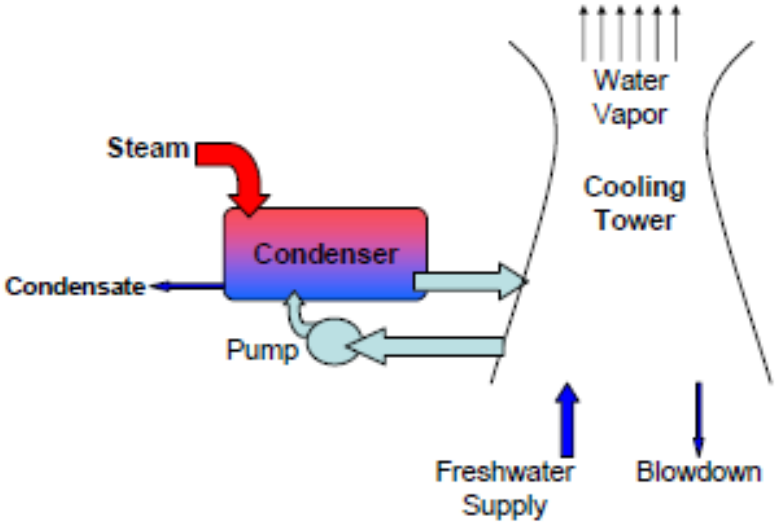
Exhibits 8-11 and 8-12 illustrate the two types of wet cooling systems used in thermoelectric power plants.

EXHIBIT 8-11. ONCE-THROUGH COOLING SYSTEM



Source: DOE, 2006.

EXHIBIT 8-12. RECIRCULATING COOLING SYSTEM



Source: DOE, 2006.

Although once-through cooling systems originally predominated, most power plants constructed since the passage of the Clean Water Act in 1972 have been built using recirculating or dry cooling systems. Exhibit 8-13 summarizes the distribution of cooling systems by generation type.

EXHIBIT 8-13. DISTRIBUTION OF COOLING SYSTEMS BY GENERATION TYPE, 2005

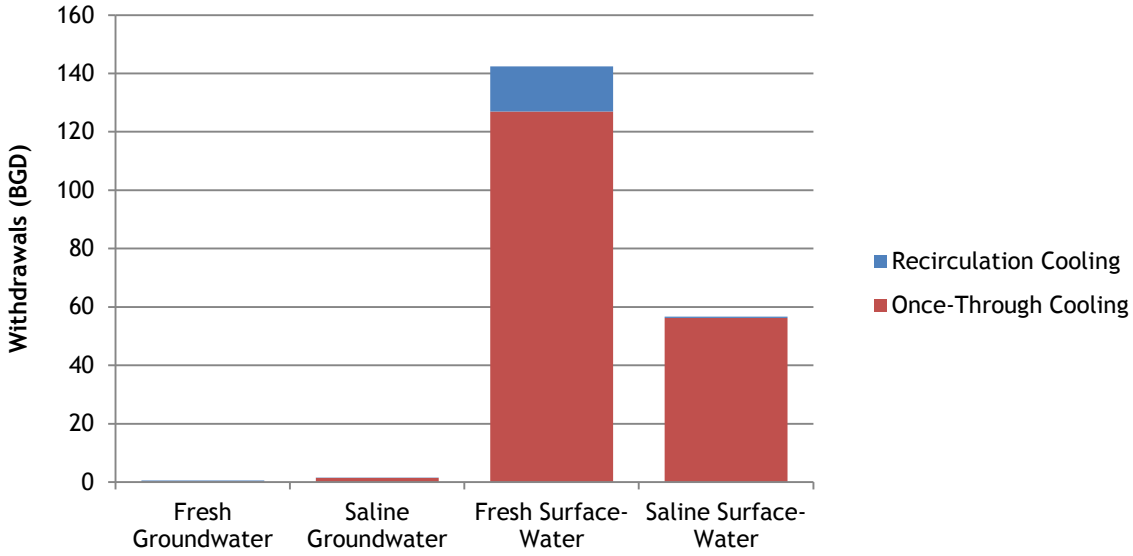
GENERATION TYPE	COOLING SYSTEM			
	ONCE-THROUGH	WET RECIRCULATING (TOWERS)	WET RECIRCULATING (PONDS)	DRY
Coal	39.1%	48.0%	12.7%	0.2%
Fossil Non-Coal	59.2%	23.8%	17.1%	0.0%
Combined Cycle	8.6%	30.8%	1.7%	59.0%
Nuclear	38.1%	43.6%	18.3%	0.0%
Total	42.7%	41.9%	14.5%	0.9%

Source: NETL, 2009a.

Note: Data for combined cycle plants is limited to only 7 percent of total plants in operation. Because of the small sample size, the percentage of combined cycle plants using dry cooling systems may be overestimated.

The two cooling systems have different implications for water withdrawals and consumption. Once-through systems require high water withdrawals, though only a very small fraction of total withdrawals are consumed. Because water is recycled after cooling, total water withdrawals for recirculating cooling systems are much lower than for once-through systems. However, the process of using ponds or towers to cool the water involves high rates of evaporative losses. Exhibit 8-14 shows the use of water in thermoelectric cooling by source and by cooling method.

EXHIBIT 8-14. WITHDRAWALS OF WATER FOR THERMOELECTRIC COOLING BY SOURCE AND COOLING METHOD, 2005



Source: USGS, 2009.

Water Use per Unit of Electricity Produced

The cooling system used by a thermoelectric power plant affects the rate of water use per unit of electricity generated. A 2007 study by the American Water Resources Association found that once-through cooling systems withdrew about 570 gallons per kWh, but consumed less than one gallon per kWh, while recirculating cooling systems withdrew less than 20 gallons and consumed about 7-10 gallons per kWh generated (Yang and Dziegielewski, 2007). The authors of the study also found that rates of both water withdrawal and water consumption varied widely among plants that use similar cooling systems, suggesting that water use is also affected by factors like fuel type, water source, operational conditions, and cooling system efficiency.

A report prepared by the Congressional Research Service on the water demands of domestic energy production collected estimates of the amount of water consumed per unit of electricity produced at different types of thermoelectric power plants. The estimates include both water consumed for cooling and water consumed in other plant processes, such as equipment washing, emission treatment, and human use. These estimates, which all assume the use of recirculating cooling systems, are presented in Exhibit 8-15.

EXHIBIT 8-15. UNIT CONSUMPTION OF WATER FOR ELECTRICITY GENERATION BY POWER SOURCE

POWER SOURCE	EVAPORATIVE COOLING WATER AT POWER PLANT (GAL/MWH)	OTHER WATER USED FOR POWER PLANT OPERATIONS (GAL/MWH)	TOTAL WATER USED (GAL/MWH)
Coal	243-449	53-68	296-517
Natural Gas	192	0	192
Nuclear	720	30	750
Biomass/Waste	300-480	30	330-510
Geothermal	0	175-585	175-585
Concentrating Solar Power	750-920	80-90	840-920
Source: Carter, 2010.			

Of the three main thermoelectric power sources, natural gas-fired plants appear to be much more efficient in their use of water than coal-fired and nuclear plants, though some of that difference may be due to the fact that natural gas-fired plants are, on average, newer than coal-fired plants and may use more efficient wet cooling systems.

Future Use

Although electric power generation is projected to increase steadily over the next few decades, it is less clear whether water withdrawals and consumption for thermoelectric cooling will experience similar growth. As noted in Chapter 3, water withdrawals for thermoelectric power generation peaked in 1980 and declined by 11 percent afterwards, though they have gradually increased since 1985. As new thermoelectric plants increasingly rely on recirculating cooling systems and older plants are retired, future water withdrawals for thermoelectric cooling may actually decrease, though water consumption in the sector would increase.

A 2009 NETL study of thermoelectric water use trends assumes that all new thermoelectric generating capacity will use recirculating cooling. Based on this assumption, the analysis projects that water withdrawals for thermoelectric power will decrease by about 4.4 percent between 2005 and 2030 (from 146,300 to 139,900 MGD), while water consumption in the sector will increase by about 22.2 percent (from 3,600 to 4,400 MGD) (NETL, 2009a).

HYDROPOWER

It is difficult to quantify the amount of water used for hydroelectric power generation, since this process generally does not require water to be withdrawn from its source. Nonetheless, the production of hydropower often requires disruption of river flow regimes, which can affect the availability of water for other uses. This section briefly discusses available estimates of the use of water for hydropower generation, including expected changes in future use.

Overview of Water Use

The USGS study of water use in 2005 did not estimate the use of water for hydroelectric power. USGS last provided this figure in its report on water use in 1995; at that time, it estimated that a total of 3,160,000 MGD was used in the generation of hydroelectric power. This number, which exceeds the average annual runoff in the U.S. by a factor of 2.6, is misleading because it over-counts water that is used several times as it passes through multiple hydroelectric dams on a single river (Solley et al., 1998). The USGS study of water use in 1995 also reported that 90,000 MGD was used for off-stream hydroelectric power generation (i.e., hydropower relying on diversions of water away from primary river channels), which would represent more than 25 percent of total water withdrawals from all other sources in that year. It is not clear whether that number also over-counts the total amount of water withdrawn for hydroelectric use.

Although water is not consumed in the generation of hydroelectric power, the reservoirs created for storage and pumped-storage facilities can lead to water loss in the affected water bodies through increased evaporation rates. A study by DOE's National Renewable Energy Laboratory examined the 120 largest hydroelectric facilities in the U.S. and concluded that the reservoirs created for those dams evaporated 9,063 MGD more than would be evaporated from free-running rivers. Evaporation rates varied significantly across facilities. Overall, however, evaporative losses averaged 18,000 gal/kWh. This rate of water consumption is several orders of magnitude greater than the rates for thermoelectric power plants reported in Exhibit 8-15 (Torcellini et al., 2003). It would be inappropriate, however, to ascribe the full amount of water lost to evaporation at reservoirs to hydropower generation, since these reservoirs frequently serve multiple purposes, including recreation, flood control, and providing a reliable water supply for agricultural and domestic uses.

Future Use

The 2011 AEO anticipates that hydropower generation will increase at the same rate as total electric power generation, implying the need to develop between 1,600 and 3,000 MW of additional hydropower capacity by 2035 (EIA, 2011). The construction of new large dams would create new reservoirs, which could reduce the amount of fresh water available for downstream use. It may be possible, however, to increase the generation of hydroelectricity through improved efficiency or expansion of power plants at existing dams. The Bureau of Reclamation, which currently generates about 40 million MWh at its hydropower facilities, reviewed 530 sites currently under its jurisdiction to evaluate their potential for additional hydropower development. The study found that 191 sites could be developed with a total potential capacity of 268.3 MW, though not all sites were economically viable to develop (U.S. Bureau of Reclamation, 2011). In addition, a 2007 study by the Electric Power Research Institute (EPRI) estimated that 10,000 MW of additional hydropower capacity could be developed by 2025 without construction of any new dams (EPRI, 2007a). Nonetheless, development of new hydropower capacity has slowed in recent years, due to rising awareness of the harmful impacts of large dams and reservoirs on fish and wildlife, Native American communities, and competing uses of in-

stream water. It is possible, therefore, that the predicted growth in hydropower capacity will not take place.

WATER RESOURCE CONSTRAINTS

WATER SUPPLY CONSTRAINTS

Because once-through cooling systems require large quantities of water, thermoelectric power plants using such systems are particularly vulnerable to drought conditions and other water shortages. In recent years, water shortages have curtailed power generation at a number of facilities. For example:

- In 1999, drought in the Susquehanna River basin in New York and Pennsylvania prevented power plants in the region from obtaining sufficient water supplies to meet operational needs (GAO, 2003).
- In 2006, drought along the Mississippi River caused power plants in Illinois and Minnesota to restrict operations (NETL, 2009b).
- In 2007, drought in the southeastern U.S. caused several nuclear power plants to reduce output by up to 50 percent, due to low river levels (NETL, 2009b).

The move away from once-through cooling systems has somewhat mitigated this vulnerability, but a substantial portion of the country's electricity generating capacity still relies on regular access to large quantities of water.

In recognition of this challenge, EPRI launched a 10-year research plan in 2007 aimed at helping the U.S. electricity industry adapt to current and future water supply constraints (EPRI, 2007b). The proposed areas of research include improving dry cooling technology, reducing water loss from cooling towers, using impaired water, and developing decision support tools to anticipate and respond to water shortages and climate change. Dry cooling systems, or hybrid dry-wet cooling systems, could drastically reduce water withdrawals and consumption, but they currently have much higher costs than wet cooling systems and can negatively affect plant operating efficiency. Reduced operating efficiency in turn leads to higher fuel consumption per unit of electricity produced, with associated environmental consequences of fossil fuel extraction and combustion. Use of impaired water for thermoelectric cooling—effluent from wastewater treatment plants or low-quality groundwater, for example—could also reduce the sector's use of freshwater, but such water might require pretreatment in order to prevent damage to cooling equipment (Carter, 2010). Future research into both dry cooling and use of impaired water could help reduce the dependence of the electric power generation sector on reliable access to large quantities of water.

WATER QUALITY CONSTRAINTS

Thermoelectric cooling generally does not have high water quality requirements, as demonstrated by the fact that about 30 percent of total water withdrawals for thermoelectric power generation in 2005 involved saline water. Water discharged from thermoelectric plants with once-through cooling systems, however, can have a detrimental impact on the quality of the receiving water. In addition to the temperature

difference between discharged cooling water and receiving water (which can disrupt aquatic habitats), chemicals used to protect cooling equipment can also affect downstream water quality and use (Carter, 2010).

Section 316 of the Clean Water Act (CWA) gives EPA the authority to regulate the use of water for industrial cooling, with Section 316(a) regulating the temperature of discharged water and Section 316(b) regulating cooling water intake structures. These regulations have played a large role in driving the shift from once-through cooling systems to recirculating cooling systems. New plants are already required to install recirculating cooling systems, and EPA is currently developing regulations to update requirements for existing plants with once-through systems.

As noted in the previous section, the use of impaired water for cooling could ease water quantity constraints but impose new water quality constraints. Without adequate pretreatment, impaired water could lead to scaling, corrosion, and fouling of cooling equipment (Carter, 2010).

INTERACTION WITH OTHER USES OF WATER

As a major off-stream user of water, the thermoelectric power generation sector competes for water with several other sectors, particularly agriculture and domestic supply. In Western states, prior appropriation water rights laws give precedence to those that first obtained legal right to use the water, which typically include agricultural and municipal users. Under drought conditions, users that obtained legal rights to use water at a later date – typically including thermoelectric power generators – are the first to suffer restrictions in water supply (NETL, 2009b). In contrast, the development of hydroelectric power has often served as a complement to other water use sectors, as large reservoirs created by dams are often used to provide water for domestic and agricultural users, in addition to serving as a setting for recreational activities such as boating, swimming, and fishing. As noted previously, however, these facilities can also have negative impacts on wildlife, such as salmon populations in the Pacific Northwest. Regulatory constraints have prevented development of hydropower in some areas, and allowing for fish passage through large dams can significantly increase operating costs (U.S. Bureau of Reclamation, 2011).

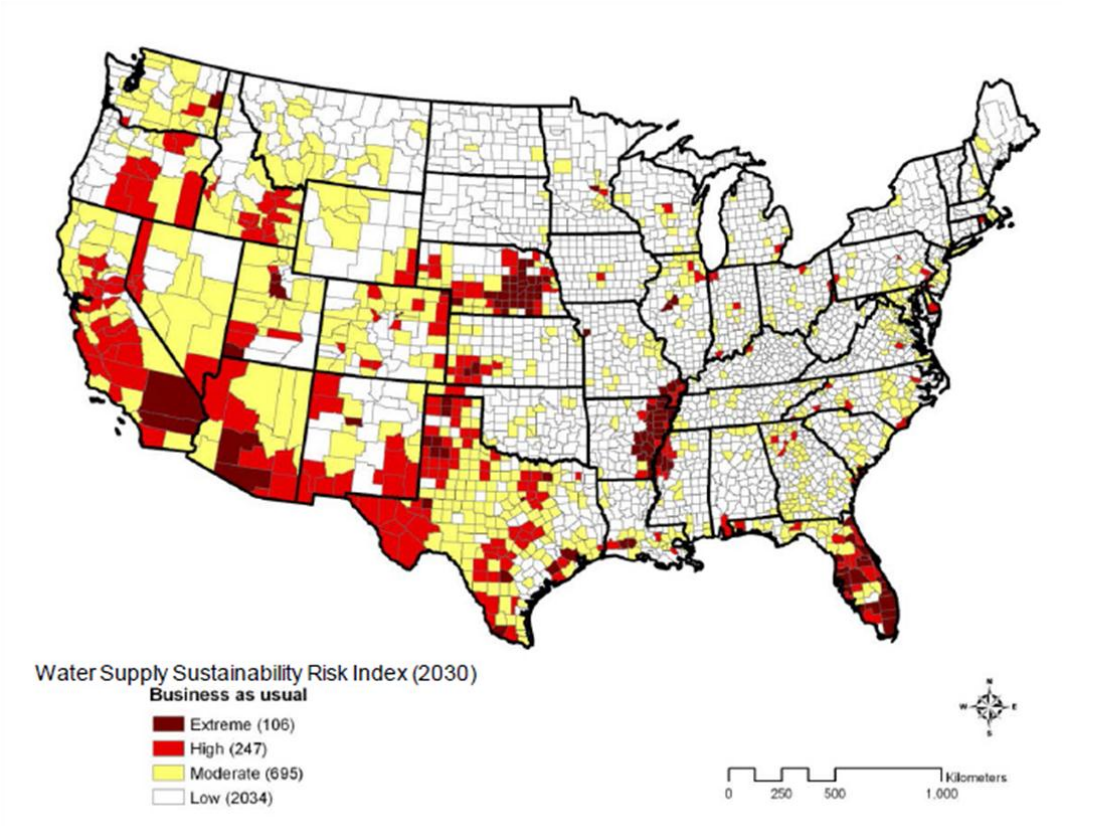
FUTURE CONSIDERATIONS

The factors that in the future are likely to have the greatest effect on the use of water in the electric power generation sector are projected limitations on the availability of water, the potential impacts of climate change on both power demand and water supply, and changing water demands due to increased reliance on renewable energy sources.

A 2011 EPRI study attempted to identify the regions of the U.S. most likely to face future constraints on thermoelectric power generation as a result of constraints on water supplies (EPRI, 2011). The authors first projected water use through 2030 and developed a water sustainability risk index that evaluated water supply constraints according to several dimensions, including the extent of development of available renewable water and

groundwater, susceptibility to drought, expected growth in water demand, and the likelihood of increased need for storage (to ensure water availability during seasonal dry periods). This index, which rates counties' water supply sustainability risk from "low" to "extreme," is mapped in Exhibit 8-16.

EXHIBIT 8-16. WATER SUPPLY SUSTAINABILITY RISK INDEX, 2030 PROJECTIONS



Source: EPRI, 2011.

The study found that about 250,000 MW of thermoelectric generation capacity, or 22 percent of total generating capacity in 2010, is located in counties with either high or extreme levels of water supply sustainability risk.

Climate change, and responses to climate change, could affect the relationship between water and electric power generation in several ways. First, the increased frequency of floods and droughts predicted by many climate models could significantly compromise the reliability of water access for both thermoelectric cooling and hydropower. Increased temperatures could also increase demand for electricity (e.g., for air conditioning during summer months). Second, regulations to reduce greenhouse gas emissions through carbon capture and storage could potentially increase demand for water in electricity generation. Carbon capture and storage increases water demands at fossil fuel-burning power plants, because operating carbon capture equipment requires both energy (thereby

reducing a plant's generating efficiency) and additional cooling. A 2009 NETL study estimated that installing carbon capture systems at fossil fuel-burning plants could, by 2030, increase water withdrawals by between 1,300 and 3,700 MGD, and water consumption by between 900 and 2,300 MGD (NETL, 2009a). Finally, increased development of electric power generation from renewable sources could affect future water demand in this sector. Although sources like wind and photovoltaic solar have no cooling requirements, other sources like biomass, geothermal, and concentrating solar power (CSP) all involve thermoelectric generation and therefore require cooling. In particular, CSP facilities, which are often located in dry, arid regions to maximize exposure to solar energy, may face significant water constraints (Carter, 2010).

Federal and state regulation could help mitigate the effects of future water constraints on electric power generation. A study by the Government Accountability Office (GAO) found that states' regulatory authority over water use by thermoelectric plants varied widely (GAO, 2009). California and Arizona, for example, have actively worked to minimize the use of fresh water in thermoelectric power generation, while other states have no official policies or permitting requirements for power plant water use.

VALUE OF WATER USE

The discussion that follows describes the challenges and difficulties of determining the value of water in generating thermoelectric or hydroelectric power. It then presents available estimates of the value of water in these uses.

CHALLENGES TO ESTIMATING THE VALUE OF WATER

In addition to the difficulties in estimating the value of water discussed in Chapter 2, valuing the water used in electric power generation faces several additional challenges:

1. Electricity prices are subject to government regulation and may not in all cases fully reflect the long-run marginal cost of supply.[28] Attempts to derive the value of the marginal product of water from the price of electricity will reflect any distortions introduced by government policy.
2. Because of the constantly changing nature of electricity demand (i.e., the difference between peak load demand and base load demand), the value of electricity can change depending on the season or time of day. As a result, the marginal value of water in this sector also varies, depending on whether it is used in the production of electricity to meet peak or base load demand.
3. Much of the water used in electric power generation is "non-rivalrous" (i.e., the use of the resource does not diminish its availability to others), since water used in hydropower generation and thermoelectric generation with once-through cooling can be withdrawn again by downstream users. In this regard, the use of

[28] See Chapter 2 for a discussion of how failure to recognize long-run marginal costs can distort pricing and lead to inefficient consumption of resources.

water for electric power generation has some characteristics of public goods, which are also difficult to value using market mechanisms (Young, 2005).

4. Where multiple hydroelectric dams are located on the same river, the value of water varies widely according to its location, since the electricity generation potential of a given unit of water depends on its "developed head," or the height of a retained body of water. For example, the cumulative developed head of water at the mouth of the Snake River in the Pacific Northwest is more than 36 times the developed head of water at the last dam along the Columbia River (Frederick et al., 1996).

Despite these difficulties, it is possible to estimate the value of water to a given electricity generating facility by using the "shadow price" of electricity, or the cost of obtaining the same amount of electric power from a different facility. Once the value of the electricity produced by a facility is estimated, the marginal value of water used to generate that electricity can be derived by comparing the total cost per kWh at that facility to the cost per kWh generated from the next-cheapest source of electricity (that does not use water). All else equal, the difference between the cost of electricity generation with water and electricity generation without water can be interpreted as the marginal value of water used in electric power generation. In practice, however, ensuring that "all else is equal" is nearly impossible.

ESTIMATES OF THE VALUE OF WATER IN THE ELECTRIC POWER SECTOR

Despite the challenges discussed above, several attempts have been made to estimate the marginal value of water used in hydropower generation and thermoelectric cooling.

- A 1996 study by Kenneth Frederick and others at Resources for the Future collected 57 water valuation estimates for the production of hydropower and six estimates for the production of thermoelectric power. The hydropower value estimates come from four water resource regions − Tennessee, the Upper Colorado, the Lower Colorado, and the Pacific Northwest − and reflect the average values of the cumulative upstream generating capability at each dam along a particular river.
- A 2005 report by the American Water Works Association (AWWA) also discussed estimates of the value of water used for hydropower on the Colorado River.
- A 2004 study by Thomas Brown at the U.S. Forest Service estimated the value of water used for hydropower generation on two stretches of the Colorado River by comparing hydropower costs to the costs of peaking power from thermoelectric plants.
- A 2011 analysis by Stacy Tellinghuisen at Western Resource Advocates estimated the value of water used in thermoelectric cooling by assuming that the only alternative to using water for this purpose would be the use of a more expensive dry cooling system. On an economy-wide scale, this assumption is not

valid, since the electricity that would be generated at a wet-cooling thermoelectric plant could always be replaced by increased electricity generation from a different source. From the perspective of a private developer, however, it may be valid to assume that the only alternative to using water for thermoelectric cooling is to install and operate a dry cooling system. This estimate can therefore be interpreted to represent the value of water for thermoelectric cooling to the developer or owner/operator of a particular plant.

These estimates are summarized in Exhibit 8-17. Where available, averages are presented together with ranges of estimates.

EXHIBIT 8-17. ESTIMATES OF THE VALUE OF WATER USED IN ELECTRIC POWER GENERATION

GENERATION TYPE	REGION	SOURCE	NUMBER OF VALUES	VALUE OF WATER ($/AF, 2010)	
				AVERAGE	RANGE
Hydropower	Tennessee	Frederick et al., 1996	9	$10	$1-$18
Hydropower	Upper Colorado	Frederick et al., 1996	13	$29	$6-$56
Hydropower	Lower Colorado	Frederick et al., 1996	2	$49	$35-$64
Hydropower	Pacific Northwest	Frederick et al., 1996	33	$43	$3-$157
Hydropower	Colorado	Powell Consortium, 1995 (cited in AWWA, 2005)	7	NA	$6-$83
Hydropower	Colorado	AWWA, 2005	1	$185[1]	NA
Hydropower	Colorado	Brown, 2004	7	$39	$9-$61
Hydropower	Upper Colorado	Brown, 2004	6	$31	$2-$50
Thermoelectric	Upper Colorado	Frederick et al., 1996	3	$76	$56-$87
Thermoelectric	None specified	Frederick et al., 1996	3	$17	$12-$25
Thermoelectric	Southwest	Tellinghuisen, 2011	1	$1,292[2]	NA

Notes:
1. Value estimate ascribes all electricity revenues to water, ignoring other inputs, and therefore should be considered an upper bound.
2. Value estimates the value of water for thermoelectric cooling assuming that the only alternative is dry cooling.

The values the exhibit presents are relatively low in comparison to available estimates of the marginal value of water in several other sectors. One possible explanation for this is the interconnected nature of the electric power grid, which makes it possible to substitute power from sources with only marginally higher costs when production from a single plant is interrupted. These costs might be significantly higher, however, if a shortage of water were to curtail power production at a large number of facilities within a region, raising the risk of power outages and interruption of activity elsewhere in the economy. For example, a recent report by the Texas Comptroller of Public Accounts noted that continuation of the 2011 drought might affect the price and availability of electrical power in Texas. The Electric Reliability Council of Texas (ERCOT) warned that another hot, dry summer could push the state's power reserves below its minimum target. More than 11,000 megawatts of Texas power generation – about 16 percent of ERCOT's total

power resources – rely on cooling water from sources that by late 2011 were at historically low levels. If the drought had continued into May of 2012, more than 3,000 megawatts of this capacity might have been unavailable due to a lack of cooling water (Combs, 2012).

SUMMARY Electric power generation plays a vital role in supporting the U.S. economy, and virtually the entire sector depends in large part on reliable access to large quantities of water, either as a coolant for thermoelectric plants or as a source of power for hydroelectric plants. Water withdrawals for thermoelectric power generation exceed 200,000 MGD, more than any other sector. Although water consumption in this sector is relatively small, future shifts away from once-through cooling to recirculating cooling systems could increase the amount of water consumed in thermoelectric cooling. Further research into alternative cooling methods, such as dry cooling systems or use of impaired water, will be needed in order to ensure that increased demand for electricity can be met without increasing the sector's vulnerability to water supply constraints.

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CHAPTER 9 | COMMERCIAL FISHING (IN-STREAM USE)

INTRODUCTION

Commercial fishing is the last major component of the global food system that involves the capture and harvest of animals from their natural environment. As such, commercial fisheries are uniquely dependent upon water resources. While many economic sectors use water as an input, the very existence of commercial fisheries depends upon a complex web of ecological interactions in the aquatic environment. Maintenance of this environment through management of water quality and other variables is fundamental to the sustainability of wild capture fisheries. This chapter describes the relationship between water and commercial fisheries, addressing the following topics:

- The economic importance of the commercial fishing sector, including landings, revenue, employment, and links to other parts of the economy; and
- The way in which management of fishing effort and management of water quality combine to ensure the long-term sustainability of key commercial species.

OVERVIEW OF KEY FINDINGS

- The productivity and long-run sustainability of the commercial fishing industry depends in part upon appropriate management of aquatic ecosystems, as well as management of fisheries to maintain fish and shellfish stocks.
- In 2010, the U.S. commercial fishing industry reported total landings of fish and shellfish of approximately 8.2 billion pounds, with an ex-vessel value of $4.5 billion. The industry, which ranks third in landings worldwide, supports a range of secondary and tertiary industries, including seafood wholesalers, processors, and retailers. Together, these industries accounted for the export of over $22 billion in fish products during 2010.
- While ex-vessel revenues in recent years have risen, physical landings of key species have diminished, with some fisheries virtually lost due to overfishing. In addition, recent research suggests that fish habitat along much of the U.S. coast is significantly degraded, a factor that may further diminish fish stocks.
- The effect that changes in water quality or fish habitat may have on the health or abundance of commercially important fish and shellfish stocks is difficult to predict, as is the subsequent impact on the commercial fishing industry. These impacts are likely to vary significantly from case to case. To the extent possible, however, it is important for water resource managers to take these relationships into account, ensuring that their decisions appropriately recognize the effect that any change in aquatic habitat may have on the revenues and profits of the industry, as well as the economic value that is ultimately realized from consumption of the commercial catch.

SECTOR OVERVIEW

The commercial fishing industry is part of the primary (extractive) mega-sector described in Chapter 2. Some of its output is sold directly to consumers. Most, however, is sold to seafood processors in the secondary mega-sector or to wholesale and retail establishments in the tertiary mega-sector. According to the Food and Agriculture Organization, annual landings by the U.S. commercial fishing fleet rank third worldwide, behind only China and Peru. There is also a growing international trade in seafood and other fish products. The U.S. is currently the world's second-leading importer of such products, and its fourth-leading exporter (FAO, 2006).

LANDINGS AND EX-VESSEL REVENUES

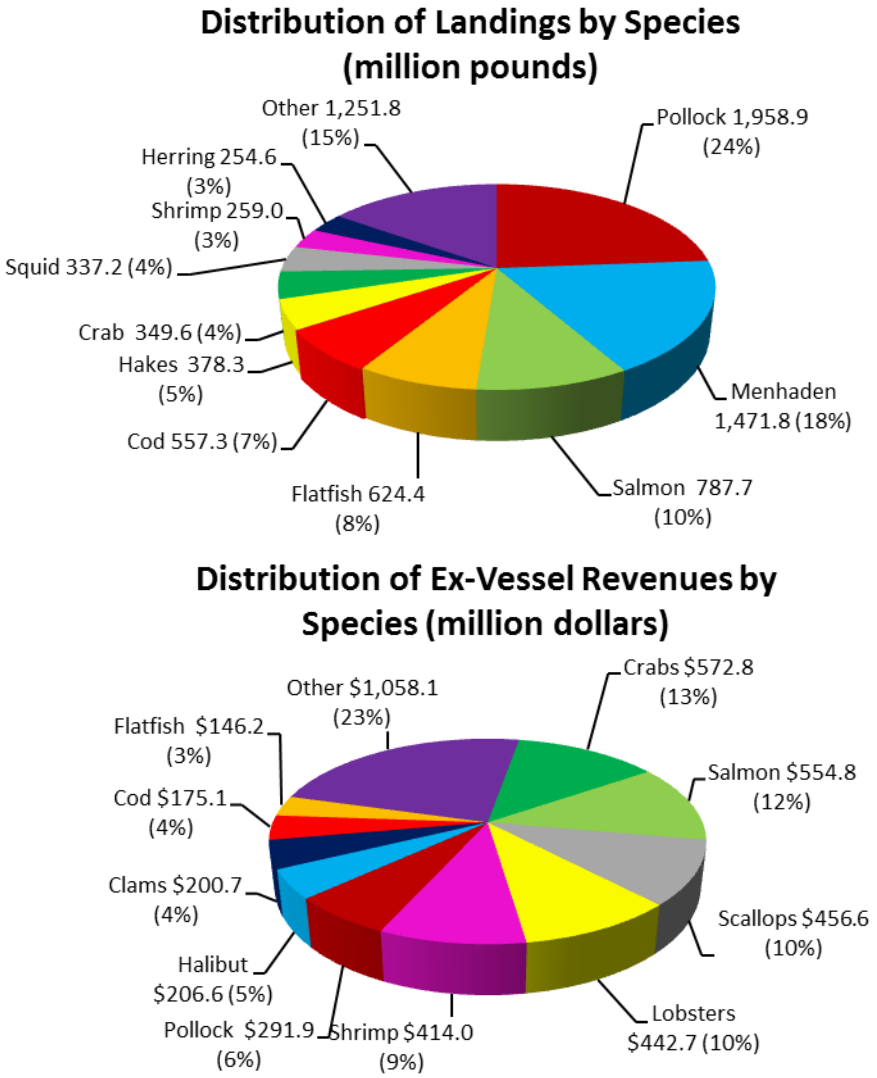
As noted above, the U.S. commercial fishing industry in 2010 reported total domestic landings of approximately 8.2 billion pounds, an ex-vessel value of $4.5 billion. Eighty-five percent of total landings by weight were accounted for by finfish, with Alaskan pollock and menhaden the leading contributors. In contrast, shellfish accounted for only 15 percent of total landings by weight but 52 percent of ex-vessel revenues. Crabs ($572.8 million) were the leading source of revenue, representing approximately 13 percent of the total. Exhibit 9-1 illustrates the distribution of the 2010 catch by species, noting the top 10 species by weight and the top 10 species by value (*FUS*, 2011).

The National Marine Fisheries Service (NMFS) also provides information on the distribution of U.S. catch by region. As Exhibit 9-2 shows, the Alaskan region reported the greatest landings in 2010, accounting for 53 percent of total landings by weight (4.3 billion pounds) and 35 percent of total landings by value ($1.6 billion). The New England region ranked second in revenue, accounting for approximately 21 percent ($954.0 million) of the total (*FUS*, 2011).

As shown in Exhibit 9-3, landings in 2010 were up slightly from 2009, when the industry reported a 20-year low in total catch. Landings remained relatively low in 2010 due to a significant decline in the catch of Alaska pollock. In contrast, ex-vessel revenues in 2010 (in nominal dollars) were the highest reported in over 20 years. The increase in ex-vessel revenues is attributable to higher prices for a number of key species. For instance, in 2007 the U.S. landed roughly 885.0 million pounds of salmon at an ex-vessel value of $381.3 million, an average ex-vessel price of $0.43 per pound. In 2010 salmon landings totaled only 787.7 million pounds but were valued at $554.8 million, an average price of $0.70 per pound. The 63 percent increase in prices netted salmon fishermen a 43 percent increase in ex-vessel revenues (*FUS*, 2011).

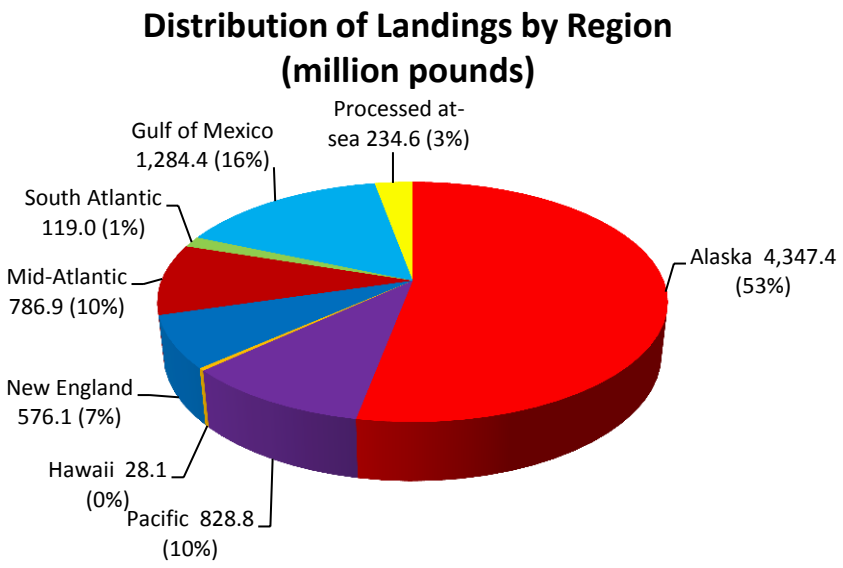
The NMFS data reflect harvests in marine waters (including estuarine waters) and the Great Lakes. The Great Lakes harvest, however, is relatively minor; landings in this region totaled 19.2 million pounds in 2010, with an ex-vessel value of approximately $18.0 million (less than one half of one percent of all ex-vessel revenues). Whitefish and perch account for over 80 percent of ex-vessel revenues in the Great Lakes region (*FUS*, 2011).

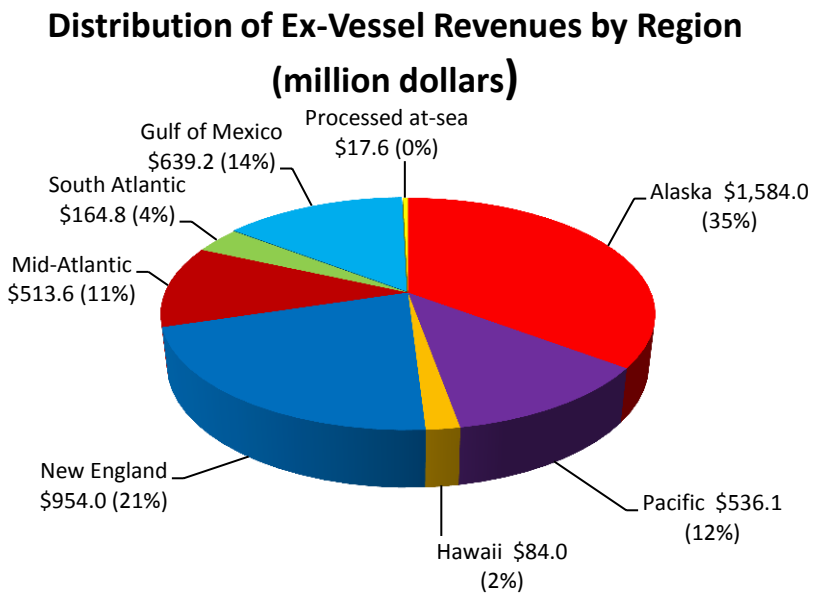
EXHIBIT 9-1. DISTRIBUTION OF 2010 LANDINGS AND EX-VESSEL REVENUES BY SPECIES



Source: NMFS, 2011.

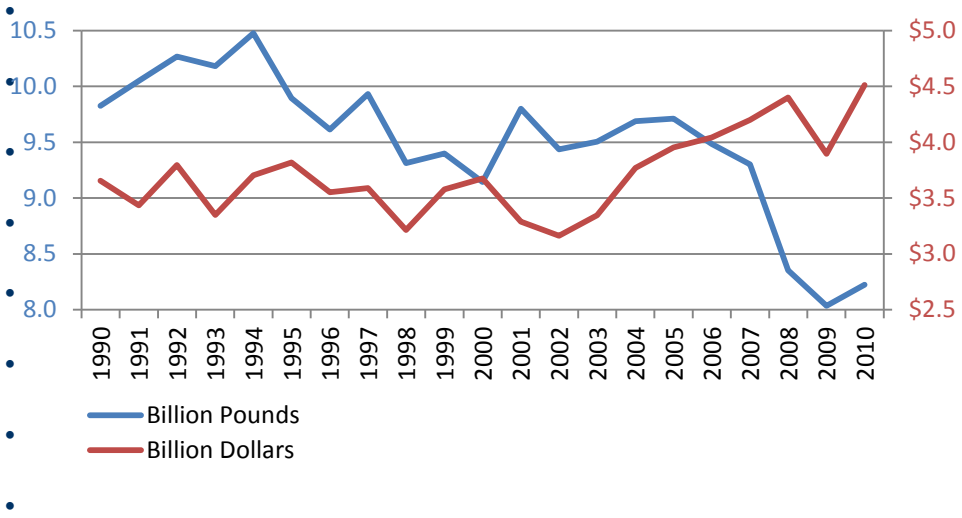
EXHIBIT 9-2. DISTRIBUTION OF 2010 LANDINGS AND EX-VESSEL REVENUES BY REGION





Source: NMFS, 2011.

EXHIBIT 9-3. U.S. LANDINGS AND EX-VESSEL REVENUES, 1990-2010



Source: NMFS, 2011.

Additional commercial harvesting of freshwater species occurs throughout the U.S., but these landings are poorly tracked in most states and represent a minor increment to the landings characterized by NMFS. For example, in many states, individuals harvest minnows and other species for sale to recreational anglers as baitfish. Some states are also home to small but regionally important specialty freshwater fisheries. For instance, freshwater commercial fisheries in Louisiana reported $16.2 million in sales in 2009; sales of crawfish accounted for the vast majority of this total (LSU, 2011).

EMPLOYMENT

Jobs in the commercial fishing industry are often transitory and poorly documented, making it difficult to track employment. As a result, the U.S. Economic Census does not report employment in the commercial fishing industry (NAICS code 1141). The Bureau of Labor Statistics does track employment in the industry; however, its data exclude jobs that are exempt from or not covered by unemployment insurance. To provide a more comprehensive estimate of employment, this report relies on both the BLS data and the U.S. Census Bureau's non-employer data, which tracks the number of commercial fishing firms that have no paid employees or are exempt from unemployment insurance.

According to BLS data, as of 2009 approximately 6,321 people were employed in the finfishing and shellfishing industries. In addition, the U.S. Census Bureau estimates that in 2009 there were 64,531 non-employer commercial fishing firms in the United States; 3,546 of these were listed as corporations, 725 as partnerships, and 60,260 as individual proprietorships. Assuming that each of these firms represents at least one commercial fisherman, employment in the commercial fishing sector in 2009 likely totaled approximately 71,000.

Exhibit 9-4 illustrates the estimated distribution of commercial fishing employment by region and state. At the state level, Alaska boasts the highest employment with 8,305 jobs, the vast majority of which are accounted for by non-employer firms. Regionally, the Gulf states (excluding the west coast of Florida) account for the greatest percentage of jobs in the industry, approximately 17 percent of the national total. If the west coast of Florida were included in that figure it would likely increase significantly, as at the state level Florida is second only to Alaska in the estimated number of jobs in the commercial fishing sector.

LINKS TO OTHER ECONOMIC SECTORS

The nation's commercial fisheries support a number of industries dedicated to the processing or sale of fish and fish products. According to the BLS, in 2010 approximately 36,469 people were employed at 846 establishments engaged in seafood product preparation and packaging (NAICS code 31171). Also linked are seafood wholesalers (NAICS code 42446), which in 2010 employed approximately 22,495 people in 2,344 establishments. Not included in that number are wholesalers of canned or packaged frozen fish, who are counted under a different NAICS code, grouped with other wholesalers of packaged frozen and canned foods.

The commercial fishing harvest is processed into both edible and non-edible products. Edible fish and shellfish are sold fresh, frozen, canned, or cured. Non-edible products are used as bait, animal food, or in an industrial capacity (i.e., manufactured into fish oils, fish meals, fertilizers, etc.). In 2010, approximately 79 percent of all domestic landings, by weight, were put towards human consumption; 93 percent of this total was sold fresh or frozen, six percent was canned, and one percent was cured.

NMFS estimates that revenues from the sale of fishery products by U.S. processors totaled $9.0 billion in 2010. The sale of edible domestic and imported fish products accounted for $8.5 billion of this total. Non-edible domestic and imported fish products generated estimated sales of $508.8 million, with 46 percent of that total accounted for by bait and animal food, 43 percent by fish meals and oils, and 11 percent by "other" products, such as fertilizers, agar-agar, oyster-shell products, kelp products, and animal feeds (*FUS*, 2011).

U.S. COMMERCIAL FISHING AND THE GLOBAL ECONOMY

As of 2006, traditional capture fisheries accounted for 64 percent (92.0 million metric tons) of global fish production (aquaculture accounted for the remaining 36 percent). The U.S. plays a significant role in that production, ranking third globally, behind only China and Peru. Most of the U.S. catch, however, went to domestic use (FAO, 2006). In 2010 the U.S. exported only 1.2 billion pounds of edible fish products, an export value of $4.4 billion.[29]

[29] Note that the import and export values reported here incorporate markups for intermediate wholesalers and shippers, and thus are not directly comparable to the revenue figures provided for the domestic seafood product preparation and packaging industry (NAICS 31171).

EXHIBIT 9-4. 2009 ESTIMATE OF EMPLOYMENT IN COMMERCIAL FISHING BY STATE

STATE	EMPLOYMENT AT EMPLOYER FIRMS (BLS)	NON-EMPLOYER FIRMS (CENSUS BUREAU)	TOTAL ESTIMATED EMPLOYMENT	PERCENT OF TOTAL
New England				
Connecticut	(ND)	366	366	0.52%
Maine	406[1]	5,687	6,093	8.60%
Massachusetts	(ND)	3,220	3,220	4.54%
New Hampshire	(ND)	292	292	0.41%
Rhode Island	60	989	1,049	1.48%
Total	466	10,554	11,020	15.55%
Mid-Atlantic				
Delaware	3[1]	178	181	0.26%
Maryland	52	1,727	1,779	2.51%
New Jersey	223	1,115	1,338	1.89%
New York	42	1,349	1,391	1.96%
Virginia	101	1,669	1,770	2.50%
Total	421	6,038	6,459	9.12%
South Atlantic				
Georgia	12	643	655	0.92%
North Carolina	17	2,697	2,714	3.83%
South Carolina	10	682	692	0.98%
Total	39	4,022	4,061	5.73%
Florida[2]	342	6,320	6,662	9.40%
Gulf				
Alabama	52	1,037	1,089	1.54%
Louisiana	179	5,981	6,160	8.69%
Mississippi	(ND)	897	897	1.27%
Texas	116	3,908	4,024	5.68%
Total	347	11,823	12,170	17.18%
Pacific				
California	505	3,016	3,521	4.97%
Oregon	284	1,936	2,220	3.13%
Washington	1,780	4,22	6,008	8.48%
Total	2,569	9,180	11,749	16.58%
Alaska	72	8,233	8,305	11.72%
Hawaii	146	1,092	1,238	1.75%
Non-coastal States[3]	(ND)	7,269	7,269	10.26%
U.S. Total	6,321	64,531	70,852	100%

ND: Non-disclosable data. Some data did not meet BLS standards for disclosure.
[1] 2008 data used.
[2] Florida counted as single region because no distinction could be made as to whether employment occurred on Atlantic or Gulf coast.
[3] Total employment for non-coastal states could not be determined because of non-disclosable data. Total employment for the subset of non-coastal states with disclosable data was 156.
Sources: Bureau of Labor Statistics, 2011; and U.S. Census Bureau, 2011.

The value of U.S. exports is much higher when industrial products (such as fertilizers) are included; the addition of this category raises the total value of fish product exports in 2010 to $22.4 billion. In comparison, U.S. imports of fish products totaled $27.4 billion, including $14.8 billion of edible products (*FUS*, 2011). As of 2006 the U.S. was the second leading importer of fish products in the world, and the fourth leading exporter (FAO, 2006).

The exhibit on the following page illustrates the distribution of fish product imports and exports in 2010 by trading partner. As it shows, Asia was the source of 52 percent ($14.2 billion) of U.S. imports, and the destination of 39 percent ($8.8 billion) of U.S. exports. At a national level, China was the leading source of foreign fish products, accounting for $4.5 billion in imports, while Canada was the top destination for U.S. fish products, accounting for $4.0 billion in exports (*FUS*, 2011).

The exhibit below summarizes the flow of value through the various sectors of the economy related to commercial fisheries, including harvesting, processing, wholesale and retail, imports, and exports. The figures demonstrate that fish harvesting, while economically important in its own right, is the root of a much larger system of economic interactions.

EXHIBIT 9-5. COMMERCIAL FISHING AND RELATED ECONOMIC SECTORS

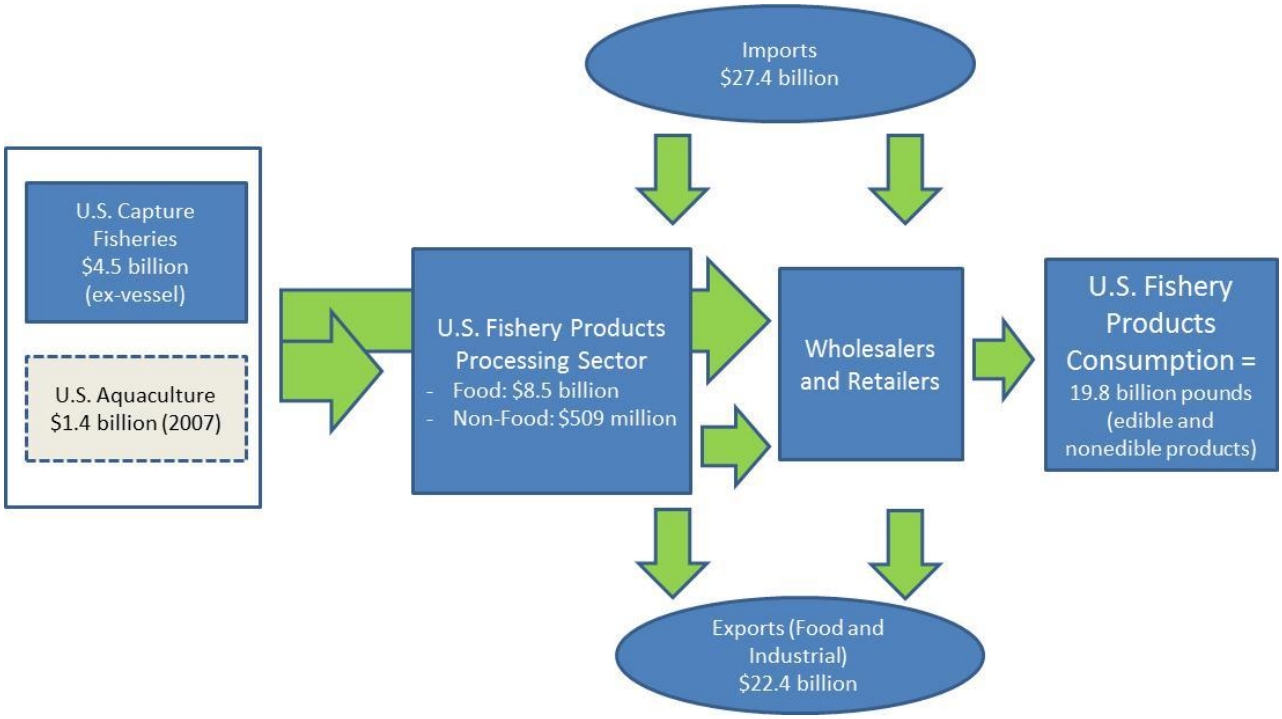
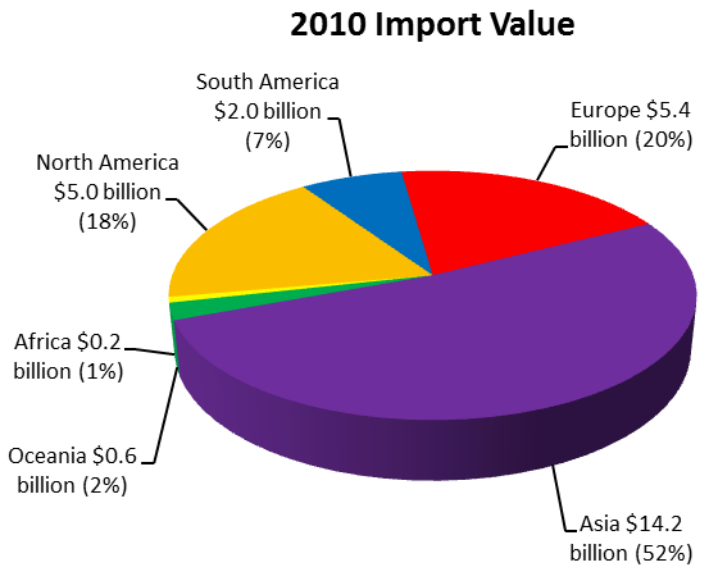
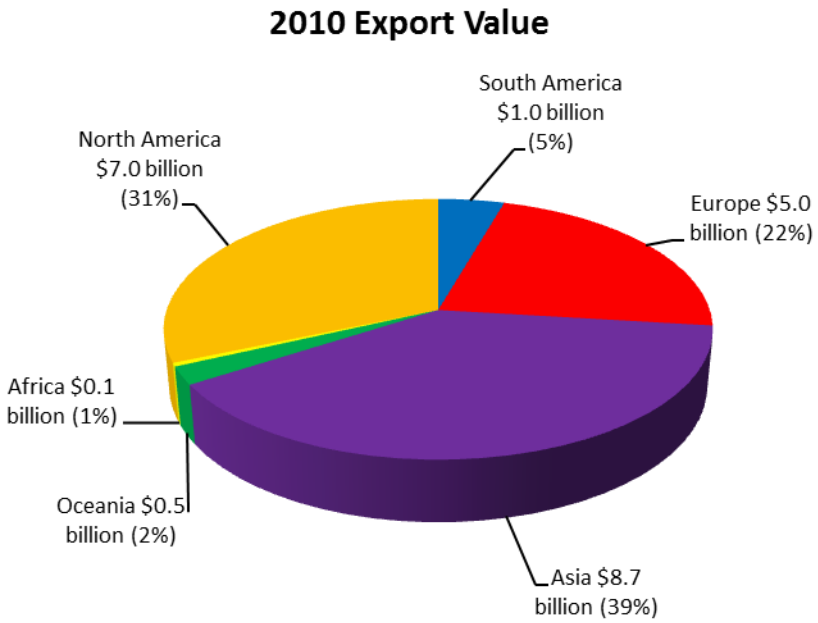


EXHIBIT 9-6. DISTRIBUTION OF IMPORTS AND EXPORTS BY CONTINENT





Source: NMFS, 2011.

COMMERCIAL FISHING AND THE ENVIRONMENT

In comparison to other economic sectors examined in this report, water plays a different role in commercial fish harvesting. Rather than being an input into a production process, water is one element in a complex biological system. Likewise, the harvested species are themselves elements in this same system. It is the maintenance of this system that supports commercial activity such as sustainable fisheries.

As described below, fisheries management agencies directly regulate commercial fishing activity to help ensure the long-term sustainability of the industry. The future productivity of the nation's commercial fisheries also depends on responsible management of the nation's coastal waters and on the long-term impact of climate change on habitat and fish stocks.

FISHERIES REGULATION

Under the authority of the Magnuson-Stevens Fishery Conservation and Management Act and other Federal statutes, the National Oceanic and Atmospheric Administration (NOAA) manages the nation's marine fisheries through regulations governing ocean resources, fishing gear, and fishing effort. NOAA employs two distinct terms in assessing the health of fish stocks: *overfishing* and *overfished*. Specifically:

- A stock is subject to overfishing when the harvest rate is above the level that allows for maximum sustainable yield (i.e., the rate of removal is too high).
- A stock is overfished when its population has a biomass level below a biological threshold specified in its fishery management plan (i.e., the population is too low).

In 2010, NOAA reviewed 528 stocks to determine their status. For 275 of these stocks, overfishing thresholds are unknown or cannot be determined; sufficient information was available to evaluate the remaining 253. Of these, NOAA classified 40 (16 percent) as subject to overfishing. Some key stocks considered subject to overfishing in 2010 were Atlantic cod in the New England region and bluefin tuna in the Pacific region, though the latter was not fished exclusively by U.S. fishermen.

With respect to overall population, NOAA was able to assess the status of only 207 stocks. Of these, it classified 48 (23 percent) as overfished and identified five others that are approaching that status. Key stocks that were classified as overfished were Atlantic cod, Chinook and Coho salmon in the Pacific region, and blue king crab in Alaska. The commercial importance of these species is clear. For example, Chinook and Coho salmon collectively accounted for six percent (46.6 million pounds) of all 2010 salmon landings by weight, and 13 percent ($73.9 million) of all salmon landings by value. Similarly, blue king crab makes up a significant portion of the Alaskan king crab catch, which in 2010 had landings valued at $122.4 million.

NMFS' Fish Stock Sustainability Index (FSSI) measures the sustainability of 230 key stocks. The FSSI assesses each stock's sustainability on a four-point scale, in which:

- Half a point is awarded if the stock's overfishing status is known;
- Half a point is awarded if the stocks overfished status is known;
- One point is awarded if overfishing is not occurring;

- One point is awarded if the stock's biomass is above the level prescribed for it; and
- One point is awarded if the stock is at or above 80 percent of the biomass required for maximum sustainable yield.

When totaled, the maximum FSSI value for all 230 stocks is 920. As of 2010, the value of the index stood at 583, 63 percent of the maximum. This is a significant increase since 2000, when the index stood at 357.5. This rise in the index, however, has been driven mainly by an increase in the number of stocks whose overfishing or overfished status is known, not by reductions in overfishing or increases in fish stocks.

In response to the fish stock assessments, NOAA administers a broad range of regulations and programs designed to restore stocks of overfished species or sustain the stocks of healthy species. NOAA's Office of Sustainable Fisheries (OSF) implements these measures, including:

- Catch limits on key commercial species;
- Catch shares that limit access to key fisheries; and
- International cooperation programs.

NOAA is assisted by Regional Fishery Management Councils (which develop fishery management plans) and state agencies (which typically focus on permitting and other support tasks) (NOAA/OFS, 2011).

HABITAT QUALITY

Commercial Fisheries Habitat Protection

Although commercial fishing occurs in both inshore and offshore areas, coastal waters play an especially vital role in maintaining fish stocks. Bays, estuaries, and coastal wetlands are essential to the life cycle of many commercial fish species. These areas serve as spawning grounds, nurseries for juvenile fish, and feeding areas for both juvenile and adult fish. Coastal areas also represent the interface between the marine environment and the built, human environment. As such, most efforts to manage the habitat of commercial fish species focus on the coastal zone.

Water quality management is one key aspect of habitat protection. As it relates to commercial fish species, water quality is especially important in estuarine areas where rivers meet ocean waters. Environmental agencies are central to water quality management, administering an array of programs under the authority of the Clean Water Act and other state and Federal environmental statutes. These efforts include the regulation of effluent discharged by conventional point sources such as manufacturing facilities or municipal sewage treatment plants. Additional programs address stormwater management, management of agricultural runoff, and other pollution sources. Many of these programs are based on collaborative relationships between and among state and Federal agencies, local governments, conservation organizations, and the private sector.

Pollution that can affect commercial fish habitat may originate in coastal areas or in areas remote from ocean waters. Hypoxia in the Gulf of Mexico provides an excellent illustration of the linkages between inland water quality management and commercial fishing impacts in marine waters.[30] The northern Gulf of Mexico receives large loadings of nutrients from agricultural operations and other runoff sources that drain to the Mississippi River, depleting oxygen levels in coastal areas and disrupting food webs. First documented in 1972, the resulting "dead zone" has been growing in size over the last several decades (EPA, 2011). Recent studies have demonstrated a direct statistical correlation between the size of the hypoxic area and landings of brown shrimp on the Texas and Louisiana coasts (O'Connor and Whithall, 2007). The action plan for addressing hypoxia in the Gulf calls for collaborative stakeholder efforts to reduce nitrogen and phosphorus loadings from farms and other sources (EPA, 2008b).

HARMFUL ALGAE BLOOMS

Harmful algae blooms (HABs) are events involving the proliferation of toxic or otherwise harmful phytoplankton. The events may occur naturally or may be the result of human activity (e.g., nutrient runoff). In the U.S., HABs frequently cause shellfish bed closures due to concerns over health risks associated with consumption of contaminated shellfish. A study conducted by researchers at the Woods Hole Oceanographic Institute found that HABs resulted in average annual commercial fishing losses of $18 million. Apart from this long-term average, HABs can result in acute losses to discrete local fisheries. For instance, blooms of a particular brown tide organism eliminated the $2 million bay scallop industry off Long Island, New York.

Source: Anderson, Donald M., et al., *Estimated Annual Impacts from Harmful Algae Blooms in the United States*, September 2000.

Habitat quality considerations extend well beyond basic water quality concerns. Numerous other aspects of habitat structure and function are influenced by human activities, which themselves are the focus of an array of management efforts. For example, a variety of regulatory and conservation programs are designed to manage coastal development and prevent wetlands loss. Under one such initiative, the National Coastal Zone Management Program, states partner with Federal agencies to protect coastal resources and manage shoreline development. Likewise, unimpeded access to coastal rivers is vital to salmon and other anadromous commercial species that migrate upstream to spawn. Increasing attention has been paid to the impact of hydropower projects, and permitting of such facilities now routinely incorporates requirements for improved fish passage. Dam removal has also become more common as resource management officials consider competing uses of river flow. Finally, invasive species – including plants, fish, and shellfish – can proliferate in aquatic environments and undermine native species. Control of invasive species that threaten commercial and recreational fisheries is an increasing concern for natural resource managers.

Assessment of U.S. Coastal Habitat

Given the range of habitat quality considerations discussed above, reliable characterization of commercial fish habitat requires an integrated analysis of coastal

[30] An aquatic system with depleted levels of dissolved oxygen is considered "hypoxic."

resources. In 2008, EPA published the National Coastal Condition Report III (NCCR3), an assessment of the condition of the United States' estuaries and coastal waters (all waters from zero to three miles offshore). The report measures coastal quality based on five factors, each of which is scored on a five-point scale from poor to good, where less than 2.0 is poor, 2.0-2.3 is fair to poor, 2.3-3.7 is fair, 3.7-4.0 is fair to good, and greater than 4.0 is good. To determine the overall score for a particular region, the scores of the five factors are averaged. The factors are:

- *Water quality*. Water quality is measured by assessing the levels of five indicators: dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chlorophyll *a*, water clarity, and dissolved oxygen. A poor score indicates that more than 20 percent of the coastal area is in poor condition; fair indicates 10 to 20 percent of the coastal area is in poor condition or more than 50 percent combined is in fair or poor condition; and good indicates that less than 10 percent of the coastal area is rated poor or more than 50 percent rated good.
- *Sediment quality*. Sediment quality is determined by looking at three factors: sediment toxicity, sediment contaminants, and sediment TOC (total organic carbon). Sediment showing high levels of any of these could contaminate or be inhospitable to benthic organisms. A poor score indicates that more than 15 percent of the coastal area is in poor condition; fair indicates five to 15 percent is in poor condition or more than 50 percent combined is in poor or fair condition; and good indicates that less than five percent of the coastal area is in poor condition or more than 50 percent is in good condition.
- *Benthic quality.* Benthic quality assesses the health of a coastal area's benthic population (i.e., bottom dwelling organisms). Quality is graded based on species diversity; high species diversity, as well as a large proportion of pollution-sensitive species, leads to a high benthic score, while low species diversity and a high proportion of pollution-tolerant species leads to lower scores. The scoring criteria differ depending on the region.
- *Coastal habitat quality*. The coastal habitat index assesses the status of the nation's marine wetlands and estuaries, many of which are adversely affected by human activities (flood control, real estate development, agriculture, etc.). The index is scored by combining two rates of wetland loss for the region being considered: the historical, an average of decadal loss from 1780 to 1990; and the modern, from 1990 to 2000 (data past 2000 was unavailable). The two scores are averaged and then multiplied by 100. The resulting figure is then used to grade the region. A poor score is given if the loss indicator is greater than 1.25, a fair score if the indicator is between 1.0 and 1.25, and good if it is less than 1.0.
- *Fish tissue contamination.* Fish tissue contamination is assessed by measuring the levels of certain contaminants (such as arsenic, mercury, DDT, etc.) in samples of fish taken off the coasts of the subject regions. A poor score indicates that more than 20 percent of the samples are in poor condition; fair indicates that 10 to 20 percent of the samples are in poor condition or more than 50 percent combined

are in fair or poor condition; and a good score indicates that less than 10 percent of samples are in poor condition or more than 50 percent are in good condition.

As stated above, regional scores are determined by averaging the scores for the five indicators. The national scores for each indicator, however, are not determined by simply averaging the regional indicator scores. Instead, each region is weighted based on the percentage of the coastline it represents. The overall national score is determined by averaging the five national indicator scores.

In 2008, the overall coastal condition of the United States scored 2.8, or fair, on the coastal condition index. The U.S. scored a 3.9 on the water quality index, a 2.8 on the sediment quality index, a 1.7 on the coastal habitat index, a 2.1 on the benthic index, and a 3.4 on the fish tissue contaminants index. Exhibit 9-7 summarizes the scores and illustrates the distribution of scores by region.

EXHIBIT 9-7. COASTAL CONDITION INDEX SCORES BY REGION

INDEX	NORTHEAST COAST	SOUTHEAST COAST	GULF COAST	WEST COAST	GREAT LAKES	SOUTH CENTRAL ALASKA	HAWAII	PUERTO RICO	U.S. TOTAL
Water Quality Index	3	3	3	3	3	5	5	3	3.9
Sediment Quality Index	2	3	1	2	1	5	4	1	2.8
Coastal Habitat Index	4	3	1	1	2	-	-	-	1.7
Benthic Index	1	5	1	5	2	-	-	1	2.1
Fish Tissue Contamination Index	1	4	5	1	3	5	-	-	3.4
Overall Condition	2.2	3.6	2.2	2.4	2.2	5	4.5	1.7	2.8

Source: U.S. EPA, 2008.

As the exhibit indicates, there are some particularly low results at the regional level. In the Northeastern region, for example, both benthic quality and fish tissue quality earned a poor rating. In this region, 31 percent of all fish sampled rated poor on the fish tissue contamination index, and 28 percent rated fair. This rating was due primarily to the presence of two contaminants: polychlorinated biphenyls (PCBs) and DDT. These are also the most common contaminants in the Pacific region, which also earned a poor score on the fish tissue contamination index. There, 26 percent of all fish sampled rated poor, and 11 percent rated fair.

Overall, the findings of the NCCR3 study highlight the potential vulnerability of commercial fish stocks to the degradation of coastal habitat, particularly along the northeast, western, and Gulf coasts.

Climate Change

Climate and atmospheric conditions are an important influence on the aquatic ecosystem supporting commercial fishing. While not an immediate threat to the viability of the commercial fishing industry, climate change could have significant long-term effects. Several physical and ecological changes have been observed or are anticipated for the marine environment:

- Water temperatures are warming, particularly surface temperatures. Effects will vary across geographic areas, however, with deeper warming possible in the Atlantic.
- Changes in salinity are already being observed, especially in low-latitude areas with rapid evaporation rates.
- Acidity is increasing, undermining the viability of coral reefs.
- Many models predict shifts to smaller species of phytoplankton, altering food webs.
- In the longer term, most models predict declines in the stocks of cold-water fish species and poleward migration of warm-water species (FAO, 2008).

Globally, these environmental changes will likely redistribute commercial fisheries. One major study by Cheung, et al. (2009) predicts a 30 to 70 percent catch increase in high-latitude areas and a 40 percent decrease in the tropics. This study predicts little net change in global fishery productivity overall. Other studies, however, forecast net economic losses. A World Bank study projects that by 2050 climate change could cause anywhere from a 10 to a 40 percent reduction in global catch relative to 2010 levels, and a global revenue loss of $10 to $31 billion per year (World Bank Group, 2010).

Like the global predictions, anticipated climate change effects on U.S. commercial fisheries vary by region. The Cheung, et al. (2009) study concludes that by 2100, the contiguous U.S. will see an approximately 13 percent decrease in potential catch. Alaska, on the other hand, may see a roughly 25 percent increase in potential catch over that same timeframe. It is unlikely, however, that the potential increase in Alaska's catch would reflect the diversity of species currently landed in the U.S. mainland (Pew, 2009).

Climate change may also influence commercial fisheries through freshwater habitat impacts. As previously noted, salmon and other anadromous species account for a significant share of U.S. commercial fishing revenues. To the extent that climate change exacerbates competition for water in the western U.S., these species could be negatively affected. For instance, studies highlight the potential for warming trends to reduce snowpack in the Pacific Northwest, reducing summer streamflow in the Columbia River basin. These studies acknowledge that increased water temperatures and reduced in-stream flow are a threat to the survival of Columbia River salmonids (NRC, 2004).

SUMMARY

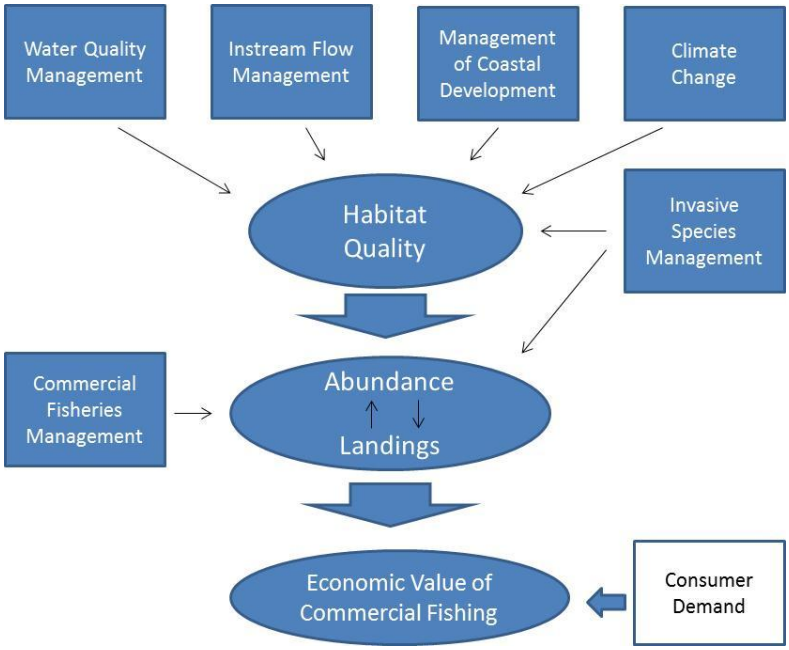
The preceding discussion of fish habitat and fisheries management highlights the complex relationship between commercial fisheries and aquatic resources. As described

in Chapter 2, economists have argued that water possesses features that differentiate it from other goods. In particular, the location, timing, quality, and supply uncertainty make water difficult to value in a conventional framework. All these factors come into play with commercial fisheries, but with an additional ecological dimension. Because commercial fishing involves the harvest of wild species, myriad aspects of habitat quality must be considered.

Exhibit 9-8 provides a simplified summary of how habitat quality relates to commercial fishing. Numerous regulatory and resource management programs exist to protect habitat quality. These include water quality programs; management of in-stream flow; management of coastal development (e.g., for wetlands conservation); management of climate change; and management of invasive species. Habitat quality, in combination with direct regulation of fishing effort, influences the abundance of commercial fish species and landings of those species. The resulting supply of fishery products combines with consumer demand to determine the prices at which these products are bought and sold, revenues and profits in the commercial fishing industry, and the economic value that is ultimately realized from consumption of the commercial catch.

Underlying all of these factors is a complex series of ecological interactions that scientists only partially understand. Models cannot predict the precise reaction of fish or shellfish stocks to habitat changes. These impacts and the resulting effects on commercial landings are difficult to specify and likely to vary significantly from case to case. To the extent possible, however, it is important for water resource managers to take these relationships into account, ensuring that their decisions appropriately recognize the effect that any change in aquatic habitat may have on the productivity and sustainability of the commercial fishing industry.

EXHIBIT 9-8. HABITAT QUALITY AND COMMERCIAL FISHING VALUATION



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CHAPTER 10 | COMMERCIAL NAVIGATION (IN-STREAM USE)

INTRODUCTION

U.S. ports and waterways are an important element of the nation's commercial transportation infrastructure. As a non-consumptive activity, the use of water for commercial navigation generally does not affect its availability for other uses. Nonetheless, commercial navigation can raise issues that require the consideration of water resource managers, including the need to dredge or maintain sufficient in-stream flows to ensure adequate channel depths. In addition, the development of canals and seaways and the maintenance of channels to facilitate shipping can have negative environmental consequences, such as creating pathways for the introduction of non-native species. Thus, the economic importance of commercial navigation, the use of water by this sector, and the impacts of commercial navigation on other uses are key concerns in management of the nation's water resources. The discussion that follows addresses these issues, describing:

OVERVIEW OF KEY FINDINGS

- In 2007, commercial navigation accounted for 78 percent of international trade by weight and 45 percent of trade by value. Within the U.S., commercial navigation handles approximately 10 to 15 percent of cargo shipments by ton-mile, including large volumes of crude oil and petroleum products, coal, chemicals, sand, gravel, stone, food and farm products, iron ore and scrap, manufactured goods, and other commodities.
- The commercial navigation sector relies on maintenance of adequate water depths at ports, locks, and channels. At the Federal level the Army Corps of Engineers has primary responsibility for maintaining commercial shipping channels. It spent $1.3 billion on dredging in fiscal 2009, but at current appropriation levels is unable to dredge all waterways and ports in need of maintenance.
- In inland waterways, water must be retained to ensure adequate depths for commercial navigation. This requirement can compete with the demands of off-stream water uses, such as irrigation. In addition, the development and maintenance of waterways to facilitate shipping can have adverse environmental impacts, such as creating pathways for the introduction of invasive species that can alter aquatic ecosystems, compete with native species, and adversely affect recreational fisheries.
- The marginal value of water in commercial navigation depends on the physical characteristics of the vessels and body of water in question, as well as the costs of shipping via alternative modes of transportation. Estimates of average values for major U.S. rivers are highly variable (less than $1 to $671 per acre-foot), suggesting the need for site-specific analysis to support resource management decisions that affect commercial navigation.

- The role of the commercial navigation sector in transportation and shipping nationwide;
- The economic importance of commercial navigation;
- The use of water by this sector, including infrastructure requirements to maintain channel depths; and
- Available estimates of the value of water used for navigation.

SECTOR OVERVIEW

Commercial navigation encompasses the movement of cargo and passengers by water. It is part of the tertiary (delivery) mega-sector described in Chapter 2 and is particularly vital to industries that rely on the bulk shipment of goods. The following discussion provides an overview of this sector, drawing on data from the U.S. Army Corps of Engineers, the Department of Transportation's Maritime Administration, and DOT's Bureau of Transportation Statistics.

CARGO SHIPPING

Cargo is shipped to, from, and throughout the United States by ship, rail, truck, pipeline, and airplane. According to the Bureau of Transportation Statistics, domestic shipments of cargo in the United States in 2007 totaled more than 4.6 trillion ton-miles (USDOT, 2011a).[31] Exhibit 10-1 shows the distribution of this shipping by mode, along with similar data for the three previous years. The exhibit shows that shipping on domestic waterways accounted for between 10 and 15 percent of total freight ton-miles during this period, less than that reported for shipping by rail, truck, and pipeline, but more than that reported for shipping by air. As the exhibit shows, overall shipments of freight remained relatively constant during this four-year period. Shipping by water, however, showed an eleven percent decline, from 621 billion ton-miles in 2004 to 553 billion in 2007.

Geographic Distribution

In 2009, U.S. waterborne shipments of freight totaled 2,210.8 million tons, with 1,353.7 million tons (61 percent) representing the shipment of imports and exports by sea. Domestic shipments accounted for the remaining 857.1 million tons (39 percent) (USACE, 2010). As Exhibit 10-2 shows, internal riverways supported most of the domestic traffic, accounting for nearly 61 percent of domestic tonnage. Coastal shipping (20 percent), shipping on the Great Lakes (7 percent), and intra-port shipping (12 percent) accounted for smaller shares of the domestic total.[32]

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[31] The Bureau of Transportation Statistics does not collect data for international shipping.

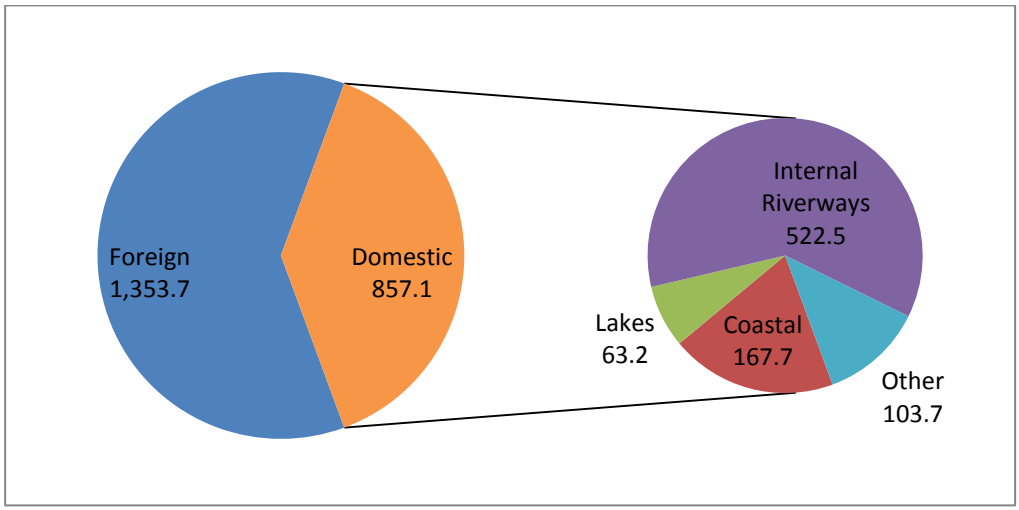
[32] For the purposes of this discussion, internal riverways include all flowing bodies of freshwater that feed into a lake or ocean. Coastal shipping refers to shipping between ports along the Atlantic or Pacific coasts or on the Gulf of Mexico. Shipping on the Great Lakes includes traffic on the lakes themselves and via all connecting canals, channels, and locks. Finally, intra-port transport refers to the shipment of cargo by vessel from one point within a port to another, usually for the purpose of storage.

EXHIBIT 10-1. DISTRIBUTION OF FREIGHT SHIPPING IN THE U.S. BY MODE, 2004-2007

TRANSPORTATION MODE	TON-MILES OF FREIGHT (MILLIONS)			
	2004	2005	2006	2007
Air	16,451	15,745	15,361	15,142
Truck	1,281,367	1,291,308	1,291,244	1,317,061
Railroad	1,684,407	1,733,329	1,855,902	1,819,633
Domestic water	621,170	591,276	561,629	553,143
Pipeline	937,442	938,659	906,656	904,101
Total	4,540,837	4,570,316	4,630,792	4,609,079

Source: USDOT, 2011a.
Note: Numbers may not sum to totals due to rounding.

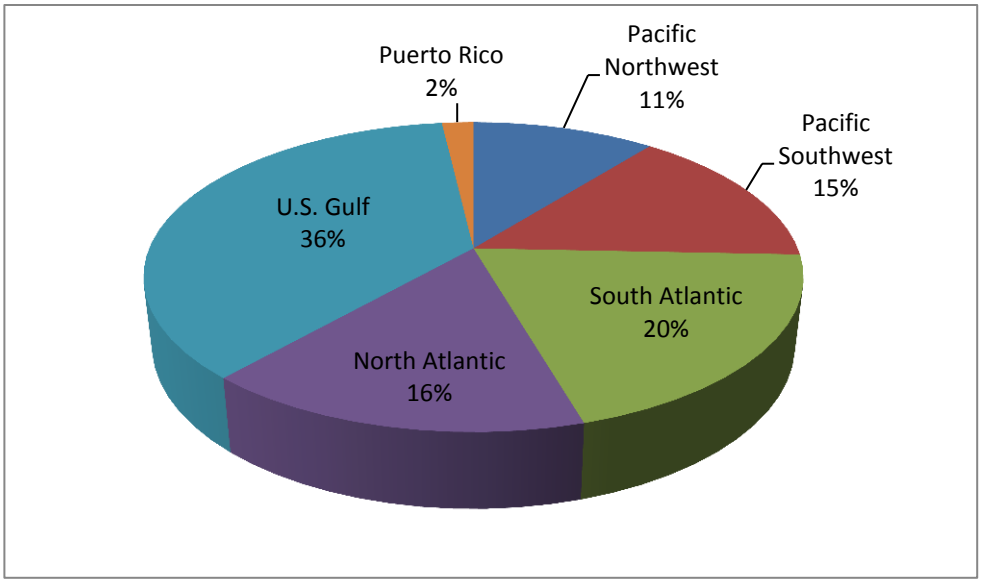
EXHIBIT 10-2. U.S. WATERBORNE TRAFFIC, 2009 (MILLIONS OF TONS)



Source: USACE, 2010. Note: Other includes intra-port and intra-territory traffic.

Water transportation is limited in its points of origin and destination by the availability of ports equipped to handle the loading and unloading of cargo. U.S. coastal ports are essential to facilitating both overseas and domestic trade. Exhibit 10-3 presents the distribution of port calls by coastal region in 2010 for domestic and international shipments. As the exhibit shows, port calls along the Gulf of Mexico accounted for 36 percent of the U.S. total, followed by port calls to the South Atlantic (20 percent), the North Atlantic (16 percent), the Pacific Southwest (15 percent), the Pacific Northwest (11 percent), and Puerto Rico (2 percent).

EXHIBIT 10-3. DISTRIBUTION OF U.S. PORT CALLS BY REGION, 2010



Source: USDOT, 2011d. Note: Data include only port calls for oceangoing vessels over 10,000 deadweight tons. Pacific Northwest includes Alaska. Pacific Southwest includes Hawaii.

Types of Cargo

Exhibit 10-4 (next page) shows the distribution of domestic cargo shipments in 2009 by commodity and waterway. Energy-related commodities, such as coal and petroleum-related products, make up the largest share of shipments by water, over 62 percent by weight. In addition, a significant amount of iron ore, a key input in the manufacture of steel, is shipped on the Great Lakes. According to the 2007 U.S. Economic Census, 182 of the nation's 352 iron and steel mills are located in the Great Lakes region; thus, the lakes are an important waterway for this industry (U.S. Census Bureau, 2007). As the exhibit shows, commercial shipping also plays a vital role in the transport of many other commodities, including chemicals, manufactured goods, stone, and agricultural products.

PASSENGER TRANSPORTATION

In addition to the movement of cargo, the nation's waterways are also used to transport passengers. The two main categories of passenger transportation relying on commercial navigation are cruises and ferries.

Cruises

Cruises, by design, launch from and return to the same port; they are meant as a form of recreation, not a mode of transportation. A cruise ship may make stops at various ports before returning to its point of origin, or it may not make any. The Department of Transportation's Maritime Administration reports that 4,208 cruises carrying 10.6 million passengers made at least one stop in the U.S. in 2010 (USDOT, 2011b).

EXHIBIT 10-4. U.S. DOMESTIC WATERBORNE TRAFFIC BY MAJOR COMMODITY, 2009

COMMODITY	MILLIONS OF TONS SHIPPED				
	COASTAL	LAKES	INTERNAL RIVERWAYS	OTHER	TOTAL
Coal	9.2	18.8	158.5	20.3	206.8
Coal Coke	0	0.4	3.3	0.2	3.9
Crude Petroleum	35.2	0	28.0	1.0	64.2
Petroleum Products	88.6	0.6	117.8	48.5	255.5
Chemical and Related Products	9.4	0	42.5	10.3	62.2
Forest Products, Wood & Chips	1.1	0	3.5	0.4	5.0
Sand, Gravel and Stone	6.9	16.2	49.3	17.0	89.4
Iron Ore and Scrap	0.2	22.4	6.0	1.7	30.3
Non-Ferrous Ores & Scrap	0.6	0	4.9	0	5.5
Sulphur, Clay and Salt	0	1.0	8.7	0.3	10.0
Primary Manufactured Goods	5.2	3.0	15.0	1.0	24.2
Food and Farm Products	4.7	0.3	75.0	1.2	81.2
All Manufactured Equipment	6.5	0	6.8	0.8	14.1
Waste and Scrap	0	0	1.0	0.8	1.8
Total	167.6	62.7	520.3	103.5	854.1

Source: USACE, 2010.
Note: Other includes intra-port and intra-territory traffic.

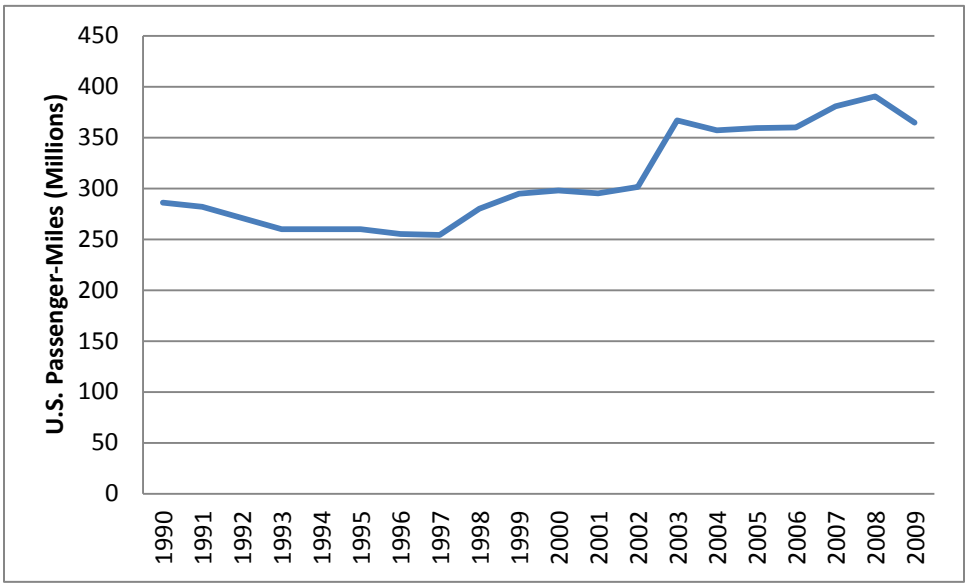
Ferries

Ferries help to connect island communities to the mainland but also, in some cases, provide faster, more direct routes than roads. In many communities west of Seattle, for example, it is faster to ferry across Puget Sound than to access the nearest bridge by road. The Washington State Ferry System is the largest ferry system in the country with respect to the number of both passengers and vehicles transported (Washington State DOT, 2011). This system transports over 22 million riders and 10 million vehicles annually, linking growing residential communities with nearby urban economic centers. For comparison, the nation's second largest ferry system, which primarily connects mainland North Carolina to the Outer Banks, services only 2.5 million passengers and 1.3 million vehicles each year (North Carolina DOT, date unknown). Other regions that rely to a significant extent on ferry transportation include the eastern end of Long Island, where ferry services provide access to southern New England, and the islands of Martha's Vineyard and Nantucket off the coast of Massachusetts.

Even though ferry services exist only in regions with specific needs, their use has increased over the last two decades. Exhibit 10-5 shows the growth of U.S. passenger-

miles traveled on ferry systems from 1990 to 2009. Though current ferry use is less than one hundredth of one percent of total passenger miles by all modes of transportation, it provides a service that, in most cases, would be impractical for other modes to provide.

EXHIBIT 10-5. U.S. PASSENGER-MILES BY FERRY



Source: USDOT, 2011a.

ECONOMIC IMPORTANCE

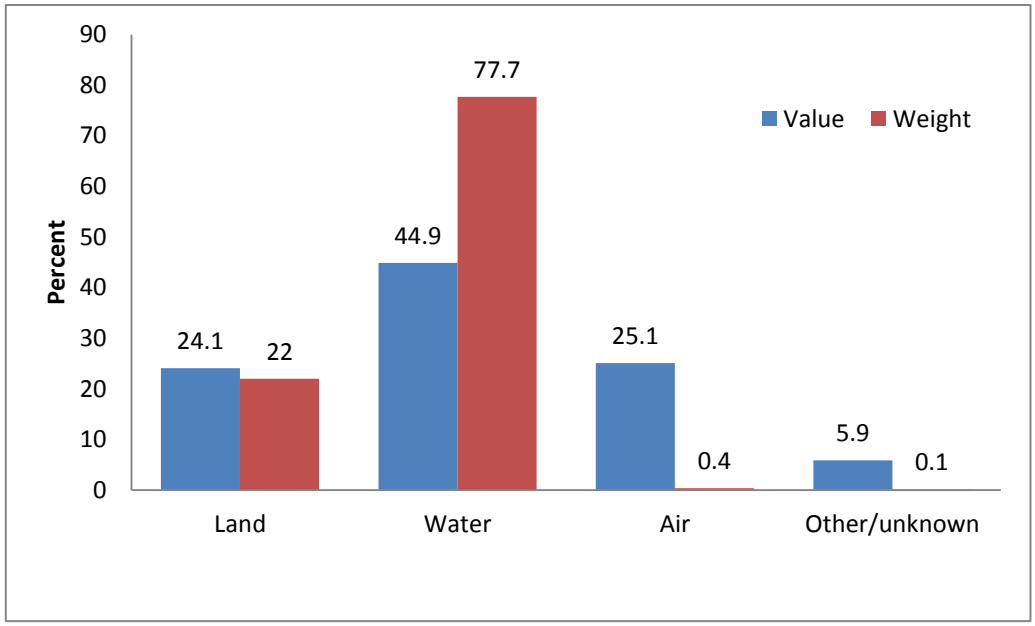
A large number of industries rely on commercial navigation directly or indirectly, making it a vital sector of the economy. In addition to the economic activity directly related to commercial navigation, the sector also drives economic activity in supporting industries, such as shipbuilding and repair. This section discusses the economic importance of commercial navigation; it presents the total value of goods shipped by water, compares waterborne shipping to shipping by other modes, and discusses employment and wages in commercial navigation and related industries.

Value of Goods Shipped

The total value of all U.S. cargo freight in 2007, regardless of mode, was $11.7 trillion, including international trade (USDOT, 2011a). When compared to U.S. GDP, which totaled $14 trillion in 2007, the importance of cargo shipping is immediately apparent (World Bank, 2012). Exhibit 10-6 shows that water transport accounted for 77.7 percent of international shipments by weight in 2007, but only 44.9 percent of shipments by value, illustrating the competitive advantage that water transport offers in moving large quantities of lower value goods over long distances. Conversely, air transport accounts for 0.4 percent of shipments by weight but 25.1 percent of shipments by value. This demonstrates that even within the shipping sector, not all modes of transport compete for the same business. In general, different modes of shipping are not perfect substitutes for

one another. They will compete, however, when circumstances and available infrastructure allow them to move cargo between two points at comparable costs.

EXHIBIT 10-6. MODAL SHARES OF INTERNATIONAL U.S. MERCHANDISE TRADE HANDLED BY LAND, WATER, AND AIR GATEWAYS BY VALUE AND WEIGHT, 2007



Source: USDOT, 2010. Note: Land includes truck, rail, and pipeline modes.

Comparison of Waterborne Shipping to Alternatives

Most cargo uses multiple modes of transport to arrive at its final destination, with each mode providing different services. For example, cargo that can be brought to a U.S. port by ship safely and inexpensively might then require rail or truck transport, or both, to reach its final inland destination. Different modes of transportation can either be complements or substitutes, depending on the particular requirements and destination of the cargo. A large volume of waterborne cargo consists of bulk commodities that are shipped long distances where speed is not a high priority.

Shipping freight by water offers a number of advantages over alternative methods of transport. As Exhibit 10-7 shows, shipping by inland water is the most fuel-efficient mode, as measured by gallons of fuel used per ton-mile. Consequently, it releases the smallest amount of greenhouse gases per ton-mile. Waterborne shipping is also the safest mode with respect to the number of injuries per ton-mile and the number of gallons of oil spilled per ton-mile (Texas Transportation Institute, 2007). Waterborne shipping, however, also suffers a number of disadvantages, the most obvious of which is its inability to deliver cargo where navigation is not feasible. Additionally, water transport tends to be much slower than transport by truck, rail, or air, making it undesirable for

perishable or time-sensitive shipments. In addition, waterborne shipping requires the development and maintenance of port facilities to dock and load/unload shipments (Young, 2005).

When comparing shipping by inland waterway to shipping by truck or rail, it is important to note that the natural course of rivers can force ships to take a more circuitous route to their destination than would shipments by other means. This can lengthen a trip and reduce the competitiveness of shipping by water. In some instances, however, the situation is reversed. This is the case with the Great Lakes, where a ship may be able to travel a direct route between ports, while a train or truck may have to travel a greater distance to circumvent a large body of water. Comparisons of miles traveled should, therefore, be considered carefully.

EXHIBIT 10-7. COMPARISON OF SHIPPING METHODS

	GALLONS OF FUEL USED PER MILLION TON-MILES	TONS OF GHG PER MILLION TON-MILES	GALLONS OF OIL SPILLED PER MILLION TON-MILES	INJURIES PER BILLION TON-MILES
Truck Freight	6,452	71.6	6.06	99
Railroads	2,421	26.9	3.86	5.8
Inland Marine	1,736	19.3	3.60	0.045
Source: Texas Transportation Institute, 2007.				

Shipbuilding and Repair

Though not strictly part of the commercial navigation sector, shipbuilding and repair is a closely linked industry. Demand for water transportation services increases demand for ship construction and maintenance. According to the DOT Maritime Administration, capital investments in the industry totaled $270 million in 2006 (USDOT, date unknown). The passage of the Oil Pollution Act of 1990 has been a major driver for growth in the shipbuilding industry. The act requires the phase-in of double hull vessels through 2015 to reduce the risk of an oil spill in the event of a collision or some other accident. By the time the phase-in is complete, almost $5 billion will have been spent on construction to comply with this requirement.

In addition to serving commercial navigation, the shipbuilding and repair industry is a major contractor for the U.S. Navy. In 1998, 70 percent of industry revenues came from the military (USDOC, 2001). These revenues are obviously critical to the industry's long-term sustainability.

Employment in Commercial Navigation and Related Industries

The Bureau of Labor Statistics classifies commercial navigation under six different NAICS codes based on the type of shipping (freight or passenger) and the type of waterway (deep sea, coastal and Great Lakes, and inland). Exhibit 10-8 summarizes

total employment and wages in these sectors in 2010, as well as the number of establishments, both private and government, operating in each industry. The exhibit includes similar data for ship and boat building and water transportation support activities. As the exhibit shows, employment in the ship and boat building industry or in support activities for waterborne transportation is significantly greater than direct employment in commercial navigation. Within the commercial navigation sector itself, the transport of freight accounts for a greater share of employment and wages than does passenger transportation.

EXHIBIT 10-8. EMPLOYMENT IN COMMERICAL NAVIGATION AND RELATED INDUSTRIES, 2010

CATEGORY	SUBCATEGORY	ESTABLISHMENTS	TOTAL EMPLOYMENT	TOTAL WAGES (MILLIONS)
Freight	Deep sea	500	11,616	$1,160
	Coastal and Great Lakes	312	10,355	$864
	Inland water	548	20,998	$1,466
Total Freight		***1,360***	***42,969***	***$3,491***
Passenger	Deep sea	123	8,375	$510
	Coastal and Great Lakes	187	7,064	$357
	Inland water	238	4,115	$202
Total Passenger		***548***	***19,554***	***$1,069***
Other	Support activities for water transportation	2,828	93,557	$6,004
	Ship and boat building	1,826	151,837	$8,946
Total Other		***4,654***	***245,394***	***$14,950***
Total		**6,562**	**307,917**	**$19,510**

Source: USDOL, 2012. Accessed 2/13/12.

Notes:

1. The following NAICS codes are included: 483111, 483112, 483113, 483114, 483211, 483212, 4883, 3366.
2. Support activities for water transportation include Port and Harbor Operations, Marine Cargo Handling, Navigational Services to Shipping, and Other Support Activities for Water Transportation.
3. A large portion of the ship and boat building industry is not related to commercial navigation (e.g., in 1998, 70 percent of shipbuilding revenues come from the U.S. military).

WATER USE

As noted above, commercial navigation is an in-stream, non-consumptive use of water. The importance of water to this sector is primarily related to its depth at important junctures, namely ports, rivers, locks, and channels. The U.S. Army Corps of Engineers (USACE) regularly dredges these areas to maintain a minimum navigable depth. The USACE is also responsible for the construction and maintenance of locks, which allow ships to travel on waterways that might otherwise be unnavigable. This section summarizes the work that the USACE does to maintain the navigability of the nation's waterways and ports. It then briefly discusses how climate change might affect the ability of waterways to support commercial navigation in the future. Finally, it

summarizes some of the ways in which the commercial navigation sector can affect other water use sectors discussed in this report.

INFRASTRUCTURE REQUIREMENTS OF COMMERCIAL NAVIGATION

The USACE was originally charged to clear, deepen, and otherwise improve and maintain selected waterways by the General Survey Act of 1824. Since that time, its mission has expanded to include the creation of canals to expand transportation routes and link previously unconnected bodies of water. Today, the USACE oversees and provides maintenance nationally for 12,000 miles of inland and intra-coastal waterways, as well as 13,000 miles of coastal waters and navigable channels greater than 14 feet deep, including nearly 200 locks and dams. Its jurisdiction in this area reaches 40 states.

Dredging

Sediment, such as silt, sand, or gravel, is picked up and carried by currents or the faster flowing segments of a river and deposited where the current slows. Over time, these deposits build up and can be a hazard to passing ships. Dredging, the removal of these buildups, is essential to maintaining access to water bodies and ports. The depth of water at the shallowest point determines how much cargo a vessel can safely carry without grounding. According to the Lake Carriers' Association, the Great Lakes fleet gives up 200,000 tons of cargo for each foot of draft lost (USACE, 2009).[33]

According to the Navigation Data Center at the USACE, 263.6 million cubic yards of total material were dredged nationally at a cost of $1.3 billion in the 2009 fiscal year (USACE, 2010). One area where this service is needed is the Port of New York and New Jersey, where navigation and commerce generates about $20 billion annually in direct and indirect benefits (USACE, 2011b). Each year, USACE maintenance dredging removes between one and two million cubic yards of sediment from New York Harbor, which comprises about 24 separate channels. Additional dredging will be required in the future to deepen some channels, allowing larger vessels access to the harbor.

The USACE currently is not able to provide all of the dredging services that are needed to maintain the navigability of the nation's waterways and ports. Exhibit 10-9 shows harbors and projects (red) in the Great Lakes region that currently fail to provide the services for which they were originally designed due, in part, to the lack of adequate funding for dredging or the lack of sufficient capacity at dredged material disposal facilities. Many areas are experiencing a backlog in maintenance dredging, and those not slated to receive dredging services will continue to operate at a sub-optimal level until funds can be freed to make the necessary upgrades.

[33] Draft refers to the vertical distance from the bottom of a ship's hull to the waterline.

EXHIBIT 10-9. GREAT LAKES NAVIGATION SYSTEM INFRASTRUCTURE QUALITY, 2009

Source: USACE, 2009.

Locks and Dams

A lock is an area on a waterway, or connecting two waterways, that has the ability to raise or lower boats to allow passage between bodies of water at different levels. Dams allow for a degree of control over river flows so that depth can be increased during periods that would otherwise experience low flows. Both are vitally important to navigation in rivers and canals that connect major shipping routes and link the Great Lakes to each other and to rivers that travel further inland. Critical lock sites are among the areas with failing infrastructure highlighted in Exhibit 10-9.

Locks are essential to shipping on the Great Lakes because they allow vessels to transit otherwise impassable stretches separating the lakes from each other. The Soo Locks are a set of parallel locks along the Saint Mary's River which connect Lake Superior to the lower Great Lakes by allowing ships to safely avoid rapids and a 21-foot drop. Only one of these locks, the Poe lock, is large enough to accommodate all vessels operating on the Great Lakes (USACE, 2009). Closure of the Poe lock would create a barrier to 70 percent of the commercial cargo capacity that currently utilizes the waterway. Estimates put the cost to industry of an unplanned 30-day shutdown of the Soo Locks at $160 million.

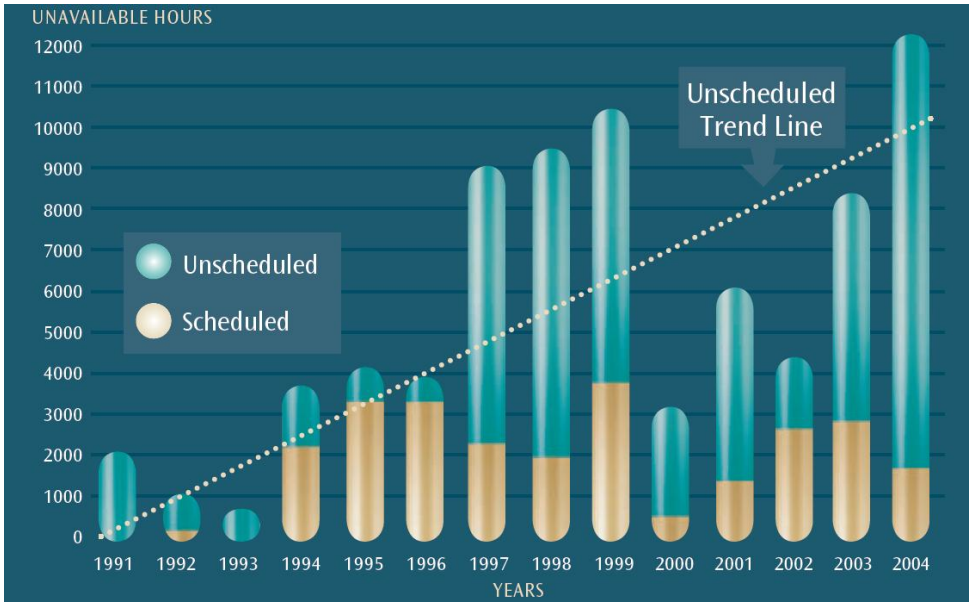
Another example illustrating the importance of lock maintenance is the Upper Mississippi River Basin, which comprises the Upper Mississippi River, the Illinois Waterway and Missouri River system. The Waterways Council estimates that waterborne shipping in this basin saves consumers approximately $1 billion in annual transportation costs (Waterways Council, Inc., 2007). Most of the system's 38 locks, however, are 600

feet long, half the length of an average barge tow.[34] Using these locks requires splitting a tow into segments and bringing each segment through the locks separately, which causes delays and backups. Additionally, many of the locks were constructed over 70 years ago and, while still operable, have begun to experience elevated failure rates (see Exhibit 10-10). These malfunctions translate into longer delivery times and increased shipping costs throughout the region.

POTENTIAL EFFECTS OF CLIMATE CHANGE ON NAVIGATION IN THE GREAT LAKES

The effects of climate change are relevant to any discussion about the future availability of water resources. In regards to navigation, its impact will be most apparent in inland bodies of water, such as the Great Lakes region. The discussion below addresses the two greatest potential impacts to navigation in this region: decreased water levels and reduced ice coverage.

EXHIBIT 10-10. UPPER MISSISSIPPI RIVER BASIN LOCK CLOSURES, 1991-2004



Source: Waterways Council, Inc., 2007.

Decreased Water Levels

Unlike the oceans, the Great Lakes are expected to experience decreased water levels as a result of climate change (Quinn, 2002). While most of the area of the lakes will continue to have more than sufficient depth for navigation, there are critical points where reduced depths will have a significant impact on vessels, namely locks, harbors, and channels. Depending on vessel size, the loss of an inch of draft on the Great Lakes can translate to lost cargo capacity of from 100 to 270 tons per trip. Exhibit 10-11 shows the predicted

[34] An average barge tow is typically 15 barges pushed by a towboat.

reduction in the mean base level of each lake at various points in the future. Even as early as 2030, these estimates suggest potential problems in maintaining sufficient depths without adversely affecting shipping. As vessels are forced to carry less cargo per trip, traffic will increase to accommodate demand, increasing the likelihood of backups at locks and ports.

EXHIBIT 10-11. POTENTIAL IMPACT OF CLIMATE CHANGE ON WATER LEVELS IN THE GREAT LAKES

LAKE	Δ 2030 (FT)[1]	Δ 2050 (FT)	Δ 2090 (FT)
Superior	-0.72	-1.02	-1.38
Michigan-Huron	-2.36	-3.31	-4.52
Erie	-1.97	-2.72	-3.71
Ontario	-1.15	-1.74	-3.25

[1] Changes in water levels are calculated relative to recent means.

Reduced Ice Coverage

Another attribute of the Great Lakes that will be affected by climate change is seasonal ice coverage. Depending on annual temperature variability, the Great Lakes become unnavigable for 11 to 16 weeks each winter. Industries dependent on a year-round supply of certain commodities, such as coal-fueled power plants, must stockpile goods that cannot be delivered during this period. To extend the shipping season as much as possible, the U.S. and Canadian Coast Guard jointly provide ice breaking services. Reduced winter ice from climate change could extend the shipping season by one to three months (Quinn, 2002). This will have a two-fold economic benefit. First, it will reduce the cost of warehousing commodities while shipping is unavailable, creating a steadier flow of cargo. Second, it will reduce the need for the Coast Guard to provide ice breaking services to maintain navigable channels. This will help offset some of the increased costs associated with lower lake levels.

INFLUENCE ON OTHER USES OF WATER

Because commercial navigation relies on water simply as the medium by which ships travel, it is generally unaffected by the potential impacts of other uses of water on water quality; however, commercial navigation can affect other water uses in several ways:

- *Impacts on Benthic Habitat and Water Quality* – As noted above, the maintenance of shipping channels demands regular dredging, which can have an adverse impact on benthic habitat and increase turbidity in the water column. Similarly, the disposal of dredged materials requires careful management to avoid or reduce environmental impacts. These issues become particularly critical if the dredged materials contain heavy metals, PCBs, or other potential contaminants.
- *Impacts on Water Supply and Fish Habitat* – The use of locks and dams to maintain in-stream flows can compete with other demands for water, such as the

use of water for irrigation. Dams can also have a variety of effects on fish habitat, such as reducing the amount of dissolved oxygen in the water, increasing its temperature, and creating obstacles to the migration of anadromous species.

- *Introduction of Invasive Species* – The development of canals and seaways to facilitate shipping can also create pathways for the introduction of non-native species that can have a variety of ecological and economic impacts. The development of the Welland Canal, for example, led to the introduction of the sea lamprey in the Great Lakes above Niagara Falls, contributing to the decline of native species important to both commercial and recreational fishing. More recently, the discharge of ballast water from a trans-Atlantic freighter on the Great Lakes provided a vector for the introduction of the zebra mussel, an invasive species that has altered the ecology of the lakes and forced water users in both the public and private sectors to retool their systems to prevent the mussels from clogging water intake pipes (USGS, date unknown).

VALUE OF WATER USE

Because commercial navigation is an in-stream, non-consumptive use of water, it is difficult to estimate the value of water used for this purpose. Companies that operate barges on waterways in the U.S. do not pay any fees for their use of water for navigation, so there is no functioning market that could allow one to infer the value of water. Even if there were markets for water used in navigation, the fact that this use is not strictly "rivalrous" (i.e., water used for navigation can be used again downstream for other purposes) would suggest that its true value would be underestimated by markets.

Several other factors complicate any efforts to estimate the value of water for navigation:

1. Commercial navigation generally requires that water levels remain within a certain range. Too little water means that channel width and/or depth are inadequate for vessel traffic, and too much water can interfere with loading and unloading of cargo. As a result, the marginal value of water for navigation is generally zero, unless the increment in question is the specific amount that determines whether or not a waterway is navigable for vessels of a particular kind.
2. Seasonal variation in river flows affects the baseline navigability of waterways, so the value of additional water for navigation may be negative during springtime high-flow periods and positive during summertime low-flow periods.
3. Comparing the value of cargo shipping by barge to cargo shipping by alternative means is made difficult by the fact that alternative modes of shipping are not directly comparable. Shipping by truck or by air, though relatively expensive, is faster and therefore more appropriate for time-sensitive cargo. And although rail shipping is more closely comparable to barge shipping, railway pricing differs by route, so railway companies may charge less for routes that compete directly with barge shipping, or employ seasonal price discrimination by charging more for

routes during seasons when competing waterways are not navigable (Young, 2005).

Because of these difficulties, few studies have attempted to estimate the value of water in support of commercial navigation. A 1986 study by Resources for the Future estimated the average value of water used in commercial navigation by comparing the costs of barge transportation to the costs of rail transportation. Using Army Corps of Engineers data on six river systems, the study estimated the cost savings of barge transport vs. rail transport, subtracted the operation and maintenance costs for each waterway, and divided the remaining savings by the amount of water required for each river to support barge traffic, yielding estimates of the average annual values per acre-foot of water used for commercial navigation (Gibbons, 1986). Exhibit 10-12 presents these values, inflated to 2010 dollars. This valuation method assumes that the difference between the cost of rail transport and the cost of barge transport on these rivers is entirely attributable to the value provided by the water that allows the rivers to remain accessible to commercial shipping. As the exhibit shows, the resulting estimates of the value per acre-foot of water, which vary from less than one dollar per acre-foot on the Missouri River to over $670 per acre-foot on the Ohio River, depend in large part on the flow required to maintain navigation in each river, which is a function of the river's physical characteristics. For example, though commercial navigation on the Mississippi is estimated to provide the greatest annual savings relative to rail transportation ($1.8 billion per year), it has the third-lowest estimated value per acre-foot because of the large volume of water needed to maintain navigation (over 131 million acre-feet per year).

EXHIBIT 10-12. ESTIMATES OF THE VALUE OF WATER USED FOR COMMERCIAL NAVIGATION

WATERWAY	ANNUAL COST SAVINGS ATTRIBUTABLE TO COMMERCIAL NAVIGATION (THOUSAND 2010$)	WATER REQUIREMENT (THOUSAND AF/YR)	VALUE OF WATER PER ACRE-FOOT (2010$)
Ohio	$406,000	605	$671
Tennessee	$52,000	412	$126
Illinois	$70,000	120	$583
Mississippi	$1,819,000	131,040	$14
Missouri	$8,000	23,968	$0.3
Columbia/Snake	$50,000	7,168	$7
Source: Gibbons, 1986.			

SUMMARY Water used for commercial navigation supports a vital economic activity, one which cannot easily be replaced by available substitutes. Estimating the value of water used for this purpose could inform water management decisions, as commercial navigation may compete for water with off-stream, consumptive uses. Relatively few studies, however, have examined the value of water used for commercial navigation, and available estimates – which measure average, not marginal values – depend in large part on the physical characteristics of a river, which determine the total amount of water necessary to support navigation.

The discussion of the work conducted by the USACE suggests that channel depth and width are the key variables in determining the viability and economic efficiency of commercial navigation at particular ports or on particular waterways. Site-specific analyses of the economic benefit (or cost) of marginal changes in these variables appear necessary to support water resource management decisions that may affect commercial navigation interests.

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CHAPTER 11 | RECREATION AND TOURISM (IN-STREAM USE)

INTRODUCTION

Water is a vital resource for the recreation and tourism sector. Water-based activities such as fishing, boating, and swimming rely upon water resources to create recreational opportunities, and recreational pursuits such as hiking, hunting, and wildlife viewing can be enhanced by proximity to water. This chapter analyzes the role of water in recreation and tourism, focusing in particular on how the characteristics of a water resource affect people's willingness to pay for recreational activities, which in turn affects consumption of market goods. The chapter discusses:

- The relationship between participation in water-based recreation and market expenditures in the recreation and tourism sector;
- Economic data related to water-based recreation, including participation and expenditure data;
- Issues that currently affect, or in the future may affect, the ability of the nation's waters to support recreational activity; and
- Available estimates of the economic value of participating in water-based recreational activities, as well as the potential impacts of changes in in-stream conditions on these values.

SECTOR OVERVIEW

OVERVIEW OF KEY FINDINGS

- Historically, water regimes gave greater priority to off-stream water uses, such as irrigation or municipal supply, than to the preservation of in-stream flow or water levels for recreational purposes. In recent years, however, states have begun to enact legislation designed to preserve flows or levels that support recreational activities, as well as other in-stream uses.
- Access to many water-based recreational activities and settings is not priced in competitive markets. Thus, it is difficult to use market data to estimate the importance of water to recreation and tourism.
- Nonetheless, demand for water-based recreation drives economic output through market transactions for complementary goods and services associated with the recreation and tourism industry (e.g., transportation, food, lodging, and equipment).
- Economists have developed methodologies to analyze the non-market, economic values associated with water attributes such as quality and flow. This literature helps explain how changes in various dimensions of a water resource influence people's demand for recreational activity, which affects consumption of complementary goods or services in the market economy.

THE IMPACT OF WATER-BASED RECREATION ON THE MARKET ECONOMY

The recreation and tourism sector is unique in that a wide range of recreational activities are not typically priced in conventional markets. Access to activities such as swimming and wildlife-viewing is often free in public recreation areas, and other activities such as fishing and hunting can frequently be pursued for nominal license fees. Thus, while some demand for recreational activities may be explicitly reflected in market transactions, the information provided by the direct purchase of recreational opportunities is incomplete. Demand for recreational activity, however, can be indirectly reflected in market transactions for complementary goods and services (e.g., expenditures on transportation, food, lodging, and recreational equipment). These expenditures, along with the GDP and employment impacts associated with them, are at least in part attributable to demand to participate in recreational activities. The following discussion examines these impacts in greater detail, beginning with an overview of the travel and tourism industry.

THE TRAVEL AND TOURISM INDUSTRY

Though the full extent of demand for water-based recreational activities such as swimming and fishing is not explicitly reflected in market transactions, the costs that people incur to pursue these recreational activities (e.g., hotel accommodations, transportation costs, equipment expenditures, etc.) are reflected in national income accounts. In this manner, recreational demand contributes to market activity in the travel and tourism industry, elements of which span the tertiary and quaternary mega-sectors of the economy (see Chapter 2). The discussion that follows provides a brief economic profile of the travel and tourism industry.

Neither the U.S. Economic Census nor the Bureau of Labor Statistics (BLS) provides data exclusively for the tourism industry. Thus, to develop a basic economic profile, we rely on the Bureau of Economic Analysis' (BEA) Travel and Tourism Satellite Accounts. The BEA Satellite Account data reveal that the travel and tourism sector accounted for $379 billion in value added to the economy in 2009, which translated to approximately 2.68 percent of U.S. gross domestic production. The real direct output of the travel and tourism industry, as measured by goods and services sold directly to visitors, increased 3.1 percent in 2010 to a total of $650.9 billion (2005 dollars). This represented a reversal in recent trends in the travel and tourism industry, which had declined by 9.3 percent in 2009 and 4.4 percent in 2008 (Zemanek, 2011). Exhibits 11-1 and 11-2 provide highlights of the real output from the travel and tourism sector over the last five years; the goods and services highlighted in the exhibit are not intended to be comprehensive, but are shown as examples of areas in which demand for recreational activities such as beach visits or fishing trips could drive industry output.

The BEA Satellite Accounts show that direct employment in the tourism industry decreased 0.45 percent in 2010, to 5,382,000 jobs. This rate of loss was much lower than experienced in 2009 (-8.14 percent) or 2008 (-3.45 percent). Nonetheless, direct employment in the tourism industry remained well below the 2007 peak of 6,096,000 jobs (Zemanek, 2011).

EXHIBIT 11-1. ANNUAL REAL OUTPUT OF TRAVEL AND TOURISM INDUSTRY, MILLIONS OF $2005

COMMODITY	2006	2007	2008	2009	2010
All tourism goods and services	**712,684**	**728,563**	**696,417**	**631,366**	**650,898**
Traveler accommodations	128,211	134,915	136,922	122,717	130,084
Food and beverage services	116,309	118,200	110,637	96,272	96,563
Passenger air transportation	109,834	112,377	108,535	101,692	110,830
Passenger water transportation	11,272	12,044	12,717	12,317	12,283
Highway tolls	608	580	532	562	516
Gasoline	59,420	59,746	53,017	48,942	48,498
All other recreation and entertainment	17,361	17,550	16,842	14,733	15,106
Source: Zemanek (2011)					

EXHIBIT 11-2. ANNUAL GROWTH IN REAL OUTPUT OF TRAVEL AND TOURISM INDUSTRY

COMMODITY	2006	2007	2008	2009	2010
All tourism goods and services	**2.9%**	**2.2%**	**(4.4%)**	**(9.3%)**	**3.1%**
Traveler accommodations	3.5%	5.2%	1.5%	(10.4%)	6.0%
Food and beverage services	3.0%	1.6%	(6.4%)	(13.0%)	0.3%
Passenger air transportation	1.7%	2.3%	(3.4%)	(6.3%)	9.0%
Passenger water transportation	8.2%	6.9%	5.6%	(3.1%)	(0.3%)
Highway tolls	(11.2%)	(4.6%)	(8.3%)	5.6%	(8.1%)
Gasoline	2.8%	0.5%	(11.3%)	(7.7%)	(0.9%)
All other recreation and entertainment	(1.3%)	1.1%	(4.0%)	(12.5%)	2.5%
Source: Zemanek (2011)					

In considering the role of the travel and tourism industry in the U.S. economy, it is important to consider how tourism expenditures affect other economic sectors. The BEA estimates that each dollar of U.S. tourism output stimulated $0.69 in nominal output in related economic sectors; thus, the $746.2 billion in direct nominal output for tourism in 2010 stimulated $514.9 billion in additional economic activity. Further, for every 100

direct tourism jobs generated, 41 jobs are indirectly generated in related sectors (Zemanek, 2011).

The overall data for the travel and tourism industry are not solely reflective of demand for water-based recreation and tourism; however, costs that recreational participants incur in order to realize demand for water-based recreational activities contribute to overall output for travel and tourism. The discussion that follows examines the market impacts of specific water-based recreational activities.

WATER-BASED RECREATION: PARTICIPATION AND EXPENDITURES

Beach Recreation

The National Ocean Economics Program estimates that tourism and recreation accounted for 1,737,156 jobs and contributed $69.65 billion in GDP to the economy of coastal regions of the United States in 2004. The majority of this economic output comes from the food and accommodations sectors, which combine to account for 92 percent of sector employment and 85 percent of sector GDP (Kildow et al., 2009). This economic output is driven in part by demand for ocean-based recreation in beach settings. The 2000 National Survey on Recreation and the Environment (NSRE) provides data on beach visitation by state. The NSRE data on participation rates indicate the percent of the U.S. population over the age of 16 that participated in recreational activities or visited recreational settings over the course of the year. Exhibit 11-3 summarizes this information for the ten states that report the highest rates of beach visitation.

EXHIBIT 11-3. BEACH VISITATION BY STATE, 2000

STATE	PERCENT OF U.S. ADULTS THAT VISITED A BEACH IN THIS LOCATION	NUMBER OF PARTICIPANTS (MILLIONS)	NUMBER OF DAYS (MILLIONS)
Florida	7.39	15.246	177.153
California	6.11	12.598	151.429
South Carolina	2.15	4.434	33.302
New Jersey	1.92	3.965	40.881
Texas	1.87	3.851	35.239
Hawaii	1.75	3.598	101.149
North Carolina	1.55	3.185	27.936
New York	1.44	2.964	29.225
Massachusetts	1.35	2.779	28.681
Maryland	1.23	2.530	18.696
U.S. Total	**30.03**	**61.922**	**853.288**

Source: Leeworthy et al. (2001)

Note: To the extent that beach users visit beaches in more than one state, there is overlap in the NSRE participation data.

As the leading travel destination for tourists, beaches are a key contributor to the economic output of the U.S. travel and tourism industry (Houston, 2008). According to the 2000 NSRE, beach visits were the number one recreational pursuit of participants in coastal recreation. The survey reported that 61.9 million Americans, or 30 percent of Americans aged 16 or older, visited a beach in 1999 (Leeworthy, 2001). Popular recreation activities pursued in conjunction with beach visits include swimming, snorkeling, scuba diving, surfing, and wind surfing.[35] Exhibit 11-4 provides an overview of national participation in these activities.

The pursuit of these and other coastal recreation activities drives economic output in the market economy, particularly in the travel and tourism sector. This is highlighted by the fact that in 2006, coastal states accounted for approximately 85 percent of U.S. tourism revenues (Houston, 2008). Though there is no national database for economic output related to beach recreation, there have been several case studies that have analyzed expenditures (e.g., parking, lodging, and rental equipment) associated with beach visits. For example, studies analyzing beaches in Southern California estimate beach trip expenditures ranging from $20.33 per person-day for day trips (Wiley, Leeworthy, and Stone, 2006) to $170 per person-day for overnight trips (Department of Boating and Waterways and State Coastal Conservancy, 2002). These expenditures in turn contribute to economic output and employment in the tourism industry.

EXHIBIT 11-4. COASTAL RECREATIONAL PARTICIPATION BY ACTIVITY, 2000

ACTIVITY	PARTICIPATION RATE (PERCENT OF U.S. ADULTS)	NUMBER OF PARTICIPANTS
Visit Beaches	30.03	61,922,234
Swimming	25.53	52,637,390
Snorkeling	5.07	10,459,568
Scuba Diving	1.35	2,786,215
Surfing	1.59	3,285,611
Wind Surfing	0.39	800,016
Any Coastal Activity	43.30	89,270,965

Source: Leeworthy (2001)

Note: To the extent that recreational users participate in more than one recreational activity, there is overlap in the NSRE participation data.

[35] Fishing and boating are also popular pursuits that may be associated with a visit to a beach. These activities will be explored in more detail in later sections of this report.

Fishing

Recreational fishing is one of the most popular outdoor recreation activities in America. In 2006, according to the U.S. Fish and Wildlife Service's (USFWS) National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, 30.0 million Americans ages sixteen and older participated in recreational fishing in the United States. Freshwater fishing accounted for the majority of this fishing effort, with 25.4 million participants. In the same period, saltwater fishing attracted 7.7 million anglers.[36] The FWS survey found that collectively, these 30.0 million anglers accounted for 516.8 million angler days and 403.5 million fishing trips over the course of 2006, which translated to $42.0 billion in recreational fishing-related expenditures (USFWS, 2006a). Exhibit 11-5 displays a breakdown of these expenditures, including trip-related expenses, equipment purchases, and other miscellaneous expenditures.

Recreational fishing is especially important in that it is considered a "gateway" recreational activity. A 2008 joint report by the Recreational Boating and Fishing Foundation (RBFF) and the Outdoor Foundation (OF), based on a national survey of recreation participants, found that over 77 percent of anglers participate in additional outdoor recreational activities (RBFF & OF, 2009). Fishing is particularly significant in driving demand for boating, as the survey found that 33 percent of anglers own a boat and 67 percent of anglers went boating in 2008. Fishing is therefore important not only for fishing-related economic impacts, but also for its contribution to participation in other recreational activities.

EXHIBIT 11-5. RECREATIONAL FISHING EXPENDITURES, 2006

EXPENDITURE CATEGORY	AMOUNT
Total trip-related	**$17.9 billion**
Food and lodging	6.3 billion
Transportation	5.0 billion
Other trip costs	6.6 billion
Total equipment expenditures	**$18.8 billion**
Fishing equipment	5.3 billion
Auxiliary equipment	0.8 billion
Special equipment	12.6 billion
Total other fishing expenditures	**$5.4 billion**
Magazines, books	0.1 billion
Membership dues and contributions	0.2 billion
Land leasing and ownership	4.6 billion
Licenses, stamps, tags, and permits	0.5 billion
Total Fishing Expenditures	**$42.0 billion**
Source: USFWS (2006a)	

[36] Some individuals participate in both freshwater and saltwater fishing, creating an overlap in participant estimates.

Boating

Recreational boating encompasses a broad range of activities, including float-based recreation (e.g., kayak and canoe trips), non-motorized boating (e.g., sailing), and motorized boating (e.g., power boats). The U.S. Forest Service (USFS) estimated in 2009 that approximately 89.1 million Americans, or 35.6 percent of the population, participate in some form of recreational boating (Cordell et al., 2009). Exhibit 11-6 displays a breakdown of recreational boating activity based on data from the 2000 NSRE.

EXHIBIT 11-6. RECREATIONAL BOATING PARTICIPATION, 2000

ACTIVITY	PARTICIPATION RATE (PERCENT OF U.S. ADULTS)	NUMBER OF PARTICIPANTS
Motor boating	24.79	51,113,437
Sailing	5.07	10,445,548
Personal Watercraft Use	9.42	19,423,722
Canoeing	9.71	20,027,169
Kayaking	3.26	6,723,240
Rowing	4.48	9,234,883
Water-skiing	8.05	16,604,129
Source: Leeworthy (2001)		

As mentioned in the overview of recreational fishing in the U.S., fishing activity is a primary driver for participation in boating: 25.8 million anglers, or 67 percent of all anglers in the RBFF & OF (2009) survey, participated in 427 million boating days in 2008. This correlation between fishing and boating activity implies that any restrictions to fishing activity, whether due to poor water quality or other concerns, could negatively affect boating as well.

According to data collected by the National Marine Manufacturers Association (NMMA), the recreational boating industry reported $30.8 billion in sales of goods and services in 2008, including over $21 billion in trip expenditures (quoted in Haas, 2010). In 2007, recreational boating expenditures helped support 18,940 boating businesses that employed over 154,300 people (quoted in Haas, 2010). Exhibit 11-7, based on data from a 2010 survey of recreational boaters in Massachusetts, illustrates the distribution of recreational boating expenditures by category (Hellin et al., 2011).

EXHIBIT 11-7. RECREATIONAL BOATING EXPENDITURES IN MASSACHUSETTS, 2010

EXPENDITURE CATEGORY	AMOUNT	PERCENT OF TOTAL
Total Trip and Visit Spending (May-Oct 2010)		
Auto gas and oil	12,924,954	2.44%
Boat fuel and oil	84,197,955	15.91%
Fishing gear, bait, ice, etc.	13,386,277	2.53%
Groceries	24,924,326	4.71%
Launch Fees	5,166,429	0.98%
Lodging (camping or B&B)	2,638,773	0.50%
Lodging (hotel or motel)	6,362,194	1.20%
Pump-out fees	264,420	0.05%
Recreation and entertainment	4,054,272	0.77%
Restaurant meals and drink (including take-out)	31,842,663	6.02%
Shopping and souvenirs	4,350,731	0.82%
Transient / guest dockage (marina fees)	33,307,190	6.30%
Total	**$223,420,184**	**42.23%**
Seasonal Maintenance		
Installation of new engine	18,888,545	3.57%
Installation of new products	15,191,344	2.87%
Routine maintenance	63,051,859	11.92%
Vessel repair	33,957,951	6.42%
Total	**$131,089,699**	**24.78%**
Seasonal Other		
Boat insurance	34,220,645	6.47%
Boat loan payment	44,535,093	8.42%
Dockage, mooring, seasonal storage	66,008,923	12.48%
New or replacement products	5,005,599	0.95%
New trailers	19,567,206	3.70%
Other	5,246,477	0.99%
Total	**$174,583,943**	**33.00%**
GRAND TOTAL SPENDING FOR MA	**$529,093,826**	**100%**
Source: Hellin et al. (2011)		

Wildlife and Nature Viewing

According to the USFWS 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, 71.1 million Americans, or 31 percent of the U.S. population ages 16 and older, participated in wildlife and nature viewing in 2006. Of these 71.1 million participants, 23.0 million engaged in trips away from home for wildlife viewing purposes (USFWS, 2006a). To the extent that wildlife and nature viewing occurs in environments near water resources, water attributes that can influence both the abundance of wildlife and the aesthetic quality of the environment can affect activity. The 2000 NSRE analyzed recreational viewing activity in all natural settings and in water-based environments. Exhibit 11-8 summarizes this information, providing participation data for wildlife and nature viewing across the U.S. As the exhibit indicates, a significant share of those who participate in wildlife and nature viewing do so in water-based settings.

EXHIBIT 11-8. WILDLIFE AND NATURE VIEWING BY SETTING, 2000

ACTIVITY	WATER-BASED SETTINGS		ALL NATURAL SETTINGS	
	PARTICIPATION RATE (PERCENT OF U.S. ADULTS)	NUMBER OF PARTICIPANTS	PARTICIPATION RATE (PERCENT OF U.S. ADULTS)	NUMBER OF PARTICIPANTS
Bird Watching	30.2	62,200,000	31.8	67,800,000
Viewing Other Wildlife	22.4	46,200,000	44.1	93,900,000
Viewing or Photographing Scenery	37.0	76,300,000	59.5	126,800,000
Source: Leeworthy (2001) & NSRE (2001)				

Data on the market impacts of wildlife and nature viewing in water-based surroundings are not available; however, the USFWS 2006 survey provides expenditure data for all wildlife and nature viewing activity in the U.S. The survey results indicate that wildlife and nature viewing expenditures for 2005 totaled $45.7 billion, including $12.9 billion for trip-related expenditures and $23.2 billion for equipment expenditures. Exhibit 11-9 provides detail on the distribution of expenditures across different expense categories.

EXHIBIT 11-9. WILDLIFE AND NATURE VIEWING EXPENDITURES, 2006

EXPENDITURE CATEGORY	AMOUNT
Total trip-related	**$12.9 billion**
Food and lodging	7.5 billion
Transportation	4.5 billion
Other trip costs	0.9 billion
Total equipment expenditures	**$23.2 billion**
Wildlife-watching equipment	9.9 billion
Auxiliary equipment	1.0 billion
Special equipment	12.3 billion
Total other expenditures	**$9.6 billion**
Land leasing and owning	6.6 billion
Plantings	1.6 billion
Membership dues and contributions	1.1 billion
Magazines, books	0.4 billion
Total Wildlife-watching Expenditures	**$45.7 billion**
Source: USFWS (2006a)	

Hunting

The USFWS 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation found that 12.5 million people ages 16 and older pursued hunting in 2006. These hunting participants took 185 million trips that accounted for 220 million hunting days (USFWS, 2006a). Similar to wildlife-viewing, hunting is a wildlife-dependent recreational activity. Therefore, to the extent that water attributes such as quality and

availability influence natural habitats and wildlife populations, these attributes can affect participation. Hunting for waterfowl, such as geese and duck, may be particularly sensitive to the quality of the aquatic environment. According to an addendum to the USFWS survey, waterfowl hunting accounted for 1.3 million unique hunters and more than 13 million hunting days in 2006. These waterfowl hunters incurred over $900 million in trip-related and equipment expenditures (USFWS, 2006b).[37] Exhibit 11-10 provides a more detailed look at waterfowl hunting participation and related expenditures.

EXHIBIT 11-10. WATERFOWL HUNTERS, DAYS, AND EXPENDITURES, 2006

CATEGORY	AMOUNT
Hunters	
Duck	1,147,000
Geese	700,000
Total	**1,306,000**
Hunting Days	
Duck	12,173,000
Geese	6,008,000
Total	**13,071,000**
Total Waterfowl Hunting Expenditures	
Trip Expenditures	$493,987,000
Food and Lodging	$177,125,000
Transportation	$184,329,000
Other Trip Costs	$132,533,000
Equipment Expenditures	$406,298,000
Total	**$900,285,000**
Source: USFWS (2006b)	

WATER USE

OVERVIEW OF WATER-BASED RECREATION

In contrast to off-stream water uses such as irrigation, which involve the withdrawal and consumption of water resources, water use for recreational activities is considered a non-consumptive, in-stream use. While recreational fishermen, boaters, and others rely upon surface water to engage in recreational activities, none of these pursuits requires the diversion or withdrawal of water from a water resource.

The surface water resources used to support recreation and tourism can be divided into two main categories: freshwater and saltwater. Freshwater recreation consists of recreational activity occurring in or on freshwater resources such as rivers, streams, and lakes. Saltwater recreation involves the use of saltwater resources such as oceans, bays, and tidal portions of rivers. Exhibit 11-11 draws on data from the 2000 NSRE to illustrate

[37] Hunting expenditures across all species and environments totaled $22.9 billion in 2006, including $6.7 billion for trip-related expenditures, $10.7 billion for equipment expenditures, and $5.5 billion for other expenditures (e.g., licenses and membership dues) (USFWS, 2006a).

the distribution of water-based recreational activity across freshwater and saltwater resources.

EXHIBIT 11-11. RECREATIONAL ACTIVITY IN FRESH- AND SALTWATER RESOURCES, 2000

ACTIVITY	FRESHWATER		SALTWATER	
	PARTICIPATION RATE (PERCENT OF U.S. ADULTS)	NUMBER OF PARTICIPANTS	PARTICIPATION RATE (PERCENT OF U.S. ADULTS)	NUMBER OF PARTICIPANTS
Visit Beaches	17.12	35,294,236	30.03	61,922,234
Visit Waterside Besides Beaches	24.71	50,943,698	4.50	9,269,685
Swimming	28.51	58,771,631	25.53	52,637,390
Snorkeling	1.90	3,922,436	5.07	10,459,568
Scuba Diving	0.66	1,350,584	1.35	2,786,215
Surfing	0.00	0	1.59	3,285,611
Wind Surfing	0.46	939,651	0.39	800,016
Fishing	29.63	61,091,330	10.32	21,283,808
Motor boating	20.52	42,306,567	7.11	14,660,277
Sailing	2.70	5,563,676	2.98	6,136,163
Personal Watercraft Use	7.60	15,665,261	2.57	5,304,476
Canoeing	9.07	18,708,611	1.05	2,171,666
Kayaking	2.23	4,593,991	1.33	2,746,502
Rowing	4.08	8,411,523	0.53	1,098,999
Water-skiing	7.22	14,894,922	1.15	2,375,709
Bird Watching in Water-based Surroundings	16.84	34,718,973	7.17	14,784,752
Viewing Other Wildlife in Water-based Surroundings	20.20	41,641,844	6.45	13,303,288
Viewing or Photographing Scenery in Water-based Surroundings	24.76	51,046,395	9.19	18,943,684
Hunting Waterfowl	2.21	4,558,051	0.33	680,380

Source: Leeworthy (2001)

Note: To the extent that recreation participants engaged in both freshwater and saltwater recreation, there is overlap in the participation data.

COMPETITION IN RECREATIONAL WATER USE

As population growth and other demographic trends intensify demand for water resources, the competition between recreation and other uses of water, as well as potential conflicts between or among various forms of water-based recreation, is likely to increase (CBO, 1997). The discussion that follows examines the nature and implications of these issues in greater detail.

Recreation Versus Other Water Uses

Historically, water law has given greater priority to off-stream water uses (e.g., irrigation) than to in-stream water uses such as recreation. The traditional water rights regime was

reinforced in part because the economic values of in-stream flows, whether for recreational purposes, ecosystem services, or natural habitat protection, were not well understood. In-stream water uses were thus marginalized in favor of consumptive water uses such as irrigation, which provides market benefits by supporting crop production, and municipal water uses, which provide essential water supplies to industrial, commercial, and residential users. This traditional system, particularly in western states with scarce water resources, commonly resulted in significant reductions in water levels and in-stream flows, which in turn negatively affected water resources' ability to support ecosystem services, natural habitats, and recreational activities (Zellmer, 2006).

As the economic value of ecosystem services, recreational activity, and habitat protection have become better understood in recent decades, state governments have begun to modify their approaches to water resource management. In particular, states have begun to enact protective in-stream flow legislation designed to preserve water flows and support ecological habitats and recreational activities (Zellmer, 2006). This in-stream flow protection represents progress in protecting in-stream flows for recreational uses, but the effort to adopt this legislation has not yet been comprehensive. As of 2009, "over 90% of stream miles in most states do not have full in-stream flow protection," and "in more than half of all states and provinces, over 75% of all streams have no legally recognized in-stream flow protection" (Annear et al., 2009). Thus, though the spread of this legislation has begun to help restore and protect water flows for recreational uses, pressure from competing water uses is likely to persist. With a large portion of the economic value of recreational activity consisting of non-market impacts, recreational water use of in-stream flows is likely to remain at risk of being marginalized in favor of in-stream or off-stream water uses that support crop production, manufacturing, or other market-based activities.

Competition Among Recreational Users

Competition between recreational and alternative uses of water is not the only factor that affects demand for water-based recreation; inter-activity and intra-activity competition also affects participation in recreational activities (Kakoyannis et al., 2002). Inter-activity conflict consists of competition among recreational activities for scarce water resources; an example of this would be recreational boaters and swimmers competing for access to river or lake resources. Intra-activity conflict consists of competition among recreational participants engaging in the same activity; crowding, which can be defined as a "negative evaluation of a certain density or number of encounters," is the most common example of intra-activity conflict (Shelby et al., 1989). The potential for inter-activity and intra-activity conflicts represents an additional challenge for water resource managers when determining how to provide for recreational uses in a water management framework.

LONG-TERM CHALLENGES

Two of the greatest long-term challenges to water resource management worldwide are climate change and population growth. Though the projected impacts of climate change on U.S. water supplies are not as significant as those for low-latitude and low-precipitation countries, climate change is expected to affect both water temperatures and

streamflow or water levels (Morris et al., 2009). Water temperature changes as a result of climate change could negatively affect habitat conditions in cold water fisheries, such as valuable trout fisheries in New England (Kimball, 1997). With anglers ranking fish abundance as a key attribute in determining their demand for recreational fishing, any negative effects of water temperature increases upon fish populations in cold water fisheries could result in decreased recreational fishing activity and corresponding economic losses in the local or regional economy (Freeman, 1995). In other regions, water temperature increases could have mixed impacts on fishing populations as temperature increases affect different species in different ways. A study in North Carolina found that while increased water temperatures could reduce rainbow trout populations, brook trout populations could grow as their range of suitable habitat increases (Morris et al., 2009). Climate change also has the potential to affect flow rates and water levels, as higher temperatures can result in reduced snowpack and therefore reduced snowmelt. Studies have shown that recreational boating is "sensitive to lake, reservoir, and stream levels;" thus, reductions in water flows or levels due to climate change could alter recreational boating demand (Morris et al., 2009). Reductions in streamflow could also affect demand for water-enhanced recreational activities such as hiking, camping, and hunting, where participants have shown that proximity to water resources positively influences recreational demand. The projected impacts vary by region, with western states most vulnerable because of their reliance upon snowmelt to supply streamflow (Morris et al., 2009).

Population growth represents another long-term challenge for water management regimes. As population growth drives increasing demand for food and water, water demand from the agricultural and municipal use sectors is projected to increase, resulting in even more competition for scarce water resources. This could present an additional strain on in-stream flows that support recreational activity and natural habitat preservation.

WATER QUALITY ISSUES AFFECTING RECREATIONAL WATER USE

The Clean Water Act mandates that each state develop and implement water quality standards designed to support the national goal of "fishable/swimmable" waters. The supply of water for recreation is dependent on the application of these standards to determine whether a water resource can support recreational uses. If these standards cannot be met, the resource may be deemed unsuitable for recreational use, and public health authorities may restrict recreational access. In the context of recreational uses of water, these water quality standards focus on physical, chemical, and biological attributes of water quality that impair the aquatic environment and/or pose health risks to people engaging in water-based recreational activities. The discussion below briefly summarizes the nature of potential impairments to both fishing and swimming.

Water Quality Issues Affecting Fishing

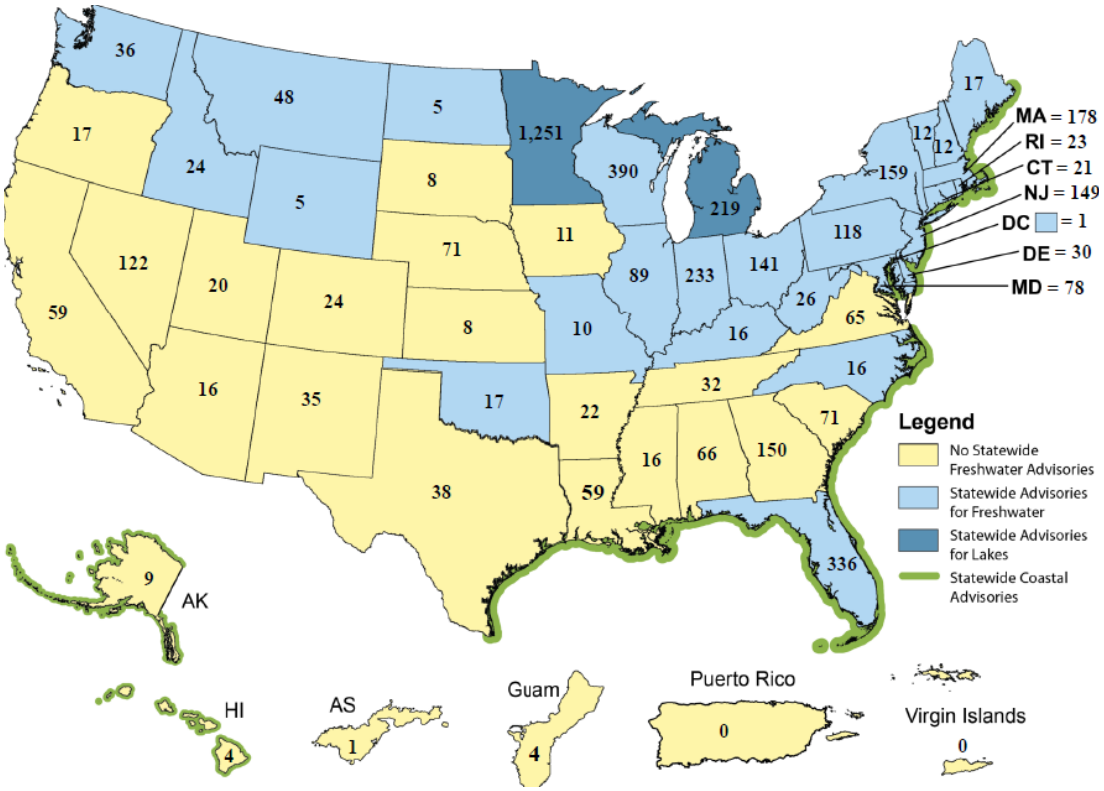
Water quality can have significant impacts on the supply of recreational fishing. With fish populations requiring water of sufficient quality to survive and thrive, and recreational fishermen rating fish abundance among the most important factors affecting

fishing demand, it is important to note the types of issues that can impair a water resource's ability to support recreational fishing (Freeman, 1995).

- **Bioaccumulative Substances:** Toxic substances such as metals, PCBs, and pesticides bioaccumulate in fish tissues; as larger fish or animals consume contaminated fish, the contamination is passed through the food web in a process called biomagnification. Contamination of fisheries from bioaccumulative substances represents a threat to people and to wildlife who consume fish (EPA, 2002).
- **Eutrophication:** Nutrient-rich pollution from urban and rural sources such as sewage, stormwater, and agricultural fertilizers fuels biomass production in aquatic ecosystems. This biomass production depletes the dissolved oxygen concentrations of the nutrient-enriched water resources, which in turn decreases the ability of these aquatic habitats to support fish populations (Selman et al., 2009). Further, biomass production in the form of algal blooms can decrease water clarity and give rise to unpleasant odors in the water resource (Dodds et al., 2008).
- **Pathogens:** Pathogenic microorganisms from inadequately treated sewer and other wastewater discharges can cause disease from ingestion of contaminated water. These risks can be severe in the context of primary contact recreation (i.e., activities that involve submersion in water, such as swimming). In addition, the recreational harvest of shellfish from waters containing bacterial or viral contaminants poses a health risk to those who consume them (NY-NJ HEP, 1996).

These contamination issues can negatively impact fish populations and frequently result in advisories that restrict or ban the consumption of fish in affected waters. Based on state and Federal data, 4,598 fish advisories were in place in 2010 covering 17.7 million lake acres and 1.3 million river miles in the U.S. This means that 42 percent of national lake acreage and 36 percent of national river miles were affected by sufficient contamination problems to require advisories that ban or restrict fish consumption (EPA, 2010b). Exhibit 11-12 shows how these fishing advisories were distributed across the U.S.

EXHIBIT 11-12. NUMBER OF FISH ADVISORIES BY STATE



Source: EPA, 2011a.

Water Quality Issues Affecting Swimming

Similar to fishing, water quality requirements determine the supply of water resources that can support recreational swimming. For the purposes of water quality standards, swimming falls into the category of "primary contact recreation," which encompasses activities that involve submersion in water. The two main contamination issues affecting recreational swimming are pathogens and eutrophication.

- **Pathogens:** Again, pathogenic contamination results from discharges that introduce micro-organisms such as bacteria, viruses, and protozoans to water bodies. The presence of pathogenic contamination significantly elevates the human health risks associated with primary contact recreation in a water body, as diseases stemming from pathogenic bacteria and viruses include typhoid fever, cholera, Hepatitis A, and dysentery. To determine if water quality is sufficient for primary contact recreation, state environmental agencies monitor fecal and total coliform bacteria in water resources. Fecal and total coliform bacteria are considered "indicator microorganisms" that signal the existence of fecal contamination, which in turn indicates the potential presence of pathogenic microorganisms (Anderson et al.).

- **Eutrophication:** As discussed in the water quality section for recreational fishing, eutrophication results from pollution from sources such as sewage, stormwater, and agricultural fertilizers. Runoff or discharges from these sources can create nutrient-rich water environments that spur biomass growth such as algae. In the context of primary contact recreational activity such as swimming, the important pollution implications from eutrophication involve unattractive odors and diminished clarity (Dodds et al., 2008). While aesthetic impacts such as these do not necessarily represent significant human health risks, they do have important implications for recreational demand at affected water resources. Studies have shown that the general public makes judgments about water quality based "primarily on vision… and secondarily on smell and touch" (Kakoyannis et al., 2002). Unpleasant odors and reductions in water clarity can thus diminish public perceptions about water quality and negatively impact demand for recreation.

Sufficient contamination of water resources results in the implementation of swimming advisories that ban or restrict swimming in order to preserve public health and safety. The majority of these advisories involve beach closures or restrictions resulting from bacteria-related contamination, but freshwater resources such as rivers, streams, and lakes are also affected by swimming bans and advisories due to other concerns. State water quality monitoring data through 2011 indicate that for 97,220 miles of assessed rivers and streams in the United States, 39.4 percent are impaired with respect to primary contact recreation. For lakes and reservoirs, the data indicate that 13.9 percent of the 3,077,549 acres assessed are impaired with respect to primary contact recreation (EPA 2011c). As for beaches, 2010 witnessed 24,091 "closing and advisory days" at beaches in the U.S. (Dorfman et al., 2011). While the Gulf of Mexico spill contributed in part to a 51 percent increase in the number of precautionary beach closures or advisories (7,223 days in 2010), the leading cause of beach closures or advisories in 2010 was violation of water quality standards for bacteria and other pathogens (16,828 days) (Dorfman et al., 2011).

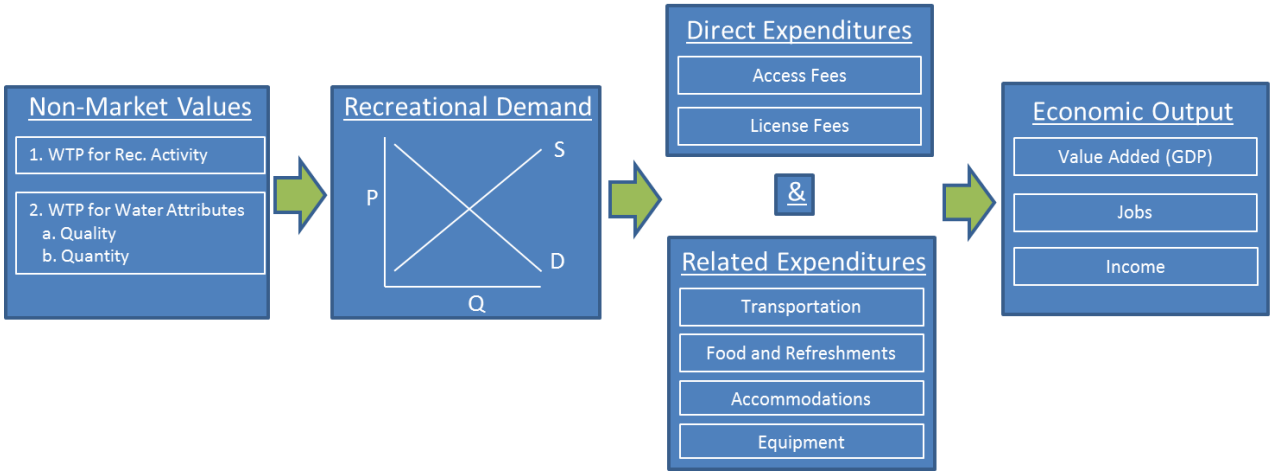
VALUE OF WATER USE

Water attributes such as quality and flow are important factors in supporting water-based recreational activities that drive output in the tourism sector. Understanding the values placed on these attributes helps explain how changes in water resources influence demand for recreational activity, which in turn affects consumption of market goods. In the context of recreation and tourism, however, attempts to derive a value for these attributes are complicated by the fact that a great deal of recreational activity occurs outside conventional markets. Because access to many water-based recreational activities and settings is not priced in competitive markets, and because water-based recreation represents a non-consumptive in-stream water use, it is difficult to use market data to estimate a monetary value for water attributes that serve as inputs to demand for recreation and tourism (Raucher et al., 2005).

In response to these analytic challenges, economists have developed alternative methods to evaluate and determine the non-market value (or benefit) of the attributes of a water resource that affect demand for water-based recreation. These methods rely on revealed and stated preference techniques that analyze willingness to pay for water attributes that

support recreation (Hanemann, 2005). This section reviews estimates from the literature on the non-market, economic values (or benefits) that the public holds for improvements in water supply or quality in the context of water-based recreational activity. While these values do not directly reflect market activity, they provide important information on how water attributes influence demand for recreational activity, which in turn drives market transactions and economic output. Exhibit 11-13 illustrates this relationship.

EXHIBIT 11-13. THE RELATIONSHIP BETWEEN NON-MARKET VALUES AND ECONOMIC OUTPUT



NON-MARKET VALUE ESTIMATES FOR WATER-BASED RECREATIONAL ACTIVITIES

Recreational pursuits such as fishing, boating, and swimming provide benefits above and beyond the costs of participating in these activities. To the recreational participant, these benefits represent non-market values known as "consumer surplus." To derive monetary estimates of these benefits, researchers use stated and revealed preference techniques to empirically analyze the consumer surplus that the public enjoys while engaged in recreation.

Comparability between individual empirical analyses on this subject is limited because values can fundamentally differ depending on factors such as geographic region, socioeconomic conditions, and model choice; however, researchers can use meta-analyses to provide a broader perspective. Meta-analyses, which involve the collection and analysis of existing studies, allow researchers to "statistically measure systematic relationships between reported valuation estimates," thereby "capturing heterogeneity within and across studies" (Bergstrom et al., 2006). Researchers can thus use meta-analyses to gain a more comprehensive understanding of the economic value of changes in the attributes of natural resources that support recreational activities, as well as a better understanding of the economic welfare benefits attributable to participation in the activities themselves.

Several meta-analyses have analyzed the value of outdoor recreational activities, including Loomis (1999), Rosenberger and Loomis (2001), and Loomis (2005). Loomis

(2005), the most recent meta-analysis, covers 1,239 observations across more than thirty years of economic research. Exhibit 11-14 displays the results of this meta-analysis, presenting average consumer surplus values per person-day of activity. The activities reported here are limited to those commonly accepted as water-based or water-enhanced recreational activities.[38] This information provides context for the discussion below, which focuses more directly on the extent to which marginal changes in the attributes of water resources can influence recreational values.

EXHIBIT 11-14. AVERAGE CONSUMER SURPLUS VALUES PER PERSON-DAY OF ACTIVITY, $2004

ACTIVITY	STUDIES	ESTIMATES	MEAN	RANGE	
Bird watching	4	8	$29.60	$5.80	$78.46
Fishing	129	177	$47.16	$2.08	$556.82
Float boating/rafting/canoeing	20	81	$100.91	$2.70	$390.82
Going to the beach	5	33	$39.43	$3.78	$117.82
Hiking	21	68	$30.84	$0.40	$262.04
Hunting	192	277	$46.92	$2.60	$250.90
Motor boating	15	32	$46.27	$3.78	$203.62
Swimming	11	26	$42.68	$2.20	$134.34
Waterskiing	1	4	$49.02	$15.13	$70.07
Wildlife Viewing	69	240	$42.36	$2.40	$347.88
Windsurfing	1	1	$395.47	$395.47	$395.47
Source: Loomis (2005)					

IMPACT OF WATER SUPPLY ON NON-MARKET RECREATIONAL USE VALUES

The amount or supply of water available to support recreational activity (e.g., streamflow or lake levels) can have a significant impact on people's willingness to pay for recreational activities. Supply factors influence recreational demand "by altering the safety of recreational activities and recreationists' perceptions of crowding, scenic beauty, and recreational satisfaction or quality" (Kakoyannis et al., 2002, p. 36). Studies analyzing the influence of water flows or levels on recreation have generally shown that recreationists' preferences follow an inverted U-shaped curve, with recreational users most valuing intermediate amounts and finding low or high amounts to be less preferable (Kakoyannis et al., 2002; Shelby et al., 1995; Brown et al., 1991; Brown, 2004). These preferences, however, vary by location, activity (e.g., boating versus fishing) and even within recreational activities (e.g., flow levels affect elements of a rafting trip such as safety and challenge-level differently); thus, it is not possible to derive a single estimate for an optimal flow rate or water level across all activities and settings (Kakoyannis et al., 2002; Brown, 2004). The discussion below provides additional information on these issues.

[38] While participation in winter sports such as skiing and snowboarding also relies upon water, these activities are not ordinarily included in discussions of water-based or water-enhanced recreation.

Fishing

Studies analyzing water flow impacts on fishing demand have found that increased streamflow and water levels of provide benefits (i.e., increases in consumer surplus) to anglers up to a certain flow level. Water flow levels help to shape recreational fishing opportunities by affecting the habitat conditions of fish populations and influencing recreational access and safety. Eiswerth et al. evaluated the recreational benefits of increasing water levels at Nevada's Walker Lake, which provides sport fishing and other water-based recreational opportunities in Walker Lake State Park. The lake is in danger of drying up and is one of only three lakes in Nevada that support recreational fishing. Results indicated that lake users valued a one-foot increase in lake level in the range of $12-$18 per user per year. Non-users of the lake maintained an option value in the range of $0.60-$0.90 per person per year for each additional foot of water (2000 dollars; Eiswerth et al., 2000). Similarly, Loomis et al. found that potential streamflow reductions as a result of hydropower development could substantially reduce both recreational benefits and angling trips on an Idaho river that is popular with anglers (Loomis et al., 1985). In a national study of streamflow benefits, Hansen and Hallam found that for recreational fishing, the benefits of marginal increases in streamflow can sometimes exceed the marginal value of agricultural water use (Hansen et al., 1991).

While these studies indicate that increases in water flow have the potential to increase benefits to anglers, streamflow beyond a certain level can negatively affect recreational opportunities by reducing the suitability of fish habitats and decreasing fish abundance. This maximum-benefit flow level varies depending on the water source and fish type, but all else equal, "given a certain fish population, fishing quality tends to increase with flows up to a point and then decrease with further flow increases, exhibiting the familiar inverted-U relation" (Brown 2004).

Boating

Access to recreational boating opportunities is dependent upon streamflow and water level conditions. Water supply determines what boating activities (e.g., power boating, sailing, kayaking, and canoeing) can take place by influencing factors such as recreational access, safety, and "floatability," which is defined as the "capacity of the river to support boating without excessive hits, stops, drags and portages" (Brown, 2004). Studies analyzing boaters' preferences for flow levels have also generally found that preferences follow the shape of an inverted U-curve, with intermediate flows being preferred above either low or high flow levels (Shelby et al., 1995; Brown et al., 1991; Shelby et al., 1992). As with fishing, the exact flow level that provides maximum benefits depends on the water body and on the type of boating activity. For certain boating or paddling activities, such as canoeing, this benefit-maximizing flow level may be lower than other activities, such as white-water rafting, where users can value higher challenge-levels as part of the recreational experience (Shelby et al., 1995). Overall, the economic benefits of different stream flows to participants in recreational boating are similar to those for other water-based recreational opportunities: up to a certain point, marginal increases in flows increase benefits; beyond a certain level, however, marginal increases diminish

recreational benefits as concerns such as safety come to outweigh increased access opportunities.

Swimming

In-stream flows and water levels in streams and lakes influence the benefits provided to recreational swimmers by influencing variables such as "water depth, velocity and temperature" (Brown, 2004). While preferences vary depending on user-specific factors such as skill level, studies have generally found that preferences for flow follow the familiar inverted U-curve. A case study on the Clavey River in California found that swimmers considered flows ranging from 10 to 250 ft^3/second to be acceptable, but rated the range from 20 to 50 ft^3/second as optimal. Flows over 350 ft^3/second were deemed unsafe and flows below 20 ft^3/second were found to create water quality issues, particularly if the low flow levels persisted for an extended period of time (Brown, 2004). In general, high flows create safety hazards and can decrease water temperature to uncomfortable levels, while low flows can create water quality issues. Thus, intermediate flows are generally most preferred.

Wildlife and Nature Viewing

While wildlife and nature viewing is not a water-dependent recreational activity, proximity to water resources has the potential to enhance the quality of a user's recreational experience. In an analysis of streamflow impacts on aesthetic appeal, results indicated that moderate flow levels maximize aesthetic quality. Intermediate flows were most preferred because, among other factors, flow levels that are too high can wash away sand bars, create excess turbidity and "create an unwelcome sense that events are out of control," while flow levels that are too low can limit the aesthetic appeal of waterfalls and rapids (Brown, 2004). Another study focusing on recreation in the San Joaquin Valley in California analyzed how increases in flows up to an ecologically "optimal level" (as determined by biologists) affected recreational benefits for hunters, anglers, and wildlife viewers. This study found that increases in flows, particularly in dry areas, could provide recreational benefits in the range of $303 to $348 per acre foot of water (1992 dollars; Creel et al., 1992). The value estimates of these benefits were found to be competitive with other uses of water such as irrigation.

IMPACTS OF WATER QUALITY ON NON-MARKET RECREATIONAL USE VALUES

The quality of water resources is also a key factor in determining supply and demand for water-based recreational activities. As noted above, contamination problems can force public health authorities to restrict or ban recreational use of a water resource; in these cases, the economic benefits provided by water-based recreation can be lost to the local economy as recreational participants travel to other sites or make the decision not to recreate at all. On the demand side, the literature indicates that water quality can have significant effects on how recreational users perceive the quality of their recreational experience. In this manner, water quality will directly influence the non-market benefits that users experience from participating in various recreational activities. These non-market benefits influence demand for recreation, which in turn affects consumption of

complementary goods and services in the market economy; thus, water quality can impact economic output related to water-based recreation.

While benefits associated with water quality improvements may vary depending on factors such as initial water quality, the recreational activity of interest, and location, the literature generally shows that improvements in water quality increase the quality of recreational experiences and the economic benefits associated with these experiences. For example, Ribaudo and Epp (1984) analyzed the recreational benefits of restoring water quality in Lake Champlain's St. Albans Bay. The bay had historically provided water-based recreational opportunities for swimming, fishing, boating, and more, before eutrophication problems caused a significant decline in recreational demand. Results indicated that restoration of water quality would provide a mean level of annual benefits of $123 to current users and $97 to former users (1984 dollars; Ribaudo et al., 1984). The discussion that follows provides additional details on how water quality can affect the quality of recreational experiences, demand for recreational outings, and the economic benefits associated with recreational trips across different recreational activities.

Fishing

The quality of water resources directly affects supply and demand for recreational fishing. On the supply side, elevated levels of bioaccumulative contaminants (e.g., PCBs and metals) can require that fish consumption be restricted or banned. Studies have shown that fish consumption advisories implemented due to contamination concerns can negatively affect angler welfare (Jakus et al., 2002). Exhibit 11-15 summarizes the results of a literature review performed by Jakus et al. with respect to how fish consumption advisories affected economic benefits for angling trips.

EXHIBIT 11-15. ESTIMATES OF LOST ECONOMIC BENEFITS DUE TO FISH CONSUMPTION ADVISORIES

AUTHORS	MODEL[1]	LOCATION	LOST ECONOMIC VALUE PER TRIP[2]
Chen and Cosslett (1998)	MNL	41 Great Lakes sites	$4.93
Chen and Cosslett (1998)	MNP	41 Great Lakes sites	$5.51
Breffle et al. (1999)	MNL	Green Bay, WI	$4.40
Montgomery and Needelman (1997)	MNL/MRW	2,586 New York ponds, lakes	$2.04
Parsons and Hauber (1998)	MNL	2,029 Maine lakes, rivers	$2.25
Jakus et al. (1997)	MNL/MRW	14 middle Tennessee lakes	$2.13
Jakus et al. (1997)	MNL/MRW	14 east Tennessee lakes	$3.29
Jakus et al. (1998)	MNL/MRW	12 east Tennessee lakes	$2.49
Parsons et al. (1999)	HLM	14 middle Tennessee lakes	$2.04
Parsons et al.	MRW	14 middle Tennessee lakes	$2.12

Source: Jakus et al. (2002)

[1] MNL = Multinomial logit model; MNP = Multinomial probit model; HLM = Hausman, Leonard, and McFadden index; MRW = Morey, Rowe and Watson index.

[2] In 2000 dollars.

As previously noted, contamination problems have the potential to negatively affect recreational fishing demand by diminishing the ability of water resources to support fish populations (Freeman, 1995). In a 2003 study of the effect of water quality improvements on recreational use benefits in six northeastern states, Parsons et al. found that average benefits for recreational fishing ranged from approximately $3 to $8 per person (in 1994 dollars), depending on the level of water quality achieved (see Exhibit 11-16).

Boating

The water quality standards that determine if water resources can support non-contact recreation such as boating are not as stringent as those for fishing and swimming. There are cases where debris or excessive biomass growth can inhibit boating, and there are some secondary contact recreation guidelines for bacteria levels, but the presence of contaminants in waters generally does not require the restriction of boating activity. However, to the extent that recreational boaters participate in boating in conjunction with other water-based recreational activities, such as fishing or swimming, water quality issues can affect demand for boating. In a case study focusing on the value of improved water quality in Chesapeake Bay, participants in recreational boating estimated water quality on a scale of one to five and were asked to give a willingness to pay value for a one-step improvement in water quality. Results indicated that boaters' median willingness-to-pay was $17.50 per year (mean of $63 per year in 2003 dollars) for one-step improvements in water quality (Lipton, 2003). The Lipton (2003) study quoted an earlier study by Bockstael, McConnell, and Strand (1992) that found that fishing drove a significant amount of demand for recreational boating in Chesapeake Bay; 72 percent of boaters who stored their boats on trailers, and 38 percent of boaters who kept their boats in-water, stated that they used their boats "always or usually for fishing" (Lipton, 2003). This would indicate that at least a portion of boaters' willingness-to-pay for water quality improvements could be related to how improved water quality would affect the quality of recreational fishing trips, which in turn affects boating pressure. Returning to the Parsons et al. (2003) study cited above, the analysis found that moderate improvements in water quality had relatively little effect on boater benefits, but that significant improvements in water quality provided recreational benefits that were similar to those found for recreational fishing (see Exhibit 11-16).

EXHIBIT 11-16. AVERAGE ANNUAL PER CAPITA BENEFITS FROM WATER QUALITY IMPROVEMENTS

ACTIVITY	ALL SITES ATTAIN *MEDIUM* WQ[1]	ALL SITES ATTAIN *HIGH* WQ[1]
Fishing	$3.14	$8.26
Boating	$0.04	$8.25
Swimming	$5.44	$70.47
Viewing	$0.00	$31.45

Source: Parsons et al. (2003)

[1] In 1994 dollars.

Swimming

Because water quality standards directly determine the ability of a water resource to support full-contact recreation, water quality has the potential to affect both supply and demand for recreational swimming. In a national study focusing on the benefits of water quality improvements, Carson and Mitchell (1993) found the national benefits of achieving the Clean Water Act's swimmable water quality goal to be between $24 billion to $40 billion per year (1990 dollars). On a regional scale, Exhibit 11-16 shows the results of the Parsons et al. (2003) analysis of the effects of water quality improvements on recreational swimming benefits in six northeastern states.

As the results show, water quality improvements have the potential to significantly enhance swimmers' welfare. In fact, when comparing these benefits to other recreational activities included in the Parsons et al. analysis, the results indicate that swimming is the activity that would benefit most from improvements in water quality (Parsons et al., 2003).

Wildlife and Nature Viewing

Water resources have the potential to enhance the recreational experience of wildlife and nature viewing. The aesthetic quality of the environment is a key input in determining demand for viewing activity, and water resources have been found to enhance the aesthetic quality of environmental settings. Studies have found that participants in water-based recreation judge water quality in large part based on visual indicators and smell, despite the fact that many potential contaminants, such as PCBs, metals, and fecal coliform, are not detectable by sight or odor. This would indicate that water quality issues such as eutrophication, which can diminish water clarity and produce unpleasant odors, are very influential in recreational users' perceptions of water quality (Kakoyannis et al., 2002). Returning once more to the results of Parsons et al. (2003), which analyzed water quality impacts on recreational activities in six northeastern states, moderate water quality improvements were found to have no impact on welfare associated with recreational viewing, but greater water quality improvements could have a significant impact on user welfare. Exhibit 11-16 summarizes these results.

Beach Use

Beaches, as the leading travel destinations for tourists, are a significant source of demand for recreation and tourism (Houston, 2008). With beaches offering a variety of recreational opportunities such as swimming, boating, and fishing, water quality can influence both supply and demand for recreational beach use. Hanemann et al. (2005) analyzed the impacts of five scenarios of water quality change at Southern California beaches and found that in scenarios where water quality improved, visitation and consumer surplus were both projected to increase; in contrast, decreases in water quality were projected to result in declines in visitation and recreational user welfare. Exhibit 11-17 shows these results.

EXHIBIT 11-17. WELFARE AND VISITATION IMPACTS DUE TO WATER QUALITY CHANGES

SCENARIO	TOTAL WELFARE IMPACTS[1]	VISITATION IMPACTS[1]
Malibu Surfrider Beach improves water quality from C grade (2.13 on scale of 0 to 4) to B grade (3.0/4.0)	$140,564	$1,538
Zuma Beach degrades from A/A+ grade quality to a water quality grade of F	-$5,272,578	-$57,489
Huntington State Beach closes 1 day	-$115,657	-$1,248
Huntington State Beach closes 1 month	-$3,585,369	-$38,699
Huntington State Beach closes 1 summer (June, July, and August)	-$9,304,186	-$100,662

Source: Hanemann et al. (2005).

[1] In 2005 dollars. The study analyzed welfare and visitation impacts across four Southern California counties: Los Angeles County, Orange County, Riverside County, and San Bernardino County. The estimates for total welfare and visitation impacts represent data summed across these four counties.

In another study focusing on Long Beach in Southern California, Leeworthy and Wiley (2007) used the Southern California Beach Valuation Model (SCBVM) to estimate the effects of improvements in water quality on annual visitation and economic welfare. The water quality improvement scenario used in the study called for water quality at Long Beach to improve from its rating of 2.8545 to the 3.9150 rating (on a scale of 0 to 4) of nearby Huntington City Beach. Exhibit 11-18 shows how this improvement in water quality is projected to affect visitation and welfare for day trips and multi-day trips across users in four Southern California counties.

EXHIBIT 11-18. WELFARE AND VISITATION IMPACTS DUE TO IMPROVED WATER QUALITY AT LONG BEACH, CALIFORNIA

MEASUREMENT	DAY TRIPS	MULTI-DAY TRIPS	ALL BEACH USE
Annual person-days	5,633	1,353	6,986
Annual economic value[1]	$602,781	$321,305	$924,086

Source: Leeworthy and Wiley (2007)

[1] In 2007 dollars.

As these studies show, water quality has the potential to affect recreational demand for beach use with respect to both visitation and economic welfare. With coastal economies relying a great deal upon beach-oriented recreation and tourism, water quality can be critically important to determining the success of these economies at the local and regional scale. This is illustrated by the results of a study by Parsons and Kang (2007), which analyzed the economic impacts resulting from a closure of the Padre Island National Seashore due to a contamination event. The results of this study suggest that beach closures can cause significant losses in the output of the market economy, with

reductions in economic output ranging from $172,000 per weekend day in July to $26,000 per week day in September (in 2007 dollars; Parsons et al., 2007).

SUMMARY

In 2009, the travel and tourism industry contributed $379 billion in value added to the U.S. economy, which represented approximately 2.68 percent of total GDP. Tourism involving water resources contributes significantly to economic output, with beach use in particular representing a major draw (Houston 2008). Water-based recreational activities such as swimming, fishing, and boating represent in-stream, non-consumptive water uses and are significant drivers of economic output in the tourism industry; however, access to these activities is frequently not priced in conventional markets. As a result, it is difficult to estimate the market value of water in the context of recreation and tourism. Instead, economists have developed methodologies that use stated or revealed preference techniques to analyze the non-market value of water attributes that influence demand for recreation and tourism. Understanding the non-market value of these attributes helps explain how changes in them influence people's willingness to pay to participate in recreational activity, which in turn affects consumption of complementary goods and services (e.g., transportation, accommodations, and equipment expenditures) in the market economy.

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CHAPTER 12 | SUMMARY AND CONCLUSIONS

INTRODUCTION

This report is the first part of a broader study on the importance of water to the U.S. economy, the purpose of which is to:

- Summarize existing knowledge on the topic;
- Provide information that supports private and public sector decision-making, and
- Identify areas where additional research would be useful.

The information presented in this report focuses primarily on the first of these objectives, and lays a foundation for addressing the others. It provides a consistent set of conceptual and statistical information on key sectors of the economy, and illustrates the economic importance of water to these sectors. It also underscores the need for better information to support more optimal management of scarce water resources. This chapter summarizes the primary themes explored throughout the report, as well as the state of information on water's value.

THE IMPORTANCE OF WATER TO THE ECONOMY

As discussed throughout this report, water plays a vital role in several key sectors of the economy. Water is consumed directly by municipal users, feeds crops and livestock in agricultural applications, and plays a vital role in mining and energy resource extraction, manufacturing, and the generation of electricity. In addition, water supports economic activity in U.S. waterways and coasts by providing habitat for commercially valuable fish species, serving as a medium for shipping and transportation, and providing a setting in which recreational activity can take place.

THE IMPORTANCE OF WATER ACROSS THE ECONOMY

The off-stream water use sectors discussed in this report – agriculture, mining and energy resource extraction, public water supply, thermoelectric power, and manufacturing – are located in the primary and secondary mega-sectors of the economy. The industries within these sectors produce intermediate goods that serve as inputs to other industries within the primary and secondary mega-sectors. They also produce finished goods that are transported, warehoused, and sold by businesses in the tertiary sector of the economy, and ultimately purchased and used by consumers or by businesses in the quaternary sector. Thus, a significant amount of economic activity is either directly or indirectly dependent upon water as a factor of production.

The energy sector provides an illustrative example of the importance of water in interrelated economic sectors. Water is used in producing energy resources (hydropower and irrigation for biofuel crops), extracting fossil fuel resources from the earth, transporting fuels (both domestic transport along lakes and rivers and international

transport at coastal ports), processing and refining fuels, and converting fuels into electricity. The dependence of the economy upon a reliable supply of energy is clear. The reliability of this supply depends, at least in part, upon the nation's water resources.

WATER USE OVER TIME

Total water withdrawals in the U.S. have remained generally flat since 1980, as increased withdrawals in some sectors (primarily public supply) have been offset by reduced withdrawals in others (agriculture, thermoelectric power generation, and manufacturing). The reduction in withdrawals in the latter three sectors since the 1980 peak reflects, at least in part, a response to an economic signal: an increase in the cost of using water, due either to an increase in the cost of acquiring it – which might be the case, for example, in areas where demand has led aquifers to become depleted – or to increases in the cost of discharging wastewater, a result of more stringent pollution control standards. These signals have spurred greater efficiency in the use of water, made possible, in part, by investments in new technology (e.g., drip irrigation or recirculating cooling systems). Further increases in water use efficiency may be possible, particularly in the public supply and agricultural sectors, where subsidies in many cases keep water rates artificially low and diminish the economic incentive for efficiency improvements.

Those who adopt water conserving technologies do so primarily to improve the economic efficiency of their own operations. The benefits, however, may extend to others by reducing overall demands on a region's water resources. In discussing the implications of greater efficiency from a systems perspective, however, it is important to distinguish between withdrawals and actual consumption. As illustrated in Chapter 8, a change from once-through cooling to recirculating cooling decreases the amount of water that thermoelectric power plants withdraw, as well as the discharge of heated effluent to receiving waters; however, it increases the consumptive use of water in the thermoelectric power sector, which may have implications for others who draw on the same water source. In contrast, improving the efficiency of irrigation can reduce both water withdrawals and water consumption. Nonetheless, a shift to more efficient irrigation practices may affect hydrological dynamics within a watershed, e.g., reducing irrigation return flows that previously formed part of the available water supply to downstream users. An understanding of these interrelationships is essential to projecting the impact of technological changes on the dynamics of regional water supplies.

THE POTENTIAL IMPACT OF WATER SCARCITY ON ECONOMIC ACTIVITY

With six percent of the world's renewable freshwater supply located within the U.S., the country as a whole enjoys a relative abundance of freshwater resources. The distribution of water resources, however, is not uniform, and regional and local water shortages are an increasingly common occurrence. Where human uses of water do not exceed the rate at which surface and groundwater supplies are normally replenished, as is generally the case in the Northeast and Great Lakes regions, economic activity is relatively insulated from chronic water shortages. In areas where water withdrawals approach or even exceed the rate at which surface and groundwater supplies are likely to be replenished, as is the case in large portions of the Southwest, the potential for chronic water shortages to develop is

much greater, and exposure to the economic risks associated with seasonal droughts is more severe.

The discussion of regional perspectives on water scarcity in Chapter 3 notes several instances in which competing demands for water have raised difficult resource management issues, some of which have led to legal conflicts:

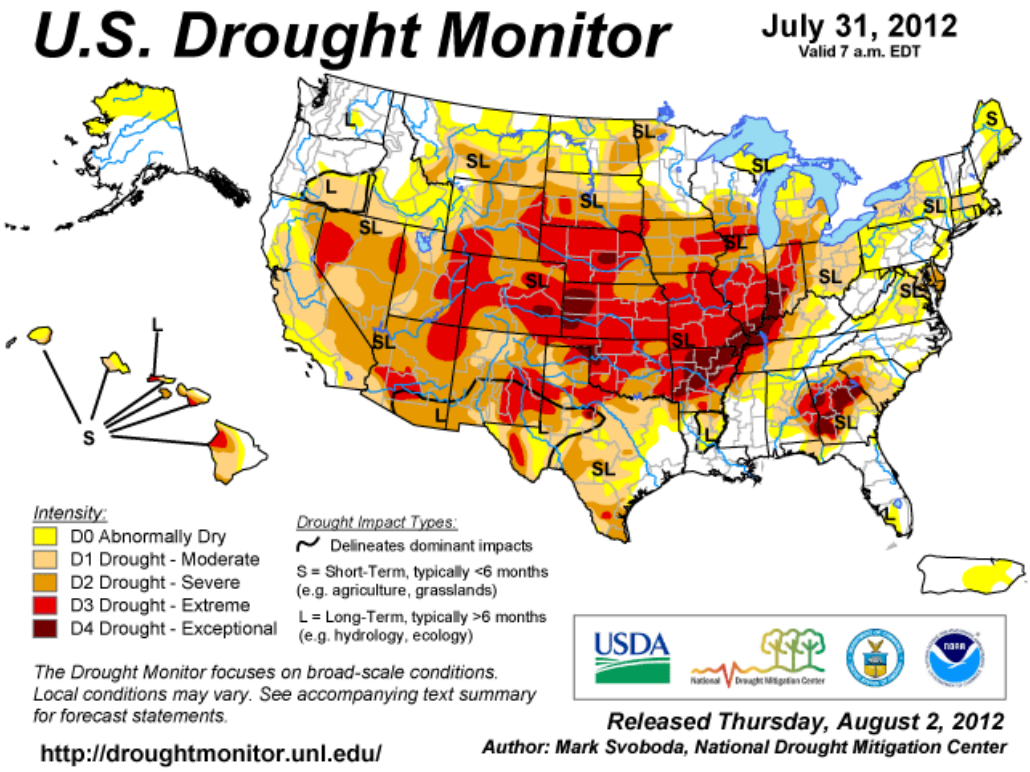
- In the Southwest and Northwest, hydropower interests compete with conservation and recreation interests over the management of in-stream flow. In some areas, this competition is intensified by large diversions and withdrawals from rivers to satisfy residential and agricultural demand.
- In the Great Plains, residential and agricultural users of groundwater resources must compete for a declining supply of easily accessible water in the High Plains aquifer.
- In the Southeast, rapid population growth in urban areas of Florida and Georgia has led to competition between residential and agricultural users, culminating in a legal conflict and an acute water shortage in 2007 and 2008.

In addition to consuming resources in legal battles, these situations represent areas of vulnerability for economic sectors dependent on reliable access to adequate supplies of water. Where water resources are not sufficient to meet competing demands, the likelihood of significant economic impacts to one or more of these sectors is greater.

The effects of acute water shortages have already been felt in many areas. As noted in Chapter 2, drought in west Texas and neighboring states from 2009 to 2011 severely limited the availability of water for crops and livestock operations. Similarly, as noted in Chapter 8, droughts in 1999, 2006, and 2007 affected the operations of power plants in the Northeast, Midwest, and Southeast. As shown in Exhibit 12-1, the drought that began during the summer of 2012 now threatens to damage agricultural productivity in large areas of the Southeast, Midwest, Great Plains, and Southwest.

In the coming decades, population growth and continuing economic development are likely to increase the demand for water and place additional pressure on water resources. Climate change may further intensify the risk of water shortfalls in some areas. Minimizing the high economic cost of acute water shortages will require a number of adaptations, including investment in water infrastructure, reforming institutions to allow water to flow to the most critical uses, and acquiring a better understanding of the marginal value of water in different uses so that decision-makers in both the private and public sectors can determine how to derive the maximum value from management and use of the nation's water resources.

EXHIBIT 12-1. EXTENT OF DROUGHT IN 2012



Source: National Drought Mitigation Center, 2012.

AVAILABLE INFORMATION ON THE VALUE OF WATER IN ECONOMIC USES

This section summarizes the information on the value of water presented in this report. It first discusses estimates of the value of water for off-stream water use sectors – public supply and domestic self-supply, agriculture, manufacturing, mining and energy resource extraction, and electric power generation. It then summarizes key issues of concern for in-stream use sectors – commercial fishing, commercial navigation, and recreation and tourism.

OFF-STREAM WATER USES

By necessity, the quantitative information presented in this report on the use of water and the value of different uses has focused on off-stream uses, where water withdrawals can be measured and where values can be estimated per unit of water used. As discussed in the body of the report, these sectors differ with respect to how much water they withdraw, what percentage of water is consumed, and whether they require water to be of a particular quality. Even within sectors, there is no single marginal value that one can assign to the use of water. Such values are dependent on a variety of case-specific factors, not the least of which are the scarcity of water within a region and the efficiency with which water is currently employed. In all cases, comparisons of value estimates should be made with caution and with these complexities in mind.

Public Supply and Domestic Self-Supply (Residential Use)

Available data on transactions from water rights markets suggest that the public supply sector, which primarily serves residential users, is a high-value water use, with estimates as high as $4,500 per acre-foot for the permanent acquisition of water rights. It is important to note, however, that the rates paid by consumers in the residential water market generally fall below the level necessary to cover the long-run costs of public water service. As a result, consumers do not receive the price signal that would encourage the optimal use of water in this sector (i.e., consumption at the point at which the marginal benefit of water use equals its long-run marginal cost).

Estimates of the price elasticity of demand for water by residential users show that demand for water in this sector is inelastic in the short term, though less so in the long term. This result suggests that, although most residential uses of water do not have readily available or comparatively priced substitutes, an increase in prices could lead to improved efficiency of use.

Protecting the quality of public water supplies provides substantial economic benefits, including reduced morbidity and mortality, avoided worker and school absences, and lower medical costs. While the literature on these benefits in the United States is sparse – perhaps because access to water of good quality is taken as a given – many economists have considered the impacts of providing higher quality drinking water in developing countries, finding that expanded access to high quality water supplies is strongly correlated with improved health outcomes that reduce the costs associated with death, illness, and reduced productivity.

Agriculture

Estimates of the value of water used for irrigation purposes are based on a variety of methods, from analyses of the costs incurred to supply water to hedonic price analyses of properties with varying access to irrigation water. The estimates vary considerably, from as little as $12 per acre-foot from a hedonic study to more than $4,500 per acre-foot for the permanent sale of water rights from agricultural to municipal users (a measure of the agricultural sector's willingness to accept compensation to forgo water rights). In addition to differences in methodology, this variation reflects regional differences in the availability of water, the crops grown, and other factors. In general, however, the available data from water rights markets indicate that the average price paid for transfers between agricultural users is substantially lower than the price paid for transfers from agricultural to municipal users. In areas where municipal users are willing to pay more for water than agricultural users would require to sell or lease their water rights, further development of water markets would allow transfers to take place that would improve the overall value derived from water's use.

Improvements in irrigation technology, particularly shifts away from flood irrigation toward sprinkler irrigation, have led to improvements in the efficiency of agricultural water use. A major driver in the shift to more efficient technology has been the increasing scarcity of water in key areas and subsequent increases in the explicit or implicit price paid for water (i.e., the cost of self-supply).

Manufacturing

It is difficult to estimate the value of water used in the manufacturing sector largely because most water used within the sector (about 80 percent) is self-supplied. Available data on total water used by different manufacturing industries is several decades old. As a result, the current literature on the value of water in manufacturing is extremely limited, and the available empirical estimates are highly variable, ranging from $14 per acre-foot (for water used for cooling) to more than $1,600 per acre-foot (for water used in the petroleum industry). Again, these estimates vary with the industry and location examined, as well as the valuation method employed. Because of this large range of estimates, greater research into the use of water in manufacturing could substantially increase the understanding of the value of water to different industries.

Empirical evidence suggests that the demand for water in manufacturing is inelastic at current prices, though more elastic than agricultural or domestic water demands. Not surprisingly, estimates of the price elasticity of demand for water tend to be higher where the cost of water is high relative to that of other inputs of production.

Mining and Energy Resource Extraction

Information on the prices paid for water used in mining or energy resource extraction is extremely limited because much of the water used for these purposes is produced water, (i.e., groundwater generated during the resource extraction process). What data do exist on water purchases for this sector indicate a median price of approximately $200 per acre-foot for an annual lease, with a minimum price of $40 per acre-foot per year and a maximum price of approximately $500 per acre-foot per year. These estimates suggest that the marginal value of water in this sector may be very high, depending on energy market dynamics and local water scarcity.

Electric Power Generation

This sector includes both off-stream water withdrawals for thermoelectric cooling and in-stream use of water for hydropower. Though the thermoelectric power sector withdraws more water than any other, much of this use is non-consumptive, and available estimates suggest that thermoelectric cooling is a relatively low-value use of water. Empirical estimates of the value of water used in electric power generation are generally based on shadow price analysis, which compares the cost of generating electricity at one facility to the cost of generating the same amount of electricity at the next-cheapest source. This approach suggests that the value of water for thermoelectric cooling ranges from $12 to $87 per acre-foot, and that the value of water in generating hydropower ranges from as little as $1 to as much as $157 per acre-foot. The variation in values primarily reflects regional differences.

One possible explanation for the relatively low estimates of the value of water presented above is the interconnected nature of the electric power grid, which makes it possible to substitute power from sources with only marginally higher costs when production from a single plant is interrupted. As noted in Chapter 8, these costs might be significantly higher if a shortage of water were to curtail power production at a large number of facilities within a region, raising the risk of power outages and interruption of activity elsewhere in the economy.

IN-STREAM WATER USES

Unlike off-stream water uses, commercial fishing, commercial navigation, and recreation and tourism make use of water without withdrawing it from its source. It can be difficult to estimate the value of water to these sectors, because marginal changes in water volume or flow do not affect the value that they derive from their use of water in consistent ways. For example, too much water in a particular river or channel can be as damaging to commercial navigation or recreational activity as too little water. Nevertheless, the discussion in this report highlights how economic activity in these sectors depends on management of the nation's water resources.

Commercial Fishing

The commercial fishing industry relies on the preservation of fishing habitat and the maintenance of adequate water quality to sustain that habitat. Water uses that adversely affect water quality could affect the viability of this economic sector. The relationship between water quality and the economic productivity of the commercial fishing sector involves a complex series of ecological interactions that varies from species to species and is only partially understood. This report does not attempt to estimate the potential impact on the commercial fishing industry of any marginal change in water quality; such impacts are likely to be dependent on site-specific conditions and could vary significantly from case to case. It notes, however, that the condition of the nation's estuaries and coastal waters ranges from fair to poor in a number of regions important to the industry, and makes clear the link between preservation of coastal habitat and the sustainability of the industry.

Commercial Navigation

The use of the nation's waterways to support transport of cargo and people relies on the depth of water at ports, rivers, locks, and channels. Marginal changes in the width and depth of channels can drastically affect their ability to support commercial navigation, as larger vessels require deeper and wider channels. Managing water levels to meet minimum depth requirements in lakes and rivers may compete with off-stream water uses, but shortfalls can impede navigation and may in some cases necessitate expensive dredging of sediment to restore channel depth.

Recreation and Tourism

Water-based recreation, such as swimming, fishing, and boating, requires water of sufficient quantity and quality to support each activity. The report presents estimates from the welfare economics literature on willingness to pay to participate in water-based recreational activities, illustrating the relationship between the demand for water-based recreation and factors like water quality. It also notes the link between demand for water-based recreation and related expenditures in the recreation and tourism sector, which can have a significant impact on regional economies.

GENERAL OBSERVATIONS

The discussion above includes a number of observations concerning available estimates of the value of water in different economic sectors. Several are worth repeating. In particular:

- Values for water by use vary widely, ranging from fractions of a dollar to several thousand dollars per acre-foot.
- The value of water often depends on factors that are highly case-specific.
- Estimates of the value of water depend on precise data about how much water is used and how it is used for a particular activity.
- The most reliable estimates of the value of water in a particular use come from observations of transactions in water markets. Such markets, however, are not widespread, and do not offer data for all sectors discussed in this report.
- Resource management decisions that only account for values of water that can be measured on a per-unit level may drastically undervalue economic sectors that rely on in-stream supplies of sufficient quantity and quality.

In order to improve the quality of information about the value of water in different uses, additional data will be needed on both how water is used in each economic sector and how each sector derives value from its use of water. The proposed USGS National Water Census discussed in Chapter 3 is a critical first step. In particular, this effort promises to provide better documentation of trends in the use and availability of water resources in different regions and for different water use sectors. This information will aid efforts to anticipate water shortages, allowing decision-makers to develop plans and make investments to adapt to, mitigate the impacts of, and possibly prevent such shortages.

CONCLUSIONS

Water is vital to the U.S. economy, directly affecting the resource extraction and processing sectors, and indirectly affecting the rest of the economy as goods and services make their way to their final users. As a general rule, when decisions on the use of a resource are based on incomplete information, economically inefficient outcomes are more likely. Based on the findings presented in this Background Report, information on water's use and economic value is scarce, and in many cases, of limited utility in guiding decision-making. It is therefore likely that the U.S. is not maximizing the economic welfare it derives from the use of water. Coordinated investment in information-producing activities, such as data collection, model development, and scientific research, has the potential to improve decision-making in both the public and private sectors. An investment of this type would help to increase economic productivity and foster long-term sustainability in management and use of the nation's water resources.

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