United States
Environmental Protection
Agency

Office of Water

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The Importance of Water to the U.S. Economy

Synthesis Report

Overview

Water is essential to life, making its total economic value immeasurable. At the same time water is a finite resource, and one for which competition is likely to increase as the U.S. economy grows. Driven by this heightened competition, the economic value of water will rise, and decision-makers in both the private and the public sectors will need information that can help them maximize the benefits derived from its use.

This report is an initial step toward (1) raising awareness of water's importance to our national economic welfare, and (2) assembling information that is critical to sustainably managing the nation's water resources. It highlights the U.S. Environmental Protection Agency's (EPA) review of the literature and practice on the importance of water to the U.S. economy, identifies key data gaps, and describes the implications of the study's findings for future research.

As the report's principal findings indicate, reliable information on the economic importance of water is, in many ways, elusive. This is partly because many major users in the U.S. supply their own water, with no explicit price paid which could be used as an indicator of marginal value to the user. Even when price data are available – as is the case for those who purchase water from an external supplier – the prices often do not reflect the full cost of supply, externalities such as those caused by pollution, or opportunity costs associated with other uses. As a result, available price data fail to indicate water's true worth, and may encourage inefficient and potentially unsustainable use of the resource.

Driven by this heightened competition, the economic value of water will rise, and decision-makers in both the private and the public sectors will need information that can help them maximize the benefits derived from its use.

It is also difficult to generalize about water's economic value because water is a complex commodity. Determining this value requires analysts to control for a number of factors where data is often limited. For example, the value of water in a particular application is likely to depend on the *amount* of water supplied, *where* the water is supplied and used, *when* it is supplied, whether the supply is *reliable*, and whether the *quality* of the water meets the requirements of the intended use. Empirical estimates of the value of water, where available, are therefore highly variable and depend on the context from which they were derived. Applying these estimates to support decision-making in other settings can be problematic.

Despite these empirical limitations, the importance of water to the total U.S. economy is clear. Direct use of water is concentrated in major sectors of the economy, which include agriculture, forestry, mining, energy resource extraction, manufacturing, electric power production, and public water supply. The output from these sectors supports activity elsewhere in the economy, creating a ripple effect as goods and services are produced and transferred through supply chains until they reach the final consumer. Thus, the economy as a whole is directly or indirectly dependent upon the output of industries for which water is an important input, and is potentially sensitive to water supply shocks or heightened competition for water resources.

For the reasons noted above, decisions made in these major sectors of the economy have a significant impact on the economic value derived from the nation's water resources. This is particularly true for energy production, water supply, and food production, which together account for over 94 percent of water withdrawals from groundwater, streams, rivers, and lakes in the United States. Interactions among these sectors have given rise to an "energy-water-food nexus," in which demands for water, energy resources, and agricultural products are interrelated. As a result, the use of water in these sectors cannot be viewed in isolation; changes in one sector can have a direct and significant impact on the demand for, and availability of, water to others.

Effectively addressing the increasing competition for water will require the adjustment of institutions that facilitate efficient and sustainable resource use. It will also require them to recognize the multiple connections, interactions, and feedback loops that characterize the use of water to support economic activity; this systems-level perspective is critical to maximizing the economic and social welfare benefits our water resources provide.

The type of information needed to guide decisions about the use and management of the nation's water resources varies to some degree by economic sector and the issue to be addressed. For farmers and manufacturers, water is primarily an input to production, in which the economic objective of profit maximization is pursued through cost minimizing strategies. Information on water conserving technologies that can reduce costs, improve productivity, and decrease exposure to the risks associated with potential water shortages would likely be of benefit to such enterprises.

Public water supply systems and water resource management agencies often make decisions that affect many aspects of social welfare, balancing the sometimes competing interests of different uses. These decisions require information on how changes in the relevant dimensions of water (quantity, quality, etc.) for each use affect the economic value associated with that use. They may also require data and tools that support detailed analysis of the implications of multiple decision alternatives for different regions, industries, and periods of time.

The breadth and diversity of these issues makes clear that collecting or generating information of good quality and developing analytic tools to use this information effectively will require a collective effort. The U.S. Geological Survey's National Water Census, which will provide improved data on water use throughout the economy and serve as a foundation for related efforts, is a key initiative in this area. Other potentially important lines of research include integrating water into economic models, which would support evaluation of the links between water use and economic output; the use of embedded resource accounting or water foot-printing techniques to estimate the virtual water content of different products; and facilitation of regional, multi-sector planning efforts to evaluate the implications of potential water supply shocks.

Glossary

Allocative efficiency – A distribution of resources which yields the greatest economic benefit to society as a whole.

Commodity – A marketable item or thing of value produced to satisfy consumer wants or needs.

Consumptive water use – A use of water which diminishes the quantity, flow, or quality of water its source can provide for other purposes.

Delivery sector – One of the economy's four mega-sectors, the delivery sector encompasses transportation, wholesale trade, and retail trade.

Embedded resource accounting – A framework for characterizing the amount of water and other natural resources required to produce different goods and services.

Empirical data – Information acquired through observation or experience.

Energy-water-food nexus – The interrelationships between and among the economy's agriculture, energy, and water supply sectors.

Externality – An effect of one economic agent on another that is not taken into account in normal market behavior.

Extraction sector – One of the economy's four mega-sectors, the extraction sector includes the agriculture, forestry, fishing, and mining industries.

Ex-vessel revenue – Revenue from the harvest of commercial fish stocks, as measured at the initial point of sale.

Fixed capital – Tangible, durable assets used in the production of goods or services (e.g., land, buildings, plant and equipment).

Information sector – One of the economy's four mega-sectors, the information sector includes finance, insurance, real estate, and public administration.

Input – A factor that contributes to the production of a good or service.

In-stream use – A use of water which does not withdraw or divert the water from its source.

Marginal value of water – The economic benefit derived from use of an additional unit of water.

Market uses of water – Uses of water which support the provision of goods or services that are bought and sold.

Mega-sector – A part of the economy comprising economic activities anchored in one of four major elements of the work process: extraction, processing, delivery, or information.

Multi-sector – A perspective encompassing the views, needs, and interests of more than one sector of the economy.

Non-consumptive water use –A use of water that does not diminish the quantity, flow, or quality of water its source can provide for other purposes.

Non-market uses of water – Uses of water which support the provision of goods or services, such as recreational opportunities, that are not ordinarily bought and sold.

Off-stream use – A use of water which withdraws or diverts the water from its source.

Opportunity cost – The value of the best alternative forgone when an action is taken.

Productive efficiency – Production of a given level of output at the minimum possible cost.

Processing sector – One of the economy's four mega-sectors, the processing sector encompasses the manufacturing, construction, and utility industries.

Production function – An equation that expresses the relationship between the use of inputs and generation of outputs in the production of a good or service.

Self-supplied water – Water a business, residence, or other entity diverts or withdraws for its own use.

Value of the marginal product of water – The value of the output that use of an additional unit of water would generate.

Virtual water content – The amount of water required to produce a particular good or service.

Water foot-printing – A technique for characterizing the amount of water required to produce a good or service.

Water supply shock – An event, such as a drought, that reduces the supply of water and may result in a sudden increase in market prices or water acquisition costs.

I. How is Water Important to the U.S. Economy?

INTRODUCTION

Water is an essential commodity: human life – and indeed all life on earth – depends upon it. Water is also a critical input to production in a number of economic sectors. Water is used to extract energy and mineral resources from the earth, refine petroleum and chemicals, roll steel, mill paper, and produce uncounted other goods, from semiconductors to the foods and beverages that line supermarket shelves. Water cools the generators and drives the turbines that produce electricity, and sustains the habitat and fish stocks that are vital to the commercial fishing industry. Rivers, lakes and oceans provide natural highways for commercial navigation, and provide places to swim, fish, and boat, helping to fuel economic activity in the recreation and tourism industry. Every sector of the U.S. economy is influenced by water.

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WATER IS ESSENTIAL TO THE ECONOMY

Because water is essential to life, its *total* contribution to the U.S. economy cannot be quantified in any meaningful way (Bockstael et al., 2000; Hanemann, 2005). Nonetheless, we can develop a qualitative sense of the dependence of the U.S. economy on the nation's water resources by considering the sectors that use water and their relationship to the economy as a whole.

To understand how water is used and how it generates value throughout the economy, we can use structural concepts developed by leading economists that provide the framework for our system of national economic accounts (Kenessey, 1987). This framework draws on four major elements of the flow of goods and services through the economy – *extraction, processing, delivery*, and *information* – to group economic activity into four major or mega-sectors:

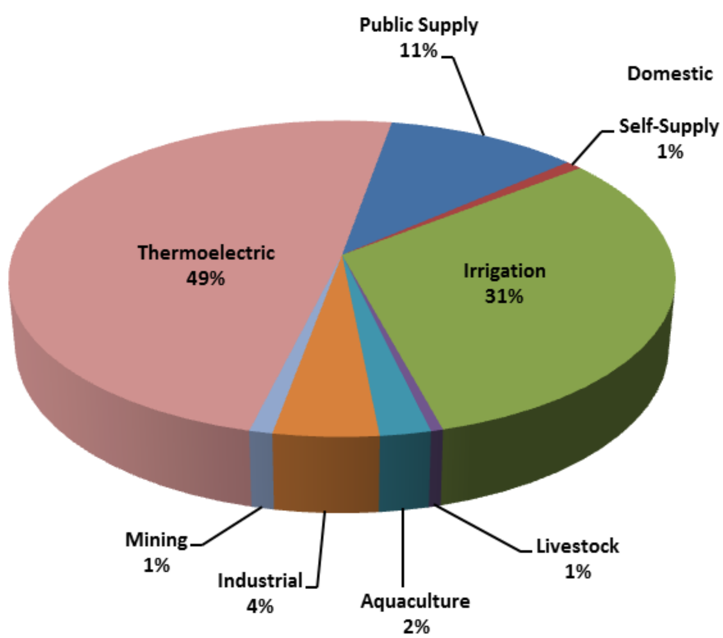
- Extraction sectors, including agriculture, forestry, fishing, and mining;
- Processing sectors, including utilities, manufacturing, and construction;
- Delivery sectors, including transportation, wholesale trade, and retail trade; and
- Information sectors, including finance, insurance, real estate, and public administration.

This framework is useful to illustrate how the direct use of water ultimately affects the production of goods and services in other sectors. As discussed below, it also provides a basis to evaluate how changes in the availability or quality of water can affect the structure and performance of the economy as a whole.

Distribution of Water Withdrawals by Sector

The U.S. Geological Survey (USGS) estimates that in 2005, water withdrawals from groundwater and surface water in the United States totaled approximately 410 billion gallons per day (BGD) (USGS, 2009).[1] USGS reports withdrawals for eight water use categories: public supply; domestic self-supply; irrigation; livestock; aquaculture; industrial; mining (including oil and gas extraction); and thermoelectric power. Exhibit 1 shows the distribution of withdrawals in 2005 by category. As the exhibit indicates, water withdrawal is heavily concentrated in the previously mentioned major extraction and processing sectors of the economy. The extraction sectors – including agriculture (irrigation, livestock, and aquaculture), mining, and oil and gas extraction – account for approximately 35 percent of all water withdrawals. The processing sectors – including manufacturing, public water supply, and thermoelectric utilities – account

EXHIBIT 1. DISTRIBUTION OF 2005 U.S. WATER WITHDRAWALS BY OFF-STREAM USE



Source: USGS, 2009.

[1] Of the total noted above, approximately 80 percent (327.5 BGD) was withdrawn from surface waters. The remaining 20 percent (82.6 BGD) was groundwater. More than 85 percent of the water withdrawn in 2005 was fresh; 15 percent was saline. All sectors draw from both surface and groundwater sources. Most, however, rely exclusively on fresh water. Only the industrial, mining, and thermoelectric power sectors use saline water.

for another 64 percent. In contrast, private wells for domestic use (domestic self-supply) account for just one percent (USGS, 2009).[2]

Sector Interactions

Although water withdrawals are heavily concentrated in extraction and processing, analysis of the flow of goods and services throughout the economy reveals that economic output in all sectors is dependent upon and influenced by activity in others. Exhibit 2 summarizes the current input-output data for the U.S. economy, showing the commodities consumed by each industry and the source of those commodities. All four mega-sectors interact, exchanging goods and services and delivering final goods to consumers.

EXHIBIT 2. FLOW OF INTERMEDIATE INPUTS BETWEEN MEGA-SECTORS ($ MILLIONS, 2010)

SOURCE OF COMMODITIES PURCHASED	MEGA-SECTORS PURCHASING INTERMEDIATE COMMODITIES			
	EXTRACTION	PROCESSING	DELIVERY	INFORMATION
Extraction	$99,107	$719,764	$6,671	$16,306
Processing	$157,254	$1,882,746	$339,373	$1,117,804
Delivery	$45,090	$427,768	$241,127	$314,851
Information	$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.

For example, the processing sector requires over $700 million of output from the extraction sector, approximately 85% of the extraction sector's total output. Likewise, output from the processing sector is used in the extraction sector, as well as more heavily in the other three sectors. It is clear that the extraction and use of natural resources lies at the base of much economic activity. The entire economy directly or indirectly relies on the output of industries for which water is a critical input.

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[2] It is important to note that these percentages represent 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. As noted in *The Importance of Water to the U.S. Economy. Part 1: Background Report* (EPA, 2012a), approximately 58 percent of the water withdrawn by public water supply systems is delivered to residential users; the rest is delivered to industrial, commercial, or institutional consumers or is unaccounted for due to losses in transmission.

The Sensitivity of the Economy to Water Supply Shocks

One important implication of the interrelationships described above is that, to some extent, every sector of the economy is sensitive to water shortages or supply shocks. The most familiar example is a drought. For example, droughts affecting U.S. agricultural output result in a shortage of inputs for a variety of industries, such as the food and beverage industry. If these industries are forced to curtail production, others are affected as well: food and beverage producers purchase less packaging from the paper and plastics industries; rail and truck transporters of food and beverage products haul less freight; wholesalers sell fewer food products; and so on. This dependence on reliable water supply and the threat presented by water shortages has led to interest by businesses in evaluating, reporting and addressing water risk, as can be seen in the following textbox.

BUSINESS AND INVESTORS MOBILIZE TO ADDRESS WATER RISK

Companies are responding to the demands of shareholders, customers, and investors for greater accountability by expanded tracking and reporting of social and environmental risk factors. Understanding current and future water risk, and mitigating that risk, is central to this trend. The 2012 Carbon Disclosure Project Global Water Report received feedback on perceived water risk from almost 200 of the world's largest companies, 75 of which are in the United States. More than half of U.S. respondents (55%) believe they are exposed to risks (such as floods and drought) in their direct operations or supply chains. They are responding with corporate water policies, plans or strategies (79%), and internal conservation or other goals and targets (50%). Interestingly, nearly two-thirds (62%) see opportunities to improve their financial "bottom line" by mitigating risks that lead to new products and services.

The business of reporting and supplying tools and standards for reporting is also growing. The Global Reporting Initiative (GRI) is the most widely used reporting framework. The GRI guidelines encourage companies to assess water withdrawals and discharges, as well as consequent impacts on other uses and biodiversity. The World Resources Institute (WRI) launched the open-source *Aqueduct* interactive measuring and mapping tool which allows companies (as well as investors, public leaders and others) to assess relative water risk at the watershed level. The tool considers a wide range of water quantity risks, from droughts to floods to some biodiversity factors. Ceres, a U.S.-based consortium, has developed the *Aqua Guage* framework to help companies do a better job at measuring and managing water availability and quality, while improving engagement with stakeholders. Ceres has also led efforts to encourage water and wastewater utilities to bolster resilience to water risk as a means to improve financial performance and sustainability. Their Disclosure Framework encourages measuring and reporting in 6 key areas – supply security, demand management, asset management, water quality, energy use and generation, and water rates.

www.cdproject.net/water; www.globalreporting.org; www.wri.org; www.ceres.org/issues/water

The economic repercussions of a water supply shock are not hypothetical. For example, the U.S. Department of Agriculture estimates that the summer drought of 2012 damaged agricultural productivity in large areas of the Southeast, Midwest, Great Plains, and Southwest (USDA, 2012). The drought also adversely affected commercial navigation on the Mississippi River, forcing barges to operate at reduced capacity to avoid running aground, and causing businesses to rely on alternative means of transport to get their products to market. Similarly, from 2009 to 2011, large parts of west Texas and neighboring states experienced a severe drought. The drought reduced water levels in reservoirs and limited water availability for cotton, wheat, and peanut cultivation, livestock operations, and other agricultural activity. Immediate effects on the agricultural sector included failed crops and a sell-off of cattle (Galbraith, 2011). Potential longer-term impacts included increases in the price U.S. consumers might face for wheat and beef, as well as potential erosion in U.S. cotton exports (Hylton, 2011). As these examples illustrate, the impact of a water supply shock can extend well beyond the industries that are immediately affected, with implications for consumers and ripple effects on activity in other areas of the economy. These cases also help to illustrate a fundamental point: protecting and efficiently managing our water resources is essential to maintaining a strong, vibrant economy.

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EVERYTHING IS CONNECTED

A major theme that emerges from analyzing water's economic importance is that everything is connected. Although water is a local resource, water use is connected at a regional or watershed level; through commerce, trade, and other economic linkages, it is connected at a national or international level as well.

Changes to water use or impacts in one sector or region can produce ripple effects across the economy. The interconnectedness of water use and economic activity means that a systems-level perspective is needed when evaluating water's economic importance. An integrated approach helps to illuminate the multiple direct and indirect relationships and feedback loops that characterize (1) how water is used to support economic activity, and (2) how economic activity might be affected by changes in water supply. Understanding these relationships is critical to analyze the potential effect of water supply shocks and to fully understand the consequences of alternative water resource management strategies.

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A systems approach is also valuable in considering interrelationships in the use of water from an environmental and societal perspective. The waters within a local watershed are likely to supply multiple users and support a variety of uses, both water withdrawals and in-stream uses such as commercial navigation and recreational boating. As a result, the actions of one user can affect the welfare of many. This is most clearly the case when the water use by one customer precludes its use by others. It is also the case when use of the resource impairs the quality of water available to others. For example, pollutants discharged from a facility may affect the quality of water downstream. These pollutants may affect the costs that a downstream municipality incurs to treat and supply drinking water to its residents. Other uses of water, both water withdrawals and in-stream uses, may also be affected. Because water is used and reused over and over as it moves through the environment, the impact of each use on others must be considered in a systems context.

The interrelationships described above have led to the evolution of common-law principles and the enactment of statutes that govern how water is allocated and used. They also have resulted in regulations designed to protect water resources from environmental degradation and to ensure that public supplies are safe to drink. The administration of these provisions often involves several levels of governance, including federal, state, regional, and local authorities. Equitable and efficient management of our water resources requires coordinating the efforts of these institutions, understanding the impact of management decisions from multiple perspectives, and balancing the needs of potentially competing interests.

The challenges we face in managing our water resources become even more apparent when we consider the potential consequences of unsustainable management. For example, current rates of groundwater use in some regions of the United States are causing the aquifers that supply the water to become depleted. Elsewhere, surface waters have been degraded to the point that their ecosystems have been impaired and, in some cases, fundamentally altered. Given these concerns, water resource managers are focusing increasingly on *sustainability* – creating and maintaining conditions under which the many benefits derived from our water resources can be enjoyed both now and in the future. The sustainability model encourages decision-makers to optimize environmental, economic, and social benefits, emphasizing a long-term focus. In doing so, it can show how economic activity and social welfare depend both on the use of water and – in less obvious ways – on conservation and protection of aquatic ecosystems, habitat, and water resources, not only for our benefit, but also for the benefit of future generations.

THE ENERGY-WATER-FOOD NEXUS IS FUNDAMENTAL

To further understand water's economic importance and its interconnected nature, it is helpful to focus on three areas of water use that form the core of the nation's economy: energy production; water supply; and food production. These activities and their interactions form a major economic hub – an energy-water-food nexus – that accounts for more than 94 percent of off-stream water use nationwide.

The energy-water-food nexus is easiest to understand as a series of mutual relationships between energy production, water supply, and food production:

- *Water/Energy* – The use of water is critical to many aspects of energy production, including extraction of energy resources (e.g., mining), refining petroleum, transporting fuel by barge along waterways, and generating electricity through hydropower or thermoelectric power (where water is used as a coolant). In addition, water resource management itself uses a lot of energy (e.g., supply, distribution, and treatment of water and wastewater consume about four percent of U.S. power generation (USDOE, 2006)). Due to symmetry in the use of water to produce energy and the use of energy to produce (and deliver) clean water and treat wastewater, increased efficiency of either the production or use of energy or water can yield many benefits throughout the economy.

- *Energy/Food* – Modern, large-scale agriculture is highly dependent on energy to produce our food. Energy is used directly to operate machinery and equipment, and is used indirectly to produce fertilizers and chemicals used to grow crops (Schnepf, 2004). At the same time, biofuels are increasingly becoming a major energy source, creating a link between agricultural production and energy production. Ethanol and biodiesel – produced from corn and soy, respectively – currently account for about four percent of the energy consumed by the transportation sector. This share is expected to grow (DOE, 2012). Biofuels also have an effect on the mix of crops produced and crop prices, both internationally and domestically (Von Braun, 2008).

- *Water/Food* – The use of water to support food production includes cropland irrigation, livestock watering, aquaculture, and food and beverage manufacturing. Irrigation is the largest consumptive use of water in the U.S., though shifts in irrigation methods and technology have improved water use efficiency in this sector (Wiebe and Gollehon, 2006).

Because of the connections described above, changes in the availability of water in one part of the country can have significant impacts on the availability of energy, food, or water in another. In addition, because the vast majority of water withdrawn in the U.S. is used in the energy-water-food nexus, economic activity in these sectors potentially affects not only the availability of water for other uses, but also its quality.

The nation's water supplies are connected to nearly all economic activity through the energy-water-food nexus.

The above discussion highlights how important the energy-water-food nexus is to understanding the importance of water to the U.S. economy. The nation's water supplies are connected to nearly all economic activity through the energy-water-food nexus. Interactions within the nexus show the complexity of the economic, social, and environmental systems that rely on water and affect its use. Important strategic economic choices related to water management are also found in the energy-water-food intersection. For example, population growth in arid parts of the country, such as California and the Southwest, is straining the capacity of existing water supplies.[3] The growth in these regions has increased domestic and commercial demand for water, as well as demand for water to irrigate crops and cool electric power plants. Climate change is expected to further stress local water resources, increasing the risk of drought in these areas (EPA, 2012c). If these trends continue, choices will need to be made either to limit demand (for energy, water, and food) or increase supply. One potential means of augmenting current water sources is to rely on appropriate water quality for appropriate use, such as contaminated groundwater, reclaimed municipal or industrial wastewater, or brackish water for uses with which they may be compatible, such as thermoelectric cooling. Wastewater treatment facilities can also become sources of energy through biogas cogeneration, thereby reducing the energy demands of water resource management. EPA has recently updated its *Guidelines for Water Reuse*, which presents a comprehensive look at the latest developments in water reuse practices (EPA, 2012b).

[3] Population growth rates in many states in the Southwest exceeded the national average between 2000 and 2010. For example, Nevada (35.1%), Arizona (24.6%), and Utah (23.8%) experienced population growth rates more than double the national average of 9.7% (US Census, 2010).

II. What Do We Know About the Economic Value of Water?

INTRODUCTION

Decision-makers in both the public and private sectors regularly make decisions about how water is used. Ideally, these decisions should be guided by information that encourages efficient water use. This outcome depends on a number of factors, including the availability of information on the scarcity of the resource, the various options for its use, and the values people place on those uses. When this information is available, decisions concerning the use of water can be made with a clear understanding of the tradeoffs involved, providing a foundation for managing water resources in ways that are both economically beneficial and environmentally sustainable.

Unfortunately, the decisions we make today concerning the management and use of water resources are often based on a limited set of information about the availability and value of water in various uses. Developing a better understanding of that value is a considerable challenge, but is an important step to improve how we manage and use our nation's water resources.

THE ECONOMIC VALUE OF WATER IS SIGNIFICANT BUT ELUSIVE

We know a great deal at a general level about the economic importance of water. For example, we know that more than 86 percent of the U.S. population receives its household water from public water supply systems (USGS, 2009). Water revenues for these systems total more than $53 billion annually (EPA, 2012a). The economic importance of water, however, goes far beyond these simple figures. Consider the following:

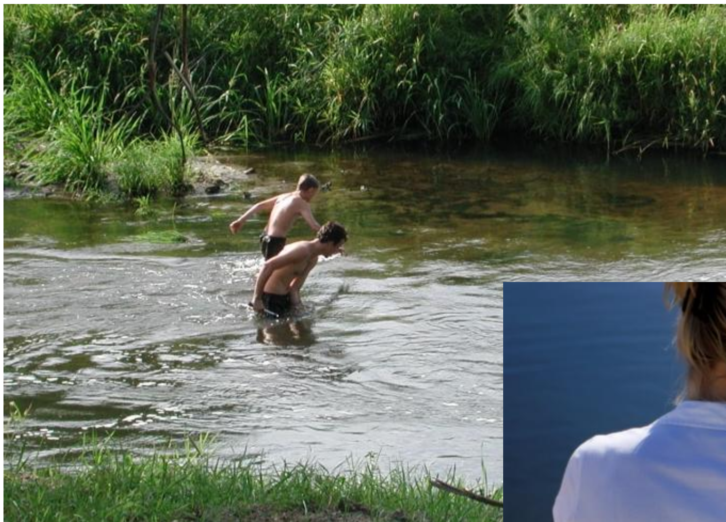
- The market value of agricultural production in 2009 exceeded $297 billion. The value of crops alone approached $144 billion; more than 50 percent of this total was generated on farms that used some form of irrigation. Water was also essential to the production of livestock, with a total market value of nearly $154 billion (USDA/NASS, 2010).

- In 2007, manufacturing accounted for approximately 17 percent of U.S. gross domestic product (GDP), with a total value of shipments exceeding $5.3 trillion and a total value added of approximately $2.4 trillion. Water is used in a wide range of manufacturing processes, but its use is most heavily concentrated in the chemical, paper, petroleum and coal, primary metal, and food industries. Together, these industries account for approximately 37 percent of manufacturing's contribution to U.S. GDP (U.S. Census Bureau, 2007).

- Mining and energy resource extraction added approximately $418 billion to GDP in 2007. Approximately two-thirds of this total was derived from the extraction of oil and natural gas, where water is used to assist production (U.S. Census Bureau, 2007).

- Revenues from the sale of electricity in the U.S. totaled $197 billion in 2007 (U.S. Census Bureau, 2007). Approximately 92 percent of this electricity was generated at thermoelectric power plants, where water is used in large volumes as a coolant. Another 6 percent was produced at hydroelectric facilities, where water serves directly as the source of power (DOE/EIA, 2012).

With the exception of hydroelectric power, the examples cited above concern water withdrawals. In-stream uses of water also make major contributions to the U.S. economy. For example, the nation's commercial fishing industry reported more than $4.5 billion in ex-vessel revenues in 2010 (DOC/NMFS, 2011). In addition, commercial navigation accounted for U.S. shipments of more than 2.2 billion tons of freight in 2009, including approximately 1.3 billion tons in international trade and 900 million tons in domestic shipments (USACE, 2010). Beyond these areas, swimming, boating, and other forms of water-based recreation serve as a major driver of economic activity in the recreation and tourism industry, accounting for billions in expenditures on everything from fishing gear to beachfront hotel accommodations (EPA, 2000). Once again, these figures are only an initial indication of water's economic importance. Because the sectors of the economy that are most directly dependent upon water influence activity in all other sectors, the economy as a whole is directly or indirectly dependent upon the output of industries for which water is a critical input.



Despite water's obvious importance, our understanding of its economic contributions is in many ways limited to general observations of the type provided above. For a variety of reasons we lack good empirical data on the value of water in different uses. This is partly because of the diverse nature of the resource and the needs that determine its value. Water's value in any particular case depends upon multiple elements – the *volume* of water supplied, *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. Its value also depends upon the pricing and availability of substitute and complementary goods, or of substitute and complementary inputs to production. Thus, it is important to recognize that water does not have one single value; even in the context of a single use, its value may change over time.

ELEMENTS 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.

In addition to the complexities noted above, a lack of observable and meaningful data on the sale and acquisition of water often makes it difficult to draw conclusions about its value. Water is often self-supplied. When that is the case, market information on the user's willingness to pay for its use – a clear signal of its value to the user – is generally not available. Even when data on market transactions are available, the usefulness of the information may be limited. This is due to a variety of factors. For example:

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- Those who purchase water from an external supplier – e.g., a public water supply system or an irrigation district – often face prices that do not fully reflect the opportunity cost of the water's use. The prices charged may be subsidized; often, they are not even sufficient to cover the long-term cost of delivering the water from the source to the user.

- The prices charged for the use of water may not reflect externalities – i.e., costs imposed on third parties – associated with the water's use.

Consequently, the prices associated with the use of water generally are an inaccurate measure of the resource's true value, which can lead to inefficient water use. Examining these prices may provide insights into the relative value of water in different uses, or to changing expectations regarding water's long-term value. It is unlikely, however, to provide a reliable basis for characterizing water's absolute value in any particular use.

ESTIMATES OF WATER'S VALUE ARE INADEQUATE TO SUPPORT MANAGEMENT DECISIONS

Estimates of the economic value of water are relatively few in number and vary greatly both within and across economic sectors. They range from as little as $1 to $4,500 per acre-foot (2010 dollars).[4] Currently available estimates from the literature suggest the following values for different uses (EPA, 2012a):

- Public supply and domestic self-supply – up to $4,500 per acre-foot;

- Agriculture - $12 to $4,500 per acre-foot;

- Manufacturing - $14 to $1,600 per acre-foot;

[4] An acre-foot is approximately 326 thousand gallons.

- Electric power generation - $12 to $87 per acre-foot for cooling water at thermoelectric power plants, and $1 to $157 per acre-foot for hydropower;
- Mining and energy resource extraction - $40 to $2,700 per acre-foot.

The variability of the estimates reflects their dependence on a variety of factors, including differences in the methods used to derive them. The variability in the estimates also reflects the multiple elements of water that can affect its value. Because the available estimates are limited in number and highly sensitive to both context and method, they cannot easily be used to draw inferences about the value of water in other contexts.

A number of other factors limit the usefulness of current data to help make water management decisions. For example, many estimates reflect average rather than marginal values. Using these estimates to evaluate marginal changes is likely to overstate the value of water. This can lead to decisions, such as public investments in inter-basin transfer projects, whose costs may exceed their benefits. In addition, estimates typically reflect the price or cost of water as an input to production, rather than the value of the output that use of an additional unit of water would generate. Estimating the latter – the *value of the marginal product of water* – is a more accurate measure of the value of water as an input to production, but requires detailed knowledge of multiple factors. These include the price at which the product can be sold, the mix of inputs employed in production, the marginal contribution of each input to production, and the extent to which the use of one input, such as water, can be substituted for another, such as labor. The nature of these relationships can vary considerably from case to case and is often known only to the producer. Because of these complexities, direct estimates of the marginal value of water in a particular use generally are not publicly available.

Given the lack of direct estimates of the marginal value of water in different uses, public sector water managers must make the best possible use of the data available. This may involve transferring value estimates derived in one context to assist with decision-making in another. This process is imperfect and can result in significant error, particularly if analysts fail to take into account differences between the context in which the estimates were developed and the situation to which they are applied. Attempts to take these differences into account may range from simple adjustments based on professional judgment to systematic analysis of the relationship between the value of water in a particular use and the variables that may affect that value (e.g., the volume of water supplied, its suitability for its intended use, etc.). Careful consideration of these factors can improve the quality of information available to decision-makers, reducing the likelihood that the transfer of value estimates from one context will fundamentally mischaracterize the value of water in another.

WATER QUALITY CAN AFFECT VALUE

Water quality is therefore a critical element affecting the value of water in economic activity.

Nearly every use of water requires a minimum standard of quality to be met. Water quality is therefore a critical element affecting the value of water in economic activity. It is important to note, however, that some uses are more sensitive to water quality conditions than others, and that different water uses are sensitive to different water quality stakeholders. For example, saline water is routinely used as a coolant at thermoelectric power plants, where the temperature of the water is more important than water salinity. In contrast, highly saline water holds little to no value for use in drinking water supply or irrigation. In general, sectors like residential use, recreation and tourism, and manufacturing have higher or varied water quality concerns depending on specific use, while other sectors like commercial navigation and mining and energy resource extraction have limited water quality concerns. Given these differences, using water of appropriate quality for each use can make economic sense.

Uses of water that involve human consumption or contact – such as drinking water, food and beverage manufacturing, or recreation – are particularly sensitive to water quality conditions and must meet standards designed to protect human health. When these standards are not met, the consequences can be severe. As Exhibit 3 below suggests, contamination of drinking water can exact a heavy cost. To avoid such impacts, public water supply systems invest heavily in capital-intensive treatment technologies. To help reduce treatment costs, they also

are investing more and more in source water protection efforts. Similarly, other off-stream users of water invest in treatment and source water protection systems to ensure that their water quality requirements are met. When these costs can be avoided – i.e., when source waters are of sufficient quality to meet the needs of the intended use – the value of the water to the user increases proportionately.

EXHIBIT 3. THE IMPORTANCE OF PROTECTING DRINKING WATER SUPPLIES

In 1993 the largest recorded waterborne disease outbreak in the United States took place when treatment plants in Milwaukee, Wisconsin failed to eliminate cryptosporidium oocysts introduced into surface waters by runoff from nearby cattle pastures. The incident resulted in more than 403,000 cases of illness (25 percent of the population) and 104 deaths in just two weeks. According to an analysis by the Centers for Disease Control, the total cost associated with the outbreak was $96.2 million (1993 dollars), including $31.7 million in medical costs and $64.6 million in productivity losses (Corso, 2003). Note that these estimates provide only 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.

With source water, it is important to recognize that water quality and water quantity are often linked. Where water resources are abundant, the capacity of source waters to assimilate contaminants and still meet the needs of a particular use is higher. Also, because different uses of water have different minimum quality standards, the effective quantity of water available for a particular use is a function of the quality of available water supplies. As noted above, the effective supply of water available for thermoelectric cooling can be augmented by the use of saline water or effluent that is unsuitable for other purposes. On the other hand, uses of water that degrade its quality can limit supplies available for more sensitive uses, such as drinking water. Groundwater is particularly vulnerable to water quality degradation, as aquifers are often the only reliable sources of water in some arid regions, and contamination of groundwater supplies can be difficult to reverse.

As emphasized in the earlier discussion of water's economic importance, everything is connected. This is especially true with water quality. When water users are jointly dependent on a shared resource, the degradation of that resource by one user can impose costs on others. These costs, when not captured in the market economy, represent externalities that reduce economic efficiency and harm social welfare. Some externalities are easily observed in market activity, such as when the cost of treating polluted water supplies is borne by users other than those responsible for the pollution. Other externalities – particularly those imposed on in-stream uses of water – are much more subtle. Long-term degradation of aquatic or coastal habitat, for example, can alter an ecosystem in ways that could have a devastating effect act on commercially viable fish stocks. The relationship between water quality and ecosystem services such as these is in many cases only partially understood, and requires further research. It is clear, however, that water resource management efforts must take these relationships into account to achieve sustainability and maximize the economic benefits our water resources provide.

BOIL-WATER ADVISORIES

A drinking water system's first priority is to provide consumers with water that is safe to drink. When natural disasters or other disruptions permit disease-causing organisms to compromise the integrity of drinking water supplies, state or local public health agencies may issue what is a called a boil-water advisory. These advisories typically recommend that customers boil any tap water they intend to ingest.

In the face of extreme storm events and the aging of our nation's water infrastructure it is possible that boil-water advisories may become increasingly common. In 2012, for example, the damage caused by Hurricane Sandy led more than 50 drinking water facilities in New York to issue boil-water advisories. The 2011 EPA Drinking Water Infrastructure Needs Survey and Assessment estimates a total national infrastructure need of $384.2 billion for the 20-year period from January 2011 through December 2030, with transmission and distribution needs representing 64 percent of this total. Water sector professionals estimate that there are close to 250,000 water main breaks in the U.S. each year. All these factors suggest increased vulnerability to supply disruptions and a potential increase in the frequency of boil-water notices.

Although boil-water alerts are necessary to protect the public from consuming potentially contaminated water, these events can have serious impacts on the well-being of the community as well. Limited access to water affects a community's quality of life and creates a business risk that can affect the local economy. Households may spend part of their grocery budgets purchasing bottled water. Hotels and restaurants face potential closure for days or weeks. For example, South Bass Island in Ohio, a popular resort area that is often referred to as the "Key West" of Lake Erie, experienced a groundwater-associated outbreak that affected approximately 1,450 residents and visitors between July and September of 2004. Wells at twelve of the island's businesses were shut down after coliform bacteria were detected. The groundwater contamination was likely caused by the transport of wastewater from septic tanks to the lake and the subsurface due to an extreme precipitation event.

III. How Do We Better Inform Our Water-Related Decisions?

INTRODUCTION

As the preceding discussion makes clear, the information currently available to guide management of our water resources falls short of what is necessary to ensure that we use those resources wisely. At the same time demand for information on the use and value of water is growing, primarily in response to growing scarcity of water in large regions of the United States. Competition for water is intensifying in much of the nation because population growth and rapid development are occurring in regions of the country where water is relatively scarce. Climate change is expected to exacerbate these difficulties by disrupting weather patterns and increasing drought risk in areas where water is already in short supply. In the face of these factors, the costs associated with inefficient use of water are growing.

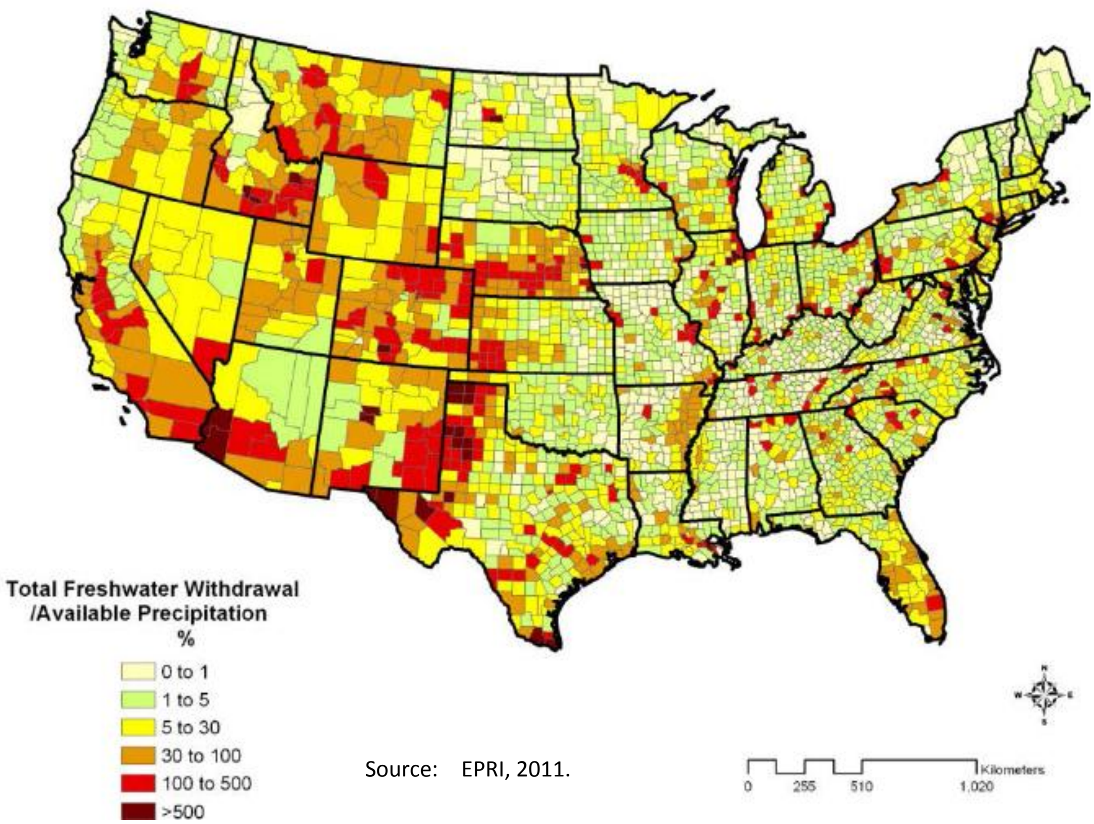
The path to making better choices in using and managing our water resources begins with a better understanding of the economic and environmental consequences of the options available to us.

The path to making better choices in using and managing our water resources begins with a better understanding of the economic and environmental consequences of the options available to us. As discussed below, developing this understanding and generating the information necessary to make better decisions will require a collective effort.

DEMAND FOR INFORMATION IS INCREASING

Recent years have seen an increase in the population and share of U.S. economic activity that is based in arid regions of the country. Constraints resulting from this increase in population and economic growth and limited water supply in the arid regions argue for an increase in information to support more informed decision-making on water issues. Exhibit 4, from a recent study by the Electric Power Research Institute (EPRI), provides perspective on this issue (EPRI, 2011). The exhibit shows total freshwater withdrawals by county 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 counties that rely on imports of water from other counties, or counties that meet demand in excess of precipitation by drawing on reservoirs of stored water – in many cases, groundwater. As the exhibit indicates, most of these counties are located in arid regions of the west. The sustainability of water use in these areas is questionable, particularly if there is evidence that their reliance on groundwater exceeds aquifer recharge rates.

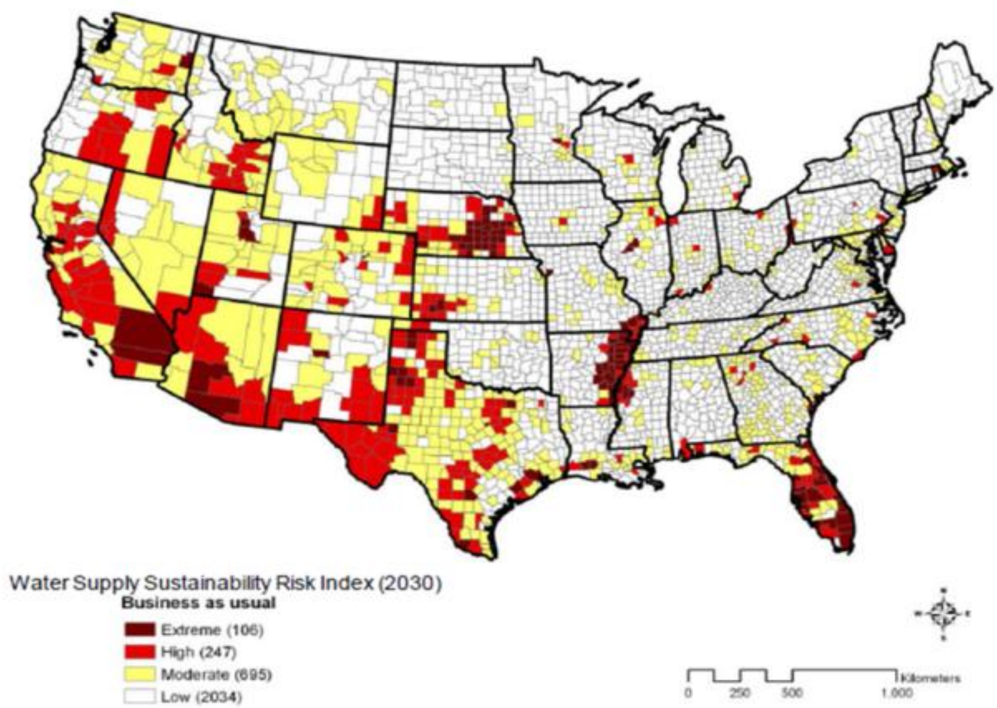
EXHIBIT 4. FRESHWATER WITHDRAWALS AS A PERCENT OF AVAILABLE PRECIPITATION (2005)



Source: EPRI, 2011.

In the coming decades, the potential for water shortages is likely to intensify. The EPRI study cited above identifies locations where water use is least likely to be 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 considerations such as access to renewable water supplies; susceptibility to drought; and the expected growth in water demand. As indicated in Exhibit 5, large portions of the Southwest, Lower Mississippi Basin, and Florida appear to be on unsustainable trajectories with respect to water use.

EXHIBIT 5. WATER SUPPLY SUSTAINABILITY RISK INDEX, 2030 PROJECTIONS



Source: EPRI, 2011.

Climate change may further 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, 2012c).

While the forecasts presented above suggest that competition for water in some regions of the U.S. will intensify in years to come, competing demands for water have already 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 (EPA, 2012c).

These situations represent areas of vulnerability for economic sectors dependent on water, as well as for the economy of the affected regions. They also serve to illustrate the rapidly growing need for better information to inform decisions concerning the management and use of water resources.

Information Needs Vary by Sector

The types of information needed to make better decisions about water use and management vary by economic sector and the nature of the decision being made. Water users in the extraction and processing sectors of the economy are likely to be concerned primarily with "productive efficiency" (the pursuit of maximum profit through cost minimization). Better information on the direct return on water-related investments or on the likelihood of water supply shocks can help firms manage their supply chains more efficiently, compete more effectively in output markets, and minimize losses during times of scarcity. Some users in these sectors – those with significant long-term water needs – may think strategically about sustainability in their use of water and see benefits in collaborating with others to economize and take advantage of synergies in water use. In general, however, firms in these sectors are likely to focus primarily on information related to their own business activities and on development of contingency plans for dealing with shortages.

Public water supply systems, federal and state power authorities and other water resource management agencies make decisions that affect multiple uses of water. These include water withdrawal and in-stream uses, both market and non-market (e.g., recreational use). Decision-makers in these sectors are likely to consider economic efficiency from a broader perspective, and will have a focus on "allocative efficiency," or optimizing water use and maximizing economic welfare for society as a whole. An example is the Tennessee Valley Authority (TVA), which manages the Tennessee River system for a variety of purposes, including commercial navigation, water supply, flood control, power generation, recreation, and maintenance of the aquatic ecosystem (TVA, 2013). The information needed to support decisions by organizations like TVA is more comprehensive and includes:

- Information on the elements of water required for each use (quantity, quality, reliability, timing, location, etc.);
- Information on how each use affects the relevant dimensions of water for other uses;
- Information on the economic welfare benefits associated with each use, including market and non-market uses;
- Information on economic interactions between sectors that use water directly and other sectors of the economy; and

- Information on how water resources contribute to economic output, both on a local level and on a regional or national level.

It is important to emphasize that a relatively high degree of resolution – i.e., a high degree of detail at a spatial, temporal, and sector level – is needed if the information described above is to be effective in improving our water resource decision making and long-term environmental or social sustainability. The increasing costs of inefficient water use are driving demand for more and better information about how water contributes to economic and social welfare, particularly in regions that already face water scarcity. To meet this demand we will need comprehensive information, both to illuminate opportunities to increase economic efficiency in water use and to identify ways in which the institutions that govern water use may need to evolve to achieve this goal.

Potential Avenues for Research

Improving our understanding of the value of water in different uses will require additional data on the relationship between water use and productivity in each sector of the economy. In the case of off-stream use, the data available in each case ideally would support analysis of the value of the marginal product of water. This requires developing production functions that show how water use, in combination with other inputs, affects output and revenues at the level of an individual firm or industry. To the extent possible, research in this area should also take into account the impact of water quality and other variables (e.g., the reliability of the supply) on the value of water in a particular use.

In addition to developing better information on the value of water in a given use, it is important to develop tools that will support analysis of the economic implications of changes in the use of water across sectors, as well as analysis of the economic consequences of water shortages. An example is provided by water management programs in nations like Australia, which employ computable general equilibrium (CGE) models to assess the economic impact of water use within a geographic region (e.g., a watershed). CGE models explicitly account for the complicated interactions and feedbacks that exist in economic systems, allowing them to capture indirect effects as well as direct effects of changes to the system. Use of water-CGE models outside the U.S. has increased in recent years, but there have been few applications to date within the U.S. A limitation to the development of water-CGEs in the U.S. is the need for water intensity factors, which reflect the amount of water required for a particular unit of economic activity in a given sector. Information on these factors would be necessary to support development of water-CGE models for U.S. regions. Once developed, however, models of this type – as well as models that focus more narrowly on water-intensive areas of activity, such as the energy-water-food nexus – could be extremely valuable in assessing the economic impact of changes in water management and use across multiple sectors of the economy (Fadali et al., 2012).

WATER-CGE MODEL OF NEVADA

Fadali et al. illustrate how a water-CGE model of southern Nevada could be used to explore the dynamics between urban and rural regions reacting to a potential pipeline to alleviate constraints on water supplies. A complete CGE model would allow the exploration of regional economies under different scenarios, including the ability to trace the dynamics associated with change in land value in rural areas, costs of infrastructure development, recession or population growth in Las Vegas, prices under different water withdrawal options, and other similar dynamics (Fadali et al., 2012).

Similarly, it would be useful to explore the use of embedded resource accounting or water "footprint" analysis to estimate the virtual water content of different products. This information has the potential to benefit both producers and consumers. Specifically, knowledge of the water intensity of different processes would help producers evaluate tradeoffs between inputs (e.g., water, energy, or other substitutes), aiding their efforts to minimize production costs. Similarly, sharing information with consumers on the virtual water content of different products could steer their purchases toward sources that use water more efficiently (Ruddell, 2012).

COLLECTIVE ACTION IS NEEDED TO FILL INFORMATION GAPS

The gap between the current state of information about water's importance to the U.S. economy and the information needed to support optimal use of water resources is large. Better information on water's use and value would be of help to many in the public and private sectors, informing decisions surrounding a broad range of important economic, social, and environmental issues. Collecting or generating information of good quality and developing analytic tools that can employ it effectively across the breadth of these issues will require a systems perspective and a collective effort – one in which government agencies, as centers and funders of research on the economy and the environment, are likely to play a significant role.

An example of the research required is an ongoing effort on the part of the USGS to undertake a National Water Census (see textbox). In addition to this vital data gathering effort, it is important for those in the public sector to collaborate with one another and with non-governmental research centers to develop environmental-economic models (e.g., water-CGE models) and other analytic tools that will improve decision-making in management and use of our water resources. These types of tools provide a conceptual framework for combining data and describing relationships among key variables. For example, environmental-economic models can use information on economic and resource flows between sectors and ecosystems to illustrate how value is added at different stages along a supply chain, to evaluate the impacts of institutional change (e.g., creating markets to allow trading of water use rights), and to test different approaches for improving the efficiency of water use and management. They also can be designed to analyze both market and non-market values, providing a broad perspective on the economic importance of water. Tools of this type are likely to be of significant value to resource management agencies in analyzing the costs, benefits, and economic impacts of alternative water management strategies, assisting them in identifying measures that promote efficient and sustainable use.

NATIONAL WATER CENSUS

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; and each factor that has caused, or is causing, a conflict or shortage. 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. Gathering information of this type is a critical first step in building the capacity to manage water resources in ways that will help preserve and increase the economic value derived from their use. http://water.usgs.gov/wsi/

More generally, it will continue to be important for water resource managers and water users in the public and private sectors to share information on the types of data and analytic tools that may be needed to improve management and use of water. Ongoing dialogue with technical experts, stakeholders, and decision-makers will be crucial to understanding the types of information needed to reduce key uncertainties and evaluate the economic implications of alternative actions. Continued communication on these issues is essential to ensure that decisions concerning future management and use of U.S. water resources will meet society's needs efficiently and sustainably.

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Page 25: Carrie Samis, Maryland Coastal Bays Program

Additional Information

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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*.