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The Agricultural and Economic Value of Water

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Abstract

Water is an essential resource that sustains not only agriculture and human communities but also the natural environment. It provides a suite of ecosystem services, such as recreation and habitat for wildlife, that affect the well-being of the public. However, the use and allocation of water involve tradeoffs, especially in the context of competing demands and limited availability. This report presents a targeted review of the economics literature on the economic value of water for agriculture and environmental flows, leveraging both observed behavior and survey methods. It examines the economic implications of these tradeoffs, with a focus on environmental and resource economics, energy economics, and applied econometrics. The report also highlights the challenges and opportunities associated with measuring the economic value of water, including the complexity of the systems involved, the heterogeneity of preferences and behaviors, and the uncertainty of water availability.

Keywords: Irrigated agriculture, groundwater, surface water, drought, ecosystem services, hedonic price method, nonmarket values, water market

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A report summary from the Economic Research Service *April 2025*

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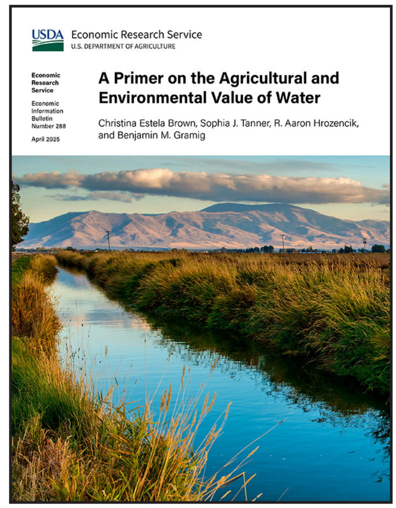
What Is the Issue?



Water is vital to communities. It is an input to agriculture, a source of municipal drinking water, and provides a variety of ecosystem services. Severe and long-term droughts demonstrate the importance of considering the value of water resources across these alternate uses. Water markets provide an opportunity to transfer water to buyers who derive the most value from its use. Yet prices in water markets often fail to fully reflect value across sectors, especially water for environmental flows. Policy, regulatory barriers, and physical infrastructure may prevent the unrestricted transfer of water across users and may distort prices. Understanding the value of water for differing end uses, along with rights and ownership, informs water allocation decision making among local, regional, and Federal entities.

What Did the Study Find?

- Active markets for temporary leasing or the permanent transfer of water offer a means to directly assess how the agricultural and environmental sectors value water resources. High transaction costs may complicate these values in some situations.
- Water markets exist in only a few regions of the United States. The absence of markets for water necessitates the use of other methods to value water resources. The economics literature has primarily relied on land transaction data to value access to surface or groundwater in agriculture.
- The value of water for recreation purposes in lakes and rivers is at times comparable with benefits from diverting water to alternate uses; however, this depends on current conditions and the alternate use.
- Much of the nonconsumptive value of water is attributable to water's role in supporting aquatic and riparian habitats and providing services such as recreation and cooling.

How Was the Study Conducted?

A selective literature review of 60 water studies published from 1962 to 2021 was conducted to compare the methods used for valuation. The most relevant findings were synthesized from studies valuing water access for agriculture and the ecosystem service value of water to the public. Two appendices to the report contain additional detail from the literature reviewed and a novel case study of leases and permanent sales of water rights in California from 2010 to 2019.

The Agricultural and Environmental Value of Water

Introduction

The issues of water scarcity and allocation are among those with which agricultural producers, Government agencies, and other stakeholders with interests in water throughout the United States must contend. These issues are likely to grow as population pressures, environmental conditions, and shifting consumer preferences affect where and how water is used (IPCC, 2022). Recent severe droughts in California, the Central High Plains, and the Southeast highlight the importance of water resources in supporting the agricultural economy and well-being of the population (NOAA, 2019). Periods of water scarcity also highlight the competition that occurs between different sectors of the economy that demand water. Optimizing the allocation of water using economic criteria requires quantifying its total economic value (TEV) across different uses. Economic optimization would put water to its highest value use, but in practice, physical, legal, and cultural considerations are also important factors. This report examines the economic value of water across different sectors, specifically, the agricultural sector and water for environmental flows.

Water's TEV as an environmental resource includes both its value derived from directly using the resource (either consumptively or nonconsumptively) and the nonuse value that individuals derive from water even if they do not use it themselves (Pearce & Turner, 1990), whether as an input, through direct consumption (e.g., drinking water), or through nonconsumptive use (e.g., water-based recreation). For example, water serves as an input to agricultural production that directly affects annual farm revenues through yield (yield × price = revenue). This relationship is inherent in farmland real estate and rental markets, as access to water supplies (e.g., aquifers underlying farmland or surface water rights) is reflected in the value of agricultural land (Sampson et al., 2019). This water value relationship is also an important factor, after considering costs, in the decision to invest in or upgrade irrigation systems. Recreation that depends on adequate amounts of water and aesthetic appreciation of waterflows is another example of use value.

Nonuse values are not derived from direct consumption or use but require water, often through intermediate processes, in order for people to receive benefits from the consumption of a good or service. Water has nonuse values, in addition to the use values mentioned, because it is a key component of properly functioning ecosystems whose TEV[1] is not reflected by prices in established markets for crops, land, or electricity.[2]

Agriculture is an intensively managed ecosystem, often referred to as an agro-ecosystem, that supplies society with different ecosystem services, each of which has different values. Provisioning services are those that can be extracted from nature (e.g., crops or food, timber, water for drinking or irrigation). Regulating services provided by ecosystem processes assist in moderating natural phenomena (e.g., pollination, carbon storage, flood control, etc.) and have nonuse values (Millennium Ecosystem Assessment, 2005). Provisioning services tend to be directly consumed and have use values, while the value society derives from regulating services are generally nonuse values. Water is an input to crop production, which is a provisioning ecosystem service with observable prices for different crops exchanged in markets. In addition to directly provisioning fresh water, surface water also supplies supporting ecosystem services by providing biodiversity habitat and cultural

[1] Nonuse values, when aggregated across households or people, can represent a large component of total economic value (TEV) of a resource even if willingness to pay per person or household is small.

[2] The value of water for ecosystem services has gained prominence in local and State-level environmental policy (e.g., Colorado's instream flow laws) (Bassi et al., 2018).

ecosystem services when used for recreation. When combined, the value of these provisioning, supporting, and cultural ecosystem services equals the TEV of water to society.

Across the breadth of water users, significant variation exists in how water is valued,[3] depending on environmental conditions and current allocation. That is, some use values are directly priced or capitalized in markets while others are not (e.g., publicly provided recreation). Additionally, the nonuse value of nonexcludable public goods (available to everyone, such as public roads) cannot be efficiently priced by markets. This variation in water value across different uses and across time complicates policymaking that seeks to optimize water use, particularly when external events (e.g., droughts, defined as a protracted period of less than average precipitation relative to historical averages (Lloyd-Hughes, 2014)) force local, State, and Federal stakeholders to make decisions regarding the allocation of constrained water resources. In times of scarcity, allocating water across users involves tradeoffs, and when values differ or are unclear, it is difficult to characterize these tradeoffs.

The goal of this report is to illuminate the value of water for both consumptive use by agriculture and conserved water for recreation and ecosystem-service provision. The authors summarized the policy and management implications of the water valuation literature.[4] This information can help stakeholders better assess the costs and benefits of programs designed to improve irrigation efficiency and augment in-stream flows for ecosystem and recreational purposes.

Classification of Value

The use value of water can be classified into consumptive and nonconsumptive values. Consumptive values of water are those that are derived from diverting or removing water from the landscape, such as through absorption by crops, watering livestock, or use in manufacturing; water is then not immediately available for downstream use (Dieter et al., 2018). Nonconsumptive values are those that allow the water to remain on the landscape. Consumptive and nonconsumptive values of water are not always mutually exclusive. One example of this is agricultural return flows that are not absorbed during irrigation and are returned to surface or groundwater after a period of time. Nonconsumptive uses directly affect individual wellbeing. However, an individual can benefit from water without affecting someone else's ability to also benefit (e.g., by viewing or swimming in the water).[5] The agricultural sector diverts water for irrigation to support production where natural precipitation is insufficient and uncertain to meet crop water requirements, as well as to provide reliable timing. Irrigation is the largest consumptive use[6] of water in the United States (Dieter et al., 2018). Some irrigation water is eventually returned to the environment, but the remainder is lost to evapotranspiration, evaporation, or lost in transit. In historically drier regions of the Western United States, irrigation is essential for high or reliable yields, but in historically water-abundant areas irrigation has not been necessary except for specialty crops or commodity crops harvested for seed. As a result, property rights and institutions governing water use and the availability of infrastructure to transfer water between farms and regions are drastically different in the West compared to the East. The primary source of water used for irrigation, whether surface

[3] Water value depends on its utility to consumers and producers. Well-functioning markets reveal a price to associate with the value of water. When markets are thin (i.e., not enough buyers or sellers), weak (i.e., contain information asymmetries, excessive transaction costs, poor property rights, etc.), or nonexistent, then water cannot be accurately priced—but people still value it. Thus, economists employ both market and nonmarket techniques to see how accurately the market price reflects the value.

[4] The social science literature evaluating the value of water is vast, and this report does not purport to provide a comprehensive account of the literature. Readers interested in learning more about how social scientists think about and value water should consider referencing the following more comprehensive books and journal articles: Gibbons (1986), Young (1996), Ward & Michelson (2002), Hanemann (2006), Birol et al. (2006), and Young & Loomis (2014).

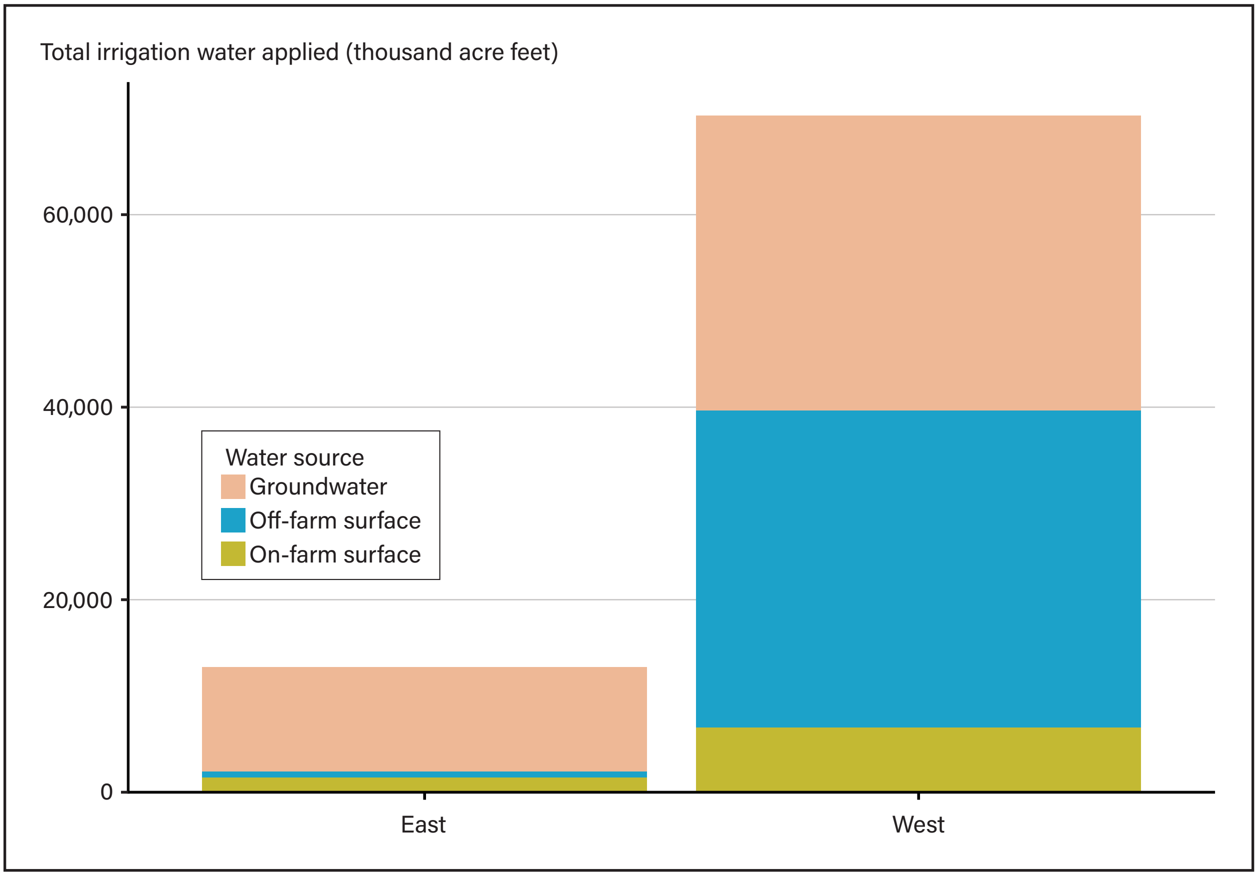
[5] Sergeson (2017) further divides nonconsumptive values into direct nonconsumptive and indirect nonconsumptive uses.

[6] Municipal drinking water supplies and water in some industrial uses are also categorized as consumptive, as they reduce availability for alternate uses. See Gibbons (2013), chapters 1 and 3, for information on valuation of municipal and industrial water.

water or groundwater, is also considerably different when comparing Western and Eastern agriculture. Figure 1 illustrates how irrigation water use and source differ between the Eastern and Western United States, with much greater volumes of water used for irrigation in the West and a larger share of groundwater diverted for irrigation in the East. The water diverted for irrigation by the agricultural sector is not available to meet the downstream demand of municipal, commercial, and recreation sectors or provide services for downstream riparian (land adjacent to rivers and streams) and aquatic ecosystems. Although some diverted water eventually returns to replenish water sources, much of it is used consumptively in the irrigation process.

Figure 1

Share of total water applied by source in 2018, Eastern versus Western United States



Note: The Eastern United States comprises Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin. The Western United States comprises Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. Water applications from Hawaii and Alaska are not included.

Groundwater refers to water applied for irrigation purposes deriving from wells, including both pumped and artesian/flowing wells. On-farm surface water refers to “water from a surface source not controlled by a water supply organization. It includes sources such as streams, drainage ditches, lakes, ponds, reservoirs, and on-farm livestock lagoons on or adjacent to the operated land” (USDA, NASS, 2019). Off-farm surface water is “water from off-farm water suppliers, such as the U.S. Bureau of Reclamation; irrigation districts; mutual, private, cooperative, or neighborhood ditches; commercial companies; or community water systems. It includes reclaimed water from off-farm livestock facilities, municipal, industrial, and other reclaimed water sources” (USDA, NASS, 2019).

Source: USDA, Economic Research Service analysis of data from USDA, National Agricultural Statistics Service, Irrigation and Water Management Survey.

Water used in irrigation diminishes the source and is not available for other uses, except for irrigation runoff stored in irrigation and drainage tailwater recovery systems and reused later for irrigation. Water used for recreation, however, stays in the system or is immediately returned to the aquifer or surface water. Activities such as wildlife viewing, hunting, fishing, boating, and whitewater sports all depend on the availability of water resources. The quality of recreational experiences is affected by stream flow and the health of riparian ecosystems (Eiswerth et al., 2000). In addition, the preservation and restoration of riparian habitats have significant economic value to local communities and visitors (Holmes et al., 2004). These uses are considered nonconsumptive, as water is still available downstream. Water that remains on the landscape is important to maintain properly functioning ecosystems and to provide erosion regulation, soil formation, nutrient cycling, and other ecosystem services that benefit communities (Martin-Ortega et al., 2015; Johnston et al., 2017).

Tradeoffs between uses often result in conflict between the agricultural sector and other water users, particularly in the Western States, where the doctrine of prior appropriation[7] governs most water-right allocations and many of the most senior (and therefore secure) water rights belong to agricultural producers. Conflict also arises over water quality when upstream activities impair water quality for downstream users, whether for consumptive (i.e., drinking water) or nonconsumptive use (i.e., recreation). States have used various legal and policy approaches to manage water rights allocation. Individual States generally manage instream flow regulations, undertake programs to study the impacts of streamflow, and guide policy at multiple levels to maintain acceptable levels of environmental protection. Federal policy also plays a role in the regulation of environmental flows in certain cases. For example, the Endangered Species Act (ESA) prohibits destruction or adverse modification of a critical habitat, which may require maintaining minimum instream flows (16 U.S.C. § 1532). The Central Valley Project Improvement Act (CVPIA) in California mandates changes in the management of the Central Valley Project for the protection, enhancement, and restoration of wildlife and fish.

The California Water Board, for example, is required to consult with the California Department of Fish and Wildlife (CDFW) to determine appropriate environmental flows for wildlife before appropriation decisions are made (California Water Code § 1707). The CDFW conducts studies on instream flow to determine criteria. Similarly, the Texas Water Code outlines an Environmental Flows Advisory Group that adopts environmental flow standards and establishes the amount of water to be set aside (Texas Water Code § 11.02361). Market-based solutions such as watershed-level, State, or regional water markets are increasingly utilized as a means to alleviate conflicts by allowing the trade and sale of water rights. However, this is only possible where property rights, institutions, and water infrastructure allow water to be transferred. Transactions in water markets provide a lens through which to study variation in value across different uses of water.

Methods for Estimating Value of Water

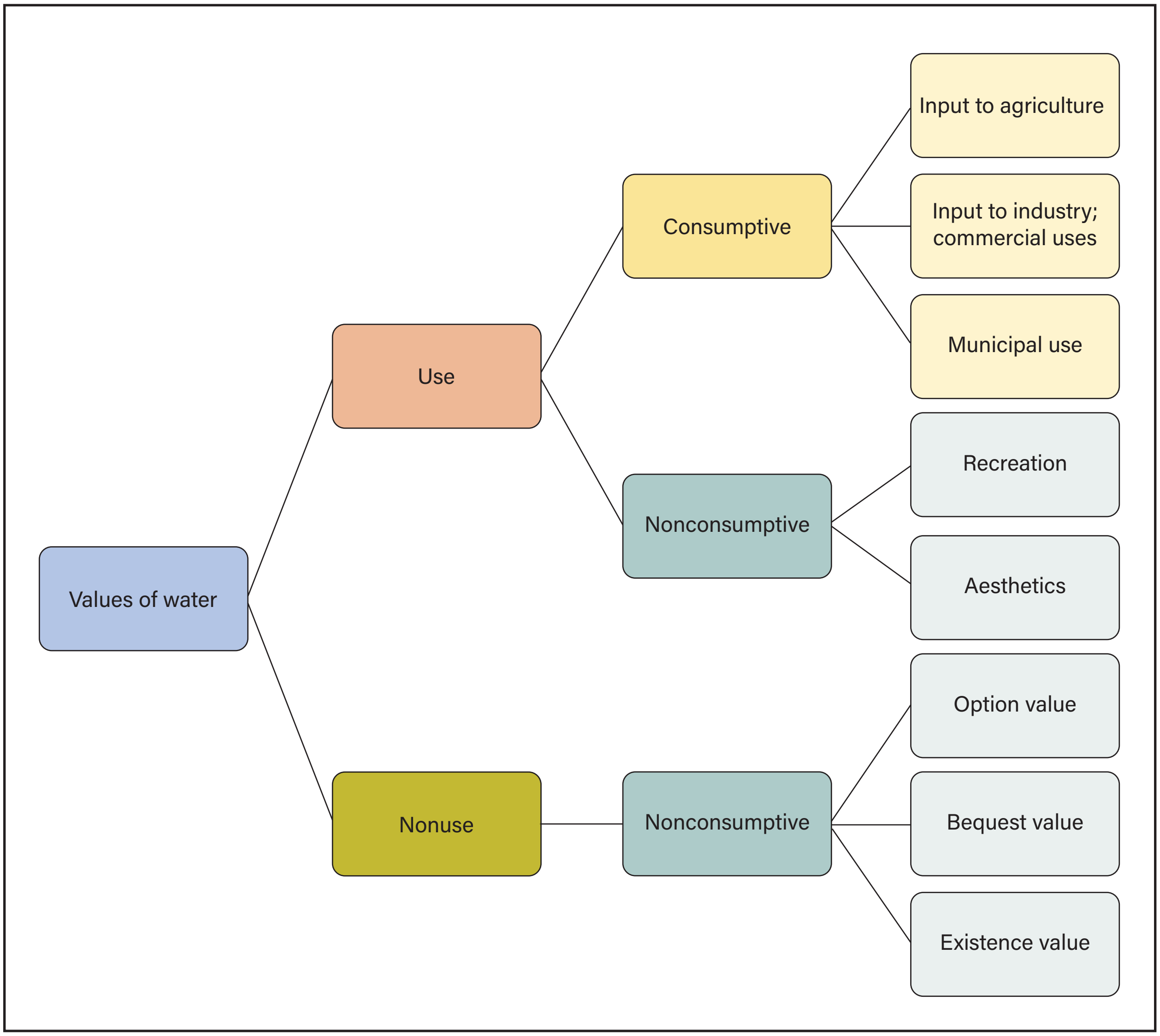
The prices paid for private goods that are bought and sold in competitive markets reveal consumers' willingness to pay. Environmental and natural resources, which are often not valued in competitive markets, do not have well-defined property rights. That is, individuals or firms may not have the legal right to prevent others from consuming or degrading the quality of these resources. Looking beyond physical quantities of water and considering water-based ecosystem services that are not exchanged in markets illustrates the problem of missing markets for some services that are valued by society despite not having observable prices and transactions. Missing or incomplete markets do not eliminate the need to make resource allocation decisions that are subjected to increased scrutiny during periods of greater water scarcity. This underscores the usefulness

[7] The doctrine of prior appropriation, functionally "first in time, first in right," is predominant in the Western United States. It assigns water rights based on the beneficial use of water, prioritizing those with seniority in terms of available water for diversion (Haar & Gordon, 1958; Huffaker et al., 2000; Zellmer & Amos, 2021). In contrast, the riparian doctrine, which is most common in the Eastern States, assigns water rights based on the ownership of riparian land.

of characterizing the economic benefits and costs—tradeoffs—of water under different uses and in different institutional contexts.

Many methods are used to value natural resources when markets are not available and generally fall into one of two categories. Revealed preference methods use observed behavior in a market for a good or service related to the water resource. Stated preference methods rely on stated responses to a hypothetical scenario or change. Figure 2 illustrates the various use and nonuse values of water and the methods generally associated with the estimation of each.

Figure 2
Approaches of valuing use and nonuse values of water



Note: Approaches to use and nonuse values of water, classified by consumptive and nonconsumptive use. How these values can be calculated are shown using stated preference (e.g. contingent valuation method) and revealed preference (e.g., hedonic and travel cost methods) methods.

Source: USDA, Economic Research Service adapted from Pearce & Turner, (1990), Goulder & Kennedy (1997), Millennium Ecosystem Assessment (2005) and Barbier (2009).

Revealed Preference Methods

Revealed preference methods estimate the value of environmental goods and services using observed behavior. Revealed preference methods are used to value the direct use of water as an input to agriculture, industry, or municipal use and can also be used to measure nonconsumptive values based on observed behavior in markets for related goods and services. The two most common revealed preference methods used to estimate the value of water are the hedonic price method (hedonic method) and the travel cost method (see box, "Valuation Methods"). The hedonic method uses prices from the observed sales of land or property, while the travel cost method uses the costs incurred by visitors to a site combined with their number of trips to estimate a demand curve from which visitor willingness to pay is calculated.

Access to water is a valuable resource for farmers, which may be reflected in agricultural land values. Using the hedonic method, the value of access to groundwater can be revealed through transactions in agricultural land markets when other differences have been accounted for. Similarly, proximity to a lake or a river, the landscape visible from a property, and quality attributes of an environmental amenity (e.g., water clarity, lake levels, or stream flow) can influence the prices paid for houses. The variation in sales prices for residential properties can also be used to value changes in nearby environmental amenities using the hedonic method.

Applied to water, the hedonic method can capture both consumptive (e.g., agricultural land) and nonconsumptive (e.g., residential properties) values of water depending on the property market studied. Nonagricultural homeowners may purchase property near water resources for recreation opportunities and aesthetic enjoyment (nonconsumptive). The hedonic method can also be used to estimate the value of irrigation water access in agricultural land (consumptive). However, the hedonic method is limited in its ability to estimate value. It can only capture the value of environmental attributes or ecosystem services that are related to housing or land prices, and the impact on homeowners and landowners is a function of proximity (Hanak & Stryjewski, 2002). Lakes, rivers, and streams may provide other ecosystem services that are not captured in the hedonic model because they accrue to other consumers or are not directly related to housing or land prices.

Stated Preference Methods

Stated preference methods estimate value through direct elicitation in surveys, focus groups, or experiments. These are particularly useful when the goal is to value changes in quantity or quality that are hypothetical or the subject of a proposed program or policy change, or when estimating the nonuse value[8] of resources (e.g., existence value for endangered species). These methods are particularly useful when estimating the value of water to overall ecosystem health and the value of water on the landscape for aesthetic or cultural reasons. Two widely used stated preference methods in the water economics literature are contingent valuation and choice experiments (Champ et al., 2017). Surveys for both of these methods present respondents with hypothetical scenarios regarding changes to the ecosystem service being valued.

[8] Nonuse values can only be estimated using stated preference methods.

Valuation Methods

Net Present Value for Irrigation

Standard methods for calculating the net present value of an investment are not the focus of this report but can be used to calculate the private costs and benefits of supplemental irrigation that accounts for the capital cost of an irrigation system, operation and maintenance, and crop yield benefits. The cost of debt financing and the opportunity cost of capital can be considered when using this method. However, it can only be used to estimate the private consumptive use value of water for agricultural production under different rainfall, water access, and use conditions. This approach only considers private economic tradeoffs, not public benefits and costs beyond a farm.

Residual Value or Production Function

The residual value or production function approach recognizes that water is used as an intermediate input in the production of agricultural goods. It calculates the implicit value of water by measuring the resource's contribution to firm-level profit. This is accomplished by taking the difference (the residual) of the value of the agricultural output and the costs of all nonwater production inputs and is sometimes done using optimization models (see García Suárez (2019) for an application of this approach).

Hedonic Method

The hedonic method is built on the idea that some goods are composite or differentiated goods whose total value is derived from their component characteristics (Lancaster, 1966). The hedonic method was formalized by Rosen (1974), who demonstrated that the observed market equilibrium price of a differentiated good can be used to estimate the implicit price (willingness to pay) of its component characteristics (Taylor, 2017). In the case of environmental resources, the hedonic method is most frequently applied to property or land values. For example, home value is a function of the number of rooms, square footage, lot size, age of the structure, and other physical characteristics. Nonphysical characteristics such as the location of the home in relation to various amenities (e.g., schools, city center) are also included in property value. In the environmental economics literature, the hedonic method has been used to value many environmental amenities and disamenities, including parks/urban green space, forests, coastal resources, and flood risk.

Travel Cost Method

The travel cost method relies on observed behaviors in a market related to the ecosystem good or service in question. In this case, information about the costs of travel reveals the recreational value of lakes, rivers, and other water bodies, as well as changes in their quality. This method estimates the demand for recreation trips as a function of trip expenditures, including the cost of gasoline and the opportunity cost of time spent traveling. Variation in environmental quality between sites or across time is used to identify the value of changes in ecosystem services. Early examples of recreation demand models were used to value wilderness recreation, big game hunting, and water quality (Smith, 1975; Loomis, 1982; Smith & Desvousges, 1985). Recreation demand models capture the consumptive use values related to recreation of the study population, and like hedonic models, underestimate the total ecosystem service value of sites.

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Contingent Valuation

In contingent valuation studies, respondents value the change directly in monetary terms. Sometimes, this is in the form of a hypothetical voting referendum where the change is supported by collection of an individual tax or fee. The level of the tax or fee is varied across respondents. Contingent valuation has a long history of being used for the valuation of natural resources (Carson, 2012). The best practices for contingent value studies were outlined in the report of the NOAA Blue Ribbon panel that sought to formalize guidelines for the development, administration, and analysis of contingent value surveys (Arrow et al., 1993) and have been updated with more recent guidance (Johnston et al., 2017).

Choice Experiment

Choice experiment studies elicit respondent values indirectly. Respondents are presented with two or more scenarios or profiles, each consisting of a bundle of attributes that are systematically varied among profiles. Observed choices between the profiles are used to estimate the marginal willingness to pay for attributes. Choice experiments have a history of use in marketing and transportation research, as well as wide use in the economics literature on food product attributes (Louviere & Woodworth, 1983; McFadden, 1986; Loureiro & Umberger, 2007). These studies have been more frequently used in the valuation of ecosystem services in recent years, as they can be used to value tradeoffs between different attributes of a resource.

Use Value of Water

Agricultural Use

Water is a valuable agricultural sector input for crop irrigation, livestock watering, and aquaculture. The U.S. Geological Survey (USGS) reports that among all sectors, withdrawals[9] by the irrigated agricultural sector accounted for the largest share of water withdrawals in 2015 (Dieter et al., 2018). Growing water scarcity and increasing demand from other sectors have prompted economics literature that aims to estimate the value of water use and access in irrigated agriculture[10] to inform policymaking and cost-benefit analyses related to water resource allocation. The literature has used both revealed preference and stated preference methods to uncover the value of water in agriculture.

The hedonic price model is the most common revealed preference method used to estimate the value of water access and use in irrigated agriculture. The application of the hedonic method to value water resources leverages the connection between land and water, or appurtenance restrictions,[11] to measure how a parcel's water characteristics (e.g., surface water right, access to groundwater) capitalize into the price of the land. Notable early examples of this literature include Selby (1945), Milliman (1959), and Hartman and Anderson (1962), all of which state the value of farmland water access as a means to assess the potential benefits of investments in irrigation infrastructure.

[9] U.S. Geological Survey defines water withdrawals as "water removed from a groundwater or surface-water source for use" (Dieter et al., 2018).

[10] Water withdrawals for livestock and aquaculture are also important for the agricultural sector. However, very few economic studies explicitly estimate their value, and neither livestock nor aquaculture account for a significant proportion of total water withdrawals (Dieter et al., 2018). This report primarily focuses on agricultural water values associated with irrigation.

[11] Appurtenance restrictions legally bind land and water together (i.e., the right to use water is appurtenant to the land upon which the water is applied). When land is transferred to a new owner, the new owner will also acquire the water rights as well, unless otherwise specified by the grantor.

Crouter (1987) was among the first to apply the formalized hedonic method to calculate how access to water influences observed farmland real estate prices. Crouter measured how farmland values were affected by prior appropriation water rights and water allotments from a Bureau of Reclamation project (The Colorado-Big Thompson Project) associated with farmland located in the Northern Colorado Water Conservation District. In related work, Torell et al. (1990) compared sales of irrigated and nonirrigated lands in the High Plains region and found that between 30 percent and 60 percent of the sale price of irrigated farmland was derived from the value of the land's access to water. Faux and Perry (1999) leveraged the hedonic method to assess the value of access to water among farmland sales in Oregon. Their work was the first to explicitly control for variation in land productivity when measuring the value of water in agriculture.

More recent work includes Petrie and Taylor (2007), Butsic and Netusil (2007), Yoo et al. (2013), Buck, et al. (2014), Brent (2017), and Sampson et al. (2019). Petrie and Taylor (2007) were unique in this literature because they measured the value of usufructuary water rights (i.e., the right of use) in the southeastern United States by exploring how farmland values were affected by a moratorium on issuing water use permits. Yoo et al. (2013) found that how water rights were capitalized into agricultural land prices differed according to urban and suburban development pressures. Buck et al. (2014) were among the first researchers to assess water values using a panel data approach.[12] Results suggested that the value of irrigation water in California was much higher than previously estimated, which the authors attributed to unobserved differences creating bias in past empirical studies. Sampson et al. (2019) estimated the value of water in storage using parcel-level transaction data from Kansas between 1988 and 2015. They found that, on average, values for irrigated parcels were 53 percent higher than nonirrigated parcels and that the premium awarded to irrigated land was growing over time.

The hedonic literature discussed used data on individual land transactions to estimate water values. Several studies relied on county-level data or self-assessed land valuations to estimate the value of water. Notably, Schenkler (2007) and Ifft et al. (2018) used self-assessed land values to estimate how water availability and restrictions on water use capitalized into farmland values. Hornbeck and Keskin (2014) relied on USDA, NASS reported average values of agricultural land for counties overlying the High Plains aquifer and nearby counties to estimate the value premium associated with access to the aquifer. Using survey or county-level data may be useful when data on real estate transactions are sparse or unavailable.

Outside of hedonic and revealed preference methods, the economics literature has utilized the development of markets for water as another more direct means to assess consumer willingness to pay for water. Much of the economics literature related to water markets aimed to quantify the efficiency gains associated with market-based water allocation mechanisms (e.g., Chong & Sunding, 2006; Brooks & Harris, 2008) or to assess the institutional characteristics facilitating markets for water (e.g., Grafton et al., 2011). A relatively smaller body of literature used data from these markets to characterize the value of water applied as irrigation or used for other purposes. For example, Brookshire et al. (2004), Brown (2006), and Brewer et al. (2008) all used data on individual water market transactions to characterize market prices and trade volumes by sector. A key result from these analyses was that water markets varied over space and time, reflecting geographic differences in the transaction costs of trade and variation in water scarcity. (See Hansen et al. (2006) for an analysis of market option value under supply uncertainty.) Additionally, market data revealed that the agricultural sector generally had the lowest willingness to pay for water compared to other sectors. More recent work by Schwabe et al. (2020) documented current water market trends in the United States but did not report sector-level water prices.

[12] Panel data refers to data with multiple observations of the same unit (e.g., individuals, firms, parcels of land) in multiple dimensions across time. This type of data is sometimes referred to as longitudinal.

Early applications of the residual value or production function approach (e.g., Norton & Hazell, 1986; Chaudhry & Young, 1989) used linear programming models of a representative farm with a known cost and profit structure to identify how water affects net income by varying water use. More recent studies have leveraged insights from the agronomic literature to characterize the relationship between water applications and yield more accurately (e.g., Quilloy et al., 2018) and used county-level data paired with production theory to value an entire groundwater resource (García Suárez et al., 2018). Rimsaite et al. (2021) also used county-level data to explore how the value of water applied as irrigation varied across time and space. Their results indicated that the value of water was mostly determined by the productivity gains associated with irrigation.

Economists have also employed, to a lesser extent, stated preference methods to value water resources in agriculture.[13] In this literature, experiments to elicit respondent preferences between different hypothetical situations related to changes in water availability were the most commonly used stated preference method. Among several international studies, Price et al. (2016) conducted a survey among agricultural households in Nepal to evaluate preferences for water storage to augment water availability for traditionally rain-fed agriculture. Their results suggested significant welfare gains associated with the adoption of on-farm water storage, although cost constraints for lower income households affected the distribution of the gains. In a related study, Rigby et al. (2010) evaluated marginal water values among horticultural producers in southern Spain and found that willingness to pay for irrigation water was generally above the prices that were currently paid for water. Another important study was by Barton and Bergland (2010), who paired data from a survey instrument with observations from a water market to compare water valuations using differing methods in a study area in India. Their results demonstrated that the choice of valuation methodology affected the estimated value of irrigation water. The agricultural use value of water has been measured many ways in many climatic, institutional, and market contexts using different types of data. Which past studies shed the greatest light on a specific contemporary water allocation setting will be a function of multiple factors affecting the site.

Environmental Use

Because the focus of this report is on trade-offs between agriculture and other water uses, literature on the ecosystem services valuation of freshwater lakes, streams, and reservoirs was reviewed rather than coastal resources. Much of the literature on ecosystem services centers on recreation, which constitutes a use value of water and may be observed using surveys or visitation data. In multi-use contexts where water is also used for hydropower, agriculture, or industry, the benefits to recreational users of higher reservoir water levels may compete with other uses that require impounded water to be released.

Some of the earliest recreation studies used contingent valuation to estimate willingness to pay for alternate management scenarios that would maintain lake or reservoir water levels for longer periods of time (Walsh, 1980; Walsh et al., 1980; Cordell & Bergstrom, 1993). However, the majority of the studies leveraged either primary data the authors collected using surveys or secondary sources of recreation trip data, to estimate travel cost (recreation demand) models of the effects of water level changes (e.g., Huszar et al., 1999; Jakus et al., 2000). These studies relied on the variation in water levels over time or across different recreation sites to identify the impact of water on visitation and recreation value. In settings where not enough variation in water levels was observed, some studies used observed trip data combined with stated responses to hypothetical changes to estimate net economic benefits (e.g., Eiswerth et al., 2000; Lienhoop & Ansmann, 2011).

Multi-use lakes and reservoirs provide a good opportunity to compare values across different sectors. Many studies estimated the nonmarket value of recreation at a reservoir or group of reservoirs. In some cases, however, the authors compared estimates of the recreation value of water with estimates of value for other

[13] The stated preference studies presented here are international. Agricultural practices may differ from those in the United States, and values may not be directly comparable.

uses such as hydropower or irrigation. For example, Cordell and Bergstrom (1993) used contingent valuation to estimate recreation values generated by four reservoirs in North Carolina under alternate water level management scenarios corresponding to delaying the drawdown, or lowering, of reservoir water levels in the summer. They found that maintaining high water levels during summer and fall resulted in significant recreational values. However, when compared to losses in power generation from the Tennessee Valley Authority, the authors found that the economic gains from recreation only outweighed the power generation and capacity losses at the four reservoirs when summer reservoir drawdown was delayed 3 months. When drawdowns were delayed for shorter periods, the resulting economic gains from recreation were lower than the power generation and capacity losses. When recreation gains were compared to system wide power sector impacts, all three drawdown scenarios examined produced net losses. Several studies of western lakes also found that the losses from water drawdowns or reservoir draining were comparable with the value to irrigated agriculture, or that estimates of value from agriculture intersected the range of estimated value to recreation (Ward, 1989; Fadali & Shaw, 1998; Eiswerth et al., 2000). These studies suggested that although recreational values from reservoirs are significant, the gains from diverting water to other uses may be equally high, especially when considering use values arising from hydropower generation.

Some studies combined estimates of the nonmarket value of recreation with impacts on recreation-related expenditures.[14] In a study of Alabama reservoirs, Hanson et al. (2002) found that for each foot of lowered water level, recreational expenditures decreased by 4 to 30 percent across the six reservoirs in the study. In the entire region, a permanent 1-foot decrease in water level decreased estimated recreation-related expenditures from $442 million to $398 million annually, approximately a 10-percent decrease. Connelly et al. (2007) conducted a survey of boat owners on Lake Ontario and the St. Lawrence River and found that they spent $178 million in bordering counties in 2002. The authors also used contingent valuation to estimate that boaters were willing to pay an additional $69.36 per day per boat and estimated their willingness to pay at various water levels. They found that recreational boaters experienced a large increase in net losses at water levels below 245 feet; however, they did not estimate the impact of water level fluctuations on expenditures.

The hedonic method has been applied to many contexts, including the valuation of natural amenities and environmental risks such as floods or hurricanes (Tyrväinen, 1997; Garrod & Willis, 1992; Bin & Kruse, 2006). In the case of valuing water resources, homeowners likely consider the aesthetic value of being close to a water feature as well as potential recreation opportunities. Hedonic models, therefore, capture both aesthetic and recreational values to a localized population of interest but would not capture the value from travel or tourism from people who do not live close by.

Much of the water hedonic literature has focused on water quality, which may directly impact human health as well as recreation opportunities (e.g., Leggett & Bockstael, 2000; Poor et al., 2007). Other studies focused on lake proximity, which also captures the recreational and aesthetic amenities of water in property values. However, less work in the hedonic literature focused on the variation of ecosystem services within a lake or reservoir. Greater competition for reservoir resources from competing uses (e.g., agriculture or hydropower) during times of drought offers a useful way to estimate the impact of water quantities on nearby housing markets. Lansford & Jones (1995) examined both the impact of proximity and water levels of Lake Travis in central Texas. They found that waterfront housing prices (of a representative 2,200 square-foot residence) were $3,200–$8,000 higher when the lake was at its long-term average level compared to when it was 6 feet below its average at the time of sale. They also found not only greater demand for waterfront properties with higher lake levels but greater demand for nearby properties as well. In another hedonic study, Loomis and Feldman (2003) estimated the benefits of high lake levels at Lake Almanor in California, which is also drawn down for hydropower. They found that 1 additional foot of exposed shoreline decreased sales prices by an

[14] Despite being a significant component of the total economic value of a water resource to a regional economy, recreation expenditures are an underestimate of true welfare measures. They do not include the opportunity cost of traveling to a site and exclude any nonuse value.

average of $108–$119, less than 1 percent of the house value. A more recent study of White Bear Lake in Minnesota found large decreases in property value due to lower water levels, a marginal loss of 8.5 percent of the value when lake levels were 6 feet below average (Liu, 2020). Consistent with recreation studies showing that moderate water flows were highly valued, the authors also found that property values were maximized when water levels were at the ordinary highwater level and decreased at either lower or higher water levels.

The literature on recreation and instream flow to rivers also includes many contingent valuation studies of alternate river flow scenarios, especially early in the literature; travel cost models have become more prominent in the past two decades. Like the lake and reservoir recreation literature, most of the U.S. studies on instream flow were in western States, where competition for water resources is more evident, though there were also a few studies in Connecticut (Poulos et al., 2012; Loo et al., 2015); Oklahoma (Chapagain et al., 2021); and Florida (Bi et al., 2019). In general, the instream flow literature estimated the economic value of recreation for certain uses (e.g., fishing, whitewater rafting, and boating). Duffield et al. (1992) used contingent valuation to estimate the recreational value of two Montana rivers by using onsite surveys of recreationists participating in a variety of activities. They found that moderate water flows were more highly valued than very low or very high flows. They estimated that marginal values of instream flow peaked at $10 per acre-foot when the river was flowing at 100 cubic feet per second (cfs) on the Bitterroot River and $25 per acre-foot at 100 cfs on the Big Hole River. Other studies of whitewater boaters also found the highest values for midrange water flows at the Grand Canyon (Neher et al., 2019) and the Poudre River in Colorado (Loomis & McTernan, 2014). Chapagain et al. (2021) estimated a model of demand for river access by nonmotorized boaters in national forests. They found a per trip value of $56 to $73 and a significant value for river flow velocity; however, river discharge was not statistically significant in their model.

To a lesser extent than the reservoir recreation literature, the river flow literature also compares recreation and other use values. Most of these authors compared recreation values to estimates for irrigated agriculture (Daubert et al., 1979; Duffield et al. 1992; Loomis & McTernan, 2014). Others compared values to reservoir recreation (Loomis, 2002; Bi et al., 2019) or hydropower (Loomis, 1996). A common theme among the agriculture comparisons was that timing and current flow levels matter. Several studies found that when rivers were at low flow levels, the marginal value of another acre-foot of water inflow was higher for recreation than for other uses, while marginal values for recreation were lower at times of high river flow and, therefore, less competitive with agriculture and other uses (Ward, 1987; Daubert et al., 1979; Duffield et al., 1992). However, this finding was not consistent. Using contingent valuation, Loomis & McTernan (2014) found that willingness to pay for whitewater boating in a Colorado river was highest at the highest flow level (1,900 cfs), exceeding the value to irrigation. In the Grand Canyon, whitewater boaters were found to have the highest willingness to pay for midlevel flow scenarios (13,000 cfs and 22,000 cfs) based on a choice experiment (Neher et al., 2019). When instream flows and reservoir recreation were in direct competition, the gain to river recreation from dam removal typically exceeded the costs to lost reservoir recreation (Loomis, 2002; Bi et al., 2019).

Nonuse Value of Water

Fresh water is a source of multiple ecosystem goods and services beyond direct use as recreation or agricultural irrigation. It provides habitat for wildlife, including fish and game species, and cultural services (e.g., aesthetic enjoyment) in addition to recreation, to name only a few. A number of studies estimated other ecosystem services or nonuse values of water such as protection of endangered species or fish habitat (Berrens et al., 1996 and 1998; Douglas & Taylor, 1998; Berrens et al., 2000; Loomis, 2012; Weber et al., 2016; Loomis, 1996; Richardson & Loomis, 2009) as well as the benefits of nutrient reduction to improve general water quality (Moore et al., 2018; Nelson et al., 2015).

For example, in a Washington State study, Loomis (1996) used contingent valuation to estimate willingness to pay to remove dams created for hydroelectric power and restore river flow. Because recreation benefits would not be accrued immediately and the effect primarily benefited salmon migration, the estimated value could be considered existence or bequest value (types of nonuse values) of river restoration. Even so, aggregate benefits to residents in Washington State totaled $138 million per year for 10 years and were larger when aggregated to the whole United States. Douglas and Taylor (1998) supplemented a travel cost model with a contingent valuation study to compare recreation at different water levels in the Trinity River (California) and nonuse values of a pristine restored river. They found that the existence value of an 840,000-acre-foot flow was significantly higher than the recreation benefits from a 340,000-acre-foot flow; however, the differences in flow levels made the comparison of use and nonuse values difficult.

Loomis (2012) conducted two simultaneous contingent valuation studies of a Colorado river, one which measured the total value of restoration and one which only measured recreation benefits. The study found that the recreation values were 32 percent of the estimated total value, with nonuse values the remaining 68 percent. In another approach to estimating the nonuse values of river restoration, a study of Arizona residents used a choice experiment to estimate marginal willingness to pay for preserved riparian habitat and safe contact recreation (Weber et al., 2016). The study found strong support for preserving riparian habitat and mixed support to make water levels safe for swimming.

Conclusion

A better understanding of the value and ownership of water across sectors is vital for decision-makers who must assess the costs and benefits of alternate water management strategies in times of scarcity. Water is not only valued as an input to agriculture, industry, and municipal drinking sources but also for recreation, aesthetic enjoyment, and a suite of other ecosystem services. The literature on valuing water includes revealed preference methods, such as hedonic and travel cost methods, and stated preference methods, such as contingent valuation and choice experiment surveys. Revealed preference methods use observed behavior to estimate the use values of water. Stated preference methods are used when valuing hypothetical changes or when estimating nonuse values of water.

Water is a valuable input to the agricultural sector that is necessary to produce many crops, particularly in arid U.S. regions. The existence of water markets provides an opportunity to directly measure the agricultural sector's willingness to pay for water. Evidence from California's water market (see appendix B) suggests this willingness to pay varies significantly across time according to water scarcity. Where water markets do not exist, the economics literature has leveraged land transaction data and hedonic pricing models to uncover how access to water is capitalized into real estate prices. The literature illustrates the significant value of water in agriculture. In some contexts, water access has been found to constitute 30 to 60 percent of the value of transacted land (Faux & Perry, 1999). To a lesser extent, the economics literature has employed other research methodologies for water valuation, notably the production function approach and stated preference methods. The results in the literature on these methods largely align with the hedonic pricing model research.

Substantial literature exists on the value of ecosystem services from water; however, much of it is on the value of water quality impacts. When considering surface water allocation between agricultural and environmental sectors, the literature can be divided into the impacts of water level changes in lakes and reservoirs and the value of instream flows. In lakes and reservoirs, water for recreation often competes directly with lowering water levels for irrigation or hydropower or even downstream recreation. The literature suggests that trips are negatively affected by drawing down reservoir water, but that benefits to recreationists from keeping water levels high are on par with or less than costs to other sectors. However, these results are highly dependent on current conditions and the timing of drawdowns. Hedonic studies of property value impacts have found that sales prices decreased when lakes dropped below normal levels.

Significant benefits are derived from instream flows. Travel cost studies found that, as with the lake level literature, the marginal value of additional instream flows was dependent on current water levels. In many cases, if water levels were already high, the value of increased flow for recreation was less competitive with other uses compared to when water levels were low. Several instream flow studies also used stated preference methods to estimate nonuse or existence values of water. A study in Colorado estimated that roughly one-third of the total economic value of instream flow could be attributed to recreation, while the rest came from nonuse values.

Water markets are increasingly considered useful tools for allocating water to users who value water the most in times of drought. However, market prices paid for environmental flows may not fully reflect the value of keeping water on the landscape. The literature on the valuation of water reveals significant benefits from water not only for recreation, maintaining property values, and aesthetic value to residents and visitors but also for the preservation of habitat and other ecosystem services that are difficult to account for. This report summarizes the components of the value of water and methods used to estimate the nonconsumptive, ecosystem service values.

While a better understanding of the findings of the literature and methods is necessary, challenges remain if nonmarket values are to be fully integrated into benefit-cost analyses and decision-making. More research is needed into regional and national-level impacts of water use changes that consider ecosystem service values in order to improve understanding of spatial and temporal variation in impacts. Widely agreed-upon general economic principles exist for efficient allocation of scarce resources, including water (see Young & Loomis, 2014, 24–33 for an exposition). There are also principles for conducting an applied economic analysis to reach an efficient solution using benefit-cost analysis (Ward, 2009 and 2012). Due to the diversity of uses of water within a given watershed and the differing institutional settings across States, a site-specific analysis (e.g., a reservoir, a river basin) usually must be undertaken to determine the specific economically efficient allocation of water.

References

Berrens, R. P., Bohara, A. K., Silva, C. L., Brookshire, D., & McKee, M. (2000). Contingent values for New Mexico instream flows: With tests of scope, group-size reminder and temporal reliability. *Journal of Environmental Management,* 58(1). 73–90.

Bi, X., Borisova, T., & Hodges, A. W. (2019). Economic value of visitation to free-flowing and impounded portions of the Ocklawaha River in Florida: Implications for management of river flow. *Review of Regional Studies,* 49(2), 244–67. https://doi.org/10.52324/001c.9754.

Boyer, T. A., Melstrom, R. T., & Sanders, L. D. (2017). Effects of climate variation and water levels on reservoir recreation. *Lake and Reservoir Management,* 33(3), 223–33.

Brewer, J., Glennon, R., Ker, A., & Libecap, G. D. (2007). *Water markets in the West: Prices, trading, and contractual forms.* National Bureau of Economic Research.

Brewer, J., Glennon, R., Ker, A., & Libecap, G. D. (2008). 2006 presidential address water markets in the West: Prices, trading, and contractual forms. *Economic Inquiry,*46(2), 91–112.

Brookshire, D. S, Colby, B., Ewers, M., & Ganderton, P. T. (2004). Market prices for water in the semiarid West of the United States. *Water Resources Research,* 40(9). https://doi.org/https://doi.org/10.1029/2003WR002846.

Brown, T. C. (2006). Trends in water market activity and price in the Western United States. *Water Resources Research,* 42(9). https://doi.org/https://doi.org/10.1029/2005WR004180.

Buck, S., M. Auffhammer, M., & Sunding, D. (2014). Land markets and the value of water: Hedonic analysis using repeat sales of farmland. *American Journal of Agricultural Economics,* 96(4), 953–969.

California Water Code § 1707.

Cameron, T. A., Shaw, W. D., Ragland, S. E., Callaway, J. M., & Keefe, S. (1996). Using actual and contingent behavior data with differing levels of time aggregation to model recreation demand. *Journal of Agricultural and Resource Economics,* 21(1), 130–149.

Carson, R. T. (2012). Contingent valuation: A practical alternative when prices aren't available.*Journal of Economic Perspectives*, 26(4), 27–42.

Chapagain, B. P., Poudyal, N. C., Bowker, J. M., Askew, A. E., English, D. B. K., & Hodges, D. G. (2021). Demand for and economic value of nonmotorized boating access in rivers at U.S. national forests. *Journal of Forestry,* 119(3), 275–90. https://doi.org/10.1093/jofore/fvab006.

Connelly, N. A., Brown, T. L., & Brown, J. W. (2007). Measuring the net economic value of recreational boating as water levels fluctuate. *Journal of the American Water Resources Association,* 43(4), 1016–1023. https://doi.org/10.1111/j.1752-1688.2007.00083.x.

Daubert, J. T., Young, R. A., & Gray, S. L. (1979). Economic benefits from instream flow in a Colorado mountain stream. Colorado Water Resources Research Institute completion report No. 91.

Duffield, J. W., Neher, C. J., & Brown, T. C. (1992). Recreation benefits of instream flow: Application to Montanta's Big Hole and Bitterroot Rivers. *Water Resources Research,* 28(92), 2169–2181.

Eiswerth, M. E., Englin, J., Fadali, E., & Shaw,W. D. (2000). The value of water levels in water-based recreation: A pooled revealed preference/contingent behavior model. *Water Resources Research,* 36(4), 1079–1086.

Fadali, E., & Shaw, W. D. (1998). Can recreation values for a lake constitute a market for banked agricultural water? *Contemporary Economic Policy,* 16(4), 433–441.

García Suárez, F., Fulginiti, L. E., & Perrin, R. K. (2018). What is the use value of irrigation water from the High Plains Aquifer? *American Journal of Agricultural Economics* 101(2), 455–466.

Hanson, T. R., Hatch, L. U., & Clonts, H. C. (2002). Reservoir water level impacts on recreation, property, and nonuser values. *Journal of the American Water Resources Association,* 38(4), 1007–1018.

Hartman, L. M., & Anderson, R. L. (1962). Estimating the value of irrigation water from farm sales data in northeastern Colorado. *Journal of Farm Economics,* 44(1), 207–213. https://doi.org/10.2307/1235499.

Huffaker, R., Whittlesey, N., & Hamilton, J. R. (2000). The role of prior appropriation in allocating water resources into the 21st century. *International Journal of Water Resources Development,* 16(2), 265–273.

Ifft, J., Bigelow, D. P., & Savage, J. (2018). The impact of irrigation restrictions on cropland values in Nebraska. *Journal of Agricultural and Resource Economics,* 43(1835–2018–2978), 195–214.

Israel, M., & Lund, J. R. (1995). Recent California water transfers: Implications for water management. *Natural Resources Journal*, *35*(1), 1–32.

Jakus, P. M., Dowell., P., & Murray, M. N. (2000). The effect of fluctuating water levels on reservoir fishing. *Journal of Agricultural and Resource Economics,* 25(2), 520–532.

Ji, X., & Cobourn, K. M. (2018). The economic benefits of irrigation districts under prior appropriation doctrine: An econometric analysis of agricultural land-allocation decisions. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie* 66(3), 441–467.

Kashian, R., Walker, A., & Winden, M. (2016). Lake drawdown revisited: The value of two inches of water. *Journal of Business & Economics Research,* 14(1), 7–18.

Lancaster, K. (1966). A new approach to consumer theory. *Journal of Political Economy,* 74(2), 132–157.

Lansford, N. H. Jr., & Jones, L. L. (1995). Recreational and aesthetic value of water using hedonic price analysis. *Journal of Agricultural and Resource Economics,* 20(2), 341–355. https://doi.org/10.22004/ag.econ.30776.

Liu, W. (2020). Valuation of water level: A spatial hedonic analysis on lakeshore properties. *Journal of Agricultural and Resource Economics,* 45(1), 20–37. https://doi.org/10.22004/ag.econ.298432.

Lloyd-Hughes, B. (2014). The impracticality of a universal drought definition. *Theor Appl Climatol*, 117, 607–611.

Loomis, J. (2012). Comparing households' total economic values and recreation value of instream flow in an urban river. *Journal of Environmental Economics and Policy* 1(1), 5–17.

Loomis, J., & McTernan, J. (2014). Economic value of instream flow for non-commercial whitewater boating using recreation demand and contingent valuation methods. *Environmental Management,* 53, 510–519.

Loomis, J. (2003). Estimating the benefits of maintaining adequate lake levels to homeowners using the hedonic property method. *Water Resources Research* 39(9). https://doi.org/10.1029/2002WR001799.

Loomis, J. (1996). Measuring the economic benefits of removing dams and restoring the Elwha River: Results of a contingent valuation survey. *Water Resources Research* 32(2), 441–447.

Loomis, J. (2002). Quantifying recreation use values from removing dams and restoring free-flowing rivers: A contingent behavior travel cost demand model for the Lower Snake River. *Water Resources Research,* 38(6). https://doi.org/10.1029/2000wr000136.

Loomis, J. (1982). Use of travel cost models for evaluating lottery rationed recreation: Application to big game hunting. *Journal of Leisure Research,* 14(2), 117.

Loureiro, M .L., & Umberger, W. J. (2007). A choice experiment model for beef: What U.S. consumer responses tell us about relative preferences for food safety, country-of-origin labeling and traceability. *Food Policy,* 32(4), 496–514.

Louviere, J. J., & Woodworth, G. (1983). Design and analysis of simulated consumer choice or allocation experiments: An approach based on aggregate data. *Journal of Marketing Research,* 20(4), 350–367.

Martin-Ortega, J., Ferrier, R. C., Gordon, I. J., & Khan, S. (2015). *Water ecosystem services: A global perspective*. UNESCO Publishing.

McFadden, D. (1986). The choice theory approach to market research. *Marketing Science* 5(4).

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being*. Island Press.

Milliman, J. W. (1959). Land values as measures of primary irrigation benefits. *Journal of Farm Economics,* 41(2), 234–243.

Moore, C., Guignet, D., Dockins, C., Maguire, K. B., & Simon, N. B. (2018). Valuing ecological improvements in the Chesapeake Bay and the importance of ancillary benefits. *Journal of Benefit-Cost Analysis, 9*(1), 1–26.

Neher, C.J., Duffield, J. W., & Patterson, D.A. (2013). Modeling the influence of water levels on recreational use at lakes Mead and Powell. *Lake and Reservoir Management,* 29(4), 233–246.

Neher, C. J., Bair, L., Duffield, J. W., Patterson, D. A., & Neher, K. (2019). Convergent validity between willingness to pay elicitation methods: An application to Grand Canyon whitewater boaters. *Journal of Environmental Planning and Management,* 62(4), 611–625.

Nelson, N. M., Loomis, J. B., Jakus, P. M., Kealy, M. J., Von Stackelburg, N., & Ostermiller, J. (2015). Linking ecological data and economics to estimate the total economic value of improving water quality by reducing nutrients. *Ecological Economics*, *118*, 1–9.

Norton, R. D., & Hazell, P. B. (1986). *Mathematical programming for economic analysis in agriculture.* Macmillan.

Pearce, D. W., & Turner, R. K. (1990). *Economics of natural resources and the environment*. JHU Press.

Petrie, R. A., & Taylor, L. O. (2007). Estimating the value of water use permits: A hedonic approach applied to farmland in the southeastern United States. *Land Economics,* 83(3), 302–318.

Poor, P. J., Pessagno, K. L., & Paul, R. W. (2007). Exploring the hedonic value of ambient water quality: A local watershed-based study. *Ecological Economics,* 60(4), 797–806.

Poulos, H. M., Loo, C., Workman, J. G., De Boer, A., & Michaels, J. (2012). The economic contribution of instream flows to the lower Connecticut River watershed, New England, U.SA. *Environmental Economics,* 3(3), 93–98.

Quilloy, A .J. A., Yorobe, J. M., Ella, V. B., Lansigan, F. P., & Cruz, R. V. O. (2018). Valuing groundwater in a productive aquifer using the production function approach: The case of rice production in Lumban, Laguna, Philippines. *Journal of Economics, Management & Agricultural Development,* 4(2).

Richardson, L., & Loomis, J. (2009). The total economic value of threatened, endangered, and rare species: An updated meta-analysis. *Ecological economics*, *68*(5), 1535–1548.

Rigby, D., Alcon, F., & Burton, M. (2010). Supply uncertainty and the economic value of irrigation water. *European Review of Agricultural Economics,* 37(1), 97–117. https://doi.org/10.1093/erae/jbq001.

Rimsaite, R., Gibson, J., & Brozović, N. (2021). Informing drought mitigation policy by estimating the value of water for crop production. *Environmental Research Communications,* 3(4), 41004. https://doi.org/10.1088/2515-7620/abf160.

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy* 82(1), 34–55.

Sampson, G. S., Hendricks, N. P., & Taylor, M. R. (2019). Land market valuation of groundwater. *Resource and Energy Economics* 58, 101120.

Schwabe, K., Nemati, M., Landry, C., & Zimmerman, G. (2020). Water markets in the western United States: Trends and opportunities. *Water* 12(1), 233.

Selby, H. E. (1945). Factors affecting value of land and water in irrigated land. *The Journal of Land & Public Utility Economics* 21(3), 250–258.

Smith, V. K. (1975). Travel cost demand models for wilderness recreation: A problem of non-nested hypotheses. *Land Economics* 51(2):,103–111.

Smith, V. K., & Desvousges, W. H. (1985). The generalized travel cost model and water quality benefits: A reconsideration. *Southern Economic Journal* 52(2), 371.

García Suárez, F., Fulginiti, L. E., & Perrin, R. K. (2019). What is the use value of irrigation water from the High Plains Aquifer? *American Journal of Agricultural Economics*, *101*(2), 455–466.

Taylor, L. O. (2017). Hedonics. In P. Champ, K. Boyle, & T, Brown, (Eds.), A primer on nonmarket valuation. The economics of non-market goods and resources, vol. 13. Springer, Dordrecht.

Texas Water Code § 11.02361.

Torell, L. A., Libbin, J. D., & Miller, M. D. (1990). The market value of water in the Ogallala Aquifer. *Land Economics* 66(2), 163–175.

Tyrväinen, L. (1997). The amenity value of the urban forest: An application of the hedonic pricing method. *Landscape and Urban Planning* 37(3–4), 211–222.

U.S. Code, Title 16 § 1532.

U.S. Department of Agriculture, National Agricultural Statistics Service. (2019). *2018 irrigation and water management survey*.

U.S. Geological Survey. n.d. Water-use terminology.

Walsh, R .G., Aukerman, R., & Milton, R. (1980). Measuring benefits and the economic value of water in recreation on high country reservoirs.

Walsh, R. G. (1980). Empirical application of a model for estimating the recreation value of water in reservoirs compared to instream flow.

Ward, F. A. (1987). Economics of water allocation to instream uses in a fully appropriated river basin: Evidence from a New Mexco wild river. *Water Resources Research* 23(3), 381–392.

Ward, F. A. (1989). Efficiently managing spatially competing. *Journal of Regional Science* 29(2), 229–246.

Ward, F. A, & Michelsen, A. (2002). The economic value of water in agriculture: Concepts and policy applications. *Water Policy* 4(5), 423–446.

Ward, F. A., Roach, B. A., & Henderson, J. E. (1996). The economic value of water in recreation: Evidence from the California drought. *Water Resources Research* 32(4), 1075–1081.

Weber, M. A., & Berrens, R. P. (2006). Value of instream recreation in the Sonoran Desert. *Journal of Water Resources Planning and Management* 132(1), 53–60.

Weber, M. A., Meixner, T., & Stromberg, J. C. (2016). Valuing instream-related services of wastewater. *Ecosystem Services* 21, 59–71.

Womble, P., & Hanemann, W. M. (2020). Water markets, water courts, and transaction costs in Colorado. *Water Resources Research* 56(4), e2019WR025507. https://doi.org/https://doi.org/10.1029/2019WR025507.

Wyman, D., & Worzala, E. (2016). Dockin' USA—A spatial hedonic valuation of waterfront property. *Journal of Housing Research* 25(1), 65–80.

Yoo, J., Simonit, S., Connors, J. P., Maliszewski, P. J., Kinzig, A. P., & Perrings, C. (2013). The value of agricultural water rights in agricultural properties in the path of development. *Ecological Economics* 91: 57–68.

Young, R. A. (1996). *Measuring economic benefits for water investments and policies*. The World Bank.

Young, R. A, & Loomis, J. B. (2014). *Determining the economic value of water: Concepts and methods*. Routledge.

Zellmer, S. B., & Amos, A. S. (2021). *Water law in a nutshell*. West Academic Publishing.

Appendix A

Table A.1
Literature on use and nonuse values of water

Authors	Year	Region/ State	Method	Resource valued	Service	Value	Description
			Agricultural use				
Brewer et al.	2008	Western United States	Market	Water rights	Agriculture	$29 per acre-foot (leases), $1,747 per acre-foot (sales)	Sample mean prices for agriculture-to-agriculture
Brookshire et al.	2004	Southwest	Market	Water rights	Agriculture	$613 to $5,312 per acre-foot (sales)	Sample mean prices
Brown	2006	Western United States	Market	Water rights	Agriculture	$69 per megaliter per year (leases), $2,948 per megaliter (sales)	Sample mean prices
Buck et al.	2014	California	Hedonic	Irrigation water	Agriculture	$3,723 per acre-foot, one time estimate	Capitalized value of surface water on farmland
Butsic & Netusil	2007	Oregon	Hedonic	Water rights	Agriculture	$261 per acre-foot (sales) and $19 to $194 per acre-foot (leases)	Willingness to accept to sell
Faux & Perry	1999	Oregon	Hedonic	Irrigation water	Agriculture	$9 to $44 per acre-foot, one time delivery	Implicit market price of irrigation water
Hartman & Anderson	1962	Colorado	Hedonic	Irrigation water	Agriculture	$30 to $32 per acre-foot, one time delivery	Capitalized value of surface water
Ifft et al.	2018	Nebraska	Hedonic	Irrigated farmland	Agriculture	No impact on average from 1999–2012, 12–24% declines over specific years	Capitalized value of irrigation restrictions on cropland
Petrie & Taylor	2007	Georgia	Hedonic	Irrigation water	Agriculture	$36 per acre-foot per year	Capitalized value of surface water
Sampson et al.	2019	Kansas	Hedonic	Irrigation water	Agriculture	Average marginal value $3.42 to $15.86 per acre-foot, one time estimate	Capitalized value of water in-storage

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Authors	Year	Region/ State	Method	Resource valued	Service	Value	Description
Agricultural use							
Schenkler et al.	2007	California	Hedonic	Irrigation water	Agriculture	$568 to $852 per acre-foot, one time estimate	Estimated value of surface water availability on farmland
Yoo et al.	2013	Arizona	Hedonic	Water rights	Agriculture	$10.92 (undeveloped areas) to $23.09 (developed areas) per acre per year	Mean marginal willingness to pay for an additional acre-foot water attached to a water right
García Suárez et al.	2018	High Plains	Modeling	Irrigation water	Agriculture	$196 per acre per year	Production value of water
Rimsaite et al.	2021	High Plains	Production	Irrigation water	Agriculture	$0.10 to $0.85 per cubic meterer year	County-level realized value of water used in corn production
Environmental use							
Hill	2007	Georgia	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	1.89% decrease, one time estimate	Change in home value due to additional percent increase in distance from lake
Kashian	2008	Wisconsin	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	$447.77 to $961.61, one time estimate	Contribution of 1 foot of shoreline to home value
Kashian et al.	2016	Wisconsin	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	$8.24 to $38.78 increase, one time estimate	Change in home value due to increase per foot of shoreline
Lansford & Jones	1995	Texas	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	$6,800 increase, one time estimate	Change in value to a 2200-square foot residence if Lake Travis is at its long-term average level compared to 6 feet below normal

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Authors	Year	Region/ State	Method	Resource valued	Service	Value	Description
			Environmental use				
Liu	2020	Minnesota	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	17.7%, or $52,473 decrease for an average property, one time estimate	Change in home value per additional foot of water level decline at 6 feet below ordinary high-water level
Loomis & Feldman	2003	California	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	$108 to $119 decrease, one time estimate	Change in home value due to additional 1 foot of exposed shoreline
Wyman & Worzola	2016	South Carolina	Hedonic	Lakes/ reservoirs	Recreation, Aesthetics	45% increase, one time estimate	Dockable property price premium
Bi et al.	2019	Florida	Travel cost	Rivers	Recreation	$64.92 to $97.86 (reservoir); $26.67 to $98.20 (river) per trip	Average trip expenditures
Boyer et al.	2017	Oklahoma	Travel cost	Lakes/ reservoirs	Recreation	$60 per trip	Average trip value
Cameron et al.	1996	Pacific Northwest	Travel cost	Lakes/ reservoirs, rivers	Recreation	$13 to $99 per month	Average expected consumer surplus for 1993 water levels
Chapagain et al.	2021	Oklahoma	Travel cost	Rivers	Recreation	$56 to 73 per trip	Consumer surplus for nonmotorized boating access
Daniels & Melstrom	2017	Oklahoma	Travel cost	Lakes/ reservoirs	Recreation	0.7% decrease, or 210 fewer visitors per month per park	Change in visitation when water levels drop 1 foot below normal at Oklahoma parks
Eiswerth et al.	2000	Nevada	Travel cost	Lakes/ reservoirs	Recreation	$88 to $120 per person per trip, and a $12 to $18 per-person per season decrease associated with a 1-foot decline in water levels	Consumer surplus

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Authors	Year	Region/ State	Method	Resource valued	Service	Value	Description
Environmental use							
Fadali & Shaw	1998	Nevada	Travel cost	Lakes/ reservoirs	Recreation	$83 per person per season	Preservation of Walker Lake
Huszar et al.	1999	Nevada	Travel cost	Lakes/ reservoirs	Recreation	$472,428 per season	Preservation of Rye Patch Reservoir
Jakus et al.	2000	Tennessee	Travel cost	Lakes/ reservoirs	Recreation	87,000 more trips at $1.82 per trip	Average net benefit of maintain-ing lakes at full pool for an addi-tional summer month
Loomis & McTernan	2014	Colorado	Travel cost	Rivers	Recreation	$55.29 per trip and 1.6 trips per season per person at 300 cubic feet per sec-ond to $97.04 per trip and 14.3 trips per season per person. Marginal value per acre-foot of water peaks at $219 at 1,300 cubic feet per second	Consumer surplus
Ward	1989	New Mexico	Travel Cost	Lakes/ reservoirs	Recreation	$130 to $20,000 per acre-foot de-pending on water levels	Marginal value of water for recreation
Ward et al.	1996	California	Travel cost	Lakes/ reservoirs	Recreation	$6 to $600 per acre-foot	Annual recre-ational values
Weber & Berrens	2006	Arizona	Travel cost	Rivers	Recreation	$17 to $25 consum-er surplus per day	Consumer surplus
Ward	1987	New Mexico	Travel cost and modeling	Rivers	Recreation	$900 to $1,100 per acre-foot	
Hanson et al.	2002	Alabama	User expen-diture	Lakes/ reservoirs	Recreation, Market	4%–15% de-crease in lakefront property values; 4%–30% decrease in recreational expenditures	1-foot lower water level
Poulos et al.	2012	Connecti-cut	User expen-diture	Rivers	Market	An additional $37 million and 638 jobs	Fishing ex-penditures

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Authors	Year	Region/ State	Method	Resource valued	Service	Value	Description
Environmental use							
Neher	2013	Southwest	Visitation and expenditure models	Lakes/ reservoirs	Recreation, Market	$374,000 at $71 per person	100,000 acre-foot increase in Lake Powell volume over a year
Connelly et al.	2007	New York	User expenditure, contingent valuation, and modeling	Lakes/ Reservoirs, Rivers	Recreation, Market	$23 per person per day	Consumer surplus
Cameron et al.	1996	Pacific Northwest	Contingent behavior	Lakes/ reservoirs, rivers	Recreation	$13 to $99	Trip value
Eiswerth et al.	2000	Nevada	Contingent behavior	Lakes/ reservoirs	Recreation	$11.60 to $18.54 annually per person	Value per 1 foot change in water level
Loomis	2002	Washington	Contingent behavior	rivers	Recreation	$193 to $311 million annually	Value of recreation
Berrens et al.	1996	New Mexico	Contingent valuation	Rivers	Recreation	$29 to $90 annually for 5 years	Minimum instream flows
Cordell & Bergstrom	1993	North Carolina	Contingent valuation	Lakes/ reservoirs	Recreation	$41.70 to $75.05 per trip	Average across all lakes
Duffield et al.	1992	Montana	Contingent valuation	Rivers	Recreation	$50 per acre-foot	Instream flows
Hanson et al.	2002	Alabama	Contingent valuation	Lakes/ Reservoirs	Recreation, Market	$47 per trip	Preservation of reservoirs
Loomis & Feldman	1995	Western U.S.	Contingent Valuation	Rivers	Recreation	$1,000 for first 100 cubic feet per second to $300 for additional flow at 550 cubic feet per second	Instream flows
Loomis & McTernan	2014	Colorado	Contingent valuation	Rivers	Recreation	$108 per person per trip	Consumer surplus
Neher et al.	2019	Arizona	Contingent valuation	Rivers	Recreation	$628 to $1,382 per trip	Instream flows of 5,000 cubic feet per second to 22,000 cubic feet per second

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Authors	Year	Region/ State	Method	Resource valued	Service	Value	Description
Environmental use							
Neher et al.	2019	Arizona	Choice experiment	Rivers	Recreation	$550 to $1,384 per trip	Instream flows of 5,000 to 22,000 cubic feet per second
Nonuse							
Berrens, et al.	1998	New Mexico	Contingent valuation	Rivers	Nonuse	$73 to $80 annually for 5 years	Willingness to pay for in-stream flows
Berrens et al.	2000	New Mexico	Contingent valuation	Rivers	Nonuse	$25 to $55 annually for 5 years	Willingness to pay for in-stream flows
Huszar et al.	2001	Nevada	Contingent valuation	Lakes/ reservoirs, rivers	Recreation, Nonuse	$63	One-time willingness to pay
Loomis	1987	California	Contingent Valuation	Lakes/ Reservoirs	Recreation, Nonuse	$29.21 monthly per household	Protection of Mono Lake
Loomis	1996	Washington	Contingent valuation	Rivers	Nonuse	$59 to $73 annually per household	Restoration of Elwha River
Loomis	2012	Colorado	Contingent valuation	Rivers	Recreation, Nonuse	$171 per acre-foot, $106 of which is nonuse value	Total economic value; 38% recreation and 62% nonuse value
Loomis et al.	2005	Colorado	Contingent valuation	Lakes/ reservoirs	Recreation, Aesthetics	$368 ($59) per year	Willingness to pay for lakefront (and off-lake) residents
Weber et al.	2016	Arizona	Choice experiment	Rivers	Recreation, Aesthetics	$25 to $72 per mile of flow	Willingness to pay for in-stream flows

Note: Studies listed are cited in the text and summary information is presented for quick reference. Values are not adjusted for inflation and thus may understate current values. Some of the studies listed that estimate nonuse values of water also estimate use values (e.g., aesthetics and recreation) and do not decompose the two.

Source: USDA, Economic Research Service.

Appendix B

Case Study: Water Market Transactions in California

California has one of the most developed water markets in the United States, allowing leases and permanent sales of water rights among municipal, commercial, agricultural, and environmental water users. California's water market accounted for more than 50 percent of the total volume of water rights leased and 25 percent of water rights permanently sold in the Western United States between 2009 and 2018 (Schwabe et al., 2020).[15] Water market transactions require infrastructure to hydrologically connect buyers and sellers (Israel & Lund, 1995). The development of California's water market is to some extent related to the State's extensive water infrastructure network, which includes the Central Valley Project and the State Water Project that hydrologically connect most population and farming centers (Hanak & Stryjewski, 2012).[16] California's State Water Resource Control Board has regulatory authority to approve most[17] transfers (e.g., changes in purpose, place of use, or point of diversion) of water.

The market for water in California offers a unique lens to understand how different sectors determine the use and nonuse values of water. Sector-specific water transaction data from California demonstrate how the differing end uses of water (e.g., irrigation, instream flows) manifest in the market price for water. This report leverages California's water transaction data from the proprietary WaterLitix database curated by WestWater LLC, which compiles data on the temporary leases and permanent sales of water through regulatory filings confirmed by interviews with buyers and sellers. See Schwabe, et al. (2020) for more information and background on the WaterLitix database.

Market prices observed for water partially represent users' willingness to pay for the good as well as water scarcity.[18] Figure B.1, panel (a) demonstrates this by plotting the average prices paid for water in California, differentiating between purchases by the agricultural and environmental sectors.[19] Prices paid for water in California also reflect the scarcity of the resource. Figure B.1 (b) plots the percentage of California's land mass experiencing differing levels of drought severity. During the most intense periods of the 2014 and 2015 drought in California, when at times more than 50 percent of the State experienced exceptional drought conditions,[20] the average price paid for water by the agricultural sector more than doubled from the predrought average. Meanwhile, the prices paid for water by the environmental sector exhibit minimal variation during times of drought, suggesting that the sector's willingness to pay for water is less elastic than the agricultural sector.

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[15] Schwabe et al. (2020) consider Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Washington, and Wyoming to be the Western United States. Between 1987 and 2005, California's water market accounted for approximately 40 percent and 30 percent of total short- and long-term water leases, respectively, in the U.S. West (Brewer et al., 2007). Brewer used data from the Water Strategist to characterize water markets in the Western United States. Specifically, they used water transaction data from Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Washington, and Wyoming.

[16] See figure 1 in Hanak & Stryjewski (2012) for a map of California's water conveyance infrastructure.

[17] Transfers of water within the Central Valley Project and the State Water Project do not generally require approval by the State Water Resource Control Board as these transfers usually do not alter the purpose of use, place of use, or point of diversion.

[18] Observed water market prices only partially represent a user's willingness given the presence of transaction costs, which can be significant in many water markets (Womble & Hanemann, 2020).

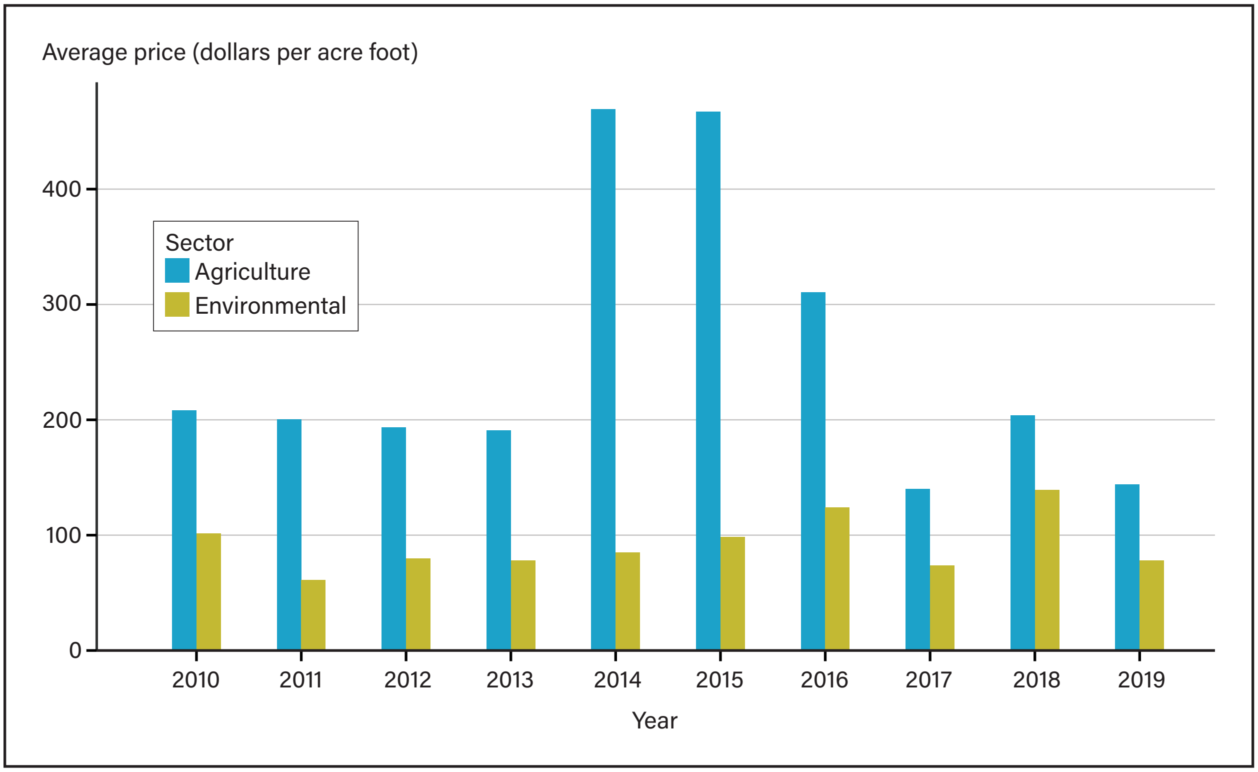
[19] The agricultural sector primarily buys water to irrigate crops and water livestock. The environmental sector is generally comprised of national, State, and local entities, particularly nonprofits, that lease water to augment instream flow and improve riparian and aquatic ecosystem health.

[20] The U.S. Drought Monitor defines exceptional drought in California as "Fields are left fallow; orchards are removed; vegetable yields are low; honey harvest is small. Fire season is very costly; number of fires and area burned are extensive. Fish rescue and relocation begins; pine beetle infestation occurs; forest mortality is high; wetlands dry up; survival of native plants and animals is low; fewer wildflowers bloom; wildlife death is widespread; algae blooms appear (U.S. Drought Monitor, 2021)."

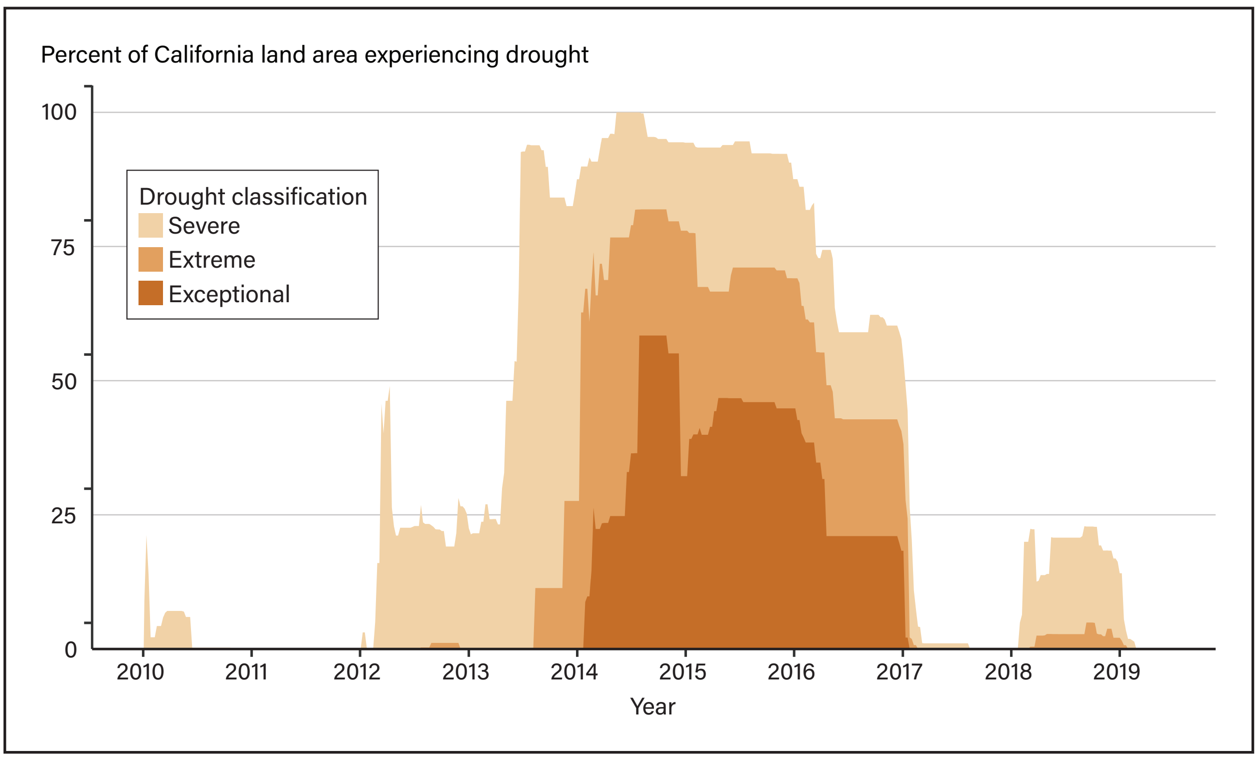
Figure B.1

Water prices and drought

(a) Average price for agricultural and environmental water buyers in California, 2010–19



(b) Drought conditions in California, 2010–19



Note: Average prices for water are inflated to 2021 prices and include only prices for leased water. Drought conditions data are weekly and report the percentage of California's land area experiencing differing levels of drought. "Exceptional" drought conditions are the most severe in the U.S. Drought Monitor's classification system.

Source: USDA, Economic Research Service using data from the WaterLitix database curated by WestWater Research, LLC (panel a) and U.S. Drought Monitor (panel b).

The variation observed between prices paid by agricultural versus environmental sectors suggests a difference in average willingness to pay for water between the two sectors. The agricultural sector is consistently willing to pay more for water than the environmental sector, which signifies the vital role that water plays in much of California's agricultural economy. However, the difference does not necessarily imply that the value of water in agriculture is greater than the value of water used for environmental purposes due to the public-good nature of the ecosystem services provided by additional instream flows. The market for water does not fully capture its value because the ecosystem service benefits generated by additional instream flows are nonexcludable; anyone can enjoy these benefits without paying the cost of additional water flows.[21] In contrast, the benefits of an additional unit of water are excludable in the agricultural sector because the agricultural producer alone reaps the economic returns of purchased water.[22] The missing environmental water market motivates much of the nonmarket valuation literature, which aims to place values on resources and environmental goods whose attributes preclude efficient market pricing.

In terms of quantities, figure B.2 panels (a) and (b) demonstrate the actual amounts of water transacted in the agricultural and environmental sectors, respectively. Figure B.2 (a) shows that a much higher amount of water by volume was bought and sold in the agricultural sector than in the environmental sector. Considering leases alone, both purchases and sales in the agricultural sector surpass those in the environmental sector every year in the study period. As shown in table B.1, the number of leases of water rights far exceeds permanent sales, by approximately 34 and 19 times for agricultural purchases and sales of leases, respectively. Note that only two transactions of permanent water rights occurred in the environmental sector during the study period, both of which were purchases.

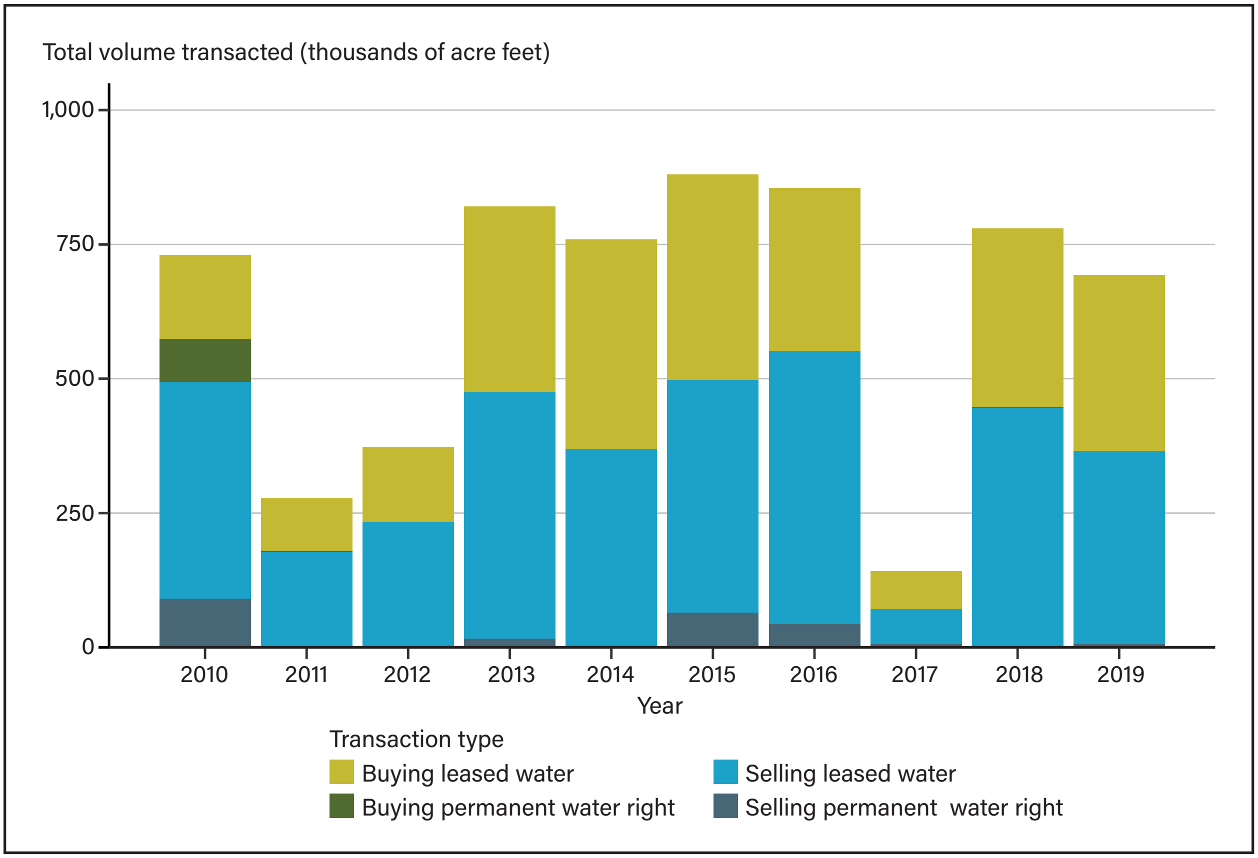
[21] When calculating their willingness to pay (hence their offer prices), purchasers of water for environmental purposes may not account for the benefits to others. This "free rider" problem suggests that prices are lower bounds for actual social value.

[22] A caveat is tailwater, a nonconsumptive use, which can be used downstream.

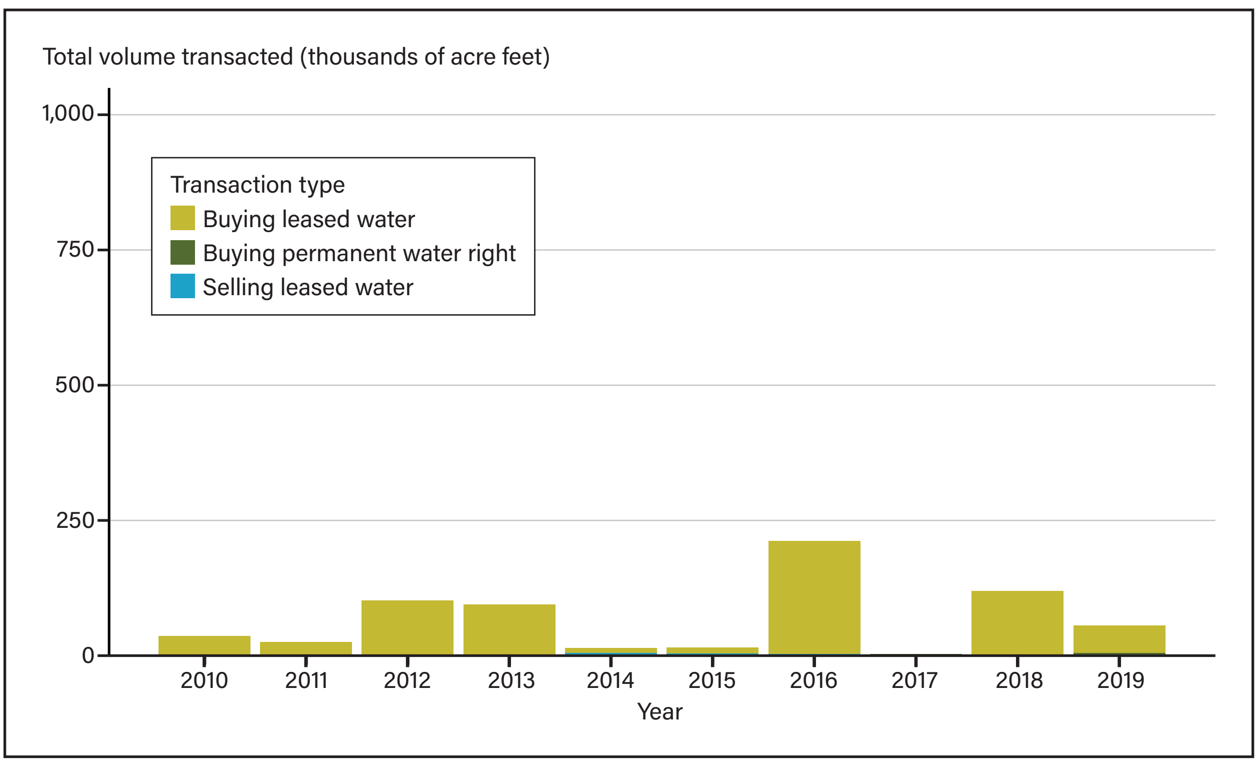
Figure B.2

Total volume of water transacted, 2010–19

(a) Agricultural



(b) Environmental



Note: Volume of water transacted in agriculture may double-count some transactions that were conducted entirely within the agricultural sector. There were no permanent sales from the environmental sector.

Source: USDA, Economic Research Service using data from the WaterLitix database curated by WestWater Research, LLC.

Table B.1
Total count of agricultural and environmental water transactions, 2010–19

Sector	Right type	Purchases	Sales
Agriculture	Lease	844	1,734
Agriculture	Permanent	27	91
Environment	Lease	128	20
Environment	Permanent	2	0
All other sectors	Lease	2,395	1,613
All other sectors	Permanent	165	103

Note: Total count of water transactions in California by sector, agricultural, environmental, and all other sectors 2010–19. "All other sectors" includes municipal and industrial water right transactions. Purchase and sale counts include transactions within agriculture and environment, as well as across other sectors.

Source: USDA, Economic Research Service using data from the WaterLitix database curated by WestWater Research, LLC.

Water market transactions reflect user willingness to pay for water resources. A lack of institutional support and physical infrastructure can increase transaction costs and discourage the formation of well-functioning water markets in many contexts. The cooperative ownership of irrigation storage and conveyance infrastructure or water rights (via membership in an irrigation district or ditch company) can diminish transaction costs and promote an active water market (Ji & Cobourn, 2018). However, water markets remain thin throughout much of the United States, forcing researchers to leverage other analytical methods to uncover the value of water in the agricultural and environmental sectors.