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Accounting for California's Water

Technical Appendix

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Accounting for Water in Dry Regions: A Comparative Review

CONTENTS

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Introduction

Managing scarce water supplies effectively in dry regions requires high-quality, timely information on water availability and use. Such information becomes especially important for water management during droughts. This Technical Appendix provides an overview of water information systems in 12 western states and 2 countries with similar climate and water management challenges—Australia and Spain. These 14 case studies explore regional systems for measuring, processing, and communicating information on water availability and use.

Water accounting practices are influenced by a region's physical characteristics—geography, hydrology, and climate—as well as by the policy-making environment, human water uses, legal foundations, and technical capabilities. Despite significant variation in the 14 cases, we found several common themes. We have organized the case studies by the following aspects, to support side-by-side comparison:

- **Regulatory framework**: The organization of entities that manage water and the legal foundation for claims to water use by users and the environment.
- **Ability to account for water**: Technical aspects of measuring, processing, and communicating information on actual and anticipated water use and water availability for effective decision making.
- **Allocation of water**: The employment of information on water availability and use to allocate water among claimants during times of scarcity.
- **Public information provision**: The pathways for public access to critical information from a water accounting system, including water rights, system monitoring, allocation during scarcity conditions, and water trading activity.

The practices described in these case studies were used to support the analysis and recommendations found in the main report, *Accounting for California's Water*.

The research methods used to create these case studies include extensive literature review and personal communications with water management experts from government and academic institutions in the 14 study regions. From the links below you can access directly to a comparative overview of water accounting practices and each individual case study:

A Comparative Overview of Water Accounting Systems

Our study focuses on 14 jurisdictions facing water scarcity: 12 western US states—California, Arizona, Colorado, Idaho, Kansas, Nebraska, Nevada, New Mexico, Oregon, Texas, Utah, and Washington—and two countries with broadly similar climates and water management challenges—Australia and Spain. For Australia, we focus especially on the Murray-Darling Basin in the southeastern part of the country, where most farming and population is located, and particularly the state of Victoria.[1]

We begin with a brief summary of the physical and governance characteristics of the water systems in 14 jurisdictions. We next compare key elements of the accounting frameworks in these study areas, using the accounting concepts developed in the main report: (1) water assets, or the assessment of how much water is available for allocation in different times and places; (2) water liabilities, including claims and actual uses; and (3) how water information is managed and shared—issues key to the effective development and use of information by managing entities and the public. A final section summarizes some best practices in water accounting observed from this comparative review.

Physical and Governance Characteristics of Water Systems

On average, the western states are much drier, and have more variable precipitation, than the eastern half of the United States (Figure 1). Australia and Spain also have relatively dry and variable climates. These climatic conditions and the large and growing economies of these regions make it necessary to manage water scarcity on an ongoing basis, and make strong water accounting systems especially important.

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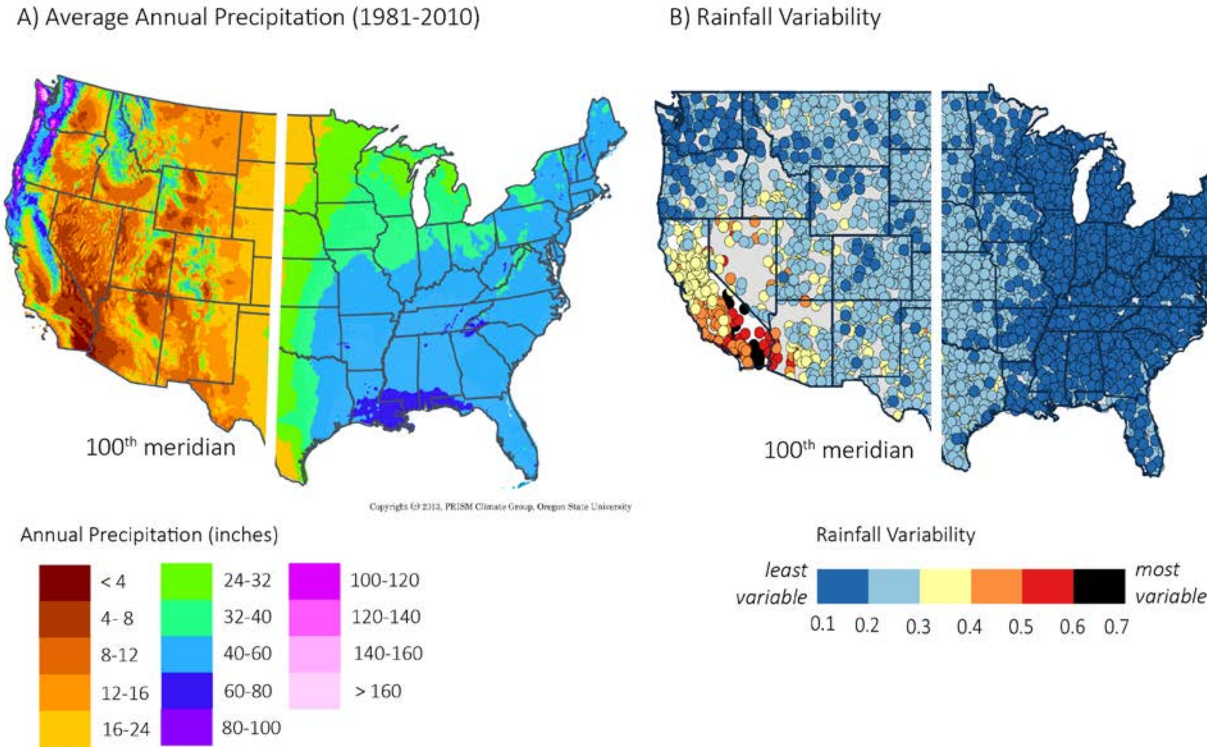
[1] Most of Australia's interior is too dry for farming and is sparsely populated; northern Australia has wetter, tropical conditions.

FIGURE 1

Precipitation in the western US is lower and more variable



SOURCE: Average precipitation: Oregon State University (2015). Rainfall variability: Dettinger (2011).

NOTES: The 100th meridian is a traditional dividing line between the eastern and western US. Dots in the rainfall variability panel represent the variation of total annual precipitation at weather stations for 1951-2008, as measured by the coefficient of variation. The larger the value, the greater the year-to-year variability.

In all of these jurisdictions, agriculture uses the lion's share of developed water supplies (Figure 2a).[2] Irrigation enables farming in areas with low annual rainfall and dry summers, conditions which are ideal for many crops.[3] In addition, many large urban areas are far from their water sources. To meet agricultural and urban demands for reliable supplies, national and state governments and regional and local agencies have invested in extensive surface water storage and water transportation systems.

Groundwater also supplies much of agricultural and urban use (Figure 2b). Most groundwater is used in areas overlying aquifers, with many irrigators and some homes having their own wells. In many places, surface and groundwater sources are hydrologically interconnected and affect each other. This creates opportunities for managing these resources together—such as by storing surface water in aquifers in wet years. But it also adds complexity to water accounting, because it requires understanding how water moves between rivers and aquifers.[4]

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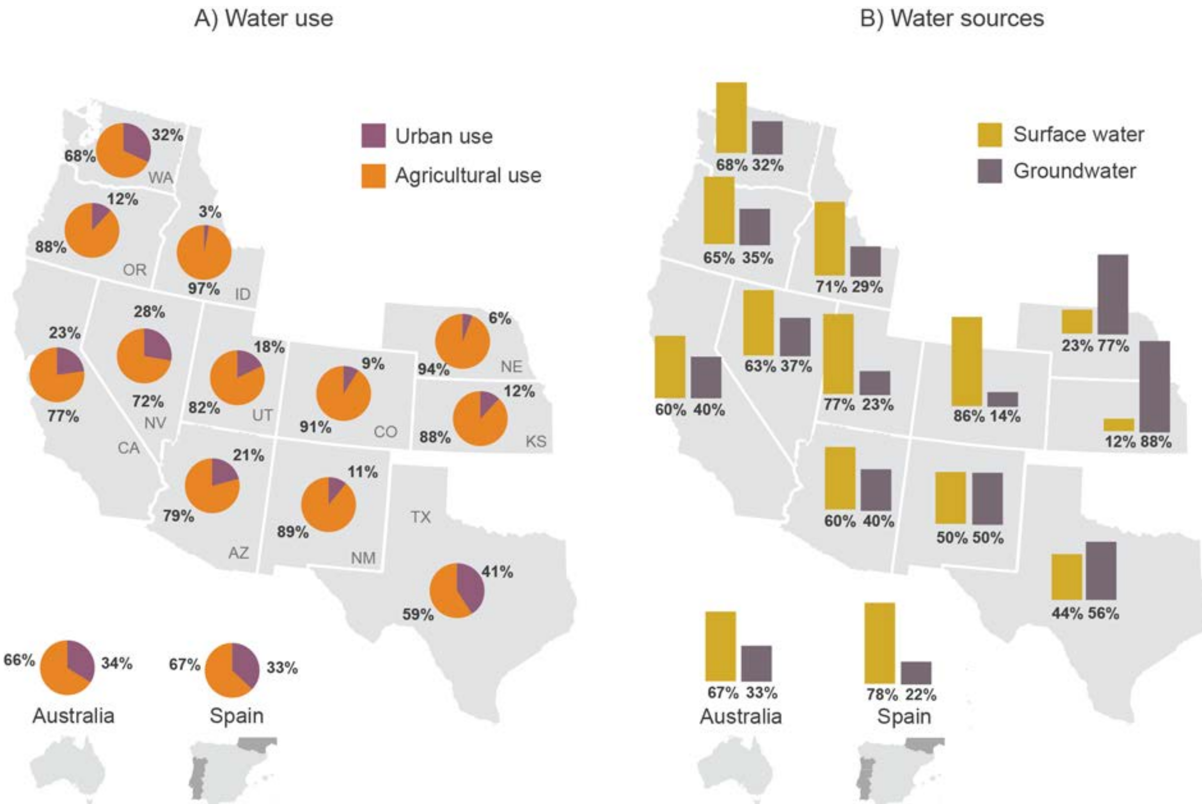
[2] This total does not include water dedicated for environmental purposes (for instance, to maintain riverine and wetland habitat and to protect water quality). Such estimates are not consistently available across states. For an explanation of how water use is accounted for in California, including agricultural, urban, and environmental uses, see Mount et al. (2014).

[3] Shares of harvested crop acreage under irrigation in 2012 in the 12 states in our study were: Arizona 96%, Nevada 96%, California 92%, New Mexico 86%, Utah 81%, Idaho 68%, Nebraska 44%, Oregon 43%, Colorado 41%, Washington 36%, Texas 25%, and Kansas 14% (author estimates using 2012 Census of Agriculture data, reported in US Department of Agriculture (2015)). States with lower irrigation shares have some regions with adequate precipitation for dryland crops (especially grains). Comparable estimates are unavailable for Australia and Spain.

[4] "Gaining streams" are areas where groundwater discharges contribute to stream flows, and "losing streams" are areas where stream flows contribute to groundwater.

FIGURE 2

Water uses and sources for urban and agricultural sectors



SOURCE: United States: Maupin et al. (2014). Australia and Spain: Food and Agriculture Organization of the United Nations (2016).

NOTE: Water use and source data are for 2010. The data exclude withdrawals for thermoelectric cooling and aquaculture, both of which are largely non-consumptive uses.

Many entities have oversight and operational roles in water management and the related water accounting. In the western United States, oversight institutions are generally established as distinct regulatory entities, insulated by design from operational functions. All states have a central institution that administers water rights and protects environmental flows—although some states delegate oversight authority to local bodies, particularly for groundwater.[5] Federal and state fish and wildlife regulators also play a role in establishing environmental flow requirements. On the operational side, the US Bureau of Reclamation (USBR) and the Army Corps of Engineers (Army Corps) own and operate most of the largest reservoirs, and some major water distribution systems.[6] Several states also have large state or regionally owned storage and distribution systems, sometimes including groundwater storage projects.[7] Local agencies across the West supply the most water and operate thousands of surface and groundwater storage and distribution systems.

[5] Examples include Nebraska's natural resource districts, Arizona's active management areas, and Texas' groundwater conservation districts. In California, the 2014 Sustainable Groundwater Management Act requires the establishment of local groundwater sustainability agencies that will have this responsibility.

[6] The Army Corps' role in the westernmost states is usually limited to operating large reservoirs—including those owned by other federal, state, and local entities— for flood management and hydropower. East of the Rockies, the Army Corps more commonly provides a water supply function as well. Large USBR water supply projects include California's Central Valley Project, the Klamath Project (serving southern Oregon and northern California), the Columbia Basin and Yakima River Projects in central Washington, the Colorado-Big Thompson Project in Colorado, the reservoirs at Palisades Dam and American Falls Dam in Idaho, and the Rio Grande Project in New Mexico, and Texas.

[7] This includes California's State Water Project and Nebraska's Lake McConaughy, as well as large regional projects such as the Metropolitan Water District of Southern California's Colorado River Aqueduct, the Southern Nevada Water Authority's Robert B. Griffith Water Project, and the Central Arizona Project (financed by the federal government but owned and operated by a regional agency).

In contrast to the American West, water management institutions in Victoria (Australia) and Spain blend oversight and operational functions within the same institutions. Regional authorities—Victoria's Water Corporations and Spain's Basin Authorities—have primary responsibility for both oversight and operations, delegated by the state of Victoria and the Spanish national government respectively.[8]

Understanding Assets: Water Availability

Accounting is often defined as comparing assets with uses or liabilities. Oversight and project-operating agencies must understand the asset side of their water accounts—current and expected water available in rivers and streams and in storage (surface reservoirs, aquifers, soil moisture, and snowpack)—and how these volumes change with allocation and use throughout the system. This generally involves a combination of measurement and monitoring of field conditions and modeling of overall system behavior.

Measurement and Monitoring

It is difficult to compare the comprehensiveness of measurement and monitoring systems across states and regions. Some common challenges are evident, especially across the western United States, where the federal government plays a central role. Many states rely almost exclusively on federal measurements of surface water availability—and some do for groundwater as well (Western States Water Council 2014). Some key water assets include:

- **Surface reservoirs.** Surface reservoirs are extensively monitored everywhere due to their essential roles for flood and drought management and ease of measurement. Agencies that operate large reservoirs usually report reservoir levels and volumes, as well as outflows and inflows; information sharing is less reliable for smaller reservoirs operated by local agencies and private companies.
- **Surface flows.** In the United States, the US Geological Survey (USGS) is the primary source of surface water flow data. These data are transmitted to USGS offices via satellite, telephone, and/or radio and often become available for online viewing within minutes. The budget-related decline in the USGS stream gage network—which now has 10 percent fewer gages than in the 1970s—is a problem for western states.[9] Even at peak capacity, the stream gage system—which prioritizes gages in places most critical for understanding water supply and flood risks—had significant gaps on smaller streams that are less important for floods and water supplies, but often critical for ecosystems.[10]
- **Snowpack.** For most western states, snowpack is a major form of seasonal storage. The US Department of Agriculture has a cross-state network for monitoring snowfall and water content in the snowpack, but coverage is spotty. Some states augment this data. Notably, California has an extensive cooperative snowpack monitoring system, combining federal, state, and local data gathering.
- **Groundwater reserves.** Groundwater levels are an important metric for tracking the availability of water stored in groundwater basins and flows in and out of aquifers. The USGS monitors these across the US, using data from a network of monitoring wells. However, in most states this network is too sparse for active groundwater management, and data reporting lags considerably, so additional state and local monitoring is necessary.[11]

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[8] In Australia, the Murray-Darling Basin Authority also plays some oversight and operational roles within the larger river basin, which covers parts of Victoria and three other states.

[9] On the stream gage decline, see http://water.usgs.gov/nsip/history1.html. See also Western States Water Council (2015).

[10] In California, for instance, the State Water Resources Control Board has found that California lacks any federal or state stream gages on half of nearly 250 HUC 10 watersheds (hydrologic unit code 10) that contain critical habitat (personal communication, Barbara Evoy, April 15, 2016).

[11] See, for instance, the difference in density between Nebraska, where this network has extensive coverage, and states like Arizona and California, where coverage is much spottier (US Geological Survey 2016).

A common challenge is getting a comprehensive picture of system-wide water availability for real-time management. Information management systems centralized at the scale of river basins or water projects—which update both water availability and use at high frequencies—are useful for this purpose. Good examples include Colorado's Satellite-Linked Monitoring System, and the Automatic Hydrologic Data Collection Systems developed for each basin in Spain. Many western states have similar centers for flood management.

Some larger regional and local agencies also have sophisticated information management systems. In California, for instance, many of the large urban and agricultural water agencies track numerous metrics related to water availability and use and employ SCADA (Supervisory Control and Data Acquisition) systems to manage the storage and delivery of water resources within their system. But these local and regional systems are often not well-integrated into broader state or basin-level water accounting systems.

Modeling Support

Because it is impossible to directly measure all aspects of a water system, models are essential for many aspects of water accounting. This is especially true for understanding current and expected water availability, and how different uses will affect water availability throughout the system. Some key modeling uses and challenges in these jurisdictions include:

- **Forecasting flows.** Hydrologic models combine pumping, evaporation, climate, and other processes to forecast flows at different groundwater and surface locations. An important—and challenging—area is improving the ability to forecast water availability beyond a few days or weeks (Mount et al. 2016a). This can improve the accuracy of water allocation announcements and help water managers and end-users with cropping, pumping, and water trading decisions, as well as for managing flood storage. Although its initial focus will be on flood management, modernization of the National Oceanic and Atmospheric Agency (NOAA) forecasts should improve water supply forecasts in the western United States (National Oceanic and Atmospheric Agency 2016).
- **Modeling environmental flow requirements.** Improving environmental flow modeling is a priority in many systems, both to enhance ecosystem management and to reduce uncertainties for urban and agricultural water users. Surface water models often are used to assess water availability in reservoirs, rivers and streams. The ongoing western US drought, which has seen record-high temperatures along with record-low flows, highlights the importance of including temperature and other water quality parameters important for protecting sensitive species, such as salmon (Mount et al. 2016a).
- **Determining availability for new appropriations and curtailments.** Surface models, combined with information on operating rules and claims, are also used to determine if water is available for new appropriations and whether some uses need to be curtailed. Models range in complexity from simple but effective assessments based on exceedance curves in Oregon to full-scale river and reservoir system models such as the Water Rights Analysis Package (WRAP) modeling system used in Texas (Wurbs 2015).[12]
- **Managing groundwater.** Groundwater models are essential for assessing how much groundwater is available and how aquifers function (e.g., how quickly they recharge and how water moves within them). In conjunction with monitoring data and long-term forecasts of precipitation and surface water availability for recharge, groundwater models inform key elements of basin management plans, including: What is the long-term level of safe yield? How should pumping rights be allocated among users? How should users be credited

[12] In California, the State Water Project and the federal Central Valley Project also use an exceedance curve approach to forecast allocations of water to their agricultural and urban customers.

for recharging the aquifer? Many states and regions with active basin management already benefit from strong groundwater models.[13] In others, significant work is still needed to fine-tune basin-specific tools.[14]

- **Integrating surface and groundwater management.** Because many groundwater basins are hydrologically connected to surface water, integrated models of surface and groundwater flows are needed to understand and quantify these interactions.[15] This is another major area where modeling improvements are needed. Advances have been especially noteworthy where the two resources need to be tightly managed because of obligations to downstream states under river basin compacts (e.g., Colorado, Kansas, Nebraska, New Mexico) or in-state obligations to more senior surface water users (Colorado, Idaho).

Understanding Liabilities: Water Claims and Uses

Despite some differences in how they administer and track legal claims on water and actual uses, managers in these 14 jurisdictions face some common challenges in understanding liabilities. For anticipating and enforcing claims, key issues relate to uncertain volumes of some surface and groundwater rights, separate legal treatment of surface and groundwater rights in hydrologically connected systems, and unclear or incompletely defined environmental water requirements. For understanding water uses, problems include incomplete or unverified reporting by users, gaps in measuring or estimating both applied uses and return flows, and lags in reporting and validating this information.

Establishing and Tracking Legal Claims on Water

Water rights

Water rights systems establish and organize legal claims to the use of water, including how water is allocated when supplies are scarce. For surface water, water rights systems generally require an ability to curtail diversions during droughts, and in some places even during average years.[16] For groundwater, water rights systems require an ability to limit pumping to avoid long-term depletion of aquifers—a problem in many basins—or to avoid undermining senior surface water rights. Water rights systems also set rules on trading—the voluntary leasing or sale of water—which is an important mechanism for reallocating supplies in response to droughts and long-term shifts in demands.

Water rights systems in the 14 study areas generally have transparent rules for issuing new rights, and oversight entities have a relatively clear understanding of claims issued since the establishment of modern regulatory water codes—for western states, in the late 19th to early 20th centuries.[17] Trading of rights is authorized to some degree in all study areas. However, some gaps remain in the definition of rights, which can frustrate system oversight and limit the transparency needed for water management and a well-functioning water market:

- **Validating claims by pre-code appropriative water-right holders.** In the western US, many early claims on surface and groundwater use were established under the "prior appropriation doctrine." This doctrine defines rights in terms of their establishment date; point of withdrawal; season, purpose and place of use; and quantity (volume and flow rate) of water used. In times of scarcity, the establishment date defines the

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[13] Most states use the MODFLOW platform developed by the USGS for this purpose.

[14] The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) simulates water movement through the linked land surface, groundwater and surface water flow systems in California's Central Valley—the state's largest agricultural region. It can assess groundwater pumping required to meet remaining demand and levels of pumping that exceed long-term safe yield. However, it may not have sufficient accuracy to serve as a detailed basin-management tool.

[15] Howard and Merriman (2010) discuss modeling to understand ecological impacts of water use in hydrologically connected basins.

[16] For instance, in some western states it is common to curtail diversions late in the irrigation season, even in average years.

[17] In Spain, the national law establishing the modern surface water rights system dates from 1879. Basin authorities were created in 1926, and joint administration of surface and groundwater rights at the basin scale dates from 1985. As described below, Australian water rights reform occurred in the 1990s.

right's priority. Although the original state water codes enacted in the late 19th and early 20th centuries recognized these pre-existing rights, most water regulatory entities established by these statutes did not systematically validate their authenticity or record volumes claimed.[18] In recent decades, many states have undertaken lengthy adjudications to clarify rights, with many still underway.[19] Others, including California, still have large volumes of surface water under pre-code appropriative rights that have not been validated.[20]

- **Quantifying riparian surface water rights.** Some western states and Australia also recognized riparian rights for some surface water, following an English common law doctrine that lets landowners divert water flowing past their property for use on that land (Figure 3B). Unlike appropriative rights, riparian rights remain valid even when they are not exercised, and they are not limited to a specified volume. This lack of certainty about the volume of riparian rights claims poses a challenge for anticipating demands on the system. It also limits trading, since riparian rights are attached to the land. In the 1990s, Australia undertook a wholesale conversion of riparian water rights—previously the dominant form of rights there—to a tradable, simplified share-based system.[21] Kansas, Nebraska, Oregon, and Texas have quantified most riparian water rights and made them tradable, and a similar process is underway in Washington.[22] All of these places, including Australia, still have some unquantified riparian rights for domestic uses and stock watering, which consume small volumes of water. California stands out as having significant riparian rights with no quantification process planned.[23]

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[18] Validation can include documenting the initial claim as well as continued use under that claim, because appropriative rights may be lost or diminished by forfeiture for sustained non-use and by abandonment.

[19] Several states have completed significant stream adjudications, including Kansas, Nebraska, Oregon, Texas, and Washington. Idaho recently completed the Snake River Plain adjudication, the largest in the West. Several important adjudications currently underway include Washington's Yakima River basin, Oregon's Klamath River basin, and Arizona's Gila and Little Colorado River basins.

[20] California's water rights permitting system became effective in 1914, and the law exempts riparian rights and existing appropriative rights from the permitting requirements. Water use reporting data from 2010–13 suggests that these rights collectively accounted for nearly a quarter of all surface water use in the Sacramento-San Joaquin River basin (including water exported to locations south and west of the Sacramento and San Joaquin River basins). Pre-1914 appropriative rights made up 14 percent of the total, riparian rights made up 3 percent, and uses that were reported as having both riparian and pre-1914 rights made up 7 percent. These estimates understate the total volume of pre-1914 rights, because many of these right holders are now served by the CVP and SWP under post-1914 rights. (Author calculations using "2010-2013 Average Demand Dataset" from the State Water Resources Control Board, accessed on September 3, 2015.) See Gray et al. (2015) for a discussion of these issues.

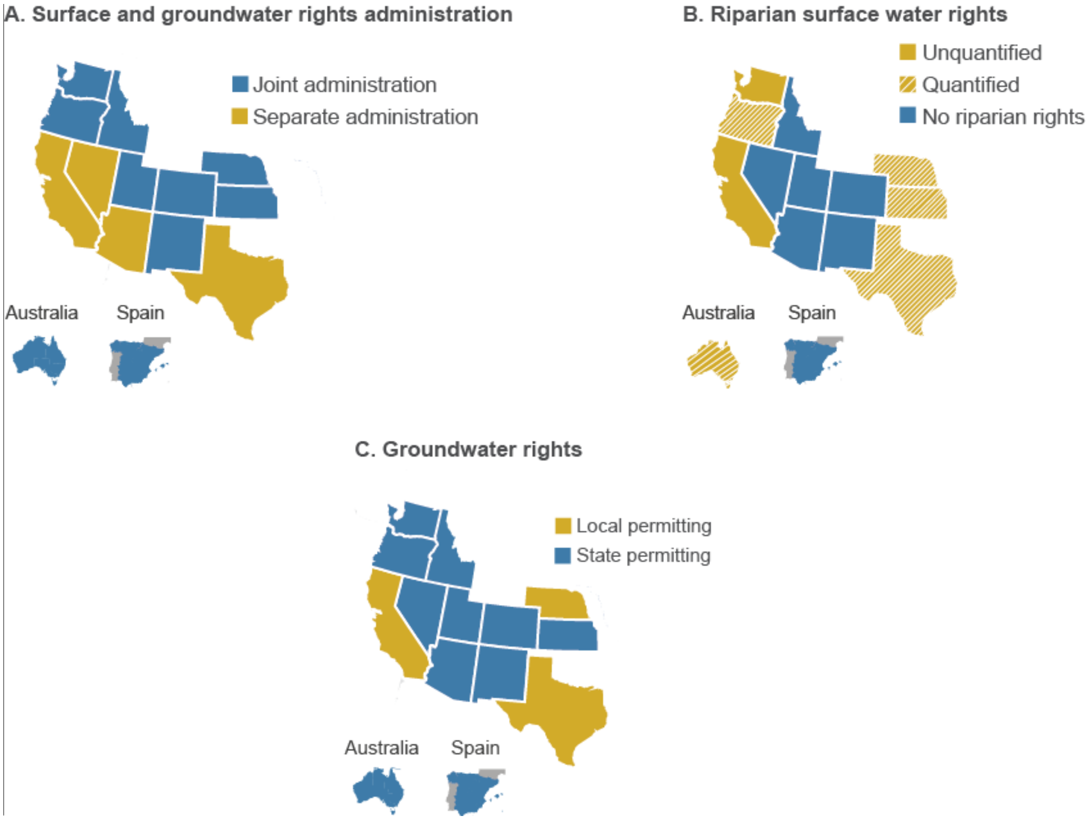
[21] Australia's main system now has simplified priority classes (two or three, depending on the state), and right holders within each class are cut back proportionally during shortages.

[22] Most of the western states that originally recognized riparian rights enacted statutes in the early 20th century that barred prospective riparian claims. Several have also converted their existing riparian rights to appropriative rights that are separable from the land and tradable. In the 1990s, Australia, which had a riparian-based rights system, undertook a similar conversion for most water rights. Only California and Nebraska still authorize the establishment of new riparian claims (Getches et al.1997). Information on states that have quantified riparian water rights is based on personal communications: Jim Bagley on April 13, 2016 (Kansas); Jesse Bradley on April 21, 2016 (Nebraska); Dwight French on April 13, 2016 (Oregon); and Buck Smith on April 19, 2016 (Washington).

[23] In the Water Commission Act of 1913, which created California's permitting system, the legislature attempted to extinguish all riparian rights that were not exercised for any period of 10 consecutive years after the effective date of the statute. In *Tulare Irrigation District v. Lindsay-Strathmore Irrigation District*, 3 Cal. 2d 489, 531 (1935), however, the California Supreme Court held that the 10-year forfeiture provision was contrary to the express recognition of riparian rights in the 1928 amendment to the California Constitution, now codified as Article X, Section 2, and therefore was unconstitutional. Although the state has not sought to quantify these rights, it has begun verifying the validity of some of these claims, which requires landowners to establish a constant chain of ownership of the riparian lands. California also regulates riparian uses of water through the reasonable and beneficial use mandates of Article X, Section 2 (Gray 2015). See footnote 20 for recent estimates of volumes diverted under these rights.

FIGURE 3

A comparison of water rights systems



SOURCE: Author assessments from case studies (for details, see technical appendix).

NOTE: Panel A: States with separate administration of surface and groundwater rights have some watersheds where the rights are administered jointly. Panel B: Australia, Kansas, Nebraska, Oregon, and Texas still recognize some remnant unquantified riparian rights, principally for domestic uses and stock watering. These were preserved when each state enacted legislation that either extinguished riparian claims for other uses or prospectively abolished all riparian claims for new uses of water. Washington is in the process of quantifying riparian rights. Panel C: In Spain, groundwater permitting is done by basin authorities. Permitting is less comprehensive in states with local permitting.

- **Quantifying groundwater rights.** Australia, Spain, and most western states regulate groundwater with comprehensive statewide permitting systems that seek to avoid or limit long-term basin overdraft by quantifying and capping pumping rights (Figure 3C).[24] In general, these permitting systems exempt small users, including wells for domestic uses and stock watering, from the pumping limits imposed on larger urban and agricultural wells.[25] Several states have instead delegated permitting authority to local oversight entities, and permitting is less comprehensive. Nebraska (1984), Texas (2005), and most recently California (2014) have enacted groundwater laws that require local entities to sustainably manage groundwater basins. These statutes authorize, but do not require, permitting and quantification of extraction rights.[26] In basins without pumping permits, extraction rights are generally not quantified, although they may be legally

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[24] In Spain, these permits are issued by the basin authorities. In Arizona, the state's 1980 groundwater law required permitting within relatively densely inhabited and intensively farmed Active Management Areas, but not elsewhere.

[25] In Colorado, these small wells are also exempt from administration in the integrated surface and ground water system, so they can divert water regardless of whether they would be in priority (personal communication, Ann Castle, May 12, 2016).

[26] In California, the Sustainable Groundwater Management Act of 2014 prohibits quantification or alteration of groundwater rights (California Water Code § 10720.5(b)), but it does allow the groundwater sustainability agencies to regulate and cap individual pumping.

limited—at least in principle—to levels that do not harm others in the basin.[27] Nebraska has the most comprehensive local permitting, and many local entities there allocate pumping rights based on irrigated acreage. In some parts of California, adjudicated basins have quantified rights, and the state's new groundwater law strengthens incentives for additional basin adjudications.[28] Texas has quantified groundwater rights in the environmentally sensitive Edwards Aquifer, and groundwater conservation districts elsewhere are making progress in quantifying rights.[29]

- **Linking surface and groundwater rights.** Most of the study area jurisdictions legally recognize the relationship between surface and groundwater resources in hydrologically connected basins, and take this into account in issuing new licenses and allocating water during times of scarcity (Figure 3A). Joint administration reduces the risk of harm to uses that share the same system and can increase the range of options for water-right holders, by facilitating trading, storing, and borrowing water. For instance, groundwater pumpers in Idaho's Snake River basin are purchasing surface water to help meet their replenishment obligations following the recent basin-wide adjudication (Times-News 2016).[30] Joint administration of rights has become more important in the context of interstate river basin compacts, which have required upstream states to limit the effects of groundwater depletion on river flows to downstream states.[31] The few states that do not systematically recognize a hydrologic connection between groundwater and surface water—Arizona, California, Nevada, and Texas—have a few local exceptions where rights are administered jointly.[32]

Water dedicated to the environment

Water for the environment supports river and wetland ecosystems and the plant and animal species that depend on them. Sometimes this water has not only volume and timing requirements, but also specific quality requirements, such as temperature or clarity. In addition, because the volume of water can affect salinity and other measures of water quality, some environmental flows are designated to protect water quality for urban and agricultural uses. Understanding these requirements is important for effective oversight and management of ecosystems and other water uses within shared watersheds.

There are two basic legal approaches to dedicating water to the environment: setting aside water through regulations and establishing water rights:

- **Regulatory set-asides.** These are legal requirements to meet environmental flow and quality conditions. They are not water rights, but they constrain the water available to water-right holders. All of our study areas have some regulatory set-asides for the environment. In the western United States, these set-asides are often driven by requirements to protect species listed as threatened or endangered under the federal and

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[27] The exception is Texas, which is unique in regulating groundwater according to the absolute ownership (or "rule of capture") doctrine. This authorizes landowners overlying an aquifer to extract an unlimited amount of groundwater without mitigating the impacts to nearby landowners. This doctrine has been modified in areas managed by a groundwater conservation district under the state's 2005 groundwater management law.

[28] California has roughly two dozen adjudicated basins, mostly in Southern California (Department of Water Resources 2014). In addition to defining overall rules for the sustainable management of groundwater levels in these basins, many of these adjudications quantify rights for pumpers (Langridge et al. 2016).Two bills passed in the wake of the 2014 Sustainable Groundwater Management Act were designed to streamline the adjudication process in other basins (Chappelle and McCann 2015).

[29] Groundwater management in the Edwards Aquifer was required under special legislation enacted in 1993.

[30] In this case, groundwater pumpers are required to recharge the basin to reduce negative streamflow impacts from years of excess pumping.

[31] Examples include compacts on the South Platte River between Colorado and Nebraska (requiring Colorado to monitor hydrologically connected groundwater use), the Republican River between Colorado, Nebraska, and Kansas (requiring Nebraska to regulate hydrologically connected groundwater use), and the Rio Grande between Colorado, New Mexico, and Texas (where the first two states have obligations to deliver water to Texas).

[32] In Arizona, this includes management within the Santa Cruz Active Management Area. In California, this includes management within some adjudicated basins (e.g., Scott River, Mojave Basin, Upper Los Angeles River Basin) and some initial regulatory efforts in the Russian River watershed. California's new groundwater law also requires basin management plans to take surface water interactions into account. In Nevada, groundwater rights were issued to supplement surface water rights in the Walker River during years when there is not a full allocation of decreed or stored water rights. In addition, the Truckee-Carson-Pyramid Lake Settlement allows claimants to maximize use of surface water when it is available to reduce pressure on groundwater supplies.

state Endangered Species Acts or to meet water quality standards under the federal Clean Water Act and state counterparts. Broader watershed-based approaches are less common; most rivers and streams do not have minimum flow requirements, even where they might be justified under existing law.[33] Some exceptions include Kansas, Texas, and Washington, which have established instream flow programs in many watersheds. In Australia, regulatory set-asides known as "planned environmental water" or "passing flows" ensure minimum streamflow for multiple purposes, including the environment. In Spain, minimum environmental flows are defined in basin management plans and considered as a general restriction on the management of water systems, rather than a water use.

- **Environmental water rights**. These are dedications of water for environmental uses within the regular water rights system, with priorities and permits like other water rights. All study areas except Spain have recently authorized water rights for the environment. Australia has gone furthest, acquiring large water-right holdings to manage river and wetland systems for ecological benefits. Colorado and Oregon have also established considerable water rights for the environment, whereas the volumes are generally still small elsewhere in the western United States.[34] In Colorado, Idaho, Oregon, Nebraska, and Victoria, environmental water rights are held by a single institution; elsewhere environmental water rights are often held by non-profit organizations for use on local streams.[35] Many states use their water markets to temporarily acquire water for the environment to supplement regulatory flows and permanent water rights. Victoria's Environmental Water Holder appears unique in its ability to lease its water right holdings, both to move environmental water around to where it is most needed and to raise funds for environmental projects (Mount et al. 2016b).

From an accounting perspective, there are two major information gaps for environmental water claims, particularly in the western United States:

- **Lack of clarity on environmental flow needs.** This is an issue in the many watersheds that lack specific targets or regulatory set-asides. Quantifying these flows—and establishing either regulatory set-asides or environmental water rights to meet them—would improve the ability to manage aquatic ecosystems and reduce uncertainty for environmental managers and other water users. In some cases, this will also require establishing clearer conditions regarding water quality, such as temperature, and the interactions between flows and quality.
- **Lack of clarity on the priority of regulatory flows.** At issue is the priority of these flows relative to water rights established before the regulations were introduced. This has heightened tensions over environmental water allocations during California's latest drought.[36] Some western states have addressed this issue by assigning priority dates to their instream flow dedications.[37]

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[33] For a discussion of this issue in California, see Gray et al. (2015).
[34] In both states, as in Australia, these rights were established through a combination of dedication of unappropriated water to the environment and acquisition of rights from other right holders. California also allows existing water-right holders to dedicate all or a portion of their water rights to instream use under section 1707 of the California Water Code, though the volumes are still quite small (Szeptycki et al. 2015 and Hanak and Stryjewski 2012).
[35] Victoria's Environmental Water Holder (VEWH) is an independent statutory body for holding and managing the state's environmental water rights. It also manages environmental water rights held by the federal government.
[36] Gray et al. (2015) point out that although there is a legal basis for treating these flows as having precedence in California under several federal and state laws, this understanding is not fully reflected in the administration of water rights or the understanding of water-right holders. See also Gillilan and Brown (1997) for a discussion of this issue.
[37] In Colorado, Kansas, Texas, and Washington, the instream flow dedications under state law are given the priority date corresponding to when they were established. This means that they may be cut earlier than water rights with earlier priority dates when water is scarce. In general, water dedicated to the environment under the federal Endangered Species Act has precedence relative to water rights throughout the US.

Understanding Water Use

Accounting systems usually need to distinguish between two types of uses: "applied" or "gross" use—the amount initially used for a given purpose—and "net" or "consumptive" use—the amount of use that is actually consumed at the place of use and unavailable for reuse.[38] The difference is return flows—the water that returns to rivers, streams, or aquifers and is available for reuse. Return flows include urban wastewater discharges and irrigation water not consumed by crops and are often substantial.[39]

Understanding gross and net use (and the corresponding return flows) is important to verify compliance with allocation rules and to assess how much water remains available for other uses. Water rights and other legal claims on water are almost always for applied or gross water uses. But water trading is often limited to net use, to reduce potential harm from trading to water users who rely on return flows.

Our study areas use both data gathering from water users (bottom-up) and external estimation (top-down) approaches to acquire water use information, with a combination of self-reports, direct and indirect measurement, and estimation.

Applied or gross use

Central governments in most areas require surface water users to self-report their usage—usually monthly use on an annual basis. States with groundwater permits typically also require groundwater use reporting to a central authority. Governments in most areas also can require users to install measuring devices of verifiable accuracy, but these requirements are typically only enforced in areas where water is especially scarce.[40] Although better than no information at all, self-reporting can have questionable value.[41] Accuracy is much improved when measurement and reporting are required.

Rather than relying on direct user reports to a central authority, Colorado and Idaho have put local appointees—watermasters or water commissioners—in charge of tracking and reporting water use to the state. This process ensures an initial quality control of user data. Some highly monitored systems—including Colorado, Australia, and Spain—also use a comprehensive monitoring network to measure large agricultural and urban diversions. Advances in telemetry are now making direct, real-time water-use reporting possible. When measurement devices are connected with centralized information platforms (as in Colorado and parts of the Pacific Northwest), they can inform real-time operations, which significantly increases their usefulness.[42]

Net use and return flows

Despite their importance for understanding water availability in places where water is scarce, many areas still have significant gaps in tracking net use and return flows.

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[38] In some states (e.g., Colorado), applied use is more typically referred to as "diverted water" or diversions. Net uses within the system include the water consumed by people or plants, embodied in manufactured goods, or evaporated into the air (including on fields and during water conveyance), as well as discharges into the ocean or saline lakes or groundwater basins, where the water is not reusable without significant treatment. For a description, see Hanak et al. 2011, Box 2.1.

[39] In inland areas, as much as 90 percent of indoor water use returns to the system as treated wastewater (versus as little as zero in coastal areas where wastewater is discharged into the ocean). Depending on the irrigation technology and practices, irrigated agriculture may return 10 to 60 percent of applied water to the system.

[40] Colorado, Idaho, Kansas, Nebraska, New Mexico, Nevada, Utah, Washington, Australia, and Spain can all require the installation of surface and groundwater use measuring devices, and California recently enacted a law that will require surface water measurement for all but very small diversions. Some jurisdictions also authorize water users to report use based on approved estimation techniques. For instance, in some basins in Idaho, the volume of groundwater pumping can be estimated based on electricity use.

[41] Although reporting of use under surface water rights has been required by law since 1966, California first began collecting this information for riparian and pre-1914 appropriative right holders following the enactment of a 2009 law that established enforcement penalties for failure to file. Though imperfect, these reports provided critical information for determining curtailments during a drought emergency in 2014 and 2015. A law enacted in 2015 will require more regular (usually annual) reporting of most surface water diversions and the installation of measurement devices.

[42] USBR's Hydromet provides real-time data for major diversion in large basins in the Pacific Northwest. See Operation Reports at US Bureau of Reclamation (2016).

Return flow information is commonly available for urban indoor uses, because urban wastewater agencies are required to report discharges of treated wastewater under the federal Clean Water Act. However, this information often is not used systematically in basin accounting; Colorado and Idaho are notable exceptions.[43]

Because some unused irrigation water flows to the ground instead of back to rivers and streams, direct measurement alone is usually insufficient for tracking net water use and return flows for agriculture—the largest use in most basins. Most western states develop estimates of net crop water use with land use, crop survey, and climatic data. However, these estimates are not commonly available to inform real-time management, and few states have statewide programs for evaluating net use and return flows (Western States Water Council 2014). Exceptions include Colorado and Nebraska, which employ statewide models for this purpose.[44] Another interesting example is Idaho, where the METRIC model's estimates of net crop water use—derived from satellite-based remote sensing data—are used for water basin planning and management, including curtailment orders.[45] To improve the accuracy of these estimates, Idaho also measures surface water return flows from agriculture in sensitive basins.

In addition to improving understanding of water availability, these tools facilitate the authorization of water transfers and help these states meet the terms of their interstate obligations. In some Colorado basins, water rights are now effectively defined in terms of net use, because cities and farms are held accountable for maintaining return flows to meet these obligations.[46]

Managing and Sharing Information

Beyond addressing gaps in key water metrics, well-functioning water accounting systems need to make the data that *is* collected into information useful for water managers and others, including water-right holders, policy makers, and the public. Key challenges relate to developing data and modeling standards—important for comparability, transparency, and quality control—and developing useful platforms for sharing different types of information and improving information over time.

Establishing Standards

Setting standards and quality control processes for data and models can reduce uncertainties, streamline administrative processes, and improve water management decisions.

To enhance comparability, some areas use templates to standardize water accounting data. The most comprehensive standards may be those developed by Australia's Bureau of Meteorology, designed to ensure consistency in water budget evaluations nationally. Arizona's simpler Master Data Templates serve a similar function, as does basin accounting software used in Colorado. Since 2012, the Western States Water Council has been working with state and federal agencies on a Water Data Exchange (WaDE), which would facilitate the exchange of water use, planning, and allocation data within and across western states through the use of common data formats and platforms (Western States Water Council 2014).

Standards for models reduce uncertainties and improve confidence and transparency in water accounts. Without standards on the underlying assumptions and data used to calibrate model results, there is a risk of dueling models, developed by different parties to serve particular interests, and inability to compare conflicting models

[43] Texas requires annual return flow reporting, which it uses in its Water Availability Model. In California, discharges from the Sacramento Regional County Sanitation District are tracked daily as part of flow monitoring within the sensitive Sacramento-San Joaquin Delta.

[44] Nebraska's CROPSIM model and Colorado's StateCU model are both interesting examples of statewide models used for management.

[45] For a description of the METRIC model, see Allen et al. (2007).

[46] This is especially the case in the South Platte and Arkansas River basins, where large scale water transfers included quantification of consumptive use.

and model results. Many areas use one model as an authoritative representation of flows in a system. Some useful examples of authoritative models from our study areas include:

- Australia's eWater Source provides a consistent hydrological modeling and reporting framework for transparent river management decisions. The Victorian Water Register has an authoritative model for determining how much water is physically and legally available to right holders.
- Colorado's StateMod allocation model provides authoritative estimates of water availability for allocation to right holders. Web-based decision-support software products include information on net water use, daily surface water allocations, and basin-wide water balances. Data are processed in standardized ways for the whole state. Colorado has also developed numerous other water-related decision support systems.
- Idaho's ESPA modeling tools provide a common way to analyze the hydrologic impacts of new water right applications, transfers, and leases under the state's Water Supply Bank. This includes a simple publicly available spreadsheet that can be used to analyze the impact of groundwater pumping on surface water.
- Spain's Aquatool platform provides authoritative estimates of availability and allocation decisions within each river basin (Andreu et al. 1996).
- Texas is working to cover the entire state with authoritative Groundwater Availability Models for use by local groundwater management agencies. The state also developed a Water Availability Model package for use in processing new surface water rights applications.

Making Information Accessible

The deployment of new information technologies has made it easier to collect, process, and supply information, including over the Internet. But one major challenge is the variety of platforms used to present and disseminate different datasets. Here are some examples of best practices:

- **Centralized information management systems.** Some study areas have developed centralized information management systems, consolidating information from different sources in the same platform. Good examples include the Water Information Portal of Australia's Bureau of Meteorology, Nebraska's Interactive Streamgage Map, and the automated hydrologic data collection systems developed for each basin in Spain. The USGS website has a user-friendly web portal for the range of its water datasets.
- **Dashboards.** Another useful practice is to present dashboards or summaries of multiple water datasets. Good examples of short reports include the Texas Water Conditions Report, USDA's Natural Resources Conservation Service water supply forecasts, and (during droughts) Nebraska's water availability updates, all issued monthly.
- **Accessible water rights information.** Although most study areas provide online information on surface water rights, fewer do so for groundwater rights. The most advanced platforms include spatial information. Idaho's Water Rights Accounting map is an interactive mapping tool where surface and groundwater rights are presented with other accounting information. Nevada's Mapping Applications maps all points of diversions and places of use for each water right.
- **Accessible water trading information.** Although water trading generally requires administrative approval, only a handful of places—including Oregon and Nevada—systematically publish transfer applications and approvals.[47] Australia is an outlier in this regard. Each Australian state has water registers that include

[47] The Idaho Water Supply Bank is also a useful information platform for lessors and lessees of water. California's State Water Resources Control Board posts application information for transfers that it must approve, but that is only a subset of trades; detailed information on trades approved by other agencies is generally only available upon request.

information regarding water rights and transactions. The Victorian Water Register, for example, shows the trading history of the water right. It also provides tables and graphs on trading volumes and prices in different locations, updated daily. This information—combined with a transparent preapproval process that indicates conditions for water trades between parties in different locations—has facilitated the development of privately run trading platforms that enable users to rapidly conclude both temporary and permanent trades of water rights.

Seven Best Practices in Water Accounting

This review has highlighted some of the many opportunities for governmental and private parties involved in water use and management to work together to improve water accounting systems. Federal and state governments can leverage their ability to establish authoritative standards, models, and processes. Local agencies and private entities, for their part, usually have better knowledge of local data and conditions. Cooperation among the range of institutions will be needed to craft, verify, and continuously improve water accounting systems. This will work best if accounting systems are designed to serve all parties, with an eye to using the most cost-effective approaches to gathering and making available strategic information for water management.

Although strategic information needs will vary from place to place and over time, this review suggests seven best practices for areas facing water scarcity to improve the quality and transparency of water information used to make better management decisions and to inform water-right holders, policy makers, and the public.

Understanding Water Availability

Water managers and users are best served by monitoring and measurement systems that collect and disseminate real-time information on water availability at the scale of large water systems and river basins.

1. **Develop centralized, real-time flow and storage estimation and monitoring for river basins**. Colorado and Spain show the benefits of centralized monitoring systems at the river basin scale that use telemetric, real-time reporting of stream flows, large diversions, and changes in reservoir levels. Better real-time information benefits water managers and other users of water information. It can allow water-right holders to coordinate their activities, create opportunities to identify potential trades and cooperative arrangements to improve environmental outcomes, and reduce the need for curtailments.

Understanding Water Claims

For transparency and effective oversight and management of scarce resources, it is important to quantify significant water rights and clarify claims on environmental water.

2. **Quantify all major water rights.** Quantifying and validating claims relating to several types of water rights that have traditionally been managed loosely—including appropriative water rights established before the adoption of modern water codes, riparian surface rights, and groundwater pumping rights—is necessary to support tighter water management. Many jurisdictions have now done this, or are well underway. They generally focus on larger claims, allowing exemptions for small claims for domestic uses and stock watering.
3. **Clarify environmental water claims.** Many western states still have important gaps in understanding how much water should be dedicated to environmental uses under various environmental laws, as well as the priority of those uses when supplies are scarce. Designating significant water rights for the environment—as done in Australia, Colorado, and Oregon—can give environmental water managers added flexibility and create incentives to integrate the management of environmental flows with other system goals.

Understanding Water Uses

The best systems take advantage of mixed strategies, including direct measurement, remote-sensing, and modeling to understand strategic water uses and develop authoritative estimates of net water use and return flows.

4. **Measure and monitor strategic water uses.** Not every diversion or well needs a measuring device, but measuring and monitoring are essential in many places for effective system oversight and management. Having the legal authority to require installation of measuring devices is useful. Mixed strategies, combining measurement of river flows and large diversions with water balance models—as done in Colorado, Spain, and Victoria, Australia—are especially useful in large basins that must be managed carefully. Advances in telemetry—which enables real-time reporting from multiple monitoring sites—can reduce the costs and improve the accuracy of monitoring.
5. **Improve estimates of net use and return flows.** Understanding net water use and return flows is becoming increasingly important in many basins. Developing systematic, standardized estimates of return flows can help manage basins with significant groundwater-surface water interactions, and facilitate water trading. Remote-sensing technology—along with new experiments in drone-based aerial mapping—show promise in reducing costs and improve the accuracy of such estimates.

Managing and Sharing Information

Standards on data and models, and accessible portals for organizing information, are key to effective management and sharing of information.

6. **Develop standards for data and models.** Water accounting standards—such as those developed in Australia—help summarize information on water claims and use in comparable ways. This improves transparency and enables tracking of performance over time. When coupled with information on water claims—as in Victoria's Water Register—this also facilitates participation in the water market. For models, standards are needed to make assumptions and results publicly available, and to ensure replicability and comparability. Authoritative models—ranging from simple spreadsheets to more sophisticated tools—can reduce costs and uncertainty, improve confidence in the system, and reduce litigation over allocation decisions.
7. **Organize information.** Big data does not always mean good information. To make water information useful to a broad range of audiences in the Internet age, it is important to consolidate datasets and portals in ways that facilitate accessibility and transparency. Developing summary reports and dashboards of key information for decision makers—including end users— can also be valuable. Many jurisdictions have examples of good public information provision, and there is room for learning from each other. In the western US, the Water Data Exchange (WaDE) initiative is a promising step toward facilitating the exchange of water use, planning, and allocation data through the use of common data formats and platforms (Western States Water Council 2014). Organizing information typically requires coordination among agencies and users—not always an easy task—but this can significantly improve the basis for public and policy discussions about how to manage water under conditions of scarcity.

One final observation relates to broader organizational challenges for effective water management in dry places. All of our study areas face a common challenge of developing information and management systems that can address the range of competing needs within large river basins and the watersheds that lie within them. Basin-scale information and management institutions—such as those developed in Colorado, Victoria, and Spain—facilitate the collection and analysis of strategic information on water availability and use, consideration of surface and groundwater interactions, and an integrated view of economic and environmental uses of water. As other jurisdictions move toward integrated water resource management, they will benefit from the ability to do their water accounting—and strategic water management—at the basin scale. This requires setting up accounts that can incorporate information from more localized systems within the larger water system, and using clear and common standards for measurement, estimation, reporting, and analysis.

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California

Highlights

- California has one of the most complex water systems in the world, marked by an extensive supply system of reservoirs, canals, and pipelines, and managed through a complex water rights scheme and multiple agencies.
- The surface water rights system—blending unquantified riparian rights with two types of appropriative water rights—and the historic lack of groundwater regulation, complicates the legal allocation of water, especially during droughts.[48]
- California has several water-related monitoring programs with different purposes. However there are key gaps in information, including: surface monitoring in environmentally sensitive basins, real-time information on significant water uses, return flows, enhanced coverage for streamflow and groundwater measurement networks, and interactions between surface and groundwater. The lack of integration of the different monitoring and accounting systems also challenges water management.
- Although California has developed online platforms for sharing water information, comprehensive information and integration is still lacking. These systems provide some information on water rights, stream flow, surface water quality, surface reservoir operations and conditions, groundwater levels, and groundwater quality. Better information on trading volumes and prices could increase transparency of the water market and facilitate water trading.

Introduction

California has a Mediterranean climate with rainy winters and dry summers along with extreme geographic, seasonal, and inter-annual variability in water availability and demand. On average, 75 percent of California's precipitation occurs between November and March.[49] An estimated 70 percent of runoff occurs north of the Sacramento-San Joaquin Delta, but 75 percent of the state's water demand is south of the Delta (California Department of Water Resources 2012).

Due to the historic growth of agricultural and urban water demands (especially in the Bay Area, Los Angeles, and San Diego), Californians developed one of the world's most impressive water infrastructure networks over the 20th century. More than 1,400 dams and thousands of miles of aqueducts convey water from the wetter north and Sierra Mountains to more arid southern and coastal areas. The federal Central Valley Project (authorized in the 1930s and completed in the early 1970s by the US Bureau of Reclamation) and the State Water Project (developed in the 1960s and 1970s by the California Department of Water Resources) are among the largest water projects in the United States.

In an average year, California uses roughly 80 million acre-feet of water to irrigate crops, supply potable water to cities, and maintain ecosystems (California Department of Water Resources n.d.). Roughly 50 percent of this developed water is devoted to environmental flows (especially in the northern coast basins), 40 percent to agriculture, and 10 percent to urban areas.[50] Some regions rely heavily on groundwater, especially in dry years. A

[48] This changed with the approval of the Sustainable Groundwater Management Act in 2014.

number of important aquifers, especially in the Tulare Basin and along the Central Coast, have long been substantially over-drafted.

California's agricultural sector is a leader among US states; however, it generates a relatively small proportion of the state's overall economy. Agriculture is significant for local economies and the labor market in many regions.

Decades of harmful water and land management practices have degraded aquatic environments, creating harmful conditions for native fish and other species that depend on California's wetlands, streams, lakes, and estuaries (Hanak et al. 2011). One of the clearest examples of this is the Sacramento-San Joaquin Delta, where a sensitive native ecosystem struggles to cope with agricultural practices and operations of critical water infrastructure projects.

Principal demographic, economic, and water-related indicators in California

Population (in 2010):	37.3 million
GDP (in 2010):	$1,935 billion
Agriculture Value Added:	2.58 % of GDP
Annual Precipitation:	22.10 inches
Total Water Withdrawals:	42,600 TAF
Urban Use:	21%
Agricultural Use:	76%
Thermoelectric Use:	2%
Other Uses:	2%
Surface Water:	60%
Groundwater:	40%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, the source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight Agencies

Although daily management of California's water is highly decentralized, state and federal agencies administer significant aspects of the state's water supply management and oversight responsibilities. The State Water Resources Control Board (SWRCB) administers the state's surface water right system and regulates water quality with support from nine regional boards. The Department of Water Resources (DWR) performs state water planning, oversees some flood operations, and has a major water supply operation function. The California Department of Fish and Wildlife (CDFW) carries out state fish and wildlife protection and management responsibilities, including California's Endangered Species Act (CESA) (Hanak et al. 2011).

California also has water supply oversight entities that work on smaller scales. Watermasters, under state court authority, help allocate surface and groundwater in numerous basins throughout the state. Watermasters designated by DWR supervise surface water diversions during the irrigation season in nine areas of northern

California. When groundwater basins are adjudicated by court ruling, the court typically appoints a watermaster to administer the judgement and oversee the allocation of groundwater supplies among users each year. California has 24 adjudicated groundwater basins, and almost all have an appointed watermaster, usually a local water agency, DWR, or an individual. The Sacramento-San Joaquin Delta is overseen by a watermaster appointed by SWRCB who oversees and reports on the exercise of water rights.

Water supply operations agencies

The DWR also operates the State Water Project (SWP). Spanning more than 600 miles from Northern California to Southern California, the SWP includes 34 storage facilities, 20 pumping plants, four pumping-generating plants, five hydroelectric power plants, and approximately 700 miles of canals, tunnels, and pipelines. The US Bureau of Reclamation (USBR) operates the Central Valley Project (CVP), which consists of 20 dams and reservoirs, 500 miles of canals, and 11 hydropower plants, as well as other smaller water projects for other parts of California (Green 2007). DWR and USBR signed a "Coordinated Operations Agreement" in November 1986, which allows the agencies to operate the various CVP and SWP facilities in tandem fulfill their respective water supply responsibilities while also complying with environmental requirements and obligations to senior water right holders (USBR 2008).

Many other major water supply storage and conveyance systems are operated by wholesale or retail water agencies (public and private) on a regional or local scale. These agencies include urban water utilities and agricultural water agencies (such as irrigation districts and other special districts) that provide water service to farms and rural communities. Most local water agencies are either surface water-right holders, groundwater pumpers, wholesale customers of the major water projects, or some combination of the above. These local and regional projects provide a larger proportion of California's water supply and have increasingly operated conjunctively with other agencies statewide to reduce costs and to improve water supply reliability.

Legal Framework

Water rights

While surface and groundwater sources are hydrologically connected in much of California, there is little legal connection between the two types of water rights in California. In practice, most surface water and groundwater rights are administered separately.

Broadly, there are three main types of surface water rights in California: riparian, pre-1914 appropriative, and post-1914 appropriative.[51] The most senior water right is riparian, available to owners of land directly adjacent to rivers and lakes for use on that land. Riparian water rights are not quantified, meaning that diversion limits are not defined by water volumes. Rather, riparians have a shared, top-priority right to the natural flow of California's rivers as reasonably required to fulfill their beneficial uses in times of shortage.

Appropriative water rights are not tied to land, are for a specific quantity of water, and are assigned a priority *vis-à-vis* other appropriators. Generally, in times of shortage, appropriators may divert water only after riparian rights are fulfilled. Pre-1914 appropriative rights are those that were established before adoption of California's modern water code in 1914. Some of these pre-code rights have been confirmed by the courts, but most are not well-defined. Post-1914 appropriative water rights must be procured through a permit or license issued by the State Water Resources Control Board. Both types of appropriative surface rights are quantified. According to the appropriative water rights doctrine, water shortages are allocated by seniority according to priority date ("first in

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[51] Other types of rights include pueblo rights and federal reserved rights.

time, first in right") and administered by the State Water Resources Control Board, by watermasters, or the courts. To avoid conflicts and ensure the long-term sustainability of surface water right permitting, those applying for permits or permit modification must show evidence that proposed projects will not damage senior water rights or harm the public interest.

Groundwater rights have few practical limitations on extraction. Land owners who pump groundwater from beneath their land have first priority of use, followed by appropriative groundwater pumping for export. All groundwater extraction is technically limited to the safe yield of the underlying aquifer, but in practice these limitations are enforced only in adjudicated groundwater basins. [52]

Courts may be involved in adjudications for allocating surface water and groundwater in California. In general, basin adjudication involves court judgments that allocate water among competing users and appoint an oversight entity or watermaster to administer the judgment. Adjudications can also have an ancillary benefit of confirming and quantifying pre-1914 appropriative surface water rights (in surface water adjudications) and quantifying groundwater rights (in groundwater basin adjudications), depending on the nature and location of the adjudication.

Although long-term sustainability is considered in surface water right permitting, the disconnection of surface water right permitting from groundwater permitting and the historical lack of groundwater regulation creates management challenges in areas where surface and groundwater are hydrologically integrated. Conjunctive administration might be improved with legislative efforts to streamline groundwater adjudications and the enactment of the Sustainable Groundwater Management Act (SGMA) in 2014. SGMA mandates the development of a Groundwater Sustainability Plan for managing groundwater in high and medium priority basins (127 of 515 basins, containing most population and farming that uses groundwater).

Water trading

Water trading (commonly referred to as markets or transfers) is legal in California and is important in re-allocating water among agricultural, urban, and environmental water users (Hanak et al. 2011).

The SWRCB is responsible for approving transfers for any post-1914 surface water rights if they involve changes in purpose of use, place of use, or point of diversion. Transfers between contractors of the SWP and CVP usually occur without SWRCB review, because they do not require a change in the projects' water rights permits. Transfers between CVP or SWP contractors do need approval from the project operator, however (Hanak and Stryjewski 2012).

Water transfers (temporary, long-term, and permanent) are subject to several general water rights rules. The primary restriction is the "no injury rule," which provides that a water transfer must not result in an injury to other legal uses of water. Typically this means that water rights holders may transfer only the amount of water that results from a reduction in the consumptive use of their water right (Hanak et al. 2011). (See for example, Water Code Section 1702, 1706, 1725, and 1736).

Establishing methods to determine "real water" or "tradable water" is a key challenge for state oversight agencies that evaluate proposed water transfers. Many, but not all, water transfers are subject to environmental review, and must not "unreasonably affect fish, wildlife, or other instream beneficial uses" (Water Code Section 1725 and 1736). In addition, if the transfer requires the use of state or local conveyance facilities, the transfer must not unreasonably affect the environment or the overall economy of the county from which the water is transferred (Water Code Section 1810) (Hanak et al. 2011). DWR and Reclamation have prepared a water transfer white

[52] Unless otherwise stated, the source material used to write this paragraph and the two preceding paragraphs is Gray et al. 2015.

paper on the technical information needed for preparing proposals for temporary water transfers which require DWR or Reclamation approval (California DWR and USBR 2015).

Water may also be dedicated to instream beneficial uses, including water quality, fish and wildlife, and recreation, and water rights may be used to create or enhance wetlands and other aquatic habitat (Hanak et al. 2011). Instream flow dedications and transfers help to protect public trust and the environment.

Informal conjunctive use programs have long operated in California. The state also has formal conjunctive use programs ("groundwater banking") that provide reliability buffers during dry years. These storage-sale operations specialize in recharging aquifers during wet years and selling the water to users who are off-site parties (Hanak and Stryjewski 2012).

Legal treatment of environmental water use

The CDFW and the SWRCB are both responsible for studying and recommending instream flow standards for protecting and preserving fish, wildlife, and recreation in California's rivers and streams. To date, the CDFW has compiled instream flow recommendations for about two dozen rivers and streams and submitted these recommendations to the SWRCB for further investigation and potential implementation. The SWRCB was directed by the legislature to submit by 2010 a prioritized schedule and cost estimates for completing instream flow studies for high priority rivers and streams in the Delta and all major rivers and streams outside the Sacramento River.[53] If instream flow studies reveal insufficient water to meet environmental needs, these flows could be created through voluntary actions (e.g., water permits for environmental uses or voluntary water transfers to the environment), or administrative or regulatory actions. Regulatory procedures for implementing instream flows are often prohibitively expensive for the SWRCB (a simple case within a small watershed would cost approximately $600,000, while a larger watershed would cost several million dollars) (State Water Resources Control Board 2010).

Where voluntary efforts have failed to achieve instream flows to the detriment of water quality criteria under state and federal water quality laws, the SWRCB may directly modify water rights within a watershed to achieve a specified flow objective. They also may use the public trust doctrine, the state constitution's unreasonable use provisions, and the Clean Water Act as regulatory tools for achieving instream flows. This type of regulatory action has been used to protect water quality and listed species in the Bay-Delta watershed (North Coast Regional Water Quality Control Board 2015). The federal government also may issue biological opinions specifying flow objectives from federal water projects related to protecting endangered species and achieve those flow objectives through project re-operation and reducing diversions and deliveries (Meltz 2013).[54]

In March 2015, the SWRCB adopted an emergency regulation establishing minimum instream flow thresholds in three creeks that support state and federally listed anadromous fish. The regulation provides that the SWRCB may use its administrative and regulatory authorities to limit diversions of water from these waterways to achieve the desired minimum flow to protect listed anadromous fish.

Prioritization of particular uses

California Water Code prioritizes domestic water uses above other water-right holders and recognizes a human right to water for essential household purposes (Smith and Ellsworth n.d.). In recent emergency curtailment

[53] According to this directive, the SWRCB was required to perform this evaluation with the objective of having completed instream flow studies in the Delta watershed and outside of the Sacramento River watershed by 2012 and 2018 respectively.

[54] Example includes the Klamath Project during drought of 2001 and the Bay-Delta.

regulations, the SWRCB relied on California's constitutional directive to prevent waste and unreasonable use of water to protect domestic and municipal water uses required for minimum health and safety needs.[55]

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

California has several types of self-reporting requirements for surface and groundwater users. Variations in reporting types and requirements are based largely on water source, water right types, adjudication status, and geography. Most major types of reporting requirements can be completed and submitted using an online portal called the Electronic Water Rights Information Management System (eWRIMS).

Riparian and pre-1914 surface water-right holders are required to complete an initial Statement of Diversion and Use (once), followed by Supplemental Statements of Diversion and Use submitted each year.[56] The statements alone do not establish or constitute evidence of a water right. According to Section 5103 of the California Water Code, Initial Statements of Diversion and Use require right holders to report monthly diversions for the year in which the form is submitted, estimated maximum rate of diversion per month, and provide a rough estimate of historical annual water use. Reporters also must provide a description of purposes of use. For agricultural irrigation operations, users may report the number of irrigated acres. Supplemental Statements of Diversion and Use require reporters to provide the maximum rate of diversion during each month, the amount directly diverted or collected to storage each month, and the amount beneficially used each month. Reporters also must state the purposes of use, which for agricultural operations includes crop type and acreage (California Code of Regulations, Title 23, Section 920). New regulations expand measurement requirements to all water rights holders (including riparian and pre-1914) who have diverted, divert, or plan to divert more than 10 acre feet annually. SWRCB staff determines if the reporting form has been fully completed and enforces the reporting requirement, but does not validate the compliance of each statement with the terms of the water right being exercised.

Post-1914 water rights have separate reporting requirements depending on the status of the right. If the right is still in the permit stage, reporters must file an annual progress report with the SWRCB with detailed information on the purposes of use (including environmental uses). For example, irrigation operations must report crop type and acreage. Progress reports also include the amount of water taken from each point of diversion in each month (including amount diverted and amount collected to storage). Reporters must also provide the maximum rate of diversion from each point of diversion at any time during each month (California Code of Regulations, Title 23, Section 925). When the water right permit advances to the license stage, licensees must prepare reports and file them with the SWRCB annually. License holders must report the purpose of use that year (as reported in progress reports), along with monthly direct diversion and collection to storage amounts for each point of diversion and the maximum rate of diversion from each point of diversion each month (California Code of Regulations, Title 23, Section 929).

Some watermasters must provide annual reports to a court or the SWRCB (as specified in Water Code 5101 (d) and (e)). These reports must identify the party diverting water, a description of purpose and place of use, the type of use, and the quantity of water diverted from each source. Some watermasters must report monthly diversion

[55] California Constitution Article X, Section 2. Examples include curtailments on Mill, Deer, and Antelope Creek.

[56] With the passing of SB 88 in 2015 and new reporting regulations in 2016, Supplemental Statements of Diversion and Use must be submitted annually.

amounts (California Code of Regulations, Title 23, Section 921). These reports are not collected or submitted using eWRIMS.

Groundwater withdrawals after 1955 in Riverside, San Bernardino, Los Angeles, and Ventura that exceed 25 acre-feet per year are required to file Notices of Extraction and Diversion of Water with the SWRCB. Some of these reports can be filed electronically through eWRIMS, while other reports are collected by local agencies. The reports include type of diversion (groundwater or surface water), total amount extracted during the year from sources, and method of measurement (California Code of Regulations, Title 23, Section 930).

Indirect measurement of water use (top-down approach)

The most comprehensive analysis of water use at the state scale is done in the DWR's California Water Plan. The California Water Code requires the DWR to publish an update every five years evaluating water supplies and assessing agricultural, urban, and environmental water uses. Using available information from different sources and models, the plan assesses direct and indirect water use for all types of water users. The latest updates show annual data of water supply and use per hydrological region. The assessment of agricultural water use is based on an indirect approach using crop acreages from periodic land use field surveys combined with the annual reports of the County Agricultural Commissioners and crop water use depending on climatic data, soil types, crop characteristics, and irrigation efficiencies.

To supplement the lack of knowledge of agricultural groundwater use, especially important in the Central Valley, the DWR developed the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim). This integrated numerical flow model uses estimated monthly historical stream inflows, surface water diversions, precipitation, land use, and crop acreages, to dynamically calculate crop water demands and pumping requirements. The model allocates contributions from precipitation, soil moisture, and surface water diversions to calculate the groundwater pumping needed to meet the remaining estimated water use.

Remote sensing to assess crop water use is in an initial stage in California, and only a few studies are testing its regional potential. Some local studies have explored the potential of remote sensing technology by comparing estimates of water use in crop production using remote sensing estimates and traditional evapotranspiration methods based on land use, climatic and crop coefficient data (Medellin-Azuara and Howitt 2013; Howes et al. 2012).

System Analysis and Management

California's monitoring system is decentralized among several agencies and is not well equipped to support the operation of the water system under scarcity conditions. The surface monitoring system includes a mixture of real-time, forecast, and historical data. These systems include weather data (precipitation, water content in snow pack, temperature and evapotranspiration), water storage and releases from reservoirs, and water discharge in rivers. Although most monitoring networks were initially developed for flood management, they are only somewhat helpful for assessing water availability and managing water resource systems during scarcity conditions. Streamflow measurement represents a critical gap in California as more than two-thirds of the state's watersheds do not have any streamflow gages. The low resolution and frequency of water diversion data also frustrates attempts to efficiently allocate water during scarcity. Real-time measurement of major surface water diversions is also an important informational gap that may eventually be filled by new measurement and reporting regulations.

Assessment of groundwater availability and use in California has many more gaps than for surface water. Due to the historical lack of regulation and the absence of a state permitting process on groundwater resources, there are limited resources for monitoring groundwater and its use. [57] Most knowledge of groundwater use has been based in indirect estimation.[58] Groundwater monitoring by DWR and USGS provides groundwater levels and groundwater quality data, but this information is incomplete in regions with significant groundwater dependence like the Central Valley (Walton 2015). Groundwater use is even less understood as only urban utilities and a few local irrigation districts have measured use at the parcel level, mostly due to groundwater adjudication processes.

Agencies collecting water-related data in California

	Precipitation	Snow pack	Temperature	Evapotranspiration	Reservoir Levels and Operations	Streamflow	Groundwater Levels
National Weather Service (NWS)	✓	✓	✓	✓			
US Bureau of Reclamation (USBR)					✓		
US Army Corps of Engineers (USACE)	✓	✓			✓		
US Geological Survey (USGS)						✓	✓
Department of Water Resources (DWR)	✓	✓	✓	✓	✓	✓	✓
Power Agencies	✓				✓		
Local Agencies (Urban Utilities or Irrigation Districts)					✓	✓	✓

SOURCES: Authors' compilation.

NOTES: While user categories are assessed from total water withdrawals, the source of water withdrawals—surface and groundwater—is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive.

Federal, state, and local agencies operate and maintain different monitoring networks but have no common comprehensive accounting system. Some datasets are now offered by DWR through centralized online platforms like the California Data Exchange Center (CDEC), Water Data Library (WDL), and the California Statewide Groundwater Elevation Monitoring (CASGEM). There is no centralized statewide model for real-time water accounting to support water management and operations in California. Balance models used in the California Water Plan are not valid for real time or seasonal water management. Because of the complexity of California's water management issues, many types of accounting models are used for water operations at the state, regional, and local levels.

One of the most important models, based on the volume of water managed, is the Water Resources Integrated Modeling System (WRIMS model engine). DWR and USBR developed a model called CalSim 2 (based on the WRIMS modeling engine) to simulate California State Water Project (SWP) and Central Valley Project (CVP) operations. CalSim 2 is now also used for environmental management of the Sacramento-San Joaquin Delta. Diversions of the SWP and CVP from the Delta (annually 5,000 TAF on average) determine the hydrodynamics of the Delta.[59] Beyond the modeling capabilities, the Coordinated Operations Agreement between USBR and DWR is a successful institutional framework between federal and state agencies (USBR 2004).

[57] Until the approval of the Sustainable Groundwater Management Act in 2014, there was not a state regulation of groundwater extraction.

[58] DWR has estimated indirectly groundwater use in the California Water Plans. This is also the main objective of the model C2VSim referred in the previous section.

[59] file:///C:/Users/escriva/Downloads/eScholarship%20UC%20item%202mx392x6.pdf

The C2VSim model (explained above) integrates surface and groundwater flows to estimate water balances in the Central Valley. This model was developed to understand water balances and not for managing water resource systems.

Another interesting example of modeling support for water accounting in California is the Dayflow model. Using river inflows, water exports, rainfall, and estimates of agriculture depletions, this model estimates daily average Delta outflows that are key for understanding the physical, chemical and biological state of the Sacramento-San Joaquin Delta.

Many other models are used locally to assess and manage local water resources. Some examples of groundwater modeling have been done for critical problems of sensitive basins, most of them in Southern California.[60]

Surface-groundwater integration is rarely considered in the management of water resources in California. This trend is shifting due to the importance of groundwater in drought years and the realization of unsustainable groundwater overdraft and its impact on critical fishery habitat reaches. With the Sustainable Groundwater Management Act of 2014, long-term sustainability of aquifers will be required, so conjunctive management will become essential.

The state can forecast water availability and supplies for the major state water projects thanks to a comprehensive monitoring network and modeling capabilities.[61] This is demonstrated in the Drought Operations Plan for the CVP and SWP operations. These monitoring and forecasting capacities are not uniform across the state.

Allocation During Periods of Scarcity

Resource managers must allocate shortages across individual users during times of scarcity, when the supply of water is not sufficient to meet the needs of all water users. There are two major allocation schemes in California, the formal surface water rights scheme administered by the SWRCB and the allocation of water by contract for the SWP and CVP. While SWP and CVP contractors have reductions in allocations almost every year, surface water-right holders administered by SWRCB faced curtailments in water years 2013-2014 and 2014-2015, following nearly 40 years without administrative curtailment of water-right holders (Lund et al. 2014).

Recent administrative surface water curtailments were based on the seniority of water rights. Information collected by the SWRCB on surface water diversions, including historical water uses, provided critical input into the Board's curtailment actions. However, curtailment proceedings face fundamental challenges partly due to the complexity of California's surface water rights system and deficiencies in the resolution and frequency of data on surface water uses.

The SWRCB has temporary authority under the Governor's emergency drought declaration to request additional information from riparian, pre-1914, and post-1914 water-right holders on water diversion and use activity at a more frequent time-step than normally required. Throughout the drought period that began in 2011, the SWRCB has exercised this authority in several watersheds based on agency investigations into problematic diversion and use practices. New measurement requirements for large diverters may require telemetry, or at least hourly recording of diversions.

SWRCB closely monitors hydrological variables that affect water availability, however reliability of supplies are not systematically forecasted. The SWRCB is currently working with researchers at USGS, UC Davis, and other

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[60] As examples: Orange County Water District Groundwater Management Plan or Los Angeles Basin Modeling Summary.
[61] It should be noted that these models resulted in the loss of two annual runs of vulnerable fish species during the current drought (Mount 2015).

research institutions to develop technical modeling tools to support a more efficient and responsive approach to administrative curtailment (Lund et al. 2014).

Another important form of allocation occurs among contract holders on the state's major water export and delivery projects. Because of the many constraints that the Delta imposes on water exports, allocation of water to contractors of the CVP and the SWP are adjusted almost every year.[62] Even in 2011, when a 6.5 million acre-feet record in Delta exports was met, some contractors did not receive full allocation of their project water contracts. As mentioned in the previous section, federal and state agencies have collaborated since 2013 on annual Drought Operations Plans for the CVP and SWP. These publically accessible plans forecast water allocations during the latest drought years depending on the probability of water inflows and current storages for the coming year.

Water-right permit holders may request to modify or change their permit during periods of scarcity to ensure adequate supplies for urgent needs. The Temporary Urgent Change Petition (TUCP) allows any permittee or licensee to request an urgent change to the point of diversion, place of use, or purpose of that use. During the drought that began in 2011, the SWRCB approved several TUCPs that lessened water quality standards to allow the CVP and SWP to divert water for urban and agricultural uses. Between early 2014 and summer of 2015, these TUCPs shifted more than one-million acre-feet of water from instream flows and habitat protection to agricultural and urban use (Hanak et al 2015).

California does not have a state-administered curtailment process for groundwater overdraft, although adjudicated groundwater basins have their own allocation and curtailment rules. Because of the significant legal expenses and long duration of adjudication proceedings, they are relatively rare.

Public Information Provision

Water Rights

The SWRCB has implemented a computer database to track information on water rights in California called eWRIMS. This database contains information on Statements of Water Diversion and Use that have been filed by water diverters, as well as registrations, certificates, and water right permits and licenses that have been issued by the SWRCB and its predecessors. It also has an online web mapping application that displays the spatial location of water rights throughout California. The information from the month is available by the tenth day of the following month.

Lacking any groundwater permitting processes, there are no public platforms for records on groundwater rights or permits. The implementation of SGMA could result in a statewide portal for groundwater records and data.

System Monitoring

The DWR has initiated work on the Water Planning Information Exchange (Water PIE) to develop and publish online information on streamflow, groundwater levels, water quality, and climate information in standard format. It intends to compile information from different sources in one place, such as information from DWR's Water Data Library. The Water Data Library provides interactive maps with information from surface, groundwater, and quality stations around the state with significant time lags.

The California Data Exchange Center (CDEC) provides a centralized database to store, process, and exchange real-time hydrologic information gathered by various cooperators throughout the state. It provides data to different

[62] Some of the major constraints on exports of water from the Delta include risk of levee failures and intensifying conflict over flows required to protect endangered species.

agencies, publishing the information online. River conditions, natural flows, and reservoir levels can be obtained at an hourly time-step, along with real-time precipitation values.

DWR's Groundwater Information Center (GIC) and the California Statewide Groundwater Elevation Monitoring (CASGEM) program provide updated information for groundwater. GIC provides maps and figures of the groundwater situation in multiple wells across the state. The information is uploaded every quarter. CASGEM is a much more collaborative effort, where local parties voluntarily monitor and provide information on groundwater elevations.[63] If local parties (for example, counties) do not volunteer to perform the groundwater monitoring functions, and DWR assumes those functions, then those parties become ineligible for water grants or loans from the state. This information is made available to the public in real-time.

Allocation During Scarcity

When curtailments are required, the SWRCB issues a Notice of Insufficient Water Supply. This notice advises water rights holders that if dry weather conditions persist, the agency will notify them of the requirement to limit or stop diversions of water under their water rights.

Forecasts of surface availability are done annually to identify contract allocations for the SWP and CVP. During the recent drought years, DWR and USBR published annual forecasts on their ability to meet their contractual demands on the SWP and CVP, respectively.

Water Transfers

Water transfer information collected and published by the state is limited, though information that is available is publically accessible on DWR's website. New reporting requirements passed by the Water Board will require riparian and pre-1914 water rights holders to annually report water transfer activity and water consumed through transferred contract water agreements, but not pricing information.

PPIC collected and published water transfers data in *California Water Markets, By the Numbers* (Hanak and Stryjewski 2012). California's progress in the water markets and groundwater banking are reviewed, gathering information from multiple sources including SWRCB, DWR, USBR's Water Acquisitions Program, and CALFED's Environmental Water Account program, among others.

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[63] Note per the governor's EO B-29-15, item #15, local agencies in high and medium basins that do not report data through CASGEM are subject to enforcement by the State Water Board.

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Arizona

Case Study Highlights

- Forty percent of Arizona's water use is from the Colorado River, with almost half diverted directly from the river and the remainder conveyed to distribution systems through the Central Arizona Project. Twenty percent of water supply is from three in-state rivers—the Salt, the Verde and the Gila—and the remaining 40 percent is from groundwater.
- The Groundwater Code passed in 1980 established a framework for identifying groundwater overdraft and creating an innovative groundwater administration scheme with different levels of oversight and enforcement: Active Management Areas (AMAs), Irrigation Non-Expansion Areas (INAs), and the remainder of the state.
- Most water use in Arizona is directly measured or estimated: the Groundwater Code requires groundwater extraction measurements from all large wells in areas where most groundwater is used, and the *Arizona v. California* decree obligates Lower Colorado River water users to monitor and record diversions, water use applications, consumptive use, and return flows in each Lower Basin state.
- Although surface-groundwater interaction is not legally recognized in the administration of water rights, Arizona's effort to use surface water to replenish groundwater basins—surface water coming mainly from Arizona's Colorado River entitlement through the Central Arizona Project—is an explicit example of conjunctive management.

Introduction

Arizona has a dry climate, with very low precipitation throughout most of the state. Average annual precipitation varies from 23 inches in the Flagstaff area, a higher elevation region at the center of the state, to only 3 inches in Yuma at the southwestern corner of the state. Snow falls on the high elevation peaks each winter but is rare in the southern and western lowlands. Temperatures vary significantly across the state and between night and day. The range between the maximum and minimum daytime temperatures can vary by 50-60ºF. High temperatures are common in the summer months, especially at lower elevations. In the southern part of the state, temperatures are even higher, occasionally exceeding 125ºF in the desert area.

Arizona's has a wide range of growing seasons. In some areas to the north and east, the growing season is less than three months, while lower desert valleys sometimes go several years without freezes. Of the nearly one million acres of land devoted to agriculture, more than three-fourths lies between Maricopa, Pinal, and Yuma counties, all situated in the central and southern plains. Hay and alfalfa are the largest crops. However, dairy products such as milk provide larger revenues, exceeding $1 billion in 2014.

In 2015, Arizona's total water supply was 7 million acre-feet. Of this, 40 percent came from the Colorado River—almost half through on-river diversions and the remainder through the Central Arizona Project—20 percent from in-state rivers, and the remaining 40 percent from groundwater (Arizona Department of Water Resources 2015). The most important in-state rivers are the Little Colorado, Gila, Salt, and Verde. Surface water in these rivers is governed by the prior appropriation doctrine under the 1919 Public Water Code. However, the adjudication of surface water rights in most rivers is not yet completed and has been an issue of major concern. The exception is the Salt River Project's surface water rights, established by decree (the Salt and Verde Rivers). Water rights must be put to beneficial use and waste of water is prohibited, so if the water is not used, it must flow to the next senior appropriator. Non-diversionary uses can also be given a water right, known as “instream flow rights” (Arizona Department of Water Resources 2010a).

Recognizing existing concerns about groundwater overdraft and the potential impact of rapid urbanization and development, the Groundwater Code was passed in 1980. It established a regulatory and programmatic framework for managing groundwater overdraft, creating management areas focused on achieving safe-yield, developing recharge programs, and implementing the Assured and Adequate Water Supply program (AAWS) to limit municipal development to areas with renewable water resources.

Principal demographic, economic, and water-related indicators in Arizona

Population (in 2010):	6.39 million
GDP (in 2010):	$246 billion
Agriculture Value Added:	1.25 % of GDP
Annual Precipitation:	12.31 inches
Total Water Withdrawals:	6,820 TAF
Urban Use:	22%
Agricultural Use:	75%
Other Uses:	3%
Surface Water:	60%
Groundwater:	40%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS’s water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, the source of water withdrawals —surface and groundwater—is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both “Agriculture, forestry, fishing and hunting” and “Food and beverage and tobacco products manufacturing” industries.

Regulatory overview

Institutions

Oversight agencies

The Arizona Department of Water Resource (ADWR) is the primary state oversight agency for administering surface and groundwater rights, developing technical hydrological studies, and statewide water planning. Most importantly, the ADWR is primarily responsible for administering the landmark Groundwater Management Code. The Code established three levels of water management corresponding to different levels of water resource issue severity: the lowest level of management includes general provisions that apply statewide, the next level applies to Irrigation Non-Expansion Areas (INAs), and the highest level of management is applied to Active Management Areas (AMAs) (Arizona Department of Water Resources n.d.).

AMAs are hydrologic basins or sub-basins that are, or are at risk of, overdrafted groundwater. AMAs are management districts created and managed directly by the ADWR, with input from local groundwater user advisory committees. About 80 percent of the state’s population is within one of the five AMAs (Arizona Department of Water Resources n.d.). Management resources for AMAs have been severely cut back recently. Within AMAs there are mandatory conservation requirements for all groundwater use sectors, and there are withdrawal fees associated with annual pumpage. With some limited exceptions, no new agriculture is allowed in

AMAs. While there used to be one director with 5-10 staff for each AMA in the 1990s, there is now only one director for all five AMAs with only four staff due to recent budget shortfalls.

INAs are hydrologic basins in which the growth of irrigated agriculture is constrained by law. Irrigation is restricted to lands that were irrigated during the five-year period preceding designation of the INAs in the 1980s. INAs are management districts created and managed directly by the ADWR. Arizona has three INAs: Douglas, Joseph City, and Harquahala. Groundwater pumping for major agricultural irrigators (irrigating more than 10 acres) and non-irrigators (more than 10 AF/year) in INAs must be measured and reported to the ADWR annually (Arizona Department of Water Resources 2010a).

Arizona's court system is also involved in water rights throughout the state. There are currently two major general stream adjudications in progress on the Gila and Little Colorado rivers. Adjudications are judicial proceedings for determining the extent and priority of surface water rights.

Water supply operations agencies

The US Bureau of Reclamation (USBR) played a major role in constructing the Central Arizona Project (CAP) and other water supply storage and conveyance systems in Arizona. However, many of the project's operation responsibilities now belong to local conservation districts, irrigation districts, or other regional or local water supply entities.

Central Arizona Water Conservation District (CAWCD), a municipal corporation, manages and operates CAP. CAP transports about half of Arizona's Colorado River water entitlement of 2.8 million acre-feet per year to central Arizona, including the Phoenix and Tucson metropolitan areas (Arizona Department of Water Resources 2010a). CAP's physical network includes 336 miles of canals, control structures, and 14 pumping plants to regulate the flow of water. CAP is operated from a 24-hour control center in north Phoenix.

The Arizona Water Banking Authority (AWBA) is a state agency that protects Arizona's Colorado River interests, promotes use of CAP water, and supports interstate water banking with California and Nevada. AWBA stores or "banks" unused Colorado River water to be used in times of shortage to secure water supplies for Arizona. Colorado River water stored by AWBA provides a reserve of water to communities dependent on the CAP during times of drought on the Colorado River, to assist Colorado River communities during times of shortage by providing interstate water exchange mechanisms, to replenish depleted aquifers with CAP water to meet water management goals, and to provide a pool of water for use in Indian water rights settlements (Arizona Department of Water Resources 2010a). AWBA pays for the delivery of Colorado River water through the CAP every year, which it stores underground through direct recharge or delivers to irrigators as an alternative to groundwater pumping. The agency accumulates credit by storing surplus Colorado River water, which can be redeemed in the future when Arizona or a neighboring state needs access to backup supplies.

The Arizona Water Banking Authority (AWBA) was established to utilize the unused portion of Arizona's annual Colorado River entitlement in order to meet multiple water management objectives in Arizona including: (1) storing water to protect CAP and certain Colorado River municipal and industrial water users against future shortages, (2) assisting the state in meeting tribal water rights claims and (3) providing groundwater management benefits. AWBA accomplishes its mission by storing unused CAP water in underground aquifers through recharge projects and by purchasing credits already stored. Through these methods, water credits become available for use during shortages. In such an event, AWBA will coordinate with other organizations to recover those water credits for use by the intended beneficiaries. AWBA also assists Nevada through interstate water banking.

The Central Arizona Groundwater Replenishment District (CAGRD) is a subdivision of the CAWCD. CAGRD is the groundwater replenishment authority for Phoenix, Pinal, and Tucson AMAs. It was created to facilitate the implementation of the Assured Water Supply Rules; developers can use membership in the CAGRD to demonstrate an assured water supply, discussed in detail later in this report. The replenishment district recharges groundwater with excess CAP water and potentially other renewable water supplies. This is a membership-based organization that creates a mechanism for developers and water providers to develop local groundwater supplies while paying for groundwater recharge as operated by the replenishment district.

The Salt River Project (SRP) is a major water supply and power generation project in central Arizona consisting of six reservoirs, wells, canals, and irrigation laterals. The SRP delivers about 800,000 acre-feet of water annually. The project is operated and managed by a private corporation called the Salt River Valley Water Users' Association. The project was previously co-managed and operated with a political subdivision of the state of Arizona called the Salt River Project Agricultural Improvement and Power District.

Arizona also has irrigation districts, community water systems (municipal water systems), and multiple small local retail water distribution entities.

Funding

Large water supply projects in Arizona were historically funded by the Federal government (Arizona Department of Water Resources 2014). Management of the water itself and the development of a water accounting system are financed by the state.

The total ADWR state appropriation for FY2015-2016 is $15,159,400. Most of the budget goes to operational costs, while 13 percent ($1,983,200) is destined for the AAWS administration, and 8 percent ($1,251,800) is destined for adjudication support, including the establishment of water monitoring technology. Almost 3 percent ($409,400) is allocated to automated groundwater monitoring, a 7 percent ($408,300) to the conservation and drought program, and less than 2 percent ($237,400) for the Water Banking Fund (Arizona Department of Water Resources 2015).

Withdrawal fees are used to fund the state's conservation and augmentation programs within the active management areas, including some Arizona Water Banking activities. Failure to file timely the annual use reports results in an assessment of late penalties and filing fees, and collection of unpaid groundwater fees. ADWR also has responsibility for dam safety and investigates issues such as compliance with notice of intent to drill wells, unpermitted recharge/dewatering, failure to file annual water withdrawal and use reports, and compliance with conservation limits (Arizona Department of Water Resources 2010b).

Legal Framework

Water rights

Arizona is a prior appropriation state in terms of rights to surface water resources. Upon enactment of the Arizona surface water code in June 1919, individuals seeking new appropriations of surface water were required to apply for and obtain a permit from ADWR. Beneficial uses include domestic, municipal, irrigation, stock watering, hydropower, recreation, wildlife (non-diversionary uses of surface water), non-recoverable water storage, and mining uses (Arizona Department of Water Resources 2010a). Waste of water is prohibited. If allocated water is not used by a senior appropriator, it must be allowed to flow to the next senior appropriator.

ADWR administers the surface water permit system. It issues surface water permits for beneficial uses at a specific location and for a specific amount of water. Surface water rights for municipal, domestic, and irrigation may be transferred to a new location but only pursuant to statutory procedures.

Apart from the surface right permitting system, there is also a judicial process for determining the nature, extent, and relative priority of rights to use water in a river system or other source. In 2010, there were two ongoing general adjudications, one in the Gila River watershed and another in the Little Colorado River watershed. Claimants in these adjudication cases number in the tens of thousands. The final determination of a court is referred to as a "final decree of water rights" (Arizona Department of Water Resources 2010a). ADWR often provides technical expertise on local hydrology and some administrative support to courts engaged in adjudication.

Several long-standing decrees govern surface water rights to various surface water sources including the Kent (1910), Benson-Allison (1917), Norviel (1914-1923), Concho, and Globe Equity decrees. Federal reserved right claims also have been filed in recent adjudications under the Winters Doctrine.

The Groundwater Code regulates the withdrawal, use and transportation of groundwater. The Code has three primary goals: 1) control groundwater overdraft in certain parts of the state, 2) provide means to allocate groundwater to meet the needs of the state, and 3) augment groundwater supplies through development of renewable water supplies. ADWR is the principal entity in charge of administering the Code. As stated above, the Code has three tiers of groundwater management: 1) statewide provisions such as well-drilling requirements and restrictions on groundwater transportation, 2) INAs, and 3) AMAs, where groundwater overdraft historically has been the most severe. Groundwater pumpers within AMAs are required to obtain rights or permits to legally use groundwater, with the exception of domestic non-irrigation wells with a maximum pump capacity of 35 gallons per minute (exempt wells). Under the Code, all groundwater wells (including exempt wells) must be registered with the ADWR. Three broad types of rights or permits exist for individuals who withdraw water from non-exempt wells in AMAs: grandfathered rights, service area rights, and withdrawal permits.

There are three types of grandfathered rights (derived from past individual water use):

1) Irrigation Grandfathered Rights are granted to individuals who irrigated over 2 acres of land with groundwater between 1975 and 1980. These cannot be sold separately from the associated land. Irrigation grandfathered rights specify the amount of groundwater that may be used according to a formula published in each AMA management plan. A Best Management Practices (BMP) conservation program is also available, which focuses efforts on implementation of efficient on-farm irrigation practices.

2) Type 1 Non-Irrigation Grandfathered Rights are tied to land permanently retired from farming and converted to a non-irrigation use like industrial or domestic. The maximum amount of groundwater that may be pumped is three acre-feet per acre per year.

3) Type 2 Non-Irrigation Grandfathered Rights are used to pump groundwater but only for non-irrigation purposes. Type 2 rights are based on historical groundwater pumping for non-irrigation purposes (industry, livestock watering, and golf courses) and amount to the maximum volume of groundwater withdrawn in a single year between 1975 and 1980. Type 2 rights can be sold (wholly) or leased (wholly or partially) separately from the land or well.

Service area rights are another category of water right for AMAs. These rights authorize cities, towns, private water companies, and irrigation districts to withdraw groundwater from AMA areas to serve their retail customers. These rights are allowed to expand over time but are subject to the Assured Water Supply requirements.[64]

Finally, groundwater withdrawal permits are granted in AMAs. Individual, limited-duration permits for groundwater use are provided to eight types of non-irrigation uses within AMAs that are not eligible for service area rights. Under specific conditions, these permits can be issued for new industrial groundwater extraction that is not subject to Assured Water Supply rules.

Groundwater rights are really only administered within AMAs and INAs. Outside of AMAs, there is no restriction on groundwater withdrawals as long as it is put to reasonable and beneficial use. The only exception is within three areas designated as INAs where irrigation of new agricultural lands is restricted to prevent further groundwater declines.

Long-term sustainability is considered in surface and groundwater permitting. The Assured and Adequate Water Supply (AAWS) rules passed in 1995 require developers of new subdivisions to acquire certificates from ADWR certifying that 1) water is sufficient in quantity and quality to sustain the proposed development for 100 years, 2) the proposed use is consistent with AMA management objectives related to conservation and safe-yield, and 3) the developer has sufficient financial capacity to construct water treatment and delivery systems to serve the proposed development (Arizona Department of Water Resources n.d.).

Water trading

Arizona's Water Banking Authority operates a large-scale conjunctive water storage bank primarily for Colorado River water delivered through the CAP. Beside the AWBA, Arizona also allows trades between individual water-right holders. Water exchanges are authorized by the 1992 Water Exchange Act, which defines water exchange as "a trade between one or more persons, or between one or more persons and one or more Indian communities, of any water for any other water, if each party has a right or claim to use the water it gives in trade" (Arizona Department of Water Resources 2010a). Generally, Arizona's water transfer law does not distinguish between temporary and permanent water transfer agreements. As a result, Arizona lacks an expedited review process for short-term transfers (Szeptycki et al. 2015). Every exchange is subject to the "giver rule," which requires that a person who receives water pursuant to an exchange may: 1) use the water without holding a right to that water and 2) use the water only in the same manner in which the person who originally had the water right used the water. According to the ADWR, most water exchanges occur in the AMAs (the Phoenix AMA in particular).

Arizona has statutes governing the transportation of groundwater within and between basins to ensure groundwater is not depleted in one groundwater basin to benefit another. These statues are generally designed to protect hydrologically distinct groundwater supplies and rural economies (Arizona Department of Water Resources 2014). Groundwater cannot be transported between groundwater basins outside of the AMAs or from a groundwater basin outside an AMA into an AMA except for certain transfers specified in statute (see Arizona Revised Statutes 45-544 and 45-551 through 45-555). Groundwater can legally be transported within a sub-basin or within a basin that has not yet been subdivided by the state, without payment of damages (see Arizona Revised Statutes 45-541 and 45-544). Groundwater transportation between sub-basins in the same basin is subject to the payment of damages, with certain exceptions within AMAs (see Arizona Revised Statues 45-542 through 45-545) (Arizona Department of Water Resources 2010a).

[64] This description of groundwater rights within AMAs is derived from Arizona Department of Water Resources n.d.

Legal treatment of environmental water use

Non-diversionary appropriation of surface water for recreation and wildlife is recognized as a beneficial use in Arizona and referred to as instream flow rights. Instream flow rights in Arizona can be created as 1) transfers of existing water rights to instream flow rights or 2) appropriation of new water rights for instream flows.

Some water rights may be severed from the land and transferred for other uses. Water transfers for instream flow rights may be obtained by any private party or the federal government. However, the priority of the original water right is only preserved when the state or a political subdivision of the state is the purchaser or donor of the transfer. Another limiting provision is the requirement that the state agency or subdivision of the state receiving the water right must hold fee title to the riparian corridor along the stream segment that will benefit from the transfer. As mentioned above, since Arizona's water transfer laws do not differentiate transfers based on transfer duration, there is no expedited review for short-term transfers.

Instream flow rights are administered by the Surface Water Division of the ADWR. In 2014, Arizona had 29 certified instream flow rights, one issued instream flow permit, and 71 pending instream flow appropriation applications. Permits for surface water appropriations for instream flows are issued by the ADWR for a specific location and amount of water. Instream flow rights are often junior to the bulk of surface water appropriators. Regional water resource experts could not recall a situation in which the state received a call to protect an instream water right. The Permitting Unit of the Surface Water Division maintains a database that tracks the status of instream flow applications.[65]

Significantly, there are no provisions of the Groundwater Management Act that explicitly protect groundwater for environmental purposes. This is significant since many riparian areas depend on shallow groundwater or groundwater outflows to support surface flows.

Prioritization of particular uses

While Arizona is principally a prior appropriation state, with priority determined by seniority, Arizona statutes also define a secondary standard on the "relative value of uses" during times when water supplies are scarce and unable to satisfy all demands. In order of priority, the list includes domestic and municipal uses, irrigation and stock watering, power and mining uses, recreation and wildlife including fish, and non-recoverable water storage.

Ability to Account for Water

Water Use

The Groundwater Code requires annual reporting of surface and groundwater use from large wells by municipal, agricultural, and industrial users, by beneficial use, and by county, watershed, or its specific sources (point of diversion and place of use) within AMAs and INAs.[66] Municipal, industrial and agricultural users regulated by the Groundwater Code of 1980 are required to be metered (Western States Water Council 2014).

Municipal providers report water use in acre-feet for all sources, housing units delivered to, deliveries by customer type, and reclaimed, generated, discharged, and delivered water (Western States Water Council 2014). Agricultural users in AMAs must report the amount of water use in acre-feet from all sources, but they do not have to report the acres cropped or the crop type. While the number of legally irrigable acres is tracked in AMAs through the groundwater rights system, ADWR does not directly receive information on how many acres are actually irrigated each year. Crop surveys are conducted by the USGS that periodically provide information on

[65] Source material used in writing this paragraph and the two preceding paragraphs is Szeptycki et al. 2015.
[66] Some exemptions apply.

cropped acres. Industrial users report the amount of water used in acre-feet from all sources as well as related information required by specific conservation programs.

Most annual reporting within AMAs is done online. Reports must be filed with the ADWR data management team by March 31. If users do not file reports on time, they must pay a $25 penalty for filing late or part of a month that the report is late up to $150. In addition to penalties for late filing, ADWR may charge users who withdrew groundwater but did not pay the fee on time (or the proper fee) 10 percent of the unpaid fee per month or part of a month that the fees are delinquent, up to a maximum of 60 percent of the unpaid balance. According to some regional water management experts, it takes a great effort to get responses from all rights holders. Quality control on annual reporting, including manual data review, is completed by fall. Self-reported measurement via totalizing meter or other method is required to be within 10% accuracy.

Within an INA, each person withdrawing groundwater from a non-exempt well must file an annual water use report with the ADWR. The Annual Water Withdrawal and Use Report for users in INAs require users to calculate and report annual groundwater withdrawals in acre-feet for large irrigation and non-irrigation uses. Irrigation acreage also must be reported annually through the same reporting form.

Statewide, the amount of water allocated to surface water rights or claims is tracked by beneficial use using an Oracle enterprise server. ADWR may use this database to compare actual reported surface and groundwater diversions to individual water right allocations. Allocated water can be aggregated to county, watershed, or legal land description (place of use and point of diversion).

ADWR maintains spatial data records for every groundwater well in the state in two databases. The Wells 55 Registry locates wells to the center of a 10-acre parcel. The Groundwater Site Inventory (GWSI) is the state's principal water level database: it allows users to view the latitude and longitude coordinates of wells.

Community water systems outside of AMAs and INAs are required to report annual surface and groundwater use to ADWR. ADWR also contracts with USGS to estimate annual groundwater use data for agricultural, mining, drainage, and electrical power generation uses outside of AMAs. Domestic well pumping outside of AMAs is estimated by ADWR for planning purposes (Western States Water Council 2014). ADWR does not track surface water usage outside of AMAs and Community Water Systems (outside of AMAs).

As required in the Article V of the *Arizona v. California* decree, ADWR monitors and records diversions, water uses, consumptive use, and return flows in the Lower Colorado River in collaboration with the USBR. This is reflected in the annual Water Accounting Report of the Lower Colorado River.

System Analysis and Management

Because the surface water operations for the Colorado River are managed by the USBR and the remaining surface sources are mostly managed by local entities, the state of Arizona has focused its efforts on managing at-risk groundwater resources.

Surface water monitoring has been delegated to the USGS. Streamflow, gage height, reservoir storage data, precipitation, and water quality information comes from USGS through the NWIS-Web for the Arizona Water Science Center. It provides information on 230 sites across the state.

Groundwater is monitored extensively, though budget cuts have constrained some important data collection efforts. Historically, ADWR conducted "basin sweeps" in which staff collected 3,000-4,000 water level measurements annually across an AMA. This practice has been reduced to about 300-500 water level measurements per AMA per year, rotating AMAs on a five year cycle. ADWR has a network of 1,800 "index" wells for recording manual water-level measurements each year (including private individuals, water companies, cities, towns, business, irrigation districts that give ADWR permission to read wells). ADWR also has 120 automated water-level monitoring wells that have pressure transducers, data loggers, and radio telemetry systems. These automated wells are owned by third parties that agree to let ADWR install monitoring equipment.

Groundwater subsidence is also closely measured in the Phoenix and Pinal AMAs, along with a larger statewide subsidence monitoring program supported by interferometry synthetic aperture radar (InSar) technology. ADWR monitors changes in groundwater mass in the Phoenix and Pinal AMAs using manual micro-gravity measurements. Groundwater mass changes are estimated at a regional level by ADWR and used as an input for determining water budgets in these AMAs. ADWR also has a remote sensing program that uses radar technology to detect aquifer subsidence. This program funded by a joint cooperation between federal, state, county and local agencies and water providers. This collaboration has provided more than $160,000 for funding the data collection (Arizona Department of Water Resources 2015). Data produced by InSar is used for local, regional, and state level subsidence monitoring and mitigation programs.

Limited surface water modeling is done at the state level. ADWR modeling resources are primarily devoted to groundwater modeling, especially within AMAs and INAs. AMA-specific water budgets are created for management and planning. These balancing exercises involve collaboration between the Hydrological Modeling Division and the Data Management Division. The Hydrological Modeling Division uses streamflow, climate, precipitation, and geology to develop MODFLOW physical hydrology models for each AMA to simulate surface and groundwater flows. The Data Management Division uses annual reporting data to develop estimates of legal water uses, respecting complicated accounting procedures to differentiate between different types of water used in AMAs. The two groups then compile their estimates, which are incorporated into an AMA Assessment. The AMA Assessment is created through a more detailed water accounting system called Master Data Templates.

The Master Data Templates (used for all AMA Assessments) are a collection of demand, supply, artificial and natural recharge, and population data for 1985 to 2006. ADWR created the Master Data Template format to ensure consistency and standardization in water budget evaluation both between AMAs and over a long time horizon. These templates are used to evaluate water balance, assess overdraft, track historical demand and supply trends, and predict these trends into the future (most recently through 2025). They are updated annually by ADWR with the most recent annual reporting information. As mentioned above, the numbers for demand, supply and artificial recharge come from information submitted with the Annual Reports. Natural hydrologic components like natural recharge and groundwater inflow and outflow are generated by AMA's Groundwater Model (run by the Hydrologic Modeling Division of ADWR) specifically for each AMA. Master Data Templates also are summarized and turned into Summary Budgets for each AMA.

Arizona recently transitioned into the Fourth Management Plan (4MP), a planning phase in which management plans and programs are developed by the ADWR for each AMA to address impediments towards reaching individual AMA management goals. 4MPs will be developed for each AMA over the next few years. Significantly, the 4MP was supposed to be promulgated by 2008 for each of the five AMAs and adopted in 2010; the significant reduction in staff in the AMAs means that all of these plans are significantly behind schedule and only one AMA (Prescott) has a promulgated plan. Management Plans include conservation requirements and augmentation efforts to move toward the statutory management goals (which differ slightly from one AMA to another). Early in the implementation of the Groundwater Management Act these Management Plans included state of the art conservation requirements for all sectors as well as current and future supply/demand calculations.

Because there is limited surface modeling in the state, there is no recognized surface-groundwater interaction in modeling, but Arizona's efforts to use surface water to replenish the groundwater basins—surface water coming mainly from the Colorado River entitlement through the Central Arizona Project—is an explicit example of conjunctive management.

Allocation During Periods of Scarcity

Despite 16 years of drought on the Colorado River, Arizona has avoided serious water crisis. This is in part due to the management of the CAP (which introduced a new, renewable water supply to the central part of the state between 1985 and 1992) and the state's direct recharge program for surplus Colorado River water, effective regulation of groundwater pumping through the Groundwater Code, and conservation programs for agricultural, municipal, and industrial users. Planned cuts to the CAP and other lower priority Colorado River water users in Arizona may be required if drought continues in the Colorado River basin.

Arizona has a robust drought-monitoring framework consisting of an Arizona Drought Preparedness Plan and three groups that coordinate implementation of the plan—the State Drought Monitoring Technical Committee, local drought impact groups, and the Governor's Drought Interagency Coordinating Group. Water use reporting and drought planning requirements for water providers located outside of the state's AMAs also are administered through the ADWR's Drought Program.

The State Drought Monitoring Technical Committee (MTC) is principally responsible for collecting, analyzing, and presenting information about Arizona's drought status. ADWR and MTC coordinate to provide accessible drought information for resource managers, state decision-makers and the public. MTC confers weekly with the US Drought Monitor to advise them on current conditions in Arizona, including precipitation and streamflow data and impacts data. Every week, Arizona's Drought Status webpage automatically updates with the latest US Drought Monitor map of Arizona. MTC publishes a monthly short-term drought status update based on US Drought Monitor's map for the past four weeks. MTC also prepares a quarterly report indicating long-term drought status maps and a summary report. This quarterly report includes 24-, 36-, and 48-month precipitation and streamflow percentiles for major Arizona watersheds. These reports also include attributes like vegetation indices, snowpack, temperature, reservoir levels, and county-scale drought impact information. The statewide long-term drought status map is determined by comparing the precipitation and streamflow percentiles for the past 24, 36, and 48 months to a 40-year historical record.

Surface water curtailments are handled within decreed areas (which hold most of the surface water in the state) by entities assigned oversight responsibilities within the decree. There is no state entity that curtails surface water right holders; this is done by local oversight entities.

Experts see the Groundwater Management Act of 1980 as providing long term drought resilience benefits, in terms of limiting expansion of agricultural development, preserving irrigation water for future use and growth, and requiring municipal, industries, and farmers to adopt mandatory water conservation requirements in AMAs (Ferris 2015). However, it should be noted that its provisions are focused primarily on long-term water demand and supply imbalances, not on drought per se. There are no official discussions of the implications of climate change on the ability of the AMAs to meet or maintain their water management goals.

Public Information Provision

Water Rights

ADWR has a public notice watershed subscription service for sending summary information on applications processed by the Surface Water Rights Unit. This twice-monthly subscription service provides an opportunity for third party protests from those affected by new surface water appropriations.

All physical documentation is uploaded to the ADWR's Online Files platform. Here, AAWS files, community water system files, groundwater authority files, statement of claimant/adjudication files, surface water documents, well files, recharge and recovery files can be accessed. The information is uploaded weekly or more frequently.

The ADWR GIS Data has mapped information on adjudication filings, cadastral locations, surface water topography, groundwater saving facility (GSF) permits, statement of claimants (SOC), active surface water fillings, active surface water locations, surface watersheds, and wells contained in the well registry and GWSI (Groundwater Site Inventory) databases. The map is updated daily and the information can be downloaded, either in Excel or as shapefiles.

The well registry found on the ADWR GIS Data platform combines all three groundwater well data sets of the state: the Well 55 Registry, which contains all registered wells; the GWSI, with well locations, construction, and water level measurements for wells that have been located and sampled in the field by USGS and ADWR; and Wells 35 Registry, which became inactive in 1980.

The Well 55 Registry includes all well data submitted by well owners and/or well drillers. Wells can be identified by well registry number, owner name, or location (township/range, cadastral, basin, or sub-basin). A map interface displays wells and their attributes. The information provided includes the well type, well depth, coordinates, casing depth and diameter, water level, pump capacity, and whether or not it has pump data available. The data on pumping can be downloaded. Most pumping records can be found to have up to a two-year lag.

The GWSI provides information on water levels updated monthly. Wells can be searched by site ID, local ID, registration number, basin, sub-basin, township and range or USGS topographic quadrant. Also, an interactive map can be displayed to show all well records. The results include data on depth-to-water (DTW) and water level, and information on the well depth, case diameter, water use and drill date.

The Assured and Adequate Water Supply interactive map provides data related to existing and approved demand volumes. It provides information on water providers, certificates of convenience and necessity, registered wells with pumping or recovery data and recharge facilities. Data are uploaded daily. Data are mostly related to groundwater storage levels and groundwater pumping and are less comprehensive on surface water use.

System Monitoring

Information from the surface monitoring system can be found at the USGS NWIS-Arizona Water Science Center. Information from active monitoring stations is also published for each AMA. Monitoring data compiled by ADWR includes data from streamflow stations, flood alert equipment, reservoirs, and runoff contours existing for each AMA.

Also, surface watershed information is mapped through the ADWR GIS Data. The map is updated daily and provides information about watershed boundaries. The information can be downloaded, either in Excel format or in shapefiles.

For detailed climatic real-time information, the Arizona Meteorological Network (AZMET) provides hourly information on different variables of interest. It is not statewide, but it has a network of 27 stations located throughout the southern half of the state in urban and agricultural areas (Russel n.d.). Information about air temperature, relative humidity, vapor pressure deficit, solar radiation, precipitation, soil temperature (2 and 4 inch depths), wind speed, wind direction, wind gust, and reference evapotranspiration can be found through the platform. It also provides a monthly summary report. AZMET is a service provided by the University of Arizona.

A Statewide Hydrologic Monitoring Report provides data and analysis of Arizona’s groundwater conditions over the last two decades. However, the most recent report available dates from 2012 (Corkhill 2012). For each basin, groundwater modelling reports also can be found. The most recent groundwater modeling report was updated in 2014 for the Pinal AMA region.

Allocation During Scarcity

Arizona is undertaking general stream adjudications for both the Gila River and the Little Colorado River systems but these have been ongoing for decades. Information on these general stream adjudications can be accessed online through the Arizona court system website. This website hosts public copies of orders of the Superior Court and the Special Master, a review of recent court proceedings and events, and a calendar of future proceedings and filing deadlines, as well as other general information about stream adjudications. The Central Arizona Project has a customer portal designed to allow CAP's water customers to quickly and easily verify administrative and operational contact information. Also, specific documents pertinent to water scheduling and delivery are available to view and download 24 hours a day, seven days a week.

Water Transfers

Summary information on transfers is also included in the ADWR Public Notice Watershed Subscription Service. The information is updated and sent twice a month. Again, this is done to provide the opportunity for public protest for those who feel affected by the water right change.

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Colorado

Highlights

- Colorado has a complex system of water rights that integrates surface and groundwater administration and encompasses several other types of groundwater rights. Its commitment to conjunctive surface and groundwater management is reflected in the integrated modeling and accounting efforts of the Colorado Division of Water Resources.
- Colorado is the source of several major western rivers and is therefore involved in a number of interstate compacts and an international treaty. Maintaining legal agreements is a major driver for Colorado's precise accounting of water inflows (mostly from precipitation) and outflows (such as returns to the atmosphere and surface and groundwater flows to other states and Mexico).
- Day-to-day management of water allocations is conducted through local water commissioners, who can effectively balance state regulatory duties against their role as trusted members of the community. This effective example of transparent local control makes Colorado's water curtailment process swift, effective, and relatively uncontroversial.
- The state has a centralized and integrated water accounting system with a monitoring network, a modeling platform with different tools, and an online data exchange. These integrated management tools can collect and process most legal and physical variables for effective water management. This system provides an excellent accounting tool for each basin in the state.

Introduction

Colorado has a semi-arid climate, characterized by low-humidity summers and precipitation mostly during winter and spring. With an average altitude of about 6,800 feet above sea level, Colorado is the highest US State. It has 53 mountains taller than 14,000 feet in the Rocky Mountain range. As a result, wide climatic variations occur within short distances and short time periods. The state is subject to less predictable weather variations, including rapid temperature changes and weather events such as occasional spring blizzards and summer thunderstorms.

Colorado's population is concentrated in the region east of the Rocky Mountains. Multiple intra-state diversions have been constructed to transport water from western areas, including the Colorado River basin, to the urbanized eastern part of the state. Interstate conflict over the Colorado River led to the creation of the Colorado River Compact in 1921 between seven basin states and the federal government. Other important surface flows are the South Platte River to the northeast and the Arkansas River to the southeast.[67]

Agriculture is the largest water user, accounting for 89% of all withdrawals, even though it represents a small percentage of the state's GDP.

Colorado regulates its surface water according to the prior appropriation doctrine. Groundwater rights are required by the Colorado Groundwater Law of 1957, as a prerequisite to drilling a new well.

The water rights system in Colorado primarily resides in the judicial system. Colorado's system of water rights is founded on the prior appropriation system. The Act of 1969 facilitated administration of water rights by establishing clear procedures for confirming water rights and unifying surface water and tributary groundwater.

[67] Unless otherwise stated, the source material for this paragraph and the one preceding it is Doesken et al. 2003.

Colorado places a special designation on groundwater usage that is not hydrologically connected to decreed surface water rights. Such designated basins are on the Front Range of the Colorado Rocky Mountains and in eastern Colorado. Groundwater rights are administered collaboratively with the Colorado Ground Water Commission in these areas (Colorado Division of Water Resources 2012).

Principal demographic, economic and water-related indicators in Colorado

Population (in 2010):	5.03 millions
GDP (in 2010):	$253 billion
Agriculture Value Added:	2.21 % of GDP
Annual Precipitation:	18.03 inches
Total Water Withdrawals:	12,300 TAF
Urban Use:	9%
Agricultural Use:	89%
Thermoelectric Use:	1%
Other Uses:	1%
Surface Water:	86%
Groundwater:	14%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, the source of water withdrawals—surface and groundwater—is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight agencies

Colorado's current water oversight framework blends state judicial duties with administrative and management responsibilities at the river-basin scale. The Water Right Determination and Administration Act of 1969 divided the state into seven water divisions according to major river basin boundaries. Each division has a water judge (appointed by Colorado's Supreme Court), a water referee (appointed by the water judge), a water clerk (assigned by the district court), and a division engineer (appointed by the State Engineer). Consolidating these functions at the basin-scale allowed the state to effectively adjudicate water rights decisions on a continuous basis.

Colorado's principal administrative agent is the Division of Water Resources (CDWR), within Colorado's Department of Natural Resources (DNR). CDWR (also known as the State Engineer's Office) administers all surface and groundwater rights in the state. CDWR also evaluates groundwater well permits, inspects dams and wells, monitors streamflows and water use, and represents Colorado in interstate water compact proceedings (Colorado Division of Water Resources 2012).

Daily water rights administration is executed by field offices of the CDWR, known as Division Engineer's Offices. The seven Divisions align with the state's major river basins. Each Division is managed by a Division Engineer, who in turn manages local water commissioners. Water commissioners monitor diversion structures and streams for immediate administration of water rights and gather data for use in water planning and decision-making systems. Water commissioners also execute curtailments (or "calls") to ensure the proper functioning of prior appropriation water rights (Colorado Water Conservation Board 2015).

Every new groundwater well must obtain a permit from the CDWR. CDWR staff also evaluates the water quantity available to appropriate and assess potential injuries to other existing water rights according to statutory guidelines for over 10,000 applications per year (Colorado Division of Water Resources 2012). In designated basins—areas in the eastern plains with no interconnection to surface water—groundwater is regulated by the Colorado Ground Water Commission. Water courts do not have regulatory authority in these areas.

CDWR also collects, manages, and distributes water information data and records. The statewide satellite-linked monitoring system consolidates water information collected by telemetry-enabled measuring devices. Professional engineers and geologists perform analytical tasks such as forecasting streamflows, determining diversion requirements, investigating stream transit losses, establishing evaporation losses, and calculating historic use and current conditions (Colorado Division of Water Resources 2012). CDWR maintains the Decision Support System (CDSS) which processes information on streamflows, diversions, climate, water rights, call records, well permits, aquifer properties and groundwater levels through simulation and decision support models (Colorado Water Conservation Board 2015 2-10).

While CDWR assumes the state-level role of water rights administration and oversight, the Colorado Water Conservation Board (CWCB) is primarily responsible for managing the state's instream flow and natural lake level program, along with other programs. The CWCB has exclusive authority to appropriate and acquire waters in natural streams and lakes to preserve the natural environment to a reasonable degree. Their programs support cold and warm water fisheries, waterfowl habitat, riparian vegetation, and habitat for threatened or endangered fish. CWCB's other responsibilities include distributing grant funding for local water conservation projects, watershed protection, stream restoration, and providing technical support for drought planning, flood planning, and water supply planning among others. CWCB re-displays information on instream flow administrative calls as collected by the CDWR.

Streams arising within Colorado's borders are vital to the economies of 18 other states and Mexico. As a source of several major western rivers—the Colorado, the Rio Grande, and the Arkansas among others—the state is directly involved in one international treaty, two US Supreme Court decrees, one interstate agreement, and nine interstate compacts. While the compacts to which Colorado is a signatory are restrictive, they reduce the potential for more damaging court decisions. CDWR is responsible for representing the state in the negotiations and for implementing the terms of these compacts (Colorado Division of Water Resources 2012).

Water supply operations agencies

In response to growing water demand on the semi-arid Front Range and eastern plateau, transmountain diversions were constructed to move water from west to east across the Rocky Mountains. The Colorado-Big Thompson Project (C-BT) is a federally owned and operated water storage, regulation, and diversion project in western Colorado. The project diverts 260,000 acre-feet of water annually from Colorado River headwaters on the western slope of the Rocky Mountains to a tributary of the South Platte River on the eastern slope. The Alva B. Adams Tunnel, owned and operated by the Northern Colorado Water Conservancy District, is the principal transmountain diversion for the C-BT. Of the nearly 30 transmountain diversions, two are owned by the USBR and three are owned by the Colorado Division of Wildlife. The remaining 25 are owned and operated by regional water wholesalers (called conservancy districts), municipal water districts, private water companies, and individuals (Winchester 2001). Colorado also supports several types of local special districts with water-related functions, including water supply districts, sanitation districts, irrigation districts, drainage and flood control districts, and groundwater management districts (Colorado Water Conservation Board 2015 2-22).

Legal Framework

Water rights

The right to use water in Colorado is usufructuary and regulated by a statewide system of water rights.[68] The use of water in Colorado is subject to the prior appropriation system, giving priority to water users based on their seniority (Colorado Division of Water Resources 2012). Colorado integrated rights to surface and tributary groundwater (that which is hydrologically connected to surface water) into a unitary adjudication and administration in 1969 (Colorado Water Conservation Board 2015). The state created seven specialized water courts, one in each of the major river basins for allocating waters and solving any water conflict between users. Seven state water courts are responsible for issuing decrees confirming the right to use water, which is the only way users can confirm and protect a water right in Colorado (Colorado Division of Water Resources 2012).

Water users intent on developing a water right for beneficial use must file a water right application within their local water court. Applications are posted in the local newspaper to solicit public comment. Division engineers review applications, and make recommendations to the water court. Once an application is in the water court, a water referee handles it. Referees can issue a ruling on the application, or arbitrate between an applicant and opposing parties. Protests can be appealed directly to the water court judge, and then to the Colorado Supreme Court. The entire process can last from four months to two years (Colorado Division of Water Resources 2012). Decrees issued by state water courts quantify direct-flow rights, storage water rights, and exchange rights. Direct-flow and exchange rights are quantified in terms of flow (cubic feet per second), while storage water rights are quantified in terms of volume (acre-feet). A conditional water right can be procured if the applicant can demonstrate through due diligence that they “can and will” put the water to beneficial use (Colorado Water Conservation Board 2015).

In parts of the state where water shortage is expected for part or all of the year and surface and groundwater are hydrologically connected, new junior ground water rights holders may be required to have Augmentation Plans. These plans allow junior water rights holders to continue pumping during calls made by senior surface water rights holders. Under each individual plan, junior groundwater users are required to return water to the stream in order to prevent the impact of new pumping on senior surface water rights. An Augmentation Plan must be filed in and approved by a water court. Applications involve detailed engineering analysis to evaluate the effect of new groundwater uses on senior surface water rights and demonstrate how replacement water can be procured to mitigate impacts to senior water rights.

Underground water that is tributary to the stream is administered conjunctively with the stream as adjudicated by the same seven water courts. Underground water in areas where there was effectively no connection with the larger rivers were divided into “Designated Basins”. Designated Basins are regulated by a citizen commission, outside of the water courts’ jurisdiction. The Colorado Groundwater Commission regulates groundwater withdrawals in Designated Basins. The Commission has the authority to control pumping, limit extractions of groundwater, and establish reasonable pumping levels in these designated areas (Bryner and Purcell 2003).

[68] A civil law term referring to the right of enjoying a thing, the property of which is vested in another (in this case the State), and to draw from the same all of the profit, utility, and advantage which it may produce, providing it be without altering the substance of the thing (Colorado Water Conservation Board 2015).

Water trading

Water rights are property rights in Colorado, allowing water-right holders to buy, sell, and modify water uses as long as these changes do not injure other vested water rights (Colorado Division of Water Resources 2011). Water users many change their water rights by conveying it to another water user, changing it to another diversion location, place of use, manner of use, or type of use, while still retaining its priority. Changes of water rights require permission from the appropriate water court or administrative body. Applications for a change to water rights must be accompanied by a "net stream depletion" analysis for determining the time, place, and amount of decreed and historical consumptive use. This analysis indicates the water quantity legally available to trade under the water right. Making changes to a water right can be costly due to complex legal and engineering analyses (Colorado Water Conservation Board 2015 2-7).

Colorado has a program for expediting short-term transfers of historical consumptive use of absolute water rights upon a showing of no injury and approval of the state engineer. These "interruptible water supply agreements" only require administrative approval and do not require state water courts to adjudicate the agreements. These agreements are effective for a maximum of three years (Colorado Division of Water Resources 2011).

Legal treatment of environmental water use

By Colorado law, minimum streamflows and lake levels appropriated by the state to preserve the natural environment are considered beneficial uses. The CWCB has exclusive authority to appropriate and acquire waters of natural streams and lakes to preserve the natural environment to a reasonable degree. CWCB manages the state's instream flow and natural lake level program. This program supports cold and warm water fisheries, waterfowl habitat, riparian vegetation, and habitat for threatened or endangered fish.

CWCB recently completed a statewide collaborative effort to study non-consumptive uses for recreation and the environment in major river basins. An outcome of the project is a technical toolset for identifying and quantifying non-consumptive needs. CWCB also coordinates watershed restoration and protection planning in the major river basins.

Each year, CWCB holds a public workshop to solicit recommendations for protecting streams and lakes through appropriation. Appropriations are new junior water rights for environmental flow protection claimed by the CWCB. CWCB subsequently receives detailed recommendations for instream flows from state and federal agencies, members of the public, and conservation groups. Recommendations are rigorously evaluated by CWCB using criteria established by statutory requirements for an instream flow appropriation. CWCB uses a standardized method and tool (R2CROSS) for modeling instream hydraulic parameters and evaluating water availability needed to fulfill instream flow recommendations. Barring opposition or other challenges, CWCB then declares its intent to appropriate water for environmental purposes. New appropriations must be filed with and adjudicated by water courts (Colorado Water Conservation Board 2005).

CWCB also acquires water for environmental flows through donations, purchases, or leases of water rights in the short- and long-term. Administrative approval by the State Engineer is required for temporary transfers, while long-term transfers require CWCB to apply to the water court for an instream flow decree (Szeptycki et al. 2015). Water rights acquired by the CWCB preserve their original priority date and are administered within the water rights priority system. CWCB does not have authority to acquire water rights by eminent domain.

Colorado has several aquatic endangered species. Protection of these species is often achieved by collaboration between state and federal agencies. CWCB is often heavily involved, as it has both environmental flow monitoring responsibilities and exclusive acquisition authority for instream flow rights. Reservoir re-operation and adaptive management is currently occurring for Glen Canyon Dam on the Colorado River and Navajo

Reservoir on the San Juan River. Focused instream flow recovery efforts are occurring on the Upper Colorado River and the Platte River.

CWCB protects instream water rights physically and legally. It helps fund the installation of telemetry-enabled streamflow gages for monitoring decreed instream flow rights. The satellite monitoring system (SMS) allows it to monitor instream flow rights in near-real time. CWCB makes "calls" to the local Division Engineer to protect the priority of decreed instream flow rights. CWCB also legally protects decreed instream flow and natural lake level rights by reviewing other water rights applications for potential injuries inflicted on its rights (Colorado Water Conservation Board 2005).

Prioritization of particular uses

Colorado's state constitution protects domestic purposes above all other beneficial uses when water of a natural stream "are not sufficient for the service of all those desiring the use of the same." After domestic uses, agricultural users have preference over industrial water users (Smith and Ellsworth n.d.). Since statehood, this hierarchy has never been used to resolve conflicts.

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

Water commissioners within Colorado's seven water divisions, comprised of 78 water districts, are each responsible for compiling surface and groundwater diversion and use data and transmitting it to the Office of the State Engineer. The basic statewide requirement for water diversion and use reporting is that water commissioners must at a minimum provide the State Engineer with an annual description of volumes and types of water diverted along with the location, timing, and purpose of use for each diversion structure in their water district. In general, the recording, compilation, analysis, and submission of water diversion data are conducted on digital spreadsheet forms.

Measurement, recording, and collection of individual diversions vary across water districts, though water commissioners are ultimately responsible for assigning data collection and accuracy auditing processes in each district. Individual water diversion records in Colorado fall into two categories: observations made directly by water commissioners and observations of known reliability measured and supplied to water commissioners by users themselves. Both formats are equivalent in terms of data quality and accuracy from the perspective of the water commissioners, Division Engineers, and the State Engineer's Office.

Data directly observed by the water commissioner may be captured either by direct field measurements, analog flow recorders, digital flow recorders (sometimes equipped with radio, cellular, or satellite technology), or another equivalent measurement process authorized by the division engineer for a water district. Observed data is compiled into databases by the water commissioner and subsequently provided to the State Engineer's Office annually or sometimes more frequently.

User supplied data is measured and recorded by diverters using any of the approved methods described above, and subsequently collected and compiled by the water commissioner for annual reporting requirements. In this configuration, the water commissioner is primarily responsible for auditing diversion measurement equipment and the data recording and collection process to ensure accuracy and reliability. The accuracy of measurement equipment is dependent on the type of equipment installed. Once a measurement device is rated[69], it may not need to be audited for one to several years. The state of Colorado employs around 30 hydrographers to provide technical assistance to water commissioners in evaluating the accuracy of measurement devices in water districts.

The State Engineer may require any measuring and reporting needed to effect the administration of water rights in a water district. Variation in the degree of measurement frequency and use of advanced technology varies by the level of competition for water in the district. In highly competitive water districts throughout the South Platte River basin, for example, all surface water diversions may be equipped with digital flow recorders that capture data every fifteen minutes and hourly report that data to a centralized database. In smaller water districts with limited competition, water commissioners may measure diversions by hand during routine headgate inspections. Even in the most advanced water districts, groundwater extractions are not recorded in real-time as are surface water diversions. Nevertheless, many wells on Colorado's Front Range are required to report meter readings to water districts monthly.

In order to administer compacts and state decrees, the State Engineer must have groundwater pumping data from the divisions on the east side of the Continental Divide. To most efficiently and effectively enforce such reporting, the State Engineer is authorized to implement rules. Over the past twenty years, the State Engineer has published rules regarding the measurement of groundwater in those four areas. The rules require some wells to have a measurement device installed and verified by a certified well tester. [70] Also, in designated basins, the Colorado Ground Water Commission has authority to require a totalizing flow meter or other measuring device for any well (Colorado Ground Water Commission 2010).

Individual diversion records collected at the state level can be categorized by whether they were observed or user supplied, along with an indicator of data reliability based on measurement device type and auditing frequency. The State Engineer's Office has audited the accuracy of nearly every surface diversion measured in the state. A similar percentage of large capacity (over 50 gallons per minute) wells in the eastern half of the state are also audited through the measurement rules process. The majority of wells in the state, however, are small capacity wells that are not, generally, audited by the State Engineer's Office. Diversion records of unknown reliability are scheduled for audits to affirm their reliability. In any given year, such records represent less than 2 percent of the state's diversion records. CDWR also hosts an online portal for viewing real-time and reported diversion information from some diversion structures.

Indirect measurement of water use (top-down approach)

As direct measurement of diversions is done by water commissioners, there is no need to indirectly measure surface water use. Some groundwater wells in sensitive areas have flow meters, but this is not common practice. CDWR uses climate data, soil characteristics, and crop information—including acreage and irrigation characteristics—to estimate water use and develop models for simulating basin water budgets.

An interesting practice to assess surface and groundwater storage and flows for water budgeting is the measurement of consumptive water use in crops and livestock farms. The state includes all the data provided by their monitoring network and data from other sources—climate, acreage, irrigation characteristics, livestock facilities, etc.—in a model called StateCU. StateCU calculates consumptive use for indirectly estimating return flows.

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[69] "Rating" a diversion measurement device is a process in which independent flow measurements are compared to the design stage-discharge relationship developed by the engineering of the structure.

[70] Wells that pump 50 gallons per minute or less and are used for residential purposes in one to three single family dwellings, home lawn and garden irrigation of a maximum of one acre, certain livestock or domestic animal watering, or some limited commercial purposes, are exempt from installing measurement devices.

Some areas must reduce irrigation that impacts river discharge crucial for meeting interstate compact requirements. Remote sensing has been tested in Colorado not to assess water use but to analyze the potential of deficit irrigation to decrease water consumption in some areas (Taghvaeian et al 2013).

System Analysis and Management

The CDWR operates a statewide satellite-linked monitoring system (SMS) that records stream flows, reservoir storage, and diversions on a near real-time basis. In addition to using the data to administer water rights, the State Engineer makes the data available to the public where it is used for hydrologic records, flood warnings, and other types of flow alert notifications (Ley et al. n.d.). The state has around 330 stream flow monitoring stations. Big divisions have around 65 (Division 1) or 55 stations (Division 3), whereas small divisions have around 9 measuring stations (Division 4). The system provides real time data and reports made daily, monthly, and annually.

To feed the SMS, formal stream-gaging programs are administered by the CDWR and the USGS and have support from more than 60 cooperating organizations, including US Bureau of Reclamation, US Army Corps of Engineers, Northern Colorado Water Conservancy District, Denver Water, the cities of Aurora and Colorado Springs, and the Urban Drainage and Flood Control District. Also, the system has received on-going financial support from the CWCB.

The CDWR, in cooperation with local groundwater management districts, operates a statewide network for monitoring groundwater levels. Over 1,500 wells are measured to assist in projecting groundwater levels and to aid in the administration of groundwater. Also, wells installed in designated basins and in some areas are obligated to install a flow meter or measuring device.

Data collected with the monitoring network is processed in the Colorado's Decision Support Systems (CDSS). CDSS is an integrated water management system developed by the CWCB and the CDWR for each of Colorado's major water basins, which provides data, tools, and products. The principal modeling tools to support water accounting are:

- StateMod is a monthly and daily surface water allocation and accounting model capable of simulating various historical and future water management policies in a river basin. It is used to model a stream system by accounting for both physical river flow and water right operations (diversions, well pumping, reservoirs, in-stream flow demands, etc.) and to evaluate the impacts of a change to a baseline data set.
- StateCU is used to estimate historical consumptive use and return flows for a specific irrigated area based on user input data such as water supply, cropping, and climate data.
- StateWB was developed to calculate a basin-wide water balance and generate a consumptive use and losses summary.
- Groundwater and return flow third party software developed outside the CDSS: MODFLOW-CDSS is a finite-difference groundwater model developed by the USGS for use in conjunction with baseline data sets developed through CDSS; and IDS Alluvial Water Accounting System (IDS AWAS) available through Colorado State University (CSU), calculates groundwater return flows using the Glover method.

The integration of surface and groundwater resources is considered explicitly in the allocation of water rights in Colorado and is considered within their modeling platforms. Especially interesting is the assessment of consumptive use and return flows and the ability to specifically analyze groundwater return flows with the IDS AWAS model.

The state can forecast supplies because of the comprehensive monitoring network. As an example, the Natural Resources Conservation Service of the US Department of Agriculture publishes a monthly Water Supply Outlook for Colorado.

Allocation During Periods of Scarcity

Colorado is a semi-arid state, and calls to enforce the priority system among water users on the same stream may happen several times per year in some river basins.

Colorado has a long-standing system of allocating shortages based on priority. Senior users who are not receiving their full allocation of water will contact the local district commissioner, who places a "call" on the river – after notifying the division engineer. All water rights on a stream are arrayed in priority established by date of their water right decree. Everyone upstream of that point of diversion who is junior to that diverter must cease diverting water to satisfy that right. As supply increases or demand decreases, the call is adjusted. Curtailed rights can start diverting in order of priority. In some cases, the water commissioner is responsible for adjusting headgates. Usually there are multiple "calls" on every river during the year. The system is actively administered by the division staff including water commissioners and ditch riders. The water commissioner may lock individual headgates if users are not complying.

As described in the Regulatory Framework section, environmental flows (instream and natural lake levels) are administered within the priority system of water rights. CWCB protects these rights physically by actively monitoring decreed instream flows remotely and requesting calls with the water commissioners to uphold the priority of environmental flows.

Some major diversions are already reported using telemetry-enabled measurement devices and are available in near real time. At the local level, water commissioners are responsible for collecting information on all diversions within the district, and for investigating curtailment requests on a river or stream.

As described in the previous section, Colorado has several modeling support systems for evaluating various aspects of surface and groundwater conditions and to help with allocation of water during periods of scarcity. Especially important in real-time operations is Colorado's Stream Simulation Model (StateMod), a tool used by engineers, water resource planners, and anyone involved in water management decision-making for monthly or daily water allocation and accounting. StateMod can be applied to any river basin in Colorado given the availability of model inputs. The tool can simulate physically and legally available flow for specific diversion points.

Public Information Provision

Water Rights

The CDSS is an online platform updated daily that provides the definitive list of water rights. Moreover, the platform provides information regarding water rights decrees, legal locations, dates of appropriation, adjudication types, and, in some cases, pictures for each water structure—ditch diversions, reservoirs and wells, among others. It provides information on surface water and groundwater rights alike. Also, it provides information on the current status of a water right showing the amount of water that each water right is allowed to take according to its priority specifications.

From the platform, users can also download shapefiles with the geographical information of the permits given for a specific designated basin. The information is provided at a statewide level and updated monthly.

System Monitoring

CDSS also provides data on the current situation of all streams, diversion, and reservoir gages that are monitored remotely, as well as specific monitoring wells. The surface water information is updated daily, whereas the groundwater information is updated every week or two. Also, a map with the current surface water conditions shows streamflow conditions at multiple stations across the state, uploaded with at most a two hour delay.

Information on climatic variables, including precipitation, evaporation, temperatures, and solar radiation can be found daily through the Hydrobase Point data. Users can download the information through shapefiles.

Colorado also provides a modelling platform where users can obtain their own reports on crop consumptive use (StateCU), water supply, and allocation that consider water right demands and their priority (StateMod), data sets and models related to groundwater resources (MODFLOW) and reports on the overall water balance summary for a basin (StateWB). These data sets and reports have historical information, and may be used as baseline data or as a starting point for developing other data.

Allocation During Scarcity

During scarcity, if curtailments are required, the water commissioner issues a “call” on the river. This notice advises water right holders to cease diverting water until the call is changed (Jones and Cech 2009). Records of active and historical calls can be found on the CDSS platform.

The state does not publish forecasts of water supply or potential supply curtailments explicitly. The Natural Resources Conservation Service of the US Department of Agriculture publishes a monthly Water Supply Outlook for Colorado. It provides the different likelihoods of snowpack, precipitation, reservoirs storages, and streamflows within a one year window.

Water Transfers

The information that the water courts manage and publish on water transfers is limited. Information on the final volumes transferred can be found through the CDSS platform. Courts may ask for contract copies as evidence for requesting a change in water rights ownership; these contracts may contain prices. Nonetheless, it is not strictly required on the forms and courts are not mandated to publish this information.

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Idaho

Highlights

- Agriculture is the predominant water use in Idaho. Most farming is on the Snake River Plain, which lies atop the Eastern Snake Plain Aquifer. The Boise River and Henry's Fork basins are also important resources for irrigated agriculture.
- Surface-groundwater interaction in the ESPA Basin is a key management issue in Idaho. Most of the surface reservoirs in the Upper Snake River Basin are managed and operated by federal and local agencies. The state, through the Idaho Department of Water Resources (IDWR), is focused on managing and adjudicating water rights, including conjunctive administration of both groundwater and surface water rights.
- Because of the importance of surface-groundwater interactions, there are significant monitoring and modeling efforts such as USBR's Hydromet and the Eastern Snake Plain Aquifer Model (ESPAM). Some surface water return flows from irrigation districts in the Snake River Basin are monitored, and incidental aquifer recharge from irrigation canal seepage also are estimated.
- IDWR is pioneering innovative methods such as the METRIC model (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) for indirectly estimating crop water use through satellite imagery—which is used for water accounting, hydrologic modelling, water planning, enacting curtailment orders, and analyzing potential water transactions between farmers and the environment to protect endangered species in the Columbia River basin.

Introduction

Idaho has a varied climate and wide range of topography and vegetation. A mixture of sharp mountain ranges, canyons, grassy valleys, arid plains, and fertile lowlands exist across the state. Most of Idaho is over 2,000 feet above sea level. High mountains in the central and southern parts of the state raise the mean elevation to 5,000 feet, one of the highest among US states. A maritime influence on climate is most evident in the winter, resulting in cloudiness and rainy days in northern parts of the state. In summer, a continental climate prevails with higher temperatures and lower precipitation, except for the eastern part of the state that has more precipitation in summer than in winter. Most of Idaho's population is clustered around Boise in the southwest.

Agriculture is the predominant water use in Idaho, with 82% of total water use. The state produces about a quarter of the nation's potatoes, as well as wheat, apple, corn, barley, sugar beets, and hops. Farming is concentrated above the Eastern Snake Plain Aquifer (ESPA). Idaho is also the US leader in aquaculture, using 3,090 thousand acre-feet (TAF) for this sector in 2010, mostly from springs that discharge from the ESPA.[71]

The Snake River is an important source of hydroelectric power. Of Idaho's 10 largest power plants, six are hydroelectric facilities, the biggest one being the 450-megawatt Hells Canyon Complex on the Snake River located at the border with Oregon.

The methods and regulations for acquiring water rights were consolidated in 1971 from regulations dating back to before 1903. Since 1971, the only way to get new surface water rights is through application to the State. Water rights must be put to beneficial use and are contingent on the prior appropriation doctrine. Groundwater is also subject to an appropriation permitting and licensing system (Bryner and Purcell 2003).

[71] Water use information for Idaho in this paragraph is sourced from Maupin et al. 2014.

The long and arduous Snake River Basin Adjudication, completed in 2014, adjudicated most of the state's ground and surface water rights, which can now be managed more effectively by the state's Department of Water Resources.

Since the Snake River waters come from Wyoming, an inter-state compact was created for sharing this stream. There are also agreements with other neighboring states regarding the Bear River (Western States Water Council 2014).

Principal demographic, economic and water-related indicators in Idaho

Population (in 2010):	1.57 million
GDP (in 2010):	$55 billion
Agriculture Value Added:	7.58 % of GDP
Annual Precipitation:	23.7 inches
Total Water Withdrawals:	19,300 TAF
Urban Use:	2%
Agricultural Use:	82%
Thermoelectric Use:	0%
Aquaculture:	16%
Surface Water:	71%
Groundwater:	29%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory Overview

Institutions

Oversight agencies

Idaho's two principal state water oversight agencies, the Idaho Department of Water Resources (IDWR) and the Idaho Water Resources Board ("the Board"), are highly integrated and share responsibilities for administrative rule adoption and court appeals. IDWR is in charge of managing surface and groundwater rights as well as preserving the quality of water sources through management and planning. The department has several bureaus, including planning and projects, water allocation, water compliance, hydrology, and information technology service.

The Idaho Water Resource Board is an 8-member board appointed by the governor with 4-year terms. Members are required to come from different regions of the state. The Board's primary role is to create and implement a state water plan to best utilize unallocated waters for the public interest. It also conducts regional studies for comprehensive basin plans. Other responsibilities include designating natural and protected rivers, acquiring minimum streamflow rights, financing public and private water projects, and operating the state's water supply bank. Many of these responsibilities are shared by IDWR's Planning Division, which supports the board by assigning staff to Board projects.

Water districts are local oversight agencies created by order of the director of IDWR. They are formed after a basin's surface and/or groundwater rights have been adjudicated by state courts. There are 130 water districts in

Idaho, with about 80 of them actively managed by a watermaster. Watermasters are elected and funded by members of the water district. A watermaster's principal responsibility is to deliver water in accordance with priority water rights and available water supply during periods of scarcity. This activity requires knowledge of the amount of water available in the source and the relative priorities of the water rights among users. Duties include daily or frequent water measurement and recording, and regulating diversions in accordance with priority rights and calls for water delivery. Additional duties may include annual water district budgeting and water user assessments. Water districts are responsible for collecting information on annual water use and submitting that data annually to IDWR.

Water supply operations agencies

The federal government operates several water supply reservoirs in Idaho, including three major reservoirs on the Upper Snake River Basin: the Palisades Dam Reservoir with storage capacity of 1,200,000 acre-feet, American Falls with storage capacity of 1,673,000 acre-feet, and Jackson Lake with storage capacity of 847,000 acre-feet. USBR also operates several reservoirs on the Boise River, including the Arrowrock Reservoir and Dam, Anderson Ranch Reservoir and Dam, and Lucky Peak Lake.

Irrigation districts are locally formed quasi-governmental entities that hold water rights and operate water supply infrastructure for irrigation activities. While the management structures of these organizations vary, a manager is generally hired to oversee operations. Canal or ditch companies are privately owned entities that also hold water rights and manage water supply operations for irrigation customers.

Groundwater-right holders may petition local counties to authorize the creation of Ground Water Districts (GWDs). GWDs may represent members in legal or administrative issues, develop groundwater mitigation plans, and perform measurement and reporting functions required by law. GWDs may also levy assessments and/or incur indebtedness to fund mitigation plans and groundwater management activities.

Legal Framework

Water rights

Idaho's water rights system is founded on the prior appropriation doctrine and encompasses both surface and groundwater rights. Surface and groundwater rights administration were formalized by statute in 1903 and 1963 respectively. Acquisition of surface water rights was not mandatory prior to 1971. New surface water rights sought after 1971, and new groundwater rights sought after 1963, may be obtained only through the application/permit/license procedure administered by the IDWR. IDWR also has a hearing process, mediated by a neutral hearing officer, for protesting a water right application. Priority dates for water rights issued under the current statutory method are assigned according to dates of application. Water right exemptions exist for in-stream watering of livestock and ground water domestic use. Many surface and groundwater rights in Idaho were developed before the formalization of water rights administration by the IDWR. Claims may be filed with IDWR to record water uses that pre-date the surface and groundwater permitting systems. Claims play an important role in adjudications, in which all existing or claimed water rights are confirmed by administrative and court actions. Riparian water rights are not recognized in Idaho.

A general water rights adjudication in Idaho is a court procedure for creating an inventory of all existing water rights (claims, permits, and licenses) in a basin and confirming those rights in a legally binding decree. When a basin begins adjudication, it is assigned to a district court. Idaho does not have courts exclusively designated for water-related rulings. However, the district court assigned to an adjudication may spend up to 90 percent of its time on adjudication proceedings. To help with the workload, the court may hire special masters to conduct hearings on subcases and make a recommendation to the presiding judge. The district court assigned to an adjudication may not necessarily be the court nearest the basin. The current adjudication in Northern Idaho was assigned to a district court in Southern Idaho because of its experience from a previous adjudication.

IDWR reviews water right claims to make recommendations to the court, which the court finalizes if there are no objections. If a recommendation is protested, a subcase is created and IDWR and the claimant will try to sort out their disagreements. If the specifics of the water right cannot be agreed upon, the district court makes the final decision. Many water rights in a basin undergoing adjudication have already gone through a licensing process or were previously adjudicated. These rights require less investigation by IDWR and recommendations concerning them are typically uncontested.

Quantification of water rights (allowable diversion or extraction amounts) obtained by the application/permit/license procedure is completed upon issuing a license. Claims to water rights based on historical beneficial uses are not confirmed by IDWR unless or until they are included in a general water rights adjudication.

The system of water rights in Idaho is “first in time, first in right,” which creates a challenge for allocating water according to priority. In areas that have been adjudicated, the administration of water distribution based on water rights is the responsibility of local watermasters. Some watermasters employ computers for tracking allocation and distributing water according to priority and the terms of an adjudication decree.

In most of Idaho, there is effectively no more surface water left to appropriate. In regions of the state facing over-allocation of surface and groundwater, applications for new water rights are scrutinized and may only be considered if the applicant provides a satisfactory plan to offset or mitigate injury to other water right holders. The director of IDWR also has discretion to designate critical groundwater areas for a groundwater basin or portion thereof if the area lacks sufficient groundwater to provide a “reasonably safe supply” for irrigation or other uses at the current or projected rates of withdrawal. Management plans may be developed by local water users to manage the effects of water withdrawals on the aquifer. The designation of critical groundwater areas and groundwater management areas result in moratoriums of new groundwater appropriations unless new uses can be mitigated through approved management plans.

Surface and groundwater interaction is an important water management issue in the ESPA, the Boise River basin, and Henry’s Fork basin. In the mid-1990s, conflict between senior surface water-right holders and junior groundwater users reached a peak in the ESPA due in part to reduced surface water flows as a result of more efficient irrigation methods and reduced seepage from irrigation canals. Senior surface water users threatened to make “delivery calls” on their water rights, which would require junior groundwater right holders diverting water from common sources of water supply to cease all pumping. To help resolve the conflict and provide more structure to surface-groundwater debates, the state developed formal rules for conjunctively administrating surface and groundwater rights. These rules defined a formal procedure for making delivery calls on junior groundwater users causing material injury to senior water users and creating a mechanism allowing junior groundwater users to pump out of priority if impacts to consumptive use are mitigated (Bryner and Purcell 2003). However, the conjunctive management situation remains challenging due to hydrologic and legal uncertainties related to wide-spread incidental recharge and renewed interest in agricultural irrigation efficiency. Managed artificial recharge is generally seen as a promising solution to mitigating the depletion of the Snake River Basin.

Water trading

Permanent transfers of water are initiated directly by the parties involved, while temporary transfers are managed through the state’s Water Supply Bank. Permanent transfers require different paperwork depending on the nature of the transfer. This may include descriptions of the current and proposed use, maps of the current and proposed use, and explanation of how other right holders will be affected by the transfer. Applications are submitted to and approved by IDWR. IDWR provides modeling tools for applicants in the ESPA that analyzes potential impacts to the Snake River due to new water rights, water transfers, and Water Supply Bank rentals.

The water bank is operated by IDWR on behalf of the Board and manages temporary leases and rentals of surface water and groundwater rights. Average review time for a short-term transfer through the Water Supply Bank is nearly four months. Rentals must not injure existing rights. Leases and rentals of reservoir storage water is accomplished through local rental pools that have been developed for specific watersheds and are managed by local committees appointed by the Board. Temporary transfers have a standard maximum duration of five years, but the Board has authority to make exceptions and has extended transfer periods up to 20 years for some environmental instream uses.

Upon declaration of a drought emergency for an area, issued by IDWR and approved by the Governor, the administrative processing of applications for temporary changes of water rights will be eased. Water right changes made under the provisions of a drought declaration expire at the end of the year of the declaration unless extended or terminated by the IDWR director.

Legal treatment of environmental water use

There are three ways instream flows can be procured for the environment or other public interests: minimum streamflow rights, water transfers, and voluntary agreements between users and the Board.

Minimum streamflow rights are held by the Board to preserve the ecosystem, navigation, transportation, recreation, water quality, public health, and safety. Any individual or entity can ask the Board to apply for streamflow rights. Flows identified in the minimum streamflow right must be maintainable, represent the minimum, not optimum flow, and a public hearing must be held. Currently, only 291 rights are held by the Board which covers 2 percent of Idaho’s stream miles. Furthermore, minimum flow rights do not have senior priority and cannot help preserve flows in times of drought. The most senior priority instream flow right is 1978, when legislation was passed allowing minimum streamflow rights to exist.

The Board may purchase water from senior water rights to help preserve minimum streamflow rights. The water can only be transferred to existing minimum streamflow rights, which limits areas in which transfers are effective. Some transfers are arranged by third party non-profit organizations such as The Nature Conservancy.

A third method used in one region of the state is to have voluntary agreements between the Board and irrigators to either meet minimum flows or move a point of diversion off a tributary and onto the main stem. One such agreement is on the Lemhi River where a dozen senior users have agreed to curtail their use if streamflow drops below 35 or 25 cubic feet per second (cfs) depending on the season. Two similar agreements exist on smaller tributaries. The Board also may offer to mitigate the cost of moving a large diversion off of a tributary and onto the main stem to preserve fish flows on the tributary.

The Board’s Water Transactions Program seeks to implement all three approaches for improving flows to tributary streams and rivers in the Upper Salmon River Basin.

Minimum flow water rights and instream flow rights acquired by transfer are administered through the prior appropriation system. The priority of these flows is ensured by watermasters when they are within an active water district, and by IDWR where a watermaster has not been appointed.

Another major dedication of water to the environment arose from the 2004 Nez Perce Water Rights Settlement (also known as the Snake River Water Rights Act of 2004). Under this settlement, USBR will provide 427,000 acre-feet of flow augmentation water from storage reservoirs with an additional 60,000 acre-feet from private natural flow rights over a 30-year period on the Upper Snake River. The flow augmentation program is designed to benefit juvenile fall Chinook salmon below the Hells Canyon Complex.

Prioritization of particular uses

While prioritization of water users during periods of scarcity is primarily based on the prior appropriation doctrine, Idaho's state constitution also specifies a secondary standard for priority by type of use when water in a natural stream is unable to satisfy all those desiring the use of the stream. Domestic purposes have the highest priority, followed by mining (if in an organized mining district), agriculture, and manufacturing (Smith and Ellsworth n.d.).

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

Measurement and reporting of surface and groundwater use is primarily the responsibility of local water management entities including water districts, water measurement districts, and groundwater districts. The IDWR requires authorized watermasters or district hydrographers to prepare and submit annual reports to the department containing the amount of water diverted at each diversion as measured or determined during the period November 1 through October 31. The annual reports must also contain, but are not limited to, information such as local streamflows and groundwater levels, a directory of water appropriators, and financial information on the district's expenditures and fee revenues.

Water districts develop plans for measuring and reporting water diversion and extraction information to the IDWR. They may use self-reporting from individual water users supplemented by an annual inspection by the district (Idaho Department of Water Resources 2009a). Installation and maintenance of measuring devices in close proximity to diversion works is the responsibility of water users (Idaho Department of Water Resources 2013b). Various approved measurement methods can be used including magnetic or ultrasonic flow meters and a power consumption coefficient (PCC) method. In addition to water use, some district-level reporting requirements include crop type and irrigation method. Each year, water districts send collected reports to IDWR. Quality of reports varies widely between water districts depending on the level of water scarcity and conflict in the district.

Although some watermasters measure diversions in real time, some small districts might not employ measuring devices at all. The detail of reporting may even vary from year to year. When water is sufficient and all users receive their full water right, the watermaster might be less diligent in collecting diversion information from individual users. Some water districts report diversions daily via IDWR's online portal, while others send reports once a year by mail (Western States Water Council 2014). IDWR is trying to get more districts to use the data-entry program.

Domestic and stock water diversions and other de minimis water uses are typically not measured and reported. Small irrigation uses, typically under five acres, may also not be measured or reported but may be subject to estimating and a minimum water district assessment. De minimis use and small irrigation rights may still be curtailed in times of shortages.

Individuals outside of water districts can also be required to report by request of IDWR. These users can employ various methods of tracking surface diversions including weirs, flumes, submerged orifice, and closed conduit flow meters. Whichever method they choose, it must meet minimum acceptable standards set by IDWR and report measurements using a standard form. These reports are mailed in annually.

Only with the recent Snake River Adjudication has measuring and reporting of groundwater diversions been required. The adjudication began in 1987 and was not completed until 2014. Before this time, groundwater rights were not adjudicated and therefore not included in water districts.

In the ESPA, most groundwater use is reported through groundwater districts, which are quasi-governmental entities similar to irrigation districts. Groundwater districts are required to measure diversions from every user in the district. Annual volume use data or estimates are reported to the water district watermaster through an IDWR database portal. The power consumption coefficient (PCC) measurement method is most commonly used in the groundwater districts. The PCC method avoids flow meter installation costs but requires periodic manual field measurements to derive the PCC. The PCC method is only accurate for simple irrigation systems. IDWR estimates that about one-third of the reported data measured by the PCC method exceeds an accuracy plus or minus 10 percent. In 2015, ESPA groundwater pumpers agreed to install advanced flow meters as part of a settlement with senior surface water users and permanently reduce their pumping by about 13 percent in an attempt to help stabilize the aquifer.

Some collected surface and groundwater use data is made available through two online databases managed by IDWR. The “Water Measurement Information System” (WMIS) database primarily contains irrigation well pumping information from the ESPA, but also includes some ground and surface water diversions that are located outside the aquifer. The second database is the “Water District Diversion Database,” which contains surface water diversion records from some of the state’s water districts. With a few exceptions, quality control review of reported data is minimal due to limited IDWR resources.

Indirect measurement of water use (top-down approach)

As mentioned in the previous section, most water use is directly measured. Surface water use is measured at diversions and reported by watermasters, and many groundwater diversion are measured at the point of extraction.

IDWR is pioneering an innovative method for indirectly estimating crop water use through satellite image-data. Between January 2000 and February 2005, IDWR and the University of Idaho's (UI) Department of Biological and Agricultural Engineering worked on a NASA Synergy grant to develop an efficient and accurate method of mapping evapotranspiration (ET) with Landsat data. ET data are critical for settling water-resource conflicts and are especially important for agricultural water issues since irrigated agriculture is more than 90% of the consumptive water use in Idaho. “Mapping EvapoTranspiration at high Resolution with Internalized Calibration” (METRIC) is an energy balance model that uses satellite image data to compute a complete radiation and energy balance, sensible heat, and ET for each pixel of the satellite image (Allen et al. 2007). IDWR and UI, in a joint effort, used Landsat data for the project with the goal of developing METRIC into an operational tool for IDWR in administering Idaho’s water. METRIC is used by IDWR for hydrologic modelling, water planning, enacting curtailment orders, and analyzing potential water transactions between farmers and the environment that protect endangered species in the Columbia River basin. METRIC estimates of water use are trusted over reported measurements.

System Analysis and Management

Diversions for water use are recorded by water districts and some water district data are offered online through the “Water District Diversion Database and the Water Rights Accounting Map” portal. Water supply data are provided through the combined efforts of state and federal governmental agencies involved in water management in Idaho. Each agency brings a different technical aspect and expertise to provide an extensive water supply outlook. Real-time river flow data is collected from USGS, US Bureau of Reclamation (USBR), and the Idaho Power Company. Weekly maps of snow water equivalency are posted from mid-December through March or early April. Once the information concerning water supply in the upcoming year is available, IDWR analyzes the data to determine potential water shortages. In times of water shortage, IDWR alerts the governor's office, which then organizes a water supply committee to coordinate the supply operations and provide information to the public. The committee is composed of key state, federal, and private agencies that have interests, constituents, and responsibilities that might be impacted by shortages.

The IDWR Hydrology Section maintains a database of information on groundwater levels. This database, known as Hydro.Online, contains data gathered by several sources, including measurements from the USGS, USBR, IDWR contractors, IDWR staff, and other public and private entities. The Hydrology Section analyzes these data to assess regional groundwater level trends. Trends are used to evaluate groundwater availability for new water uses and to evaluate and identify areas with declining groundwater levels that may need administrative action by the IDWR.

IDWR staff currently measure over 800 wells on a semi-annual to monthly basis. USBR measures 70 wells on a semi-annual or monthly basis in the Eastern Snake River Plain. The USGS Idaho National Laboratory Project Office measures about 200 wells at varying frequencies on the ESPA. This makes a total of nearly 1,100 monitoring wells in Idaho measured on a regular basis.

The state focuses its modeling efforts on the development of the Eastern Snake Plain Aquifer Model (ESPAM), due in part to the state's heavy reliance on the Eastern Snake Plain Aquifer and surface reservoirs in the region operated by federal or local agencies. The current version, ESPAM2.1, was initiated in 2005, and includes a 28.5-year simulation period with 342 one-month stress periods, calibrated to over 43,000 observed aquifer water levels, over 2,000 river gain and loss estimates, and over 2,000 transient spring discharge measurements collected from 14 different spring complexes. This model is used to 1) justify the closed status of the basin, 2) analyze calls of senior surface water users against groundwater users and determine appropriate settlement agreements, and 3) evaluate water transfers and determine any required mitigation (Idaho Department of Water Resources 2013a).

To calibrate this model, the surface-to-groundwater interaction is analyzed in depth and there is a significant effort to characterize return flows. In some irrigation areas, the state, in collaboration with other agencies, monitors surface return flows (Idaho Department of Water Resources 2012). There is an effort to use the model for estimating groundwater recharge from irrigation losses (Sukow n.d.).

ESPAM is the most advanced groundwater modeling effort in Idaho, and the state is planning to replicate this effort in other basins throughout the state. In 2008 the legislature established the "Statewide Comprehensive Aquifer Planning and Management Program" and the "Aquifer Planning and Management Fund." The legislature also authorized characterization and planning efforts for 10 different basins in the next 10 years.

Site-specific water budgets and models exist for other basins in the state to evaluate new groundwater applications and transfers. Model results are published in the IDWR online portal, but these are not as frequently employed as ESPAM.

Water transfers are required to avoid or mitigate injurious impacts to other water right holders. To facilitate this process, IDWR provides modeling tools for applicants in the ESPA, including a modeling tool for analyzing potential impacts to the Snake River due to new water rights applications, water transfers, and Water Supply Bank rentals.

USBR's Hydromet service provides data and information collected from a network of hydrologic and meteorological monitoring stations across the Pacific Northwest. The network uses radio and satellite communications technology to transmit water and environmental data in near-real-time for management purposes. Information on operations and diversions (including some real time diversions) are also incorporated into the Hydromet system as available. This information is publically accessible through the Hydromet website.

Allocation During Periods of Scarcity

Surface water rights are curtailed annually, but groundwater rights have never been curtailed aside from one three-week period in 2009. In most regions of Idaho, surface rights with priority dates junior to 1890 will be curtailed at some point during the irrigation season.

Curtailment orders can only be issued to water users with adjudicated rights. Over the past 25 years, most of Idaho's water rights were adjudicated through the Snake River Basin Adjudication. After all the rights in a sub-basin are adjudicated, a water district is formed and a watermaster is elected to manage the district. The watermaster is to ensure allocation of water by right and determine when curtailments are needed throughout the year. A watermaster can proactively curtail surface water rights delivery to a junior user and does not have to wait for a senior user to make a call on his/her right. Most users are required to install a lockable headgate on their diversions to enable the watermaster to limit use. If a user is found to have tampered with a locked headgate, they are subject to misdemeanor charges. Information from streamflow gages, user reports, and storage releases all assist a watermaster in deciding when curtailments delivery curtailments are needed. In poorly monitored basins, the watermaster will use past experience, knowledge of the basin, and a process of trial and error to determine how many upstream junior users need to be curtailed to meet a senior user's call (Idaho Department of Water Resources 2013b).

Water districts often contact users if their water delivery will be curtailed and a few maintain websites to post public curtailment notices. In most cases, users know roughly when their delivery will be curtailed based on previous years of curtailment, but they are not always notified. A notice of curtailment may be posted on the headgate or diversion structure if the watermaster is worried about tampering (Idaho Department of Water Resources 2013b).

Surface water availability is tracked by watermasters to varying degrees of detail depending on the level of scarcity and conflict within the water district. Whenever needed, a watermaster conducts mass balance measurements using data on streamflow, diversions, transfers, stream-reach gains or losses, and reservoir releases. Monitoring is done on a daily basis in more contentious basins (Idaho Department of Water Resources 2013b). An example of a tightly managed basin is Water District #1—the state's largest water district—which manages most surface water on the upper Snake River and several tributaries. Water District #1 runs two daily computer programs to assist the watermaster in making curtailment decisions—one to calculate natural flow and another to keep account of how much contracted storage water a user has left to divert. Daily data comes from telemetered stream and canal gages at 15-minute intervals as well as smaller irrigation diversions (Olenichak 2015).

Unlike surface water, daily tracking of water availability is not done for groundwater. In general, IDWR determines groundwater availability based on the level of conflict within a basin. If senior surface water or other groundwater users are making frequent calls to the Board for curtailment of junior groundwater rights, the area will likely be closed to new groundwater appropriations that do not also have a mitigation plan (for example, ESPA).

Public Information Provision

Water Rights

Records regarding water rights are refreshed daily at a state level. IDWR maintains a computer database to facilitate water right research and water right reporting. Through the platform, information on priority dates and diversion rates can be found for many water rights. The platform has a Geographic Information System (GIS) component for displaying each point of diversion on a map.

Idaho has an online platform with all water rights mapped. Here, users can identify the name of the water right, the district where it is located and other information including historical water use data. The information is provided with a couple of months of delay.

Every water district publishes an annual water use report. Water District #1, publishes its report online. The report considers all water rights, surface and groundwater, indicating how much water each right diverted or pumped.

System Monitoring

Daily surface data comes from telemetered stream and canal gages at 15-minute intervals as well as smaller irrigation diversions (Olenichak 2015). These are mostly from USGS, USBR, and Idaho Power stations. They provide current, daily, and monthly information on stream gage height and discharge. Daily water temperature information exists for some stations. The information from water districts varies with their level of technical, managerial, and financial capability. Water District #1 gathers and publishes daily information on the streamflows on their website (Olenichak 2015).

Hydro.Online compiles some groundwater information, including measurements from USGS, USBR, IDWR contractors, IDWR staff, and other public and private entities. It displays the information on a map. Hydro.Online has significant time lags.

Allocation During Scarcity

When curtailments are needed, water districts contact water-right holders directly and a few maintain websites to post curtailment notices. Also, IWRD publishes online information about some preliminary, recommended, and final orders. In most cases, users know roughly when their water delivery will be curtailed based on curtailments in previous years. Users are not always notified in advance. A notice of curtailment may be posted on the headgate or diversion structure if the Watermaster is worried about misdemeanant tampering (Idaho Department of Water Resources 2013b).

Unpublished forecasts of surface availability and its communication to users vary across different management areas depending on the level of scarcity and conflict. Forecasts are done daily in more contentious basins, and on a monthly or annual basis in less conflicted basins. In some cases, watermasters use a process of trial and error to determine curtailments, limiting the justification and communication of the restriction (Idaho Department of Water Resources 2013b).

USBR publishes regular reports, forecasting water supplies for some major reservoirs in Idaho and displaying daily updates of available reservoir storage in all Idaho basins.

Water Transfers

State transfer forms require information on transfer volumes, but the information is not organized or systematically published. Information on transfer price is included in a copy of the sale contract included with the transfer form. This information is not processed or published systematically. Through the Water Bank, the Board establishes a rate in dollars per acre-foot for the rental—unless the involved parties decide on another price—and an appointed local committee is in charge of reporting the activity of the rental pool annually. Any additional information may be obtained by contacting the local rental pool representatives.

The ESPA groundwater modeling tool is hosted online to help analyze the hydrologic impacts of new water right applications, transfers, and Water Supply Bank rentals within the Eastern Snake Plain Aquifer. These tools enable users to evaluate the potential for a proposed transfer and how it will affect flows in the Snake River. The tools show the hydrologic impact to other water users and determine the mitigation needed to compensate for those impacts.

Information on the queries for transfer applications can be found online. This information is updated weekly. The applicant's name, requested transfer volume, and acres that will be irrigated are published on this website. The protest deadline is also published since users are allowed to contest applications if they will be affected by the new withdrawal.

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Kansas

Highlights

Almost 90 percent of water use in Kansas is from groundwater, but surface water supplies more than two-thirds of its population. Major surface water operations are managed by federal agencies, the US Bureau of Reclamation and the US Army Corps of Engineers, while the state focuses its efforts on regulating groundwater resources and maintaining interstate agreements. To improve management of sensitive water resource areas, the state has created a number of regulatory tools for managing groundwater

- Kansas recently created a voluntary program for groundwater-right holders called the Multi-year Flex Account Program. The program allows users to exceed their annual authorized quantity in any year but restricts the total pumping over the 5-year period. Those who enroll must meter and record pumping on a monthly basis.
- The Water Information Management and Analysis System program makes information on all water rights publically accessible. It provides administrative data like the point of diversion, source, authorized quantity and rate of use, as well as actual water usage reported from the year before.
- A monthly Climate and Drought Update Summary is published with information on drought levels and conditions, including where Minimum Desirable Streamflows are in effect, and where drought declarations have been executed. It shows areas that are under the three levels of drought commonly designated in Kansas. The report also compiles climate metrics, water supply conditions, ongoing curtailments, as well as soil, crop, and vegetation conditions.

Introduction

Kansas has a continental climate and is not affected by major water bodies. The state's warm summers are when most annual precipitation happens. Winters tend to be cold with moderate snowfall.

The weather is mostly subject to air masses that move across the state, making eastern areas hotter. In Fredonia, in the southeastern part of the state, temperatures reach a mean above 90ºF and precipitation during May and August average more than 5 inches/month. The Rocky Mountains in the west create a rain-shadow of low precipitation. Annual average rainfall ranges between approximately 45 inches in the southeastern part of the state to less than 20 inches in the western parts. In the western city of Colby, the precipitation during summer averages three inches per month and less than one during winter.

Despite these extremes, Kansas is known for its agriculture, with large production of wheat, grain sorghum, and beef. More than 46 million acres of land are used for agriculture. Nearly 21 million acres are used for crops. On average, irrigation is 85 percent of the consumptive use of water in Kansas. Most surface water comes from the Kansas River, Republican River, Smoky Hill River, Arkansas River, and Missouri River, all flowing from west to east. The elevated water demand for irrigation systems requires drawing water from groundwater as well. About three quarters of the total water diverted is from groundwater. The High Plains aquifer is a regional aquifer system beneath eight states, including over 30,000 square miles of western and central Kansas. Groundwater from this aquifer accounts for 70 to 80 percent of water used in Kansas each day. Decades of intense pumping has resulted in declining groundwater levels in western Kansas.

Principal demographic, economic, and water-related indicators in Kansas

Population (in 2010):	2.85 million
GDP (in 2010):	$126 billion
Agriculture Value Added:	6.3 % of GDP
Annual Precipitation:	27.16 inches
Total Water Withdrawals:	4,490 TAF
Urban Use:	11%
Agricultural Use:	79%
Thermoelectric Use:	9%
Other Uses:	1%
Surface Water:	12%
Groundwater:	88%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

In 1945, the legislature enacted the Kansas Water Appropriation Act, which modified a water allocation system based on the riparian doctrine and the absolute ownership for groundwater. Since then, water rights follow the "prior appropriation" doctrine, with their priority determined according to the date the Chief Engineer received the application to appropriate water (Peck 1995). It is illegal for individuals in Kansas to use water without holding a vested right or a permit to appropriate water. Groundwater permit applications within a groundwater management district are reviewed by the groundwater management district and recommendations are made based on the policies, rules, and regulations of that district (National Conference of State Legislatures 2013). Water-right holders may lose the right if the water is not used for five years (Peck 1995).

Regulatory Overview

Institutions

Oversight agencies

Division of Water Resources (DWR) within the Kansas Department of Agriculture has the responsibility to manage how water is allocated and used, oversee construction of stream modifications, comply with four interstate river compacts, and coordinate the national flood insurance program.

Kansas Geological Survey (KGS) at the University of Kansas houses water resource databases on water levels, water rights, and registered well locations. KGS also produces water resource bulletins, droughts and climate studies, surface-groundwater interaction studies, and other technical studies.

Kansas Water Office (KWO) is state agency established in 1981 to develop and implement the Kansas Water Plan (most recently published in 2014). KWO also has a water supply role as described in the next section (Kansas Water Office 2014).

Groundwater Management Districts (GMDs) are local subdivisions of state government that provide water-use administration, planning, and information as described in the Groundwater Management District Act. Five GMDs were created in the 1970s in the western and central parts of the state overlying the Ogallala Aquifer. Primary use of groundwater in these areas is for irrigation, but several GMDs also have municipal water suppliers drawing from groundwater. GMDs are governed by local boards that assess the research and regulatory needs within each district. GMDs are authorized to tax, buy and sell water rights and real property, and propose regulations for water use within their district. The State Engineer has the administrative and legal authorities to make GMD policies legally binding (Griggs 2014).

Intensive Groundwater Use Control Areas (IGUCAs) are groundwater management areas determined by the DWR for which extra controls are placed on groundwater allocations and withdrawals. The IGUCA statutes give the Chief Engineer authority to initiate a public hearing to determine whether additional corrective control are needed due to declining groundwater elevation, rate of groundwater withdrawal exceeding rate of recharge, deterioration of groundwater quality, the environment or other public trust concerns.[72] Eight IGUCAs are currently active, but none overlap the Ogallala aquifer. Most of these IGUCAs protect senior surface water rights from pumping of hydrologically connected groundwater by junior uses. DWR may issue corrective controls in IGUCAs such as closing areas to further groundwater appropriation, re-allocating groundwater rights according to safe yield determinations (by priority date), and rotating the use of groundwater rights.

Recognizing that depletion of the Ogallala represented a serious water management issue, and that irrigators were wary of the unpredictability of the IGUCA process, the legislature created a tool for strengthening local control over groundwater managed in GMDs. The Local Enhanced Management Areas (LEMAs) are management tools for GMDs that need additional authorities for closely managing groundwater resources. Local enhanced management plans are developed by local GMDs or five percent of irrigators within a GMD for approval by the Chief Engineer. Plans may include proposed reductions in water use, transfer schemes, or flexible water use rules. The Chief Engineer may approve the plan after a series of hearings, after which the implementation and enforcement of the plan becomes the responsibility of the KDWR. There is currently one LEMA in northwestern Kansas. The Sheridan-6 LEMA imposed a 20 percent reduction in irrigated pumping over a five year period, a reduction that was shared by all groundwater rights despite priority differences. Irrigators were allowed 55 inches of water per irrigated acre over the five year period, with the added flexibility of allocating that amount in different proportions each year. LEMAs are approved for a fixed period of time, after which water allocations are reverted back to the allocation of the underlying water right. The LEMA approach creates predictability and local control for irrigators while leaving enforcement responsibilities to the state. This approach is seen as a potentially effective way to improve groundwater management of the Ogallala and other groundwater basins.

The most recent local groundwater management innovation in Kansas is the authorization of Water Conservation Areas (WCAs). WCAs are formed by any groundwater right owner or group of water rights owners to establish conservation and corrective controls for groundwater overdraft, preventable waste of water, or unreasonable deterioration of the quality of water in an area. WCAs are similar to LEMAs, though they do not require approval by a GMD. Orders defining corrective controls are issued by the Chief Engineer at DWR. There are currently two active WCAs.[73]

Water supply operations agencies

Kansas has 24 federally constructed reservoirs. Some of these projects are devoted to flood protection, while others provide both flood control and water supply to irrigators or public water supply systems. The 1958 Federal Water Supply Act allowed the state to acquire rights to reservoir storage space as long as the state could pay a

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[72] Note that the Walnut Creek IGUCA was formed primarily to protect Cheyenne Bottoms, a critical stop-over for migratory birds in North America.

[73] Descriptions of the various types of groundwater management entities in Kansas, including GMDs, IGUCAs, LEMAs and WCAs, is based on Griggs 2014.

portion of the capital costs back over the lifespan of the project. Rights to federal storage are referred to as water reservation rights. The state owns water supply storage in 13 of the 24 federal reservoirs in Kansas. More than two-thirds of the state's population relies on the public water supplies stored in these reservoirs (Kansas Water Office 2009).

The director of KWO is legally authorized to acquire water supply reservation rights that allow the state to collect and store water in federal reservoirs for municipal and industrial water supply (Kansas Water Office 2014). By agreement in 1985, Kansas was permitted to purchase additional storage in some federal reservoirs in exchange for the obligation to acquire water quality reservation rights. Water quality storage rights are within the portion of the reservoir owned by the federal government, and are used for maintaining streamflow for instream purposes like fish, wildlife, and aquatic life support, along with recreation and general aesthetics (Kansas Water Office 2009).

Water supplies held in state-owned portions of federal reservoirs are distributed to municipal water systems through the Water Marketing Program and the Water Assurance Program. The Water Marketing Program is the state's mechanism for allocating water stored in federal reservoirs under water supply reservation rights for municipal and industrial uses. KWO, the administrator of the program, sells untreated water under short- (1 year) and long-term (10-40 years) contracts. Contracts with municipal and industrial water users require payment to the state to cover storage costs. Water from the system of 13 reservoirs is treated as one large reservoir for pricing purposes, to avoid significant price differences across the state. The state is only responsible for selling raw untreated water at the reservoir, and does not deliver or treat water. In some cases, the raw water is delivered using natural river flow. Water Assurance Districts (WADs) are another mechanism for making use of state-owned water supply reservation rights in federal reservoirs. Eligible municipal and industrial water-right holders located downstream from federal reservoirs are allowed to purchase their own storage space from the state. These water-right holders form WADs to collect assessments from members to pay the state for storage costs, and negotiate water storage and release terms with KWO, DWR, and the US Army Corps of Engineers. Members of WADs are assured enhanced flows during times of drought. Releases for WADs are protected against diversion by other users. There are currently three WADs with about two dozen members.[74]

Kansas also has irrigation districts and municipal water districts, among other forms of local water operations and supply management.

Legal Framework

Water rights

The modern water rights system in Kansas was defined by the Kansas Water Appropriation Act of 1945. Prior to the act, water rights were administered according to the riparian doctrine. Water rights exercised before the act, including riparian and appropriative, were preserved as "vested rights." Many of these riparian water rights were adjudicated by the state. Claims to a vested right were provided an opportunity to file those claims with DWR before 1980. Since 1980, only domestic vested rights remain unquantified (Wilkins-Wells 2009). Vested water rights are senior to post-1945 water rights, but share a common priority date and have no internal hierarchy. About 2,000 vested water rights exist in Kansas. These vested rights represent small quantities compared to permits issued under the modern water rights code.

Since 1945, Kansas has been a "first in time, first in right" state with respect to surface and groundwater resources, which are administered by the state according to the principle of prior appropriation. DWR issues permits to appropriate water, regulates usage, and keeps records of all water rights in the state. There are currently

[74] Unless otherwise noted, all information in this paragraph is sourced from Kansas Water Office 2009.

more than 33,000 active water rights in Kansas (Kansas Department of Agriculture 2015). Water rights are administered for both surface and groundwater points of diversion.

Individuals who wish to appropriate water for beneficial use (other than domestic use) must file an application with KDWR accompanied by a filing fee which is determined by the amount of water to be appropriated. Applications filed within a GMD are reviewed by the district staff, and recommendations are made to the chief engineer of KDWR based on the appropriation policies, rules, and regulations of that district.

DWR or the GMD will determine whether: 1) water is available at the desired location, 2) the new appropriation will not interfere with other water rights, minimum desirable streamflow, or the public interest, and 3) it meets all other KDWR requirements (including safe-yield and minimum well-spacing requirements).

After a water right has been completed, DWR conducts a field test to determine rates of diversion, where and how the water has been used, and other details. Initial water user reports and other information are analyzed to determine the quantity of water diverted and acres irrigated each year within the limits of the permit. DWR determines the extent to which the water right has been developed and issues a draft certificate of appropriation to the applicant, which may be protested within 30 days of receipt. When an applicant receives the actual certificate, it must be filed with the register of deeds in each county where the authorized point or points of diversion are located. Common attributes of a water right are 1) priority date, 2) maximum rate of diversion, 3) maximum annual quantity, 4) point of diversion, 5) place of use, and 6) type of beneficial use. In approving a water right permit, the DWR may require the installation of water flow meters. Currently, over 90 percent of active water diversions are metered.

Annual water use reporting is tied to each application to appropriate water, and is used to perfect the water right.

A water right is considered abandoned after five successive years of nonuse without due or sufficient cause. However, groundwater-right holders in areas declared closed to further appropriations have due and sufficient cause for nonuse and are not subject to the abandonment rules.[75]

DWR also issues permits for water use which will last less than six months and require less than four million gallons of water for non-domestic purposes. Temporary permits are issued mainly to oil well drilling or small construction projects, and require a fee.

Water trading

Changing place of use, type of water use, or point of diversion requires an application for change filed with the DWR. This is especially useful in parts of Kansas without enough water available for new permits, as acquiring and/or changing an existing permit may be the only way to develop water for a new use or location. DWR's chief engineer reviews the proposed changes and evaluates whether or not the changes maintain a reasonable allocation for the proposed use and that the use is beneficial. Proposed changes to water rights cannot impair an existing water right, cannot prejudicially affect public interest, and cannot represent an increase in consumptive use. In an example of a transfer of water from irrigation to municipal water use, no more water may be consumed under the proposal than was used consumptively in the irrigation practice. Changes in point of diversion under a water right are required to install flow meters that meet the specifications of the chief engineer (Peck et al. 1988).

Water transfers were specifically defined by the Water Transfer Act of 2012 as the means of diverting and transporting 2,000 acre-feet or more per year for beneficial use at a point of use outside a 35-mile radius from the original point of diversion. Water transfer proposals are heard by a panel including the chief engineer, director,

[75] According to recent law HB 2451 (2012) which eliminated the "use it or lose it" rule for groundwater rights in areas closed to new water rights development.

and secretary of KDWR, along with a formal public hearing. Approval of transfers is subject to more intense scrutiny and conditions than other changes to water rights. For instance, if the transfer supplies water to public water systems require restructuring retail water rates to send a conservation signal. The Act also contains an emergency approval process that allows short term transfers to protect public health, safety, or welfare.

As previously mentioned, KWO administers the Water Marketing Program and the Water Assurance Program that effectively uses state water supply reserved rights in federal reservoirs. Under the Water Marketing Program, the state sells raw water supply to municipal and industrial water users for a storage fee.

In 2001, the Kansas legislature passed the Kansas Water Banking Act which allows banks to process short-term water leases between willing buyers and sellers. As defined by the act, a water bank in Kansas is a private not-for-profit corporation that 1) leases water from water rights deposited in the bank, and 2) provides safe deposit accounts for surface and/or groundwater. The Central Kansas Water Banking Association (CKWBA) is a not-for-profit corporation formed in 2005 that operates a water bank within the boundaries of the GMD #5 and the only operating water bank in the state. CKWBA hosts an online site for connecting willing water rights buyers and sellers, offers text-based alerts on upcoming water availability, and provides an online record of activity and transactions, and banking forms. According to CKWBA rules, water must be leased and used in the same hydrologic unit of the water deposited. According to the Kansas Business and Industry Data Center, CKWBA is used by very few entities for water banking purposes.

Legal treatment of environmental water use

Kansas law "does not support an instream water right" (Kansas Water Office 2009). However, the legislature authorized Minimum Desirable Streamflow (MDS) requirements in 1984 for maintaining base flows in some streams, thereby protecting existing water rights and meeting in-stream water uses related to water quality, fish, wildlife, and recreation. The legislature has currently defined 33 MDS levels on 23 streams (some streams have multiple measurement points). Thresholds are defined as a target rate (cubic feet per second) for every month of the year. If streamflow in streams with MDS requirements drops below the established threshold for more than seven consecutive days, the chief engineer may order pumping restrictions or closures on junior water rights (permits or water rights granted after the law became effective in 1984). KDWR monitors streamflow at all 33 locations using real-time from USGS streamgages.

KDWR will not allow new water right appropriations (filed on or after April 12, 1984) to negatively impact an established MDS threshold, however, most Kansan streams do not have MDS protections.

As previously mentioned, IGUCAs may be formed by KDWR to manage groundwater in a manner that protects public trust concerns like the environment. The formation of the Walnut Creek IGUCA in 1992 was initiated by KDWR to manage surface water diversions and groundwater pumping to satisfy water deliveries to senior water rights dedicated to off-stream habitat restoration. Kansas Department of Wildlife and Parks (KDWP) obtained two large appropriative senior water rights to deliver water to Cheyenne Bottoms, an important migratory bird stopover point. Decades of new permits for surface water diversions and pumping of alluvial groundwater in the Walnut Creek basin eventually limited deliveries to the KDWP rights. As a result, KDWR decided to protect KDWP's rights by initiating an IGUCA process in Walnut Creek (Peck 2003).

Prioritization of particular uses

Kansas law establishes a priority of uses that is secondary to the seniority system. In this hierarchy of uses, domestic and municipal water uses are the first two priorities, followed by irrigation, industrial, industrial, recreational, and power uses.

Ability to Account for Water

Water Use

Each owner of a water right or permit to appropriate water is required by law to submit a complete and accurate water use report every year. The annual report must be delivered to the KDWR Topeka office by March 1st of every year, according to Kansas law (K.S.A. 82a-732 of the Kansas Water Appropriation Act). Domestic water rights are excluded from annual water reporting requirements.

Annual reporting by surface and groundwater users includes amount diverted, acres irrigated, crops grown, and irrigation system type. Estimates of use are calculated only when needed for site-specific analysis.

Penalties for failure to report annual water use are an important aspect of compliance and key to creating a reliable water use database. When annual water use reporting became part of state law in 1989, and fee penalties for non-compliance were established, the compliance rate grew from 60 to 93 percent. According to the law, filers of incomplete reports are subject to a civil penalty of $250 per water right permit. Individuals who knowingly submit water use reports with false information are subject to a class C misdemeanor and a fine up to $500 and/or 30 days in county jail.

Standardized water use reporting forms (preprinted with a name, address and water right file number) are completed by water users and mailed to DWR. In 2015, the first year of open online reporting, 1,507 of about 32,000 water rights reported via the online tool. If a flow meter is required by law, then meter readings and the metered quantity must be reported. More than 90 percent of active points of diversion are metered. Almost all of Kansas is now metered on active diversions, and by the end of 2016 nearly 95% of nondomestic active diversions will be metered (Kansas Department of Agriculture 2015).

Preliminary data are entered into a database and each report is reviewed by a state employee who compares the report to water-right face value (called "coding"). Each of the state's 48,100 points of diversion undergoes a preliminary analysis by environmental scientists, coding the data for further categorization. DWR environmental scientists investigate questionable data by contacting water users directly.

Annual water use reporting is a very valuable database for Kansas water management. Details from the water user reporting database are used for:

- Certifying water rights,
- Interstate compact administration,
- Water banking,
- Compliance and enforcement activities,
- Technical report preparation and modeling,
- Monitoring groundwater levels,
- Local groundwater management district water use,
- Identifying candidates for technical assistance, and
- Water management and basin planning.

System Analysis and Management

Surface data monitoring is not collected or stored by KDWR. Surface monitoring is mostly conducted by federal agencies. The United States Geological Survey (USGS) provides "real-time" information on stream stage and streamflow, water-quality, and groundwater levels for over 7,000 sites. Reservoir data can be also obtained from USBR and USACE.

Surface management is conducted at the federal level by USBR and USACE. To assist with decision making, hydrologic computer models have been developed for several river-reservoir systems: Neosho, Marais des Cygnes, Verdigris, Walnut, Smoky Hill, and Kansas rivers. These models incorporate the rules that govern operations of the systems, including reservoir regulation manuals, reservoir level management plans, assurance district operations agreements, and other agreements between federal, state, and local entities.

Groundwater monitoring wells in Kansas are collaboratively monitored by DWR and KGS. Approximately 90% of these measured wells are in the High Plains aquifer. The water-level measurement program provides a regional view of water levels in central and western Kansas. Regulatory agencies use this information to determine water appropriations, GMDs use it to better understand area status and make management decisions, and the public uses it to make decisions about where to drill wells.

Many modeling efforts have been conducted at the state level to ensure adequate groundwater management. Detailed groundwater models have been developed for the most sensitive areas of the state: the Northwest Kansas Groundwater Model, the Groundwater Flow Models of the Upper Solomon Subbasin, the Southwest Kansas GMD3 Groundwater Model, the Big Bend GMD5 Model, the Numerical Model of the Middle Arkansas Subbasin, and the Groundwater Flow Model of the Ozark Plateau Aquifer System. All studies were conducted using MODFLOW modeling software.

Surface-groundwater interaction is implicitly included in all groundwater modelling efforts, mostly to account for reductions in streamflows because of groundwater withdrawals. IGUCAs are primarily used for managing the impact of groundwater withdrawals on surface water stream flows, an example of conjunctive management.[76]

Kansas has two recent statewide water resource plans in 2009 and 2014. The 2014 Plan is roughly based on a series of water demand assessments for different beneficial uses of water and a series of water supply assessments for different water sources. The plans are mostly summaries of historical and current data on water demand and supply (mostly based on reservoir inflows) (Kansas Water Office 2014).

Allocation During Periods of Scarcity

Curtailment does not happen every year. However, recent drought conditions necessitated curtailments of hundreds of water-right holders in 2011 and 2012 (Walton 2012). As of May 2015, MDS administration was not occurring anywhere in the state, with restrictions having been recently lifted from three streams. MDS orders are issued on designated streams when actual streamflow drops below established baseflow thresholds for seven consecutive days. MDS requirements are only established on 23 streams in Kansas, representing a critical gap in monitoring and protection of instream beneficial uses.

The legislature recently created a tool that may make irrigators more resilient during periods of hydrologic scarcity. The "Multi-year Flex Account Program" (MYFA) is a voluntary program for vested and certified groundwater rights in good standing that authorizes them to use more water than their water right allows. It is a temporary increase that amounts whichever is the larger: either five times the right's annual average use, or five times the county's net irrigation requirement for corn multiplied by the acres irrigated, multiplied by 110 percent. Converting a water right to this temporary permit allows the water-right holder to exceed their annual authorized quantity in any year but restricts the total pumping over the 5-year period. Those who enroll in MYFAs must

[76] This is especially true in the Walnut Creek and Arkansas River Valley IGUCAs.

meter and record pumping monthly. MYFA is still a relatively new program and the success of the program has yet to be determined. MYFA gives irrigators additional flexibility in how to put their water to use, allowing them to pump more water than their annual limit in extreme drought circumstances.

Public Information Provision

Water Rights

DWR and KGS created the "Water Information Management and Analysis System" (WIMAS) program (Wilson et al. 2005). Water rights can be searched by source (surface or groundwater), county, township, range, section, coordinates, use type (domestic, municipal, industrial, recreation, irrigation, or stockwater), or by water right file number. It provides information on the point of diversion, authorized quantity and rate of use, and actual water usage reported. The information presented for annual water use reporting includes amount diverted, acres irrigated, crops grown, and irrigation system type. Information on water use reporting is provided with a lag of a year or more. The water rights and the results can be displayed on a map. However, users of this platform cannot determine if a water right has used more water use than allocated.

System Monitoring

A summary of surface water availability is found in the annual "Basin Field Summaries" prepared for some parts of the state. These compile historical precipitation, irrigation, streamflows, groundwater levels, pumping estimates, and other information.[77] Nonetheless, the 2010 report is the most recent that can be found online. For more updated streamflow data, information can be obtained from the USGS National Water Information System (NWIS), which provides information for 210 sites, including gage level, discharge, suspended sediments, and groundwater levels. They also provide stations with data on MDS.

KDHE has an online platform showing location of waterbody stations and stream stations (permanent and rotational), with information for water quality, specifically regarding biological and chemical aspects. Most recent data published through the platform is from before 2006.

For specific information on groundwater, DWR and KGS developed an online platform called WIZARD Water Well Levels database. Wells can be located by county, township, range, section, GMD, coordinates, or by water right file number. The results provide general well site information, including pictures of the well, construction data, and water level measurements, including the date that levels were measured and the measurement method used. The information is provided with a couple of months of delay.

The Water Well Completion Records (WWC5) Database provides information from records submitted by water well drillers including location, type, use, casing, nearest source of contamination, and a lithologic log. It includes information on well depth and static water level at the time of construction. Wells can be located by county, township, or section. The information can be displayed in a map, and is updated monthly.

The Kansas Master Groundwater Well Inventory is a central repository that imports and links together WWC5, WIMAS, and WIZARD into a single online source. The information is posted with a couple of months' delay.

Allocation During Scarcity

A monthly Climate and Drought Update Summary is posted online. Information on drought levels and conditions are presented, including streams where MDS are in effect, and where drought declarations have been made. It also

[77] For example, see Kansas Department of Agriculture 2011.

shows areas that are under drought watch, drought warning, and drought emergency. The report compiles climate metrics like Palmer Drought Severity Index (US Drought Monitor), regional temperatures (KSU Weather Library), regional precipitation (KSU Weather Library), monthly outlook temperatures and precipitation (NOAA, KSU Weather Library). Water supply conditions are summarized as well, including: reservoir inflows and outflows, percent of conservation pools in federal reservoirs (KWO), lake water safety, streamflow conditions by percentage of historical flows (USGS), and ongoing curtailments based on MDS. Soil, crop, and vegetation conditions are summarized: vegetation stress (photosynthetic activity) data are acquired by Kansas Applied Remote Sensing Program (KWO, KGS). Soil moisture data from the Climate Prediction Center at NOAA is also summarized and compared to historical averages. The monthly report also presents Crop Moisture Index data provided by USDA through the Weekly Weather and Crop Bulletin.

Water Transfers

The Kansas Water Marketing Program shows where water storage is available for short-term purchase during drought through can provide information on prices. Nonetheless, instead of determining the price for water for each basin, they estimate a uniform rate and charge the same rate throughout the state.

To help develop the water markets, there is an initiative promoting water banks, established through the Kansas Water Banking Act of 2001 (updated in 2012). As mentioned above, the CKWBA has been created to provide services to facilitate the sale or lease of water rights solely in GMD #5. CKWBA's website has information on transactions, with data on the volumes and prices traded.

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Nebraska

Highlights

- Water management is the collaboration between the Nebraska Department of Natural Resources (NDNR) and the 23 Natural Resource Districts (NRDs). These districts were established to conserve, protect, develop, and manage natural resources. Water management responsibilities include flood prevention and control, groundwater management for both quantity and quality, pollution control, drainage improvement, management of fish and wildlife habitat through instream flow protection, parks, and forestry management.
- Nebraska manages water conjunctively. In order to evaluate long-term sustainability of surface and groundwater withdrawals in each basin, (NDNR annually assesses the water balance of major river basins to determine the need for closer conjunctive management of surface and hydrologically connected groundwater. Curtailments of surface water and allocation of groundwater—and other regulatory and non-regulatory actions—may apply in drought situations.
- The state has been implementing a process of integrated water management since 2004 and relies extensively on a variety of groundwater and surface water modeling frameworks to support this water planning. Examples of this modeling framework include model linkages such as: a watershed model to assess the soil water balance (CROPSIM), a groundwater model (MODFLOW) and a surface water operations model (STELLA), among others.
- Forecasting is performed annually in highly monitored basins like the Republican and Platte River basins. These forecasts help NDNR and local water users anticipate the possibility of under-allocation as defined by terms of a decree or compact as well as opportunities for conducting conjunctive management operations to acquire excess flows for intentional groundwater recharge.

Introduction

Nebraska's climatic conditions vary greatly from one end of the state to the other due in part to significant drop in elevation from west to east. There is an elevation change of 4,584 feet in the 430 mile distance from Panorama Point in the west, to the southeast corner of the state. In Scottsbluff to the west, the average maximum and minimum temperatures range between 63.6 and 34ºF. Here, the humidity is very low, with an average annual precipitation of less than 16 inches, falling mostly during spring and summer, and an annual snowfall of 43 inches during winter. On the other hand, in places like Omaha in the east, the maximum and minimum temperatures range between 62 and 40ºF on average. The precipitation is higher, with a mean of 31 inches of annual rainfall, mostly during summer months.

Nebraska borders the Missouri River. The river drains from nearly one-sixth of North America, using about 529,400 square miles. Nebraska is also home to the Platte River (formed by the confluence of the South Platte and the North Platte Rivers) which drains the eastern Rocky Mountains near the Continental Divide. When combined with the North Platte, the river stretches 990 miles with a drainage basin of 86,000 square miles. Nebraska also has a massive supply of groundwater. The High Plains Aquifer underlying parts of eight states is most abundant in Nebraska.

This groundwater availability has been essential to the success of agriculture in the state. The main crops produced are corn, soybeans and wheat. With 9 million acres used for corn production in 2014, Nebraska is the third largest producer of corn in the country. The water is also vital for the state's livestock and dairy production, mainly based on beef and pork production. Nebraska leads in every aspect of beef production: cow/calf, backgrounding, corn growing, cattle feeding and processing.[78]

Principal demographic, economic and water-related indicators in Nebraska

Population (in 2010):	1.83 million
GDP (in 2010):	$90 billion
Agriculture Value Added:	10.18% of GDP
Annual Precipitation:	23.59 inches
Total Water Withdrawals:	9,010 TAF
Urban Use:	5%
Agricultural Use:	72%
Thermoelectric Use:	22%
Other uses:	1%
Surface Water:	23%
Groundwater:	77%
Desalination	1%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight agencies

NDNR is the principal agency in charge of administering surface water rights, complying with interstate legal obligations, enforcing statutory requirements for water management and planning practices, and providing technical support for the identification of local water management issues at several scales for both surface and groundwater sources. NDNR's five Field Offices administer surface water uses in heavily administered reaches through daily allocation of water by right monitoring streamflow records, initiating curtailments (referred to as "closures"), among other management functions. NDNR maintains the definitive database of surface water right holders in the state. NDNR also conducts the Annual Evaluation of Availability of Hydrologically Connected Water Supplies or Fully Appropriated Basin (FAB) evaluations to determine appropriation status of surface and hydrologically connected ground water, along with executing administrative and management responses to over-allocation in collaboration with local NRDs.

Nebraska is divided into 23 NRDs, which were established to conserve, protect, develop, and manage natural resources. Water management responsibilities include flood prevention and control, surface and groundwater supply management for beneficial uses, pollution control, drainage improvement, management of fish and wildlife habitat, parks, and forestry management. NRDs are the state's preferred regulators of groundwater. Established in 1972, their administrative boundaries conform with major river basins of the state. They are

[78] Unless otherwise noted, the source materials for the introductory section is Nebraska Department of Agriculture 2015.

governed by locally elected boards of directors. NRDs get most of their operating funds from local property taxes (usually about 1 to 2 percent of all property taxes collected in a county). Local NRDs have enforcement responsibilities over groundwater administration and rights. Rules and regulations can differ based on local circumstances and management issues. In some cases, groundwater management controls are strictly enforced by an NRD. In the opinion of some regional experts, the public groundwater resources managed by NRDs may be the most tightly managed groundwater resources in the western US The NRDs actually have the ability to "take" and/or regulate groundwater pumping rights from irrigators without compensation or dispute, and have exercised this on several occasions. Usually this type of taking is in response to an egregious violation like bypassing flow around a measuring device. NRDs work closely with the NDNR on developing appropriate management responses to overdraft and over-allocation of surface and groundwater. The relationship is also partially hinged on the threat of losing local control due to state intervention. NRDs generally carry out groundwater overdraft mitigation and management responsibilities.

Water supply operations agencies

The Central Nebraska Public Power and Irrigation District ("Central") delivers irrigation water to farmers in south-central Nebraska. Water structures include several reservoirs, dams, and irrigation distribution systems. The largest reservoir is Lake McConaughy, which has 1.7 million acre-feet of capacity. Central serves irrigation water directly to 113,000 acres of farmland and delivers water to irrigation districts serving more than 110,000 acres along the North Platte and Platte Rivers. Central's distribution system also provides groundwater recharge that contributes to water supplies for irrigation, municipal, and industrial users. Central also maintains an Environmental Account (EA) in Lake McConaughy for providing beneficial instream flows for endangered species in the Platte River. The EA is managed by US Fish and Wildlife Service (USFWS) according to an annual plan, but Central stores and releases the water according to the EA's schedule and upon request.

US Army Corps of Engineers operates the Harlan County Dam, a storage feature of the Bostwick Division reservoir complex within the Republican River Basin. Most of its 814,000 acre-feet of water storage capacity is used for flood control, though about 314,000 acre-feet are allocated to irrigators.

US Bureau of Reclamation (USBR) operates and maintains several smaller dams and lakes in Nebraska, of which some water is applied to irrigation uses. These complexes include Enders Dam and Reservoir, Trenton Dam and Swanson Lake, Red Willow Dam and Hugh Butler Lake, and Medicine Creek Dam and Harry Strunk Lake within the Republican River Basin. USBR also operates the Glendo Reservoir, a multi-purpose reservoir that provides about 40,000 acre-feet of water annually for irrigation in Wyoming and Nebraska. Pathfinder reservoir in Wyoming is a 1 million acre-foot capacity reservoir operated by USBR, providing irrigation water to 226,000 acres of farms in Wyoming and Nebraska. Other USBR reservoirs include the Calamus and Davis Creek reservoirs in the Loup River basin and the Merritt and Box Butte reservoirs in the Niobrara River basin.

Several types of local entities provide water to users, including community water systems and irrigation districts.

Funding

The NDNR appropriated $37.4 million for the FY2015-2016. $16.5 million came from the state's General Fund, and $20 million was sourced from Natural Resource Commission Cash Funds. Cash funds are dedicated funding sources for financing specific agency activities, loan programs, and competitive grant programs. The Nebraska Natural Resource Commission is responsible for administering several cash funds that support NDNR and local projects including: the Natural Resources Water Quality Fund, Resources Development Fund, Small Watersheds Flood Control Program, Water Sustainability Fund, Water Well Decommissioning Fund, Interrelated Water Review Board, and the Erosion and Sediment Control Program.

Local NRDs are funded primarily through local property taxes. Their collective annual budget is about $250 million.

Legal Framework

Water rights

Nebraska has administered surface water rights according to the prior appropriation doctrine since 1895. NDNR is currently responsible for executing these oversight functions, along with administration of instream uses for recreation, fish and wildlife, groundwater recharge projects for public water suppliers, and diversions by groundwater irrigation wells located within 50 feet of the bank of a surface water channel. Nebraska also recognizes riparian water rights, though only stock riparian water rights remain as surface water rights on all of its rivers have been adjudicated (Kelly 2010). Surface water diversions for irrigation, hydropower, industrial use, municipal use, domestic use, storage, and other uses are required to obtain a natural flow permit from NDNR. Permits are issued a priority date based on the date of filing. Permits have several common attributes like specified points of diversion, amount of water allowed under the permit, and location of use. The amount of water allowed under a permit is usually defined in terms of diversion rate and the total annual volume that can be diverted. Most permits for irrigation specify a three acre-feet per acre limitation. Measurement of diversion rates and volumes is done at the point of diversion, not the place of use. In filing for a diversion permit, permittees must specify land parcel(s) where the water will be used. Any change in the location of use requires NDNR approval. Permits may be subject to other conditions as well, including the time windows in which diversion is allowed under the permit. Nebraska is a "use it or lose it" state—failure to use water under a permit for more than five consecutive years may result in a cancellation of a water permit.

In order to evaluate long-term sustainability of surface and groundwater withdrawals in each basin, NDNR annually assesses the water balance of some major river basins to determine the need for closer conjunctive management of surface and hydrologically connected groundwater.[79] NDNR determines appropriation levels in each basin, which are designated as either under, fully, or over-appropriated. According to the guidelines established in 2004, NDNR may deem a basin's water supply insufficient for further appropriations after considering "the impact of the lag effect from existing groundwater pumping in the hydrologically connected area that will deplete the water supply within the next 25 years." [80] This is evaluated by projecting the ability of surface flows to meet on average 85 percent of the annual crop irrigation requirement for junior natural flow irrigation permits between May 1st and September 30th or 65 percent of annual crop irrigation requirements from July 1 through August 31st for a junior permit holder (the "65/85 rule"). In other words, the NDNR uses direct measurements and modeled estimates to characterize the effect of pumping groundwater on forecasted surface water flows. Limits on new appropriations of surface and connected groundwater will be enacted if existing junior surface water rights cannot be reliably met in that future scenario (according to the 65/85 rule). Basins categorized by the state as fully or over appropriated are subject to a combination of state and local regulations that limit additional appropriations of surface and hydrologically connected groundwater.

NRDs are also required to develop Integrated Management Plans (IMPs) as a result of a determination that a basin is fully or over-appropriated. IMPs are the principal vehicle for defining management actions for mitigating water supply imbalances and specifying the rules and regulations within local NRD boundaries. Nebraska subscribes to

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[79] Only non-fully appropriated basins and basins that haven't been assessed within four years are investigated.
[80] Groundwater that is hydrologically connected to surface water is defined as an in which "pumping of a well for 50 years will deplete a river or baseflow tributary thereof by at least 10 percent of the amount pumped in that time" (called the "10/50 area"). See definition of Fully Appropriated basin in Nebraska Administrative Code Title 457, Chapter 24, Section 001.01A.

a mixture of common law and detailed statutory provisions for the administration of groundwater rights. The state's approach to groundwater rights is founded on a "reasonable and beneficial use," with overlying provisions of the Nebraska Ground Water Management and Protection Act (GWMPA), and a provision that allocations of groundwater during times of scarcity will be done according to the correlative rights doctrine. The GWMPA delegated primary responsibility for groundwater administration and management to the NRDs, which were directed to develop groundwater management plans subject to the approval of NDNR. NRDs have the legal authority to declare groundwater management rules like pumping restrictions, temporary moratoria on new wells, measurement of groundwater use, and reduction of irrigated acreage. Allocation of groundwater within an NRD generally provides for an equal amount of water per acre throughout the district, with the potential for variations based on geological or hydrological circumstances. Within NRDs, irrigators may certify their groundwater entitlement (number of irrigated acres) to ensure that producers who have made investments in irrigation systems can continue to irrigate their existing acres despite existing or expected regulatory actions. This can be especially beneficial to irrigators when NRDs impose stays on new water wells and pumping limits. Certification is the process whereby the beneficial uses of groundwater from a regulated well are identified, recorded, and approved by an NRD. If uses are to be monitored, quantified, and controlled then the uses must be identified, verified, and certified by the district.[81]

Water trading

Interbasin transfers of surface water are administered by NDNR as an application to appropriate water (NRS 46-233). The Legislature defined seven factors specific to interbasin transfers that NDNR must consider, including investigation of adverse impacts as a result of an interbasin transfer, foreseeable beneficial uses in the place of origin, and alternative sources of water available to applicant and basin of origin.

Within NRDs, irrigators may certify their groundwater entitlement (number of irrigated acres) to ensure that producers who have made the investment in their irrigation systems can continue to irrigate their existing acres despite existing or expected regulatory actions. After the certification, local NRDs may decide to allow pooling of certified irrigation acres, which would allow irrigators to sell "groundwater rights" to other irrigators/users. This could create a local market for certified uses and acres through the NRD. This type of transfer and exchange program is being operated in by the Central Platte and Lower Loup NRDs.

The Municipal and Rural Domestic Groundwater Transfers Permit Act allows NDNR to grant and administer permits to public water suppliers: 1) to locate, develop, and maintain groundwater supplies through water wells or other means and to transport water into the served area and 2) to continue existing use of groundwater and the transportation of groundwater into the area served. Permittees under the Municipal and Rural Domestic Groundwater Transfers Permit Act are exonerated from the common-law prohibition against the transfer and transportation of groundwater.

Permits are required for the transfer of groundwater from overlaying land for large industrial uses, geothermal uses, out-of-state uses and water well spacing requirement violations. NDNR is responsible for approving or denying these permits as well as municipal and rural domestic transfer permits.

Legal treatment of environmental water use

Nebraska's legislature formally recognizes the benefit of instream flows for fish, recreation, and wildlife. Currently, Nebraska only has three instream flow rights: two on the Platte River from Overton, NE to the

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[81] Unless otherwise noted, the source material for this paragraph is Kelly 2010.

confluence with the Missouri River, the other on Long Pine Creek in the Niobrara River Basin. However, efforts are underway to establish instream flow protection in a large portion of the Niobrara River basin.

NDNR reviews and grants applications for instream flow uses according to the statutory provisions. This determination considers several factors, including the availability of a stable and reliable flow regime to satisfy the instream appropriation over the period requested. Only the Nebraska Game and Parks Commission and NRDs are allowed to hold instream flow water rights. Public water suppliers may indirectly support instream flows through a permitted recharge project.

Prioritization of particular uses

Surface water rights are principally prioritized by seniority during periods of scarcity, while groundwater rights are allocated correlatively. Nebraska statues also define a secondary standard of priority based on type of use. Domestic purposes have preference over all other uses. Irrigation uses have priority over manufacturing purposes.[82]

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

NDNR is required by the Ground Water Management and Protection Act (46-713) and Regulation 457 of the Nebraska Administrative Code to describe the nature and extent of surface and groundwater uses in each river basin, sub-basin, or reach. Water usage information is based on a variety of sources, including direct measurement and estimation via models.

Surface water diversion is only metered in certain basins and stream reaches as necessitated by interstate agreement or other water administration rules. The Director of DNR has the ability to impose metering and reporting requirements on any surface water user. These orders generally require all appropriators in a basin to file a diversion report by the end of the year (especially in the Platte and Republic River basins). Those required to report to the NDNR report their total annual volume diverted. Irrigators that are required to report must describe crop types, number of acres per each crop for land that is appurtenant, and the type of irrigation delivery system for each crop type. In highly litigated reaches of Nebraska's rivers and streams, the measuring and reporting requirements are tightly enforced by NDNR. NDNR estimates usage for users that don't measure and report using models. Local NRDs collect and store limited surface water use data for their own planning purposes and for tracking compliance with compacts.

Current Nebraska law requires the registration of all groundwater wells in the state. Several attributes of registered wells are stored in the database, including GPS coordinates and depth to water. Groundwater pumping levels are estimated by models for use as inputs into basin water balance models (Western States Water Council 2014). The only groundwater pumping data collected directly by NDNR are groundwater transfers (transported from the site of pumping to the place of use) for municipal and industrial uses.

According to the Groundwater Management and Protection Act, local NRDs play a significant role in groundwater rights administration and have the authority to require groundwater measurement and reporting from all pumpers. NRDs have the autonomy to set rules as they see fit according the management objectives defined by the Integrated Management Plan (IMP). Where NRDs and NDNR have collaborated to develop an IMP, many of

[82] The same system of prioritization is described in Article XV, Section 6 of Nebraska's Constitution.

these plans have required careful allocation of groundwater along with measuring and reporting of groundwater withdrawals. NRDs collect this data and report to NDNR annually (Western States Water Council 2014). In 2014, just over half of NRDs had established a groundwater allocation rule and only four NRDs did not have water use reporting rules. All of this information is generally shared between NRDs and NDNR during the integrated management planning process. NDNR estimates that approximately 60 percent of groundwater irrigated acres will be under a metering requirement by 2018.

Indirect measurement of water use (top-down approach)

Indirect estimation of water use at the field level is done to complement diversion and groundwater use measurements for modeling and planning purposes. The University of Nebraska–Lincoln developed a computer simulation model, CROPSIM, to compute the daily water balance for irrigated corn and the net irrigation water requirement for an array of weather stations across the state. CROPSIM incorporates weather station data, land use, soil parameters, and crop water demands to estimate recharge, runoff, evapotranspiration (ET), and pumping demands through time. Computations with the CROPSIM program were used to generate the map of net irrigation water requirements for corn grown on a fine sandy loam soil, and are also used in integrated modeling of water resources.

Remote sensing technologies are also being used experimentally in Nebraska to assess water use at the field level. “Mapping EvapoTranspiration at high Resolution with Internalized Calibration” (METRIC) is an energy balance model that uses satellite image-data to compute a complete radiation and energy balance, sensible heat, and ET for each pixel of the satellite image (Allen et al. 2007). In a joint effort, the Idaho Department of Water Resources and the University of Idaho used Landsat data for the project with the goal of developing METRIC into an operational tool for administering Idaho’s water. METRIC is used in some NRDs in Nebraska—like in the Central Platte NRD—to assess water use at the field level, comparing its results with other traditional soil models like CROPSIM (Woodward n.d.).

System Analysis and Management

NDNR operates and reports on 85 of the 187 stream gages in Nebraska. A dozen stream gages are cooperatively managed with USGS, and the USGS operates the remaining streamgages. NDNR is also in charge of 21 lake and reservoir gages and 100 canal and return flow (drainage) gages. NDNR stores administrative data on water volumes assigned to permits in a surface water rights database. Surface water diversion is only metered in certain basins and stream reaches as necessitated by interstate agreement or other water administration rules.

Current Nebraska law requires the registration of all water wells in the state. Several attributes of registered wells are stored in the database, including well location and depth to water. Groundwater levels are measured at some monitoring wells annually or semi-annually by local NRD staff, the University of Nebraska-Lincoln and USGS (Western States Water Council 2014). NDNR is funding local NRD projects to improve groundwater use data collection, like the recent addition of 80 telemetry measuring devices on groundwater wells in the Central Platte NRD (along with 20 surface water stations). Some groundwater level data is available for the public through an online portal. NDNR does not currently manage any groundwater level monitoring wells.

Nebraska took big steps in recent years to improve water modeling and management at different levels. NDNR is considering a transition from a fairly simple analytical method (partially based on the Jenkins Method) for determining basin water balance to a more sophisticated method built on region-specific models using integrated modeling. While the Jenkins method relied heavily on NDNR administrative data (surface water permits and groundwater well registration data), the new integrated modeling framework is based on Basin Water Supply and Total Demand estimation concepts. This modeling framework is formed by the integration of up to three models:

a watershed model to assess the soil water balance (CROPSIM), a groundwater model (MODFLOW) and in some cases a surface water operations model (STELLA). So far, the Upper Platte River Basin, the Niobara River, Loup River Basin, Blue River basins, and Upper Elkhorn River Basin have been modeled (Nebraska Department of Natural Resources 2015). In the remaining basins, simpler models are still being used while model development is being pursued. To run the regional water balancing models, NDNR first collects information from several monitoring networks, including the USGS National Groundwater Monitoring Network, stream gage networks (USGS, NDNR), weather stations (High Plains Regional Climate Center), land use data (CALMIT), and soil data (SSURGO and NRCS).

The hydrologic results of the different modeling frameworks are shown in the NDNR website INSIGHT. The INSIGHT website provides various levels of data and information in regard to water quantity within the state. Basin and sub-basin summaries include: 1) the streamflow water supplies available for use, 2) the current amount of demand on these supplies, 3) the long-term demand on these water supplies based on current uses, 4) the projected long-term demand on these water supplies, and 5) the balance between these water supplies and demands. Additionally, INSIGHT provides access points to the data, hydrologic tools, supporting documentation, and models necessary to perform the calculations and analyses.

Allocation During Periods of Scarcity

Forecasting is performed annually in highly monitored basins like the Republican and Platte River basins. These forecasts help NDNR and local water users anticipate the possibility of under-allocation as defined by terms of a decree or compact. These metrics might include snowpack, precipitation, and reservoir levels on the Northern Platte River which relies heavily on runoff from Wyoming. The National Drought Mitigation Center is housed at the University of Nebraska at Lincoln.

NDNR and partner research institutions collect hydrological data with relatively high frequency for purposes of day-to-day allocation of water resources and hydrological modeling. However, Nebraska does not have a statewide drought decision-making framework. Instead, drought response and adaptation actions are written into interstate water sharing agreements (like the Republic River compact) or Integrated Management Plans (created by NDNR/NRDs). Some NRDs use depletion in local groundwater levels as triggers for more intense groundwater controls.

NDNR reports to issue “closures” (curtailments) to hundreds of surface water users each year, and thousands of surface water users during dry years. There are two principal types of allocations during periods of scarcity: allocations through the prior appropriation system and limits on extraction as a result of annual basin appropriation level determinations.

NDNR actively manages surface waters covered by decree, agreement, and compact. In basins governed by interstate water sharing agreements, specifically the Platte and Republican River basins, NDNR uses real-time monitoring of surface water resources to evaluate allocation to water rights holders, calls to accommodate senior water rights calls, and curtailment actions. A good example of this monitoring is on the Platte River, a heavily litigated river, for which daily accounting is done to determine allocations. Local NDNR field offices are responsible for day to day monitoring of streamflow availability and allocations in these areas. Real-time streamgaging is also collected in other areas of the state, however, such data is typically used in a more reactive mode when NDNR is responding to senior water rights calls on junior users. NDNR operates and reports on 85 of the 187 streamgages in Nebraska. A dozen streamgages are cooperatively managed with USGS, and the USGS operates the remaining streamgages. NDNR is also in charge of 21 lake or reservoir gages and 100 canal and return flow (drainage) flow gages.

NDNR uses streamgage data, groundwater level data, weather data, soil, and land use data (and other administrative data from surface water rights records and groundwater well registration database) to calculate annual water availability of hydrologically connected water supplies in basins not already declared fully or overappropriated. The Fully Allocated Appropriated Basin reports are required annual assessments of the expected long-term availability of hydrologically connected water supplies, including every river basin, sub-basin, or reach that has not previously been determined to be fully or overappropriated or for which a status change has not occurred within the previous four years.

In general, determination of whether or not a basin is fully appropriated is based on whether the current uses of hydrologically connected surface and groundwater in the basin, subbasin, or reach cause or will cause any of the following: 1) the surface water supply to be insufficient to sustain over the long term the beneficial purposes for which existing natural flow or storage appropriations were granted and the beneficial purposes for which, at the time of approval, any existing instream appropriation was granted, 2) the streamflow to be insufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the river or stream involved, or 3) reduction in the flow of a river or steam sufficient to cause noncompliance by Nebraska with an interstate compact or decree, other formal state contract or agreement, or applicable state or federal laws. Details of this evaluation are also described in the water rights section of this case study report.[83]

When a basin, subbasin, or reach is determined to be fully appropriated, stays on new uses of groundwater and surface water are automatically imposed. These stays are specified and enforced by Integrated Management Plans (IMPs) that are a joint effort between NDNR and the NRDs. These plans must provide an approach for balancing water uses and water supplies. IMPs can use several mechanisms to gradually meet this balance, through voluntary and regulatory controls like incentives, allocation of groundwater withdrawals, rotation of use, and reduction of irrigated acres.

Public Information Provision

Water Rights

NDNR stores administrative data on water volumes assigned to permits and can be found through the Surface Water Rights Data Retrieval platform. The information provided includes section, township and range, county, water division, use, source, priority date, appropriation rate and appropriation number. Information is updated weekly. Also, users can subscribe to receive email or text updates. Nonetheless, information on the actual use of water or on last year's use report is not available online.

A website publicizes public hearings regarding temporary stays on new appropriations or for new surface water appropriations. There is also a website that shows all surface water applications filed the month before. Another platform shows orders issued on applications for surface water appropriations. It is updated according to the activity that each basin has, which currently requires weekly or bi-monthly reports. Finally, there is a website for information about the notices of preliminary determination of non-use, for unused water rights that are at risk of being cancelled.

For groundwater rights, an interactive map can be found online with administrative information on all wells. It provides data regarding section, township and range, county, NRD, use, irrigated acres, owner name and address, as well as the registration number. Updated information on certain groundwater wells levels or pumping can be

[83] For more detailed information on administrative rules for determining basin appropriation status, read Nebraska Administrative Code Title 457, Chapter 24, 001.01A.

found on the Registered Groundwater Wells Data Retrieval interactive map. The information is updated daily and shows acres irrigated, gallons/minute pumped, static level, pumping level, pump column diameter, pump depth and well depth.

System Monitoring

NDNR provides data on real-time streamgages across the state through an interactive map. It displays information on stream and canal gages operated by the NDNR and USGS that are currently active. The core network consists of approximately 110 continuous streamgages and 120 canal gages. It provides daily and instantaneous information on discharge and stages, as well as weekly, monthly or annual data.

Groundwater levels are measured at some monitoring wells annually or semi-annually by local NRD staff, the UNL and USGS. NDNR is funding local NRD projects to improve groundwater pumping information, like the recent addition of 80 telemetry measuring devices on groundwater wells in the Central Platte NRD (along with 20 surface water stations). Some groundwater level data is available for the public through an online portal. NDNR does not manage any groundwater level monitoring wells.

Regarding climatic information, the Nebraska Rainfall Assessment and Information Network (NeRAIN) is a community built platform with precipitation measurements from all across the state.

Also, different models have been developed for regions of the state and results are available online. They provide information on climatic conditions such as average precipitation and evapotranspiration, water availability such as streamgages and groundwater recharge information, as well as information on topography, transmissivity, and land use. For example, the Blue Basin Model was developed for the southeastern area, the CENEB Model was developed for central Nebraska, and the COHYST Model for the south-central area.

Allocation During Scarcity

NDNR conducts an annual Fully Appropriated Basin report, collecting data from local NRDs and other sources; it is available to the public online. This annual evaluation is available for every river basin, sub-basin, or reach that has not previously been determined to be fully or over-appropriated. The reports include public notices and other information received from interested parties, rates and volumes of stream depletion by wells, net irrigation requirements, development of groundwater irrigated acres per well, as well as other assumptions used. These reports can also be found through an interactive website map in the Surface Water viewer. It indicates areas where current water restrictions are in place.

A website was provides information on curtailments for the 1-B Republican River; it has a two-year lag. For temporary stays requested to be placed on surface water appropriations, another website provides the information with the NRD affected and the dates. The website has only one restriction published at the time this report was written. Moratoriums are also published on a website, but the site hasn't been updated since 2014.

Nebraska's drought response and adaptation actions are written into some compacts (like Republic River compact) or Integrated Management Plans (created by NDNR/NRDs) that can be found online.

Water Transfers

The state approves or rejects surface water transfers in accordance with specified statutory criteria. Very little data is available regarding transaction costs for water trades between users. NRDs also monitor and administer trades for certified irrigated acres. While hundreds of these trades have been completed across the state, these are largely transactions between private land owners, thus little data related to the costs are available. The CPNRD and NDNR have recently collaborated on a temporary groundwater transfer market that will be implemented in a pilot phase in the spring of 2016. This temporary water market will allow for trades between agricultural water users as well as agricultural water users and instream water users. This new market is aimed at creating an additional non-regulatory tool to provide streamflow mitigation needed to support requirements established in the Platte River Recovery and Implementation Program.

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New Mexico

Highlights

- New Mexico is an arid state that gets approximately half of its water from the Rio Grande basin and the other half from in-state basins such as the Rio Pecos. As most major reservoirs are operated by federal agencies, the state is in charge of the measurement, appropriation, and distribution of water at the local level.
- New Mexico is a party to eight interstate stream basins. To ensure basin compliance, Interstate Stream Commission staff evaluate, review, and implement projects in New Mexico and analyze streamflow, reservoir, and other data on the stream systems.
- The Active Water Resource Management initiative defines the protocols and tools available to the Office of the State Engineer, District Office staff, and water masters to efficiently allocate water during periods of scarcity.
- The Water Rights Abstract Bureau collects documents and organizes information for the New Mexico Water Rights Reporting System database where general public and water resource managers can access water right data online. The information includes electronic images of water right documents and downloadable well reports, driller license reports, point of diversion reports, and subdivision reports.
- The New Mexico Office of the State Engineer/Interstate Stream Commission maintains a network of stream, *acequia*, ditch and well monitoring sites that electronically transmit data via radio and satellite telemetry, and stores the data in a database. These real-time water measurement data are available for each active gage/well shown on select basin maps.

Introduction

New Mexico has a mild continental climate with low precipitation and a large annual and daily temperature range. It has numerous mountain ranges and canyons, including the Rocky Mountains coming from the north, giving the state an average elevation of about 5,700 feet above sea level. The principal source of moisture for the little precipitation and snow that falls is the Pacific Ocean to the west and the Gulf of Mexico to the southeast.

Temperatures and precipitation ranges vary significantly across the state due to topographic characteristics. In Angel Fire at the north, at an altitude of 8,406 feet above sea level, minimum and maximum average temperatures vary from 25ºF to 57ºF. With 22.63 inch of annual precipitation, mostly during summer, it is a more humid area. However, in the southern corner of the state at Carlsbad (elevation 3,117 feet), temperature ranges are larger and the minimum and maximum averages are 48ºF and 77ºF. Precipitation events and rainfall are lower in Carlsbad with only 13.43 inches a year. High temperatures increase evapotranspiration in the state. Between May and October, evaporation ranges from near 41 inches in the north-central to 73 inches in the southeast.[84]

The eastern third of New Mexico is covered by the Great Plains, where productive farming exists. The dairy and livestock industry is the state's agricultural leader, with nearly $2.9 billion in milk and livestock sales during 2014. Chilies and pecans are the most important crops, producing 25 percent of the nation's total production of both crops (New Mexico Department of Agriculture 2015). For irrigation, two important rivers run across the

[84] Unless otherwise noted, source material on New Mexico's climate is sourced from http://www.wrcc.dri.edu/narratives/NEWMEXICO.htm.

state: the Pecos River and the Rio Grande, which cuts through the Rocky Mountains. The development of the Navajo Irrigation Project has also stimulated significant irrigated agriculture in the San Juan basin.

The New Mexico Territorial Supreme Court declared prior appropriation to be the law in 1891. Since 1907, a permit from the State Engineer has been required to divert surface water (Western States Water Council 2014). The prior appropriation and beneficial use doctrines have been in place since 1907. Similar laws were adopted for groundwater by the State Legislature in 1931. Within a declared groundwater basin a permit given by the State Engineer is required to drill a well (Ortega Klett 2002). The state is divided into 33 groundwater basins, and each basin has a declaration date. If the owner of a water right or water permit fails to appropriate the water within four years, the right may be forfeited and the unused water may revert to the public (Bryner and Purcell 2003). After observing four years of non-use, the State Engineer may send a notice that forfeiture will occur if the water is not put back to use in the fifth year.

Principal demographic, economic and water-related indicators in New Mexico

Population (in 2010):	2.06 millions
GDP (in 2010):	$81 billion
Agriculture Value Added:	2.05% of GDP
Annual Precipitation:	13.95 inches
Total Water Withdrawals:	3,540 TAF
Urban Use:	10%
Agricultural Use:	86%
Thermoelectric Use:	2%
Other Uses:	2%
Surface Water:	50%
Groundwater:	50%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory Overview

Institutions

Oversight agencies

The measurement, appropriation, and distribution of both surface and groundwater are administered by the New Mexico Office of the State Engineer (OSE). The principal intrastate water oversight functions of the OSE are split into the Active Water Resource Management (AWRM) program administered by the Water Resource Allocation Program (WRAP). The AWRM program came about by a series of laws passed in response to continued drought conditions in 2004. These laws specify measuring and metering requirements, basin-specific rules and regulations, creation of watermaster districts for further administration, appointment and allocation options for watermasters, and creation of watermaster manuals. The WRAP program covers several functional areas of responsibility, including processing new or modified water rights applications (through district offices), maintaining water rights datasets for internal and external use, water use and conservation tracking, hydrological resource monitoring and modeling activities, statewide technical support, licensing of well drilling activities, subdivision review, and the dam safety bureau. The OSE also establishes administrative orders and actions within declared underground water basins.

The OSE–Interstate Stream Commission (ISC) has broad powers to investigate, protect, conserve, and develop New Mexico's waters, including both interstate and intrastate stream systems. The eight unsalaried members of the commission are appointed by the Governor. The ninth member is the State Engineer who under state law is the secretary of the commission. The ISC's director serves as the deputy state engineer. The commission's authority under state law includes negotiating with other states to settle interstate stream controversies. New Mexico is a party to eight interstate stream basins. To ensure basin compliance, Interstate Stream Commission staff evaluate, review, and implement projects in New Mexico and analyze streamflow, reservoir, and other data on the stream systems. The Commission is also authorized by statute to investigate and develop the water supplies of the state and institute legal proceedings in the name of the state for planning, conservation, protection and development of public waters.

The OSE also has a legal department consisting of Litigation and Adjudication Department, the Water Rights Hearing Unit, and the Interstate Stream Commission. The first two departments provide legal counsel to the State Engineer on on-going adjudication of water rights in New Mexico. The Interstate Stream Commission is responsible for negotiating interstate water sharing compacts in other states and for complying with interstate water sharing agreements. ISC is not part of the OSE legal department and its attorneys have the ability to represent the ISC in court without the oversight of the Attorney General's office.

New Mexico is divided into seven Water Rights Division Offices which are also referred to as the New Mexico Office of the State Engineer District Offices. District offices are responsible for administering the water rights system in their assigned basins, which translates to processing requests for new or modified water rights applications, maintaining the definitive record of water rights, issuing water use measurement and reporting standards, and providing information on basin status and watermaster activities in each division.

Twelve surface and groundwater basins in New Mexico are adjudicated at this time, while another twelve basins are undergoing adjudication proceedings (Ridgley 2010). When basins are adjudicated, the State Engineer assigns responsibility for administering water rights and allocating water among users to water masters who have "immediate charge of the diversions and distribution of waters in the water master district." The New Mexico Administrative Code gives watermasters permission to "exercise all such authority as is required to accomplish effective water rights administration."

Water supply operations agencies

The Middle Rio Grande Conservancy District (MRGCD) is a state-created entity that operates the conveyances, flood control and drainage works along 120 miles of the Rio Grande. In the 1950s the US Bureau of Reclamation initiated its Middle Rio Grande Project to rehabilitate the MRGCD. While USBR operates El Vado reservoir, where the MRGCD water is stored, the MRGCD manages that water, and is in control of its distribution. There is currently legal uncertainty about the extent of federal ownership of water works in the MRGCD.

US Bureau of Reclamation (USBR) shares operation, maintenance, and oversight responsibility for the Carlsbad Project with the Carlsbad Irrigation District. The Carlsbad Project consists of several water storage reservoirs (some of which are operated by USBR) and conveyance channels that supply irrigation water to around 25,000 acres in the Carlsbad Irrigation District.

A proposal exists for extending the Central Arizona Project (CAP) to deliver water to western parts of New Mexico, though cost considerations, lack of water demand, lack of repayment opportunities, and environmental considerations have temporarily halted progress on this water delivery concept.

USBR also operates and maintains El Vado Dam and maintains the Middle Rio Grande between Velarde and the Narrows of the Elephant Butte Reservoir. El Vado Dam has a total reservoir capacity of 196,500 acre-feet. The dam provides supplemental storage for the Middle Rio Grande project that supports irrigation of nearly 90,000 acres of irrigable land and 30,000 acres of Indian water right lands. Current irrigation in the Middle Rio Grande is approximately 65,000 acres, with up to 20,000 acres being Indian lands.

USBR participated in the design and construction of the Navajo Indian Irrigation Project, a multipurpose water storage project with total capacity of 1.7 million acre-feet. Operation and maintenance of the project is managed by the Navajo Agricultural Products Industry, with farm units and distribution systems developed by the Bureau of Indian Affairs and the Navajo Nation.

USBR operates and maintains selected dams and a power-plant along the Rio Grande Project, which is directed by the Elephant Butte Irrigation District. The Rio Grande Project provides water to irrigation land in New Mexico, Texas, and Mexico.

USBR also operates Heron Reservoir, which is a critical component of the San Juan-Chama Project that brings water from the headwaters of the San Juan River (a significant tributary to the Colorado River) into the Rio Grande system. The project provides water for municipal, domestic, and industrial users in the middle Rio Grande Valley. Heron Reservoir has a capacity of 401,320 acre-feet, providing water for municipal, domestic, industrial, recreation, and fish and wildlife purposes, as well as supplemental irrigation water.

Local storage facilities include the Carlsbad, Fort Sumner, Hammon, Tucumcari, and the Vermejo projects. Many of these projects were initially constructed with the support of USBR. USBR continues to support these local projects by sharing oversight and some operational responsibilities as described above.

Funding

Budgets are approved by the Water Trust Board which is part of the New Mexico Finance Authority. In FY 2014–2015, the OSE's annual budget was $53.4 million, with almost 30 percent coming from the state's General Fund (Office of the State Engineer 2011; State of New Mexico State Budget Division 2015). Two separate funds—the Water Trust Fund and Water Project Fund—are administered by the Water Trust Board. The Water Trust Fund is a permanent, constitutionally created fund for receiving appropriations and donations for use by the Water Project Fund. The Water Project Fund is used for loans and grants to qualified entities and projects approved by the legislature, including projects with urgent needs (public health, Safe Drinking Water Act compliance, dam safety, and wildfire management to protect public safety), regional multi-benefit projects, and projects that increase operating efficiencies. About 60–70 percent of annual funding is awarded to water conveyance projects, 15– 30 percent for conservation, 5– 15 percent watershed management, and 10 percent each for Endangered Species Act and flood protection. Since WPF's inception in 2002, it has awarded about $322 million for projects statewide, including $33 million in 2014 (University of New Mexico School of Law 2014).

Legal Framework

Water rights

The framework for New Mexico's modern water code was established by the enactment of the 1907 Water Code. Water rights established prior to the code were explicitly recognized therein. Individuals claiming water rights developed prior to the code may declare these vested water rights to the State Engineer. A declaration is an application form completed by the user with a legal description of the point of diversion and place of use, purpose of use, the quantity of water used, period of use, and any other information deemed necessary by the state engineer.[85] The State Engineer's Office investigates the information and materials submitted under the declaration. The filed declaration does not constitute validation of the right claimed, but provides a record of the vested right useful for water administration activities by the OSE or a water master.

All surface and groundwater water rights are issued as permits subject to the prior appropriation doctrine (Office of the State Engineer 2011). The State Engineer is required to review each application for a new permit or to modify place or purpose of use. While thousands of applications are submitted each year, only a handful of new appropriation water rights are granted. As defined by the Water Code, the State Engineer must consider whether sufficient water is available to meet new uses, if the new appropriation will impair existing rights, if the intended use meets the state water conservation efforts, and that the intended use is not detrimental to the public's welfare.

Water permits define the nature and extent of the water right, including the annual amount of water that may be legally diverted under the permit. Agricultural water rights are apportioned according to the average consumptive irrigation requirement for all crops grown in the area. This amount is calculated according to the Blaney-Criddle method (Ortega Klett 2002).

The adjudication process is part of the OSE's larger strategy to legally quantify all water rights in the state to aid in the active management and administration of water rights to meet statewide water management objectives. This process includes intensive hydrographic surveys conducted by the OSE for analyzing and documenting existing claims, declarations, and permits for water use on a given stream system. After the hydrographic survey, the OSE shares findings with the New Mexico Attorney General, who then files suit on the state's behalf for the judicial determination of each water right within the stream system (Office of the State Engineer 2011). The result of an adjudication is a decree that specifies the priority, amount, purpose, periods and place of use for every water right included in the decree (Bryner and Purcell 2003).

There are currently no specialized water courts in New Mexico, but a Senate bill in circulation would create three district water courts through existing judicial district courts. The bill would supply funding to enable existing courts to staff and administer water courts for their district. Because of the wide range of water right holders in the state, half of the pending adjudications are filed in state judicial district courts and half are filed in federal courts.

Surface water is considered fully appropriated across the entire state. The determination of full appropriation is made by the State Engineer based on water master reports submitted by water masters. In basins with a water master, stream and diversion information is assessed daily to determine how surface water is to be distributed.

Several groundwater basins also are considered fully appropriated. OSE manages groundwater over-allocation through the process of declaring underground basins and determining basin guidelines for pumping restrictions, measuring and reporting.

Water trading

The legal right to transfer a water right is generally the same whether the water is ground or surface, tributary or non-tributary. OSE has an obligation to conjunctively manage surface and groundwater, which sometimes results in additional conditions on groundwater users. Water can be conveyed for use from basin to basin, but within-basin consumptive use after the transfer must not be greater than before the transfer (Brown et al. 1992).

New Mexico has developed plans to expedite the water transfer process (Office of the State Engineer 2013). In cases of economic emergency, users can apply for emergency authorization and a replacement plan to address immediate water needs if a permanent water transfer cannot be made in time. For the Middle Rio Grande Basin,

[85] NMAC 19.26.2.8 "Declaration of a Water Right Developed Prior to March 19, 1907."

an economic model has been developed to assess what a water marketplace might look like. The model includes hydrologic factors and several types of water users (Broadbent et al. 2009).

ISC operates a Strategic Water Reserve for acquiring water and water rights for addressing endangered species issues and meeting interstate flow sharing agreements on the Rio Grande. ISC may purchase, lease, or accept donations of water rights, and pool them together to create instream flows. The Strategic Water Reserve priority areas are the Middle and Lower Rio Grande basins. While the reserve received $2.8 million in state appropriations in 2005, appropriations ceased in 2007 due to the state's budget crisis (University of New Mexico School of Law 2014).

Legal treatment of environmental water use

Water rights for non-consumptive uses in New Mexico are not explicitly addressed by statute. Rather the body of law pertaining to non-consumptive uses is sourced from legal opinions and a ruling made by the Attorney General in 1998. The 1998 opinion (Op. No. 98-01) allows the transfer of a consumptive water right to an instream flow right. The opinion that water rights could be obtained for instream flows for the environment did not specify a program for instream environmental flows. There is significant ambiguity as to how instream flows should be quantified and who is legally eligible to transfer and hold instream flows. Much of the discretion for granting transfers of consumptive uses to an instream flow right lies with the OSE and determinations by the State Engineer (Jackson 2009).

Minimum in-stream flows are required under US Fish and Wildlife Service Biological Opinions on the Pecos River and the Rio Grande. There is also a flow prescription on the San Juan River developed under the San Juan Endangered Species Recovery and Implementation Program. Environmental flow rights have been confirmed for sections of the Red River and Rio Chama that have federal wild and scenic designations.

Prioritization of particular uses

While New Mexico's water rights system is administered according to the doctrine of prior appropriation, a secondary system of priority exists for water leased from a conservation district when demand for beneficial uses of water exceed the supply. This secondary system specifies a ranking of preference by type of use, with domestic and municipal water supply ranked first; irrigation, manufacturing, and sanitation ranked second; and power development, recreation, fisheries, and other uses ranked third (Smith and Ellsworth n.d.).

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

Collection and organization of water rights is conducted by the Water Rights Abstract Bureaus within each district office. Public water suppliers are required to annually report their diversions to the OSE (Longworth et al. 2008). Water-right holders who are not public suppliers and exist outside of Water Master Districts are not required to report except as provided in the specific conditions of approval for those other permits.

Not every right holder in a water master district is required to measure and report their use. The State Engineer performs analysis to determine the most effective diversions to measure for water-rights administration. Water masters notify the owners of chosen diversions of the need to install measuring devices and headgates. For these measured locations, water masters submit an annual report that includes total diversions to direct use and storage as well as the amount and location of any shortages within the district.

In recent years, all newly issued permits require the user to measure and report their groundwater diversions (Brockmann 2009). Measurements are required to be made with a totalizing meter. In addition to water rights information, well reports and well drilling reports are available online through the Water Rights Reporting System. Water use from domestic, agricultural, industrial, and municipal uses can be accessed by the public through this system (Office of the State Engineer 2011).

Indirect measurement of water use (top-down approach)

Every five years New Mexico publishes a report on water use throughout the state, including water use by customer category and county. The public water supply chapter describes procedures used to calculate residential water use in gallons per capita per day (GPCD) and total withdrawals for residential purposes. Blaney-Criddle method and its modified version are used for calculating consumptive irrigation requirements for a cropping pattern to estimate water use by irrigated agriculture. Self-supplied livestock and self-supplied commercial, industrial, mining, and power categories also are estimated. Two methods for calculating reservoir evaporation are also presented.

To develop this report and to help with other activities, ISC uses geographical information systems (GIS) to support hydrologic models, mapping of crop acreages and determining consumptive use; preparation of hydrographic survey maps and data to support the adjudication of water rights in specific geographic areas; evaluation of water rights applications, declarations, and changes of ownership; evaluation of compliance with water right permits; creation of crop surveys and use surveys; analysis of evapotranspiration and consumptive irrigation requirements (Office of the State Engineer 2011).

System Analysis and Management

The Active Water Resource Management (AWRM) initiative maintains a network of stream, *acequia* (community operated watercourse), ditch and well monitoring sites that electronically transmits data values via radio and satellite telemetry and stores the data in a database. This real-time water measurement data is available for each active gage/well shown on select basin maps. Surface and groundwater gages come both from OSE and USGS networks.

Water masters are essential in managing the system locally in New Mexico. Water masters actively administer the daily distribution of water from stream systems and ensure that water is distributed fairly. The State Engineer has authority to create special water districts and hire Water Masters as the State Engineer determines necessary for administering water rights.

The OSE Hydrology Bureau performs a wide range of activities to support the OSE and ISC. USBR hydrologists collect hydrologic data, create water resource models, assist in policy development and planning, evaluate water availability, quantify hydrologic impacts, provide expert testimony for litigation, and manage technical projects. In the Lower Rio Grande, Bureau staff collaborated with the ISC on analysis of groundwater data and development of hydrologic databases. Bureau hydrologists also continued development of a Lower Rio Grande surface water model, which will allow the agency to simulate operations of the Rio Grande Project. USBR staff performed in-depth analysis of historical and recent operations of the project and implementation of the new Project Operating Agreement Settlement (Office of the State Engineer 2011).

At the federal level, USBR is working on a hydrology model for the San Juan River Basin to help assess future water availability and address how to meet both environmental and economic growth needs (Office of the State Engineer 2011).

There is increasing concern about groundwater management, and models are being developed in sensitive basins. A good example is the Española basin, considered a "critical groundwater basin" because it is the primary groundwater resource for the cities and surrounding urbanizing areas of Santa Fe, Española, Los Alamos, and eight Pueblo nations. Geologic, geophysical and hydrologic studies are being developed to improve the understanding of the three-dimensional hydrogeologic and geologic conditions of the basin.

Allocation During Periods of Scarcity

In the wake of recent droughts, the OSE recognized that while the state's water rights system is founded on the prior appropriation doctrine, the tools needed to allocate water according to priority did not exist. In response, OSE began defining tools that comprise the Active Water Resource Management (AWRM) initiative to improve water administration and allocation during periods of scarcity. AWRM is a set of administrative rules that define protocols and tools available to OSE, District Office staff, and water masters to efficiently allocate water during periods of scarcity.

The AWRM rules and regulations specify the role of water masters and the formation of water master districts. Water masters are the principal entity for the administration of water rights. As defined by AWRM, administration of water rights is the distribution by a water master of available water supplies for specific beneficial uses by the owners of administrable water rights that have assigned priorities. AWRM defines four approaches that water masters may select for administering water rights during times of scarcity, subject to the approval of the State Engineer. These forms include direct flow administration, storage water administration, depletion limit administration, or alternative water sharing agreements (like proportional distribution of allocations during scarcity, voluntary shortage sharing, and rotation of water use, among others.

AWRM also specifies a process for developing generalized hydrologic analysis and modeling at the water master district scale, measuring and reporting requirements for water masters, and requires OSE to conduct expedited review of permit transfer applications to facilitate marketing and leasing arrangements. ARWM defines a system to grant water to users out of priority through submission and approval of a replacement plan, whereby out-of-priority water rights can mitigate surface water impacts to in-priority water rights during periods of scarcity.

Any water right in New Mexico is subject to curtailment. If adjudicated decrees do not exist for a water right, the State Engineer can reference other sources to determine the priority of a right. AWRM details the hierarchy of information the State Engineer uses to determine the priority of a given water right.

Despite the fact that curtailments have not yet been required, AWRM has identified seven high priority surface water basins where OSE is focusing agency resources for implementing the AWRM framework.[86]

Public Information Provision

Water Rights

The Water Rights Abstract Bureau collects the documents and organizes the information for the New Mexico Water Rights Reporting System (NMWRRS) database were general public and water resource managers can have access to water right data online. The information includes electronic images of water right documents and downloadable well reports, driller license reports, point of diversion reports, and subdivision reports. These data are also used to create GIS mapping for a basin. The information is uploaded from the WATERS database system

[86] Unless otherwise noted, information on the rules and regulations of the AWRM program is sourced from NMAC 19.25.13.

periodically, according to when the changes or new information is provided. Also, the database is available only for some regions since the process is not completed statewide.

The NMWRRS home screen contains a list of search engines for accessing records in the database. The "Water Right Summary Report" shows all water rights according to the water right number or owner, and displays information on use, acres that it irrigates (for agricultural uses), consumptive water use, priority, and other information such as location, Point of Diversion (POD) number, owner and administrative documents available including transfer information. A second tool, the "Well Logs Report," shows either wells with or without log information, or data as in point of diversion has a meter attached. They provide POD number (may not be the same as water right number), source, location, and when available, dates when the log information was obtained, depth to water and depth of the well, as well as information on the drilling company. A third search engine, the "Water Column/Average Depth To Water Report," provides this information for all wells found in a given section. Other tools are online, such as a POD locator, and an online query that returns a list of water right files with their adjudication subfile number, or with their related historic number.

Information on water rights hearings for protested and aggrieved water rights applications are published online. However, the last decision that can be found dates back to 2007.

Regarding water use, the "Water Use Program" inventories surface and groundwater withdrawals and depletions by category, county, and river basin, every five years. The most recent report available to the public dates from 2010. It includes surface and groundwater withdrawals from all nine beneficial use categories.

The OSE has implemented state-of-the-art water use accounting in partnership with New Mexico drinking water suppliers to assess water leakage, lost revenue, and conservation potential. Through a spreadsheet-based software, cities can audit their water distribution, quantify and track water losses, and identify areas for improved efficiency and cost recovery. During 2007, several cities implemented this self-accounting tool.

System Monitoring

The "Real-Time Water Measurement Information System" is a telemetry-enabled monitoring network that provides real-time data from across the state. The network includes streams, canals, and wells, and the system provides Information on discharge (water flow in cubic feet per second for surface and gallons per minute in ground water stations), gage height, daily average flow rate and daily total volume. For some water districts, the information is published online, while for others, the contact information of the appropriate district office is available.

The Hydrology Bureau assesses water availability through basin-specific water resource models called Española Basin Technical Advisory Group. The model, including hydrogeologic and geologic characteristics, has been developed for the primary groundwater resource for the cities and surrounding areas of Santa Fe, Española, Los Alamos, and eight Pueblo nations.

For detailed groundwater information, a "Statewide Groundwater Level Monitoring Program" has been developed in collaboration with USGS. Water-level measurements are made on a semi-annual, annual, or five-year basis, and are available to the public on the USGS website.

Finally, an "Aquifer Test Index" was developed with information compiled from reports by consultants, the USGS, the OSE, the New Mexico Bureau of Mines and Mineral Resources, and other sources. It provides the specific capacity in gallons per minute per foot for each of the points where the test was made, among other information. However, the most recently available report dates from 2012, and it is based on information from 2008 and before.

Allocation During Scarcity

Curtailment has not yet been needed in New Mexico. However, information on priority for each water right can be found in the NMWRRS database, specifically in the Water Rights Summary Reports. At the same time, AWRM details different measures that watermasters can use to restrict water uses. A portal providing information on curtailments, replacement plans, or emergency administrative actions has been developed, despite the fact that curtailments have not yet been implemented in the state.

For dealing with scarcity, a monthly drought conditions report is presented online. It provides summary and detailed information on the drought index and precipitation outlook across the state.

Water Transfers

Information regarding volumes of water transferred is required in the forms received by the OSE to approve changes or transfers to water rights. The information is updated in the NMWRRS database. However, the state does not process or systematize the information in specific transferred reports.

If the transfer of a water right might result in impairment of other water rights, the OSE will provide notice and conduct a hearing. As indicated above, water rights hearing schedules and results are published online.

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Nevada

Case Study Highlights

- Nevada is an arid state that sources more than 60 percent of its water from the Colorado River in the southeast and other major river systems (including the Humboldt, Truckee, and Carson Rivers) in northern Nevada. The remaining water is sourced from pumping groundwater throughout the state.
- Most of the operational and regional management issues in Nevada are conducted by four regional agencies: the Colorado River Commission of Nevada, the Northern Nevada Water Planning Commission, the Central Nevada Regional Water Authority, and the Southern Nevada Water Authority.
- The Division of Water Resources (NDWR) is responsible for administering surface and groundwater rights, among other responsibilities. NDWR also issues supplemental groundwater rights, which are only exercised in specific circumstances. Some groundwater rights are supplemental to surface water rights and are used to augment low surface water supplies, whereas other groundwater rights are supplemental to other groundwater rights, which are useful for augmenting the supply of one well by pumping another.
- The fragmentation of water measurement and reporting requirements makes accurate statewide water accounting and summaries of water use difficult to evaluate. However, the Office of the State Engineer is increasing the quality, consistency, and comprehensiveness of water use reporting through online reporting platforms and continued administration of water-stressed basins by the State Engineer.

Introduction

Nevada is predominately a highlands plateau consisting of isolated mountain ranges and intervening valleys, a geographical configuration known as basin and range topography. The State has several mountain ranges, running generally north to south. Most of these ranges have inland-draining valleys between them.

Because of this geographic variability, the state has a greatly diverse climate, ranging from extremely hot deserts in the south to cool mountain forests in the north. The average annual minimum and maximum temperatures in Reno range between 40ºF and 67ºF. Humidity near Reno is very low, with an average precipitation of seven inches per year, occurring mostly during winter. In Wells, NV to the east, annual average minimum and maximum temperatures are more extreme, ranging between 29 and 60ºF on average and precipitation is slightly higher, with a mean of ten inches occurring year round with fewer events during summer months. In Las Vegas, at the southeastern corner of the state, the climate is much drier. The annual average minimum and maximum temperature ranges between 59ºF and 80ºF with only four inches of annual rainfall.

Since much of the state is extremely arid, the development of the Colorado River system greatly increased accessibility to potable water for municipal, industrial, and agricultural users. The Hoover and Davis dams were built on the Colorado River in the mid-20th century. The Humboldt River also provides potable water for consumption in northern Nevada. It crosses the state from east to west through the northern part, draining into the Humboldt Sink near Lovelock. Several rivers drain from the Sierra Nevada towards the east, including the Walker, Truckee, and Carson rivers.

Most residents, about 94 percent, live in urban areas (US Census Bureau 2015). The mining sector is also an important water user, with 110 mines established in the state. In 2014, Nevada's production of gold accounted for roughly 73 percent of the US total. Other important mineral production in the state includes silver, copper, gypsum, diatomite, barite, and perlite. Agriculture plays a relatively modest economic role—representing less than 1 percent of the overall economy. The most important livestock commodity by value is cattle, with annual cash receipts of $283 million in 2012. Alfalfa hay is Nevada's leading crop by value; total production was $218 million in 2012.

Principal demographic, economic and water-related indicators in Nevada

Population (in 2010):	2.7 millions
GDP (in 2010):	$118 billion
Agriculture Value Added:	0.72% of GDP
Annual Precipitation:	10.22 inches
Total Water Withdrawals:	2,940 TAF
Urban Use:	24%
Agricultural Use:	60%
Thermoelectric Use:	1%
Other Uses:	15%
Surface Water:	63%
Groundwater:	37%

SOURCES: Population: US Census Bureau, QuickFacts, Nevada last accessed April, 2016. Water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight agencies

The Division of Water Resources (also known as the Office of the State Engineer) is responsible for administering surface and groundwater rights, enforcing groundwater use statutes, and issuing measuring and reporting orders, along with other functions like dam safety, flood protection, and water planning. Because of Nevada's complex network of surface and groundwater systems, the USGS and State Engineer's Office developed a hydrographic area map to help manage these resources. There are 256 hydrographic areas (essentially valleys) nested within 14 major hydrographic regions. Hydrographic areas can be further split into hydrographic sub-areas based on unique hydrologic characteristics. Hydrographic areas are management boundaries utilized by NDWR for determining the availability of water for new appropriations and implementing administrative orders like basin closures, curtailments, and measurement and reporting requirements.

Several important surface waters of the state are operated under court decrees by court appointed watermasters. The most notable is the Truckee River Operating Agreement, which will be fully implemented in 2016 under the supervision of a federal watermaster to oversee allocations of this interstate resource.

Regional water management entities are very important in Nevada, and arguably perform the most active planning and management functions in the state. The following summarizes local, regional, and state entities: x

- Colorado River Commission: State agency with a seven-member board responsible for protecting the water and power resources from the Colorado River in Nevada.
- Northern Nevada Water Planning Commission: In 2006, the Legislature passed a bill to consolidate water resource management and planning in Washoe County, creating the Western Regional Water Commission

to manage water supplies and create a regional water management plan for most of Washoe County. The bill also created the Northern Nevada Water Planning Commission to advise the WRWC. The Truckee Meadows Water Authority and the Washoe County Department of Water Resources share planning and management responsibilities in Washoe County.

- Central Nevada: Two regional organizations—the Humboldt River Basin Water Authority and the Central Nevada Regional Water Authority—assume water planning, data collection, and legislative outreach functions.
- Southern Nevada: The Southern Nevada Water Authority (SNWA), a joint powers authority, represents several major urban water districts in Clark County, including the Las Vegas Valley Water District. SNWA has both oversight and operations responsibilities, and conducts water resource planning.. It also manages regional water resources like the Colorado River allocation, groundwater facilities, and water treatment facilities. In years when Nevada's Colorado River allocation exceeds demand, SNWA stores water in the Las Vegas Valley Groundwater Basin as a reserve. It also has water banking agreements with Arizona and California.

Water supply operations agencies

The southeastern boundary of Nevada is defined by the Colorado River. Many of the important impoundments and storages of the Colorado River are located on the border between Nevada and Arizona, including Lake Mead, Hoover Dam, and Lake Mohave. Lake Mead plays an important role in water supply for southern Nevada: the SNWA diverts water from this storage through the Robert B. Griffith project (which is designed to deliver 299,000 acre-feet of primary municipal supply water from Lake Mead to municipalities and industries in southern Nevada). Lake Mead plays an important role in other western states as well, providing power and water delivery for Arizona and California. These water works are owned, operated, and maintained by the US Bureau of Reclamation (USBR).

The federal government is a party in the Truckee River Agreement, along with the Truckee-Carson Irrigation District, the Washoe County Water Conservation District, and the Sierra Pacific Power Company. The Truckee River Agreement specifies the operation of Lake Tahoe and Boca Reservoir to meet flow targets on the Truckee River. Lake Tahoe Dam is operated by USBR.

USBR also actively manages a network of flood control and flow regulation dams in the drainage basins of the Truckee and lower Carson Rivers. This network is called the Washoe Project.

The Humboldt River Project consists of Rye Patch Dam. The project stores water from the Humboldt River, which drains 600 square miles of arid watershed in northern Nevada. It provides 213,000 acre-feet of storage for diversion to irrigated lands. Operation and maintenance of the project were transferred from USBR to the Pershing County Water Conservation District in 2016.

Funding

The NDWR total expenditures for the FY 2014-15 was $6,028,038. From this budget, $93,693 went toward IT services for collection, management, and data sharing on water allocations, wells, and dams, among others. Also, $18,739 was destined for water planning activities, including updates on the state's drought plan, groundwater basin activities, water use data, and the implementation of the water plan.

Water rights related activities took more than 90 percent of the NDWR budget, amounting to $5,484,619. Water right administration includes the allocation of surface and groundwater, determinations on new water rights, management of existing water rights portfolios, ensuring compliance with the state's water laws, and promoting long-term preservation of state water resources and the surrounding environment. Only 24 percent of the budget considered specifically for water rights activities comes from the state's General Fund; the remaining portion comes from fees.

Starting in 2014, the Division of Water Resources was allowed to keep fees from processing applications. Actual fees collected in FY2014 amounted to $3,402,112, and is projected to increase by $200,000 through FY2015.

Legal Framework

Water rights

Nevada's water right system is based on the prior appropriation doctrine and does not recognize the riparian doctrine. Its surface water laws were developed in 1905, while the regulation of percolating groundwater began in 1939. Water rights may be acquired by: 1) adjudicating a claim to a beneficial use of water that took place prior to the enactment of the water law (called a "vested right") or 2) applying for a permit through the Office of the State Engineer to appropriate unallocated water and putting that water to beneficial use (known as a "certificated" or "perfected" right).[87] Domestic wells that pump less than 2 acre-feet annually are exempt from obtaining a water right. There are three basic components of an appropriative water right: 1) beneficial use is the measure and limit of the right to use the water, 2) rights are stated in terms of point of diversion, place of use and manner of use, and 3) a water right can be lost by abandonment and forfeiture (Nevada Division of Water Planning 1999).

NDWR hosts and maintains a "Water Rights Database" containing digitized water records for all certificated water rights in the state. The database includes information on the place of beneficial use, point of diversion, allowable diversion rates and volumes, and other ancillary data.

Vested water rights are defined as rights to surface or groundwater that were beneficially used before the adoption of Nevada's Water Law. Claims to vested rights must demonstrate that the effort to beneficially use the water resources took place before March 1, 1905 for surface water, March 22, 1913 for artesian water, and March 25, 1939 for percolating water. The State Engineer has the responsibility of initiating an adjudication proceeding, the process for determining the extent of all vested rights for a particular water source. The State Engineer may initiate proceedings as petitioned by claimants or may order an adjudication. Materials and evidence used to substantiate claims are collected by the State Engineer, who inspects evidence and holds hearings. An "order of determination" is prepared by the State Engineer and submitted to all claimants and the District Court with jurisdiction. Finally, the district judge enters the "findings of facts, conclusions of law and the decree," which determines the water rights on the stream system.

According to the state water plan, almost all rights to surface water in Nevada were established in the 1800s. Sierra Nevada water rights date back to the 1850s, and Humboldt River basin water rights date back to the 1870s and 1880s. Therefore most of the surface water rights for beneficial use in Nevada were adjudicated through the vested right process and are managed in accordance with civil, state, or federal decrees (over 100 decrees in Nevada).

A water permit holder has the right to develop a certain amount of water from a particular source for a particular purpose and at a specific location. Acquiring a new permit to appropriate water (surface or groundwater) entails filing an application with a map prepared by a licensed State Water Right Surveyor, showing the proposed point of diversion and place of use within the proper legal subdivisions. The filed application, maps, and fees, are processed by the DWR office in Carson City. Notice of the proposed application is posted in a newspaper of

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[87] Unless otherwise noted, overview information on Nevada's water rights system was sourced from Nevada Legislative Council Bureau 2016 and Nevada Division of Water Resources 2009.

general circulation in the county where the point of diversion is located. Protests are considered by the State Engineer's office. After notification and hearing protests, the Office of the State Engineer makes a determination whether to grant or deny the application. This determination may be based on the availability of unappropriated water through an evaluation of perennial yield (discussed in detail below), whether or not the beneficial use is prioritized in the basin (see "designated basins" below), injury to existing water rights holders, or the project is not feasible or is for speculative purposes. Upon issuing the permit, the State Engineer establishes terms and conditions including diversion rates and annual amount of water that may be used, measuring device requirements, and a priority date. The State Engineer specifies the amount of water the permit holder will be allowed to divert annually (i.e., the duty) based on the applicant's justification of the amount requested. If a permit is for water to be beneficially used on land subject to a court decree, the State Engineer may limit the permit to the decreed duty. Permitted water rights can be perfected only after: 1) completion of the works of diversion, 2) placing the water to beneficial use, and 3) filing the proofs required to the State Engineer. All water in Nevada belongs to the public, permitted water right is usufructuary right.

Most new applications to appropriate water for beneficial use are for groundwater resources, as most major surface water resources are already adjudicated and administered by civil, state, or federal decree. Many of Nevada's smaller springs and streams have not yet been adjudicated.

The State Engineer also designates basins that are at risk of depletion, and therefore require close management and administration by the Office of the State Engineer. Designation occurs through an order of the State Engineer, which usually requires at least one public hearing. As of August 2015, 130 basins out of 256 were designated. Once a basin is designated, the State Engineer may issue orders which define preferred uses, deny certain water uses, or curtail pumping (Nevada Division of Water Planning 1999). Each designated basin is managed separately, with variation across basins in terms of rules and regulations. Basin designation status also defines the procedure for obtaining a groundwater permit. In designated basins, groundwater permittees must apply for a groundwater permit before drilling a groundwater well. In undesignated basins, drilling a well may occur before applying for a permit. Basins may also be designated with the specification of preferred uses (which are prioritized) and "irrigation denied" basins in which new permit applications to appropriate groundwater for irrigation are denied.

NDWR also issues supplemental groundwater rights, which are only exercised in specific circumstances. Some groundwater rights are supplemental to surface water rights and are used to augment low surface water supplies (such as during a drought). Other groundwater rights are supplemental to other groundwater rights, which are useful for augmenting the supply of one well by pumping another (Nevada Division of Water Planning 1999).

NDWR uses actual measured streamflow to analyze the amount of water available for permitting and planning purposes. It appears that evaluation of unappropriated surface water is site-specific or part of a larger adjudication process in a basin. Because surface waters are almost fully allocated in Nevada, new appropriations of water are mostly from groundwater.

The ultimate goal of the State Engineer is to allocate groundwater pumping up to the point of perennial yield as determined for each hydrographic area. When reviewing new groundwater rights applications, the State Engineer considers individual and regional perennial yield estimates, system yield estimates, and the "committed resources" amount. "Committed resources" is an estimate of the volume of water already permitted within a basin. The amount of groundwater available for new uses is defined as the difference between the perennial yield estimate of a basin and committed resources. The accuracy of groundwater availability tracking is based on the quality of perennial yield estimates and the completeness of state groundwater right records. Actual groundwater withdrawal and consumption amounts are less than the committed resource value for any given basin. This is due to the difference between the face-value of a right and actual consumption (Nevada Division of Water Planning 1999). The water rights database plays an extremely large part in NDWR's ability to assess physical and legal groundwater availability.

In basins with significant groundwater discharge to streams, the USGS developed system yield estimates in addition to groundwater perennial yield estimates (Nevada Division of Water Planning 1999). System yield is defined as the amount of usable groundwater and surface water that can be economically withdrawn and consumed each year for an indefinite period without depleting the source.

Water trading

In Nevada, water transfers involve modifying water rights with the effect of changing the point of diversion or the place of use within the same basin. Applications to appropriate water from one basin or county for use in another are also referred to as water transfers. New water permits, including interbasin and intercounty transfers, are evaluated by the State Engineer based on Nevada Revised Statues 533 and 534 as described in the section above on permitted rights.

Modifying an existing right to a transfer, including changes in the place of use, manner of use or point of diversion, must be approved by the State Engineer. Proposed changes may not impair existing rights or protectable interest in existing domestic wells or be detrimental to the public interest. If unappropriated water is available, existing water rights are not impacted, and the transfer does not threaten to prove detrimental to the public interest, it may be approved by the State Engineer (Nevada Division of Water Planning 1999). However, applications to change the point of diversion from one source to another (groundwater to surface water) are rarely granted. The application to change bears the same date of priority as the right proposed to be changed.

By Nevada Revised Statute 111.167, water rights are presumed to transfer with the land to which appurtenant, unless the grantor specifically reserves all or portions of that water right (Nevada Division of Water Resources 2014). Water-right holders who wish to transfer water rights must complete a "report of conveyance" (the conveyance document) and file that report with the State Engineer. The State Engineer evaluates the title, and specifies the rate of diversion and the amount of acre-feet from the conveyance documents.

In 1991, the legislature authorized counties of origin to levy a tax on receiving counties of $6 per acre-foot annually for intercounty water transfers. In 2007, the tax was characterized as a fee and raised to $10 per acre-foot (Nevada Legislative Council Bureau 2016). A county of origin may not wish to levy a tax, and instead require a mitigation plan to address the adverse economic effects caused by the transfer of water to the receiving county. Mitigation plans may include a reservation of designated water rights to the county of origin and compensation for the economic impacts of the transfer.

A high-profile intercounty water transfer is occurring in Southern Nevada, where the Southern Nevada Water Authority is diversifying its water portfolio. Southern Nevada gets about 90 percent of its water from the Colorado River and 10 percent from groundwater wells. Since the late 1980s, SNWA and the Las Vegas Valley Water District made nearly 150 groundwater applications to appropriate and export groundwater from rural areas of eastern and central Nevada to use it in the city.

Legal treatment of environmental water use

Nevada law permits instream flow rights for wildlife, environmental, and recreational purposes. Any individual or entity can apply for and hold an instream flow right. Because Nevada is a prior appropriation state, any new permit for instream flows would be assigned a priority date and would be junior to all rights issued before that date. In times of scarcity, prior appropriation framework is enforced and environmental flows are often difficult to maintain.

Nevada does not have a uniform approach to determining environmental flow standards. Instream flows are either created by applying for new water appropriation, transferring the beneficial use of a water right, or based on civil, state, or federal decrees.

Nevada Department of Wildlife (NDOW) actively procures water rights from willing sellers as opportunities arise for achieving minimum environmental flows within nine wildlife management areas (WMAs). Some of these water rights are less reliable during dry periods because they are based on surplus flow or irrigation tail water (Nevada Division of Water Planning 1999). NDOW also reviews water appropriation applications (including transfers) submitted to the State Engineer for potential impacts to wildlife and habitat. NDOW recommends minimum instream flows on a site-by-site basis which are then used to provide grounds for protesting new appropriations or transfers. NDOW has successfully protested water rights transfers on the Truckee River west of Reno and Lamoille Creek near Elko to preserve instream flow and ecosystem values. NDOW periodically assesses ecosystem values and minimum streamflow standards for major rivers and tributaries, often for developing fishery management plans. NDOW also runs hatcheries. Nevada Divisions of State Lands (NDSL) may help with the acquisition of land and water rights attached to those lands. NDSL also administers permits for new structures below the ordinary high water line on several important rivers, including the construction of diversion dams. Permits for diversion dam construction can be conditioned to preserve instream flows and/or fish passage.

The State Engineer is authorized to approve water rights applications for instream beneficial uses such as wildlife, wetlands and fisheries, and recreation. New water rights or transfers of an existing water right to an instream flow follow standard procedures as described in the following two sections. The review criteria are similar to any other type of appropriation: 1) the requested water is available, 2) the use will not conflict with the existing water rights, and 3) the use does not threaten to prove detrimental to the public interest (Nevada Division of Water Planning 1999). Once instream water rights for resource conservation are permitted and established, the State Engineer must consider impacts of proposed new uses or transfers on the instream water right. This is especially important for spring flows.

Federal agencies—including the US Bureau of Land Management (USBLM), the US Fish and Wildlife Service (USFWS), and the US Department of Interior (USDOI)—must submit an application to the State Engineer to acquire a new right or transfer a water right for instream wildlife and environmental uses (Nevada Division of Water Planning 1999). Federal agencies may seek instream flows through new appropriation or transfer according to the Endangered Species Act, Clean Water Act, Migratory Bird Treaty Act, or Wild and Scenic Rivers Act.[88] Federal protection of instream flows through assertion of federal reserved water rights has been limited.

USBLM and USFWS have been successful at protecting instream flows when issuing permits for grazing, timber harvest, mining, and water development on federal lands in Nevada, which constitute a vast majority of the state's landmass (Nevada Division of Water Planning 1999).

Prioritization of particular uses

Nevada technically recognizes a priority among applications to appropriate underground water for irrigation purposes. In the case of two or more applications submitted to extract groundwater for irrigation in the same

[88] Interestingly, the west Carson and Walker Rivers, which are located in California, are designed Wild and Scenic. This designation terminates where these rivers flow into Nevada (Nevada Division of Water Planning 1999).

basin, the State Engineer is instructed by state law to give first priority to landowners to use on the overlying land. Second priority is for use on adjacent land filed under the Carey Act or the Desert Land Entry Act. Third priority goes to an application that is preparatory to proceeding under the Carey or Desert Land Entry Act (Smith and Ellsworth n.d.).

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

The NDWR recommended an improved approach to water use data collection and accounting systems in the 1999 State Water Plan. At that time, NDWR had fragmented data collection (in terms of frequency, geography, method of estimation, and uses accounted for) and did not have the capacity for comprehensive water use estimation, relying instead on the USGS 5-year interval water use estimations. Given minimal resources for statewide data collection efforts, water use measurement and agricultural water use estimations have historically been compiled for purposes such as administering the prior appropriation system in a specific basin or stream. Thus, most of the data collected by the state represents areas with over-drafted basins or contested surface water disputes. By 1999, NDWR estimated that 65–70 percent of the total water withdrawn from groundwater and surface water sources were actually measured with detailed diversion records or estimated annually in detailed pumped water and crop inventories. Only portions of this water usage dataset were maintained in an electronic database at that time. NDWR's detailed surface and groundwater use data was primarily tied to permit conditions for water rights, along with specific basins studied on an ad-hoc basis. Since 1999, water use reporting requirements have expanded for some groundwater users in designated groundwater basins. The state is also working on an online reporting form that will help aggregate new water use data into an electronic database. Reporting of water use remains fragmented, providing only a partial picture of water use in the state. A 2013 report by the Office of the State Engineer presented a more complete estimate of statewide groundwater pumping using a variety of sources (Nevada Division of Water Resources 2013). Detailed characterization of groundwater supply and demand are prepared by the Office of State Engineer in about one-quarter of the state's hydrographic basins, often those with relatively high annual demand.

Surface water usage is tracked through measuring and reporting conditions placed on the issuance of a water rights permit. Although the State Engineer has consistently required some type of measuring device to be placed near the point of diversion and records of these measurements be kept, reporting this data to the state is inconsistent, and varies across decrees, adjudications, and other agreements. Agricultural surface water diversions are measured by federal watermasters and irrigation districts on the Truckee, Carson, and Walker rivers.

In 2015, NDWR had inventories of groundwater usage in about 60 out of 256 basins, using a mixture of self-reported data and estimates by state analysts. Many non-agricultural users like municipal and commercial right holders are required to report monthly pumping and consumptive use on a monthly, quarterly, or annual basis. Reporting requirements are roughly correlated with the State Engineer's identification of a basin as depleted. In rural areas, estimates of agricultural irrigation volumes are developed by state field staff who read meters and check crop types. There is no "rule of thumb" for determining who must report water usage to the NDWR. While there may be many water-right holders with metering and measuring requirements as a condition of their permit, there are fewer water-right holders who must report this data to the state. This reporting requirement may be based loosely on the status of the hydrographic basin from which they pump, and/or based on their beneficial use category.

Since 1999, thousands of additional groundwater permits have been issued with measuring requirements (and some reporting requirements) specified by the State Engineer. Also, additional pumping reporting requirements have been placed on some users in specific basins. Upon designation of a basin, additional measuring and reporting requirements are often imposed on some users. Some basins designated by the State Engineer over 20 years ago have long-running groundwater pumping reporting data. Domestic wells that do not draw more than 2 acre-feet per year are exempt from the State Engineer's permitting process, but records of domestic well installations are maintained through the state's well log databased and assessor records.

Most groundwater pumping and use reporting by non-agricultural users is sent to NDWR by US mail or e-mail, and the staff must input usage data into a water usage database. The State Engineer is currently developing an online portal for water rights holders to report usage, which will streamline the data collection process and create a more centralized database for state water usage.

The following are two examples describing the relationship between basin designation and reporting requirements.

- Under Order 1253 (April 2015), the State Engineer's Office designated the Lovelock Valley Hydrographic Basin due to his opinion that the basin was being depleted and in need of additional administration and oversight. The designation came with an additional requirement that owners of underground water rights install and maintain a totalizing meter near the discharge pipeline near the point of diversion by February 1, 2016. Additionally, within 30 days of installing the totalizing meter, monthly records of the amount of water pumped must be collected and sent to the State Engineer's Office on a quarterly basis. Exceptions to the measuring and reporting requirements include domestic wells, stockwatering, wells with a total authorized withdrawal that does not exceed five acre-feet annually, unless otherwise required by the terms of the permit or certificate. These measuring and reporting requirements are typical of hydrographic area designation orders as issued by the State Engineer's Office.
- In February 2015, the State Engineer's Office issued a "Meter Order" (Order 1251) requiring groundwater pumpers in 32 hydrographic areas to install totalizing meters, record monthly pumping volume data, and report these monthly records to the state on a quarterly basis. The same exceptions as Order 1253 apply also to Order 1251. A metering and reporting order is generally contextualized by the State Engineer as a method for monitoring that groundwater withdrawals are consistent with the allowable volumes as defined by underground water rights permits and mitigating depletion of groundwater levels.

NDWR has also collected well logs since the 1940s. In the mid-1990s, USGS and NDWR collaborated on a database project for inputting well log information into a computer database. All submitted well logs are on the well log database, which is available to the public through the Office of the State Engineer's webpage.

Indirect measurement of water use (top-down approach)

To complement water reporting, water use is also estimated indirectly. The "Nevada Statewide Assessment of Groundwater Pumpage" presents an estimate of total groundwater pumped in the state for calendar year 2013 (Nevada Division of Water Resources 2013). The estimate includes pumpage of all public waters appropriated by permits and certificates issued by the State Engineer, by adjudicated and unadjudicated pre-statutory vested rights, and by domestic wells. Primary sources of data were existing inventories, pumpage records from water right owners, duty of water rights, and known irrigated acres. Different methods such as basin inventories, reported pumpage, aerial imagery, and availability of surface water were used to estimate total pumpage, and the results are presented by county, hydrographic basin, and manner of use.

The report “Evapotranspiration and Net Irrigation Water Requirements for Nevada” calculated the evapotranspiration for each of the 256 hydrographic areas in Nevada using the ASCE-EWRI Standardized Penman-Monteith approach. The net irrigation water requirements were obtained using precipitation data (Huntington and Allen 2010).

System Analysis and Management

The Division of Water Resources collects information on snowpack and streamflow to determine the physical characteristics of each basin’s surface water system. Snowpack and streamflow forecasts are prepared by the Natural Resource Conservation Service (NRCS), which operates a series of snow depth measurement stations through the western US. NRCS and the National Weather Service hydrologists develop streamflow and water supply forecasts for the major surface water systems, which help guide water management and emergency management decisions. USGS also operates hundreds of surface monitoring gages on streams, canals, drains, springs, and lakes/reservoirs. The general role of the USGS stream-gaging program is to provide information to water resource managers (including the NDWR) on flow characteristics at any point on any stream (Nevada Division of Water Planning 1999).

Groundwater level data are also collected by NDWR, and through collaboration with USGS. USGS measures water level data for 145 primary observation wells and 1,000 secondary observation wells within 98 hydrographic basins. NDWR currently collects annual groundwater level data in 73 basins. Many of these groundwater level measurements are now available on the NDWR website.

NDWR uses a consistent modeling and estimation approach for evaluating surface and groundwater availability (Belcher and Welch 2006; US Geological Survey 2006). Perennial yield (annual) estimates for all 256 hydrographic basins are assessed by the State Engineer’s office. These values are used as a reference to compare estimates of annual basin yield to committed groundwater resources and to evaluate unappropriated water supplies. The State Engineer’s Office uses these comparisons as justification for issuing new (or modified) water rights, designating groundwater basins, issuing metering orders, prohibiting new appropriations of groundwater, and limiting groundwater extractions. Perennial yield (and system yield) estimates are updated on an as-needed basis, and are often validated with groundwater level measurements.

On the planning side, Nevada’s most recent State Water Plan was prepared in 1999. There is some debate among major water users (irrigation districts, municipal water suppliers, industrial users, etc.) and all levels of government on the potential value of updating the State Water Plan. The predominant water management philosophy in Nevada is that the locus of water management activities should be local and regional (among the local/regional water authorities, cities, decreed surface waters, etc.) rather than managed at the state level. Despite having a Comprehensive Water Assessment program in the mid-1990s, this program was defunded and has not been replaced with any comprehensive statewide water use and availability estimation. A Drought Response Plan was prepared in 2012 that coordinates agency roles and created a reporting system between agencies to appropriately address drought impacts (State of Nevada 2012). The 2012 Plan was developed to aid federal disaster relief agencies in identifying areas that might qualify for federal funding to mitigate drought effects. Shortly after the plan was developed, the US Drought Monitor became the primary resource for making these determinations.

At the regional level, the Colorado River Commission of Nevada, the Northern Nevada Water Planning Commission, the Central Nevada Regional Water Authority, and the Southern Nevada Water Authority have a significant role in managing and planning water resources in their respective geographic areas.

Allocation During Periods of Scarcity

There are two main types of curtailment orders issued by the State Engineer: moratoriums on new water appropriations (typical) and pumping limits on groundwater withdrawals for existing right holders (in rare cases).

The State Engineer issues curtailment orders on new appropriations within certain hydrographic areas of the state, often when basins may be nearing full appropriation (or over-appropriation). This type of curtailment may be done by placing moratoriums on new water appropriations from a particular location in a basin, either uniformly for all uses or targeting specific beneficial uses.

One example of a curtailment of a new appropriation is "Extending the Designated Area. Lifting the Prohibition of Movement of Water Rights to the Pahrump and Manse Fans, and Further Curtailment of Groundwater Appropriation Within the Pahrump Valley Hydrographic Basin in Clark and Nye Counties, Nevada" (issued April 2015). The State Engineer determined that groundwater levels in the Pahrump and Manse alluvial fans had recovered as a result of a moratorium on both new appropriations and movement of point of diversion from the valley floor to the fans. As a result of this prohibition, the valley floor basin was severely depleted. To resolve it, the State Engineer lifted the prohibition on movement of water rights to the Pahrump and Manse fans. In the same order, the State Engineer also established a moratorium on new applications to appropriate groundwater in the designated portion of this hydrographic basin.

Example 2 of curtailment of new appropriation: "Extending the Designated Area and Curtailing Groundwater Appropriation within the Antelope Valley Hydrographic Basin" (issued April 2015). The State Engineer determined that perennial yield of the Antelope Valley Hydrographic basin was 9,000 acre-feet per year, while the committed groundwater rights recorded in the basin total 31,150 acre-feet per year. The State Engineer also measured groundwater levels at 31 sites and verified the rapid depletion of the groundwater level across the basin. In response to depletion of the basin, the State Engineer placed a moratorium on any new applications to appropriate groundwater within the basin, with the exception of applications for environmental permits, temporary appropriations for establishing fire-resistant vegetation cover, temporary appropriations for stockwater purposes, and applications filed to increase diversion rate with no corresponding increase in annual allocation. This order also requires almost all groundwater pumpers to install totalizing meters, maintain monthly recording, and report pumpage to the Office of the State Engineer quarterly. Exceptions from measuring and reporting are granted for domestic wells, stockwater wells, and wells with totalized withdrawal that does not exceed five acre-feet annually.

Curtailment on groundwater pumping by existing water rights have only recently been used as a tool by the State Engineer's Office, and will be applied to the Walker River basin and potentially in the Diamond Valley basin.

Per the terms of their permit or certificate, groundwater rights holders may pump the same amount from year to year regardless of hydro-climatic conditions. The State Engineer has historically granted supplemental groundwater rights to surface water rights holders that need to augment water supplies due to drought. In the Walker River basin, the State Engineer issued 140,000 acre-feet of supplemental groundwater rights when surface water diversions were no longer feasible. Persistent drought conditions have reduced available surface and groundwater in the Walker River basin. In response, the Office of the State Engineer ordered a 50 percent curtailment of supplemental groundwater rights, though this order was appealed and eventually stayed (Nevada Division of Water Resources 2015).

Public Information Provision

Water Rights

The state maintains a water right database online where all applications—surface or groundwater, approved or not—may be accessed. The search engine has only three categories: application number, certificate number, or owner name. It provides information on the county, basin, point of diversion, source, and use, as well as duty (annual) and diversion balance (rate) for some. A second administrative water right database with more specific information on water rights, including priority date, can be found. This database is refreshed depending on the activity of the applications, but it is usually updated every two weeks. Also, water rights can be located through an interactive map application linked to the water right database. Surface water usage is tracked but the information is not available online for public use.

Monthly reports on all water rights applications are placed online too. Public awareness of any movement or new water rights is provided through these reports, and public protest or claims can be made. The results of these applications can be found on a website containing the State Engineer's Rulings. It provides weekly information on applications in the Las Vegas Valley, Long Valley, and Soda Spring Valley, including source and use of the water right, as well as definitive status and the State Engineer’s judgement statement.

For groundwater wells, there is a well log database with administrative information updated at least weekly. Wells can be searched by location (basin, county, township, etc.), type, use, drilling license, drilling contractor, or by owner. The results include information on the depth of the well, casing diameter, and the water level at time of construction.

More information on groundwater wells can be found on the Nevada hydrology data interactive map, though it does not have real-time pumping data. The website has a search engine that includes different wells classified by beneficial use, with information about their attributes and administrative data and a link to the well construction logs. Nonetheless, the information has not been updated to show more recent measurements. There are also pumpage inventories for many basins, sortable by manner of use and other characteristics. Most of them have a two or three years lag.

Some groundwater wells in Mason and Smith Valleys are connected to an online platform that shows monthly measures of the well’s activity during the irrigation season. The platform is set as an interactive map that also provides metadata on the use of the well, the metering equipment, and the permit history.

System Monitoring

For updated information on spring and streamflow, the USGS “Current Conditions” website publishes real-time information on hundreds of surface monitoring gages on streams, canals, drains, springs, lakes, and reservoirs as measured by the USGS monitoring network.

Nevada also publishes online precipitation data from different stations across the state. The search engines help users look up a specific weather station by name or county. The information is updated once a year in July. There is a website for evapotranspiration and net irrigation water requirements as well. It does not show real-time values but rather constructed values from historic data.

The Nevada hydrology data interactive map also offers information like measurements from precipitation gages, dam levels, water levels and spring and stream flows. The map links the monitoring stations to their logs. The information has not been updated to show more recent measurements.

For two specific areas—Las Vegas Valley and Soda Spring Valley in eastern Nevada)—monthly underground hydrographic summary reports can be found online. They provide data on water use according to the beneficial use specified in each water right as well as reports on potential use according to the status of applications approved or in process.

Allocation During Scarcity

There are two main types of curtailment orders: moratoriums and pumping restrictions. Both kinds of restrictions can be found online where orders are uploaded as they are published (usually weekly). The same platform includes information on adjudications, metering, designation, and other orders that are released by the State Engineer. Curtailment orders can also be found through a "basin order query" platform, where a search can be made of a specific order or by a specific basin.

Water Transfers

Monthly reports on all water rights applications are online, including transfers and change requests. Information on the basin, source, location, and amount of water requested for transfer is provided. The information is updated with one or two days of delay. Public information of any movement or new water rights is provided through these reports, and public protest or claims can be made. None of the application forms require documentation of water prices for permanent or temporary changes to water rights. Prices are negotiated directly between the buyer and seller, or agents representing them.

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Oregon

Highlights

- Because most major reservoirs were built and are operated by federal and local agencies, the state has a very limited role in water supply operations. Water supply operations are managed at the local level by local and federal agencies.
- All water is publically owned in Oregon. The main role of the state is to allocate water rights, oversee water curtailments, and improve the environmental health of rivers throughout the state. Under state authority, water masters administer and curtail water rights.
- Due to the small share of water-right holders required to report their water use and the high impact of some diversions on sensitive fish in some basins, the Oregon Water Resources Department and the Oregon Department of Fish and Wildlife developed a plan in 2000 to measure more than 2,300 diversions within 300 basins deemed significant for their impact on fish flows. While only amounting to 10% of diversion points across the state, these diversions account for 50% of the state's diverted water by volume.
- Oregon has a sophisticated statewide water availability tracking system, which it uses to determine the potential impact of new water appropriations on water availability in nearly every basin in the state. A Water Availability Basin is considered fully appropriated in a given month when either consumptive uses surpass the 80 percent exceedance level of streamflow or instream uses surpass the 50 percent exceedance level.

Introduction

With an average precipitation of 32 inches a year, Oregon is generally considered a water-rich state. Humid air moving from the Pacific Ocean is largely responsible for rain in the western part of the state. The Pacific also moderates winter minimum and summer maximum temperatures in the western region. The mountains of the Cascade Range, running parallel to the coast, divide the western and eastern sides of the state. The area west of the mountains, specifically in the Willamette Valley, contains most of Oregon's population.

While the western areas generally lack water scarcity problems, central regions of Oregon are mostly dry due to a rain shadow created by the Cascade Range. Eastern areas of the state are quite dry and water restrictions or curtailments are often required (Oregon Water Resources Department 2013). Temperatures also vary more east of the Cascade Range, with significant variations during the day and seasonally.[89]

Oregon's variety of soils and climatic regions support a diverse agricultural sector (Sorte and Rahe 2015). The state produces more than 225 agricultural commodities, making it an important component to their economy (Oregon Department of Agriculture 2016). Due to the importance of agriculture, irrigation districts and other agricultural water suppliers are encouraged to prepare a water management and conservation plan (Oregon Water Resources Department and Oregon Water Resources Congress 2007).

89 Unless otherwise noted, information on Oregon's climate was sourced from the Western Regional Climate Center and the Oregon Climate Change Research Institute.

Principal demographic, economic, and water-related indicators in Oregon

Population (in 2010):	3.83 million
GDP (in 2010):	$190 billion
Agriculture Value Added:	2.70 % of GDP
Annual Precipitation:	32.11 inches
Total Water Withdrawals:	42,600 TAF
Urban Use:	11%
Agricultural Use:	78%
Thermoelectric Use:	0%
Other Uses:	11%
Surface Water:	65%
Groundwater:	35%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight agencies

The primary state agency in charge of overseeing water resource management is the Oregon Water Resources Department (OWRD). OWRD reviews applications for new water rights, oversees watermasters to ensure that priorities of existing rights are maintained, collaborates with state courts on basin adjudications, and approves water transfers. Other duties include collecting and publishing water resource data online and facilitating supply solutions. A seven-member volunteer board of directors, the Oregon Water Resources Commission, presides over the Department and signs off on many major decisions made by OWRD.

Oregon's five geographic regions are divided into 21 water districts, all of which are under OWRD. Most regulatory decisions are made at the water district level by the presiding watermaster with some oversight from OWRD. Local watermasters are responsible for making sure that diversions are according to seniority. Watermasters and water district staff also provide public information, monitor enforcement of instream water rights, inspect wells and dams, and monitor streamflows for management purposes. Conservation and management planning is done at the local level by agricultural and municipal water suppliers and also at the state level (Oregon Department of Water Resources 2013).

The Oregon Watershed Enhancement Board (OWEB) is another state agency with water-related oversight responsibilities. This 17-member board of citizens, tribal members, and federal and state natural resource commissions has the primary mission to restore watersheds and natural habitats by financially supporting public and private projects aimed at watershed conservation.

Water supply agencies

Oregon has several types of local water supply agencies, including cities, counties, irrigation districts, and other local service districts.

The US Bureau of Reclamation (USBR) built the major water supply projects for irrigated agriculture in eastern Oregon. USBR currently operates McKay Dam in the Umatilla Basin, a small water supply project that provides 73,800 acre-feet of irrigation water for two irrigation districts. With the exception of one minor operating responsibility, USBR's role in Oregon today is mostly improving dam safety, enhancing streamflow and fish passage, and working collaboratively on watershed restoration.

The US Army Corps of Engineers operates 13 dams in the Willamette River basin. While the project's principal role is flood control, it does provide some water supply for irrigation.

Legal Framework

Water rights

The water rights system in Oregon is complex in administration, as allocation of scarcity must be done according to water right priority date. Under Oregon law, all water is publicly owned. With a few statutory exceptions for small uses, individuals or entities who wish to use water from lakes, streams, or underground sources must obtain a permit from OWRD.[90] Surface and groundwater rights are procured through the three step procedure in which an applicant progresses to a permit and finally to a certificate. The water rights system is based on the prior appropriation doctrine "first in time, first in right." The prior appropriation doctrine was established as the foundation of Oregonian water rights in 1909 with the passing of the state water code. Surface or groundwater must be used for a beneficial purpose without waste. Final certificates of water rights define the maximum rate of diversion and/or the annual volume allowed under the water right (Oregon Water Resources Department 2013).

Some beneficial water use predates the state water code of 1909. The Oregon's water code recognized the claims made under the riparian doctrine before 1909, but simultaneously created rules for extinguishing new riparian claims (Getches et al. 2015). By an act of legislation in 1987, individuals claiming vested water rights (appropriative and riparian) in areas not yet adjudicated were required to file Surface Water Registration Statements with OWRD (Oregon Water Resources Department 2013). The registration program provided a clearer picture of pre-code appropriative and riparian claims and use, but did not determine a legally allowable diversion limit. Claims to a vested water right can only be determined and quantified through an adjudication proceeding.

The state's aggressive statewide basin adjudication program has resulted in very few unquantified riparian water rights holders. Most major stream systems in the eastern and southern portions of the state have been adjudicated, representing nearly 100 individual streams for which decrees have been issued. The Upper Klamath River is the most recent basin to be adjudicated. In an adjudication proceeding, OWRD collects information on vested water rights and water rights permits and licenses and presents the information to a local circuit court. The court issues a decree describing who has the legal right to use water, the amount and location of water use, and the priority date of each right. Finally, OWRD issues water rights certificates to each decreed right (Oregon Water Resources Department 2013).

Oregon has a sophisticated statewide Water Availability Reporting System (WARS), which it uses to determine the potential impact of new water appropriations on water availability in nearly every basin in the state. OWRD

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[90] According to Oregon Revised Statues 537.141 and 537.545.

will not issue permits for new appropriations in basins that are fully appropriated. For determining levels of appropriation, Oregon was divided into 2,500 Water Availability Basins (WAB) covering most of the state. A WAB is considered fully appropriated in a given month when either consumptive uses add up to the 80% exceedance level of natural streamflow or instream uses sum to the 50% exceedance level (Cooper 2002).

Water trading

Nearly all water transfers are arranged independently by the parties directly involved and are approved through OWRD. The only entity resembling a water bank in Oregon is in the Deschutes basin where surface water rights can be leased to gain groundwater pumping credits. Transfers fall under one of three categories: temporary (5 years or less), time limited (over 5 years), or permanent. Transfer applications must be submitted any time a user wants to change the point of diversion, point of use, or purpose of use regardless of whether or not the water will be diverted by a different user (Amos 2009). Applicants must fill out a form and provide supporting documents such as maps detailing the current and proposed point of diversion. Other required documents depend on the period for which the transfer is requested and the changes being made by the transfer. OWRD determines if a proposed transfer will injure any other water right holders. This is done both through internal review and by posting the transfer for public appeal. Temporary transfers require less paperwork and can typically be processed in 1 to 2 months—as opposed to 1 to 3 years for permanent transfers. OWRD is currently backlogged at times with permanent transfer requests so that temporary transfers may be processed quickly. The Department is working to develop a streamlined approach for approving permanent transfers in as little as several months. Transfers are not approved for non-adjudicated rights because they do not have verified priority dates.

Legal treatment of environmental water use

Studies were conducted through the 1960s to recommend instream flows for much of Oregon. While many of these recommendations have yet to be given a water right, quite a few instream flow rights exist in the Willamette Basin and other regions of the state. Many of these instream flows were established through appropriations obtained by the Department of Fish and Wildlife, Environmental Quality, or Parks and Recreation. By law, these instream appropriations have the same status as other water rights and may be curtailed according to priority date (Oregon Water Resources Department 2013).

The Oregon legislature, Oregon Voters and the Water Resources Commission have created environmental and recreational flows by designating “scenic waterways.” A scenic waterway prevents new appropriations of water and “prohibits construction of dams, reservoirs, or other water impoundment facilities” on a designated stretch of stream but does not affect existing water right holders (Amos 2009). It provides a means of establishing a level of full appropriation, but it is not effective for fully appropriated basins, which is most of the state.

In most rivers and streams, instream environmental flows are attained through voluntary water transfers. Water right holders are legally allowed to sell, lease, or donate water rights for conversion to instream water rights (Oregon Water Resources Department 2013).

Prioritization of particular uses

Oregon’s revised statutes define clear priorities for domestic uses during mutually exclusive conflict or when available water supplies are insufficient to meet all needs. According to these laws, preference is given in the following order: human consumption, livestock consumption, and all other beneficial purposes. State law also specifies order of priority according to the type of diversion structure, prioritizing multi-purpose impoundments over single-purpose impoundments and upstream impoundments over downstream impoundments.

Statutes also provide some protection for minimum perennial stream flows for the environment. In a mutually exclusive conflict or shortage, maintenance of minimum perennial streamflows must be “fostered and encouraged if the existing rights and priorities under existing laws will permit” (Smith and Ellsworth n.d.).

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

According to Oregon Revised Statue 537.099, government entities that hold surface and groundwater water rights—such as federal and state agencies, cities, counties, schools, irrigation districts, and other special services districts are required to submit annual water use reports to OWRD. These reports must include the volume of water used under each water right by month and the categories of beneficial use to which the water is applied.[91]

If a region is deemed a “Critical Groundwater Area” or “Serious Water Management Area,” OWRD has authority to require water use reports from anyone in the region using more stringent measurement requirements.

In addition to government entities and water-right holders in critical management areas, many surface and groundwater rights approved for since the early 1990s are subject to metering and reporting requirements embedded in the terms of the state water rights certificate. For those groundwater users who are required to report, use is tracked through monthly measurements reported annually. Permits are not required for domestic purposes less than 15,000 gal/day, commercial use less than 5,000 gal/day, livestock watering, lawn or non-commercial gardening of less than a half-acre of land, and up to 10 acres of irrigated school grounds.

About a quarter of all water rights in Oregon (both surface water and groundwater) are required to annually report their monthly use between October 1 and September 30. Most non-governmental right holders are not required to report their monthly use.

Reports can be submitted to OWRD, which makes the data public through an online database. The department performs some quality control on reports before posting them online, but they do not accept responsibility for any errors in posted reports.

Water-right holders that are required to report are allowed to measure their surface diversions using various devices including weirs, flumes, and current meters. Permits are not required for several types of diversions: livestock watering if the stream passes through or alongside the land where livestock are held, salmon egg preservation projects, and emergency fire control (Oregon Water Resources Department 2013).

Indirect measurement of water use (top-down approach)

Because of the small share of water-right holders required to report their water use and the high sensitivity of fish to major diversions in some basins, OWRD and the Oregon Department of Fish and Wildlife (ODFW) developed a plan in 2000 to measure more than 2,300 diversions within 300 basins deemed as significant for their impact on fish. While only amounting to 10 percent of diversion points across the state, these “significant diversions” account for 50 percent of the state’s diverted water by volume (Oregon Water Resources Department 2013).

[91] According to ORS 537.099.

System Analysis and Management

OWRD operates more than 200 stream and reservoir gages throughout the state. About 110 of these gages are operated in near real-time. Information from an additional 225 gages operated by USGS and other agencies is shared on the department's website. Stream gages are used to actively manage water daily, protect instream and out-of-stream water rights, forecast floods, plan for recreational activities, better understand water availability and climate change, and plan for future growth.

Stage-discharge curves and rating tables are developed by physically measuring flow at various stages. After the end of the water year (October 1 to September 30), the streamflow data, if preliminary, are reviewed again. If discharge has not yet been determined, the data development and review process is initiated. During this process, any previous computations of streamflows are evaluated and adjustments are made to reflect changes in the stage-discharge curve which may have occurred during the year.

Groundwater well data, and their locations, are collected by a variety of public and private entities in Oregon at all levels —local, state, and federal. OWRD established a water and monitoring well data standard to specify a common method for locating and identifying water and monitoring wells in the state. Besides OWRD, other agencies that maintain their own well data are the Oregon Department of Environmental Quality, the Oregon Health Authority, USGS, Benton County, and the City of Portland. Data can be accessed through the well repository.

Because most major reservoirs are operated by federal and local agencies, the state has a very limited role in water supply operations. The state does not provide modeling support for water supply operation accounting practices. The most interesting model developed by the state is the Water Availability Reporting System (WARS), which assesses surface water availability for determining the potential impact of new water appropriations on water availability in nearly every basin in the state. OWRD maintains a database of the amount of surface water available for appropriation for most waters in the state (Cooper 2002).

At the regional level, the *Willamette Basin Review (Reservoir Study)* is a comprehensive evaluation of approaches for balancing agricultural, municipal, and industrial uses with valuable instream flows as the region grows. The Willamette Basin is only 12 percent of total land in Oregon, but includes 66 percent of the state population. The 13 federal reservoirs in the middle and upper Willamette Basin have a storage capacity over 1.6 million acre-feet. The projects provide important benefits, including flood control, generation of electricity, and water storage. Recreational use at many reservoirs is significant and releases provide instream benefits for fish, wildlife, navigation, and water quality. Only a small percentage of this storage is currently under contract for irrigation.

Population growth, increasing development, agriculture, and Endangered Species Act listings will place new demands on the reservoirs and could affect project operations. The reservoir study will determine to what extent the reservoirs may help to meet future water demands in the Willamette Valley and if changes in project authorizations are necessary to meet those needs. Funding for the study has been provided by the federal government, the State of Oregon, and more than 60 cities, special districts, organizations and commercial and industrial firms. The reservoir study will determine how operational changes or modifications in the allocation of stored water would better serve present and future resource needs in the basin.

Another analysis of the Willamette River Basin is being conducted by Oregon State University (OSU). OSU researchers are developing a robust water availability and use simulation model for the Willamette Basin (Willamette Water 2100) designed to simulate water availability up to the year 2100. The model incorporates daily precipitation, temperature, snowpack, and streamflows, as well as urban water use, agricultural crop and irrigation decisions, reservoir management, and explicit water rights allocations. OWRD is in talks with OSU about using the model for their own projections.

Allocation During Periods of Scarcity

Surface water rights are curtailed nearly every year. In some basins, it is common to only have enough water for water rights pre-dating 1900 by the end of summer. The process of curtailing water rights begins when a senior user makes a "call" on their water right (Oregon Water Resources Department 2013). Once a call is made, the local watermaster verifies the validity of the call and shuts off upstream junior users until the senior call is met. Watermasters analyze streamflow and diversion measurements to determine who needs to be curtailed and when a call has been met. In some watermaster districts, this data is measured using digital recorders and is available in real time while other districts require the watermaster to physically visit the measuring device. Not all diversions are measured, so the watermaster must use whatever data is available. Experience is also significant in a watermaster's curtailment decisions. In most years, the same calls are made and junior users have come to expect and plan for curtailment.

Notices of curtailment are sent to junior users and compliance is generally voluntary. If users do not respond, a second letter is sent identifying a date by which the user must comply or face civil penalties. On the rare occasion a user refuses to comply, the department will lock off the diversion headworks and can assess daily civil penalties. The department also intervenes in cases of illegal use.

Curtailment of groundwater rights is a very recent development and has only been done in two basins, the Umatilla and Klamath. The curtailed users were junior right holders who were causing an obvious impact on surface water flows due to their close proximity to the river.

Public Information Provision

Water Rights

Water Rights Information System (WRIS) is a platform with information pertaining water right applications, permits, certificates, transfers, leases, and related information. The system provides data on every surface, groundwater, or storage water right, including their priority date, annual start and end dates, the volumes allowed for each to withdraw, a map of the point of diversion, nearby water rights, genealogy of the water right, and the previous year's water use report.[92] Also, the Water Rights Mapping Tool locates and provides information on type, priority, and allowed rate for any water right. Data quality has been an issue.

Water rights can also be found through the Water Rights Plat Card Report, by searching township, range, and section. This platform is also connected with the WRIS platform and provides information on the legal aspects of the water right, such as the allowed withdrawal and location of the right, and information about previous water use reports.

The state also provides two databases. The first, the "Point of Diversion Summary Report," includes an estimate of the total water diverted and detailed information on all diversions allowed daily. The inquiry can be narrowed to any basin or range of dates. The "Place of Use Summary Report" provides information on all active water rights active by specific area. Both of them present estimates based on the legal allowance provided on the water rights.

Water Rights Public Notices are uploaded weekly to the OWRD website with information on new applications submitted, allowing for public comments. The information published includes the applicant's name, location, detailed source, category of use, quantity of water to be withdrawn, priority date, and current status of the water right.

[92] Note that most water right holders in Oregon do not have to submit water use reports.

System Monitoring

OWRD developed an online platform where near-real-time surface hydrographic data may be accessed. Information from different state and USGS stations is published here. The data provided considers instantaneous measurements (with a short time delay), as well as daily mean flows. The search engines can locate a particular streamgage station, differentiate by basin, and narrow the results to show active, discontinued, or stations that provide near-real-time data. Discharge, reservoirs, or canal stations can be selected as well, and all the information can be mapped.

For historical data, OWRD maintains another online platform called "Historical Streamflow and Lake Level Data." Users can download summary and specific reports for any monitoring station on mean daily flows, peak and low flows, river stages, and reservoir stages.

The state has a "Water Availability Analysis" platform, with daily reports on surface water availability at 50 or 80 percent exceedance levels.[93] Reports are made for every stream, subtracting from the natural streamflow existing instream water rights and out-of-stream consumptive uses. Reports can be located by basin, watershed, or water right. The tool is connected to the Water Rights Mapping Tool so reports can be displayed on a map.

Groundwater levels can be found for OWRD observation wells through an online map. There, information from the observation well network (generally measured quarterly by regional or district office staff) and other observation wells can be accessed. The platform provides information on the last quarter's retrieved data, as well as historic levels.

Groundwater record measurements are available in the online "State Water & Monitoring Well Repository." Information that can be searched includes specific basin, county, location, watermaster district, WRD Identifiers, and Well Standard Repository IDs. It provides information for every well about type of use, location, completion date, depth, static water, and drilling method, and other information.

The "Well Construction Information" platform retrieves well logs, including data and images of original documents on over 250,000 wells across the state. Information about the well ID, type, depth, static water level, and maximum yield can be accessed, as well as GPS information on some wells so they can be displayed on a map.

Allocation During Scarcity

Some river basins, like the Klamath Basin, provide an online portal containing information about the calls for water made by senior users, the status of those calls, whether regulation has occurred, and the priority date to which junior water rights are required to curtail. The portal also provides streamflow measurements through the OWRD Near-Real Time Hydrographics Data.

Water Transfers

State transfer forms require information on volumes transferred, however the information is not organized and processed before being published. Pricing information is not required to be included in the permanent, temporary transfers, or leasing forms.

Information on new water transfer requests and water transfer approvals are published in "Water Rights Public Notices," uploaded weekly to the OWRD website. Public and/or other state agencies may also comment on those requests. The information published includes the applicant's name, the county and basin where it will be located, the detailed source, the water right type, priority, and the quantity transferred as well as the proposed change.

93 Exceedance level refers to the probability that the streamflow will exceed a certain level. For example, a 95 percent exceedance probability characterizes low-flow conditions, as it refers to a flow level where 95 percent of all daily mean flows in the record are greater than that amount.

The Central Oregon Irrigation District (COID) provides an online calculator to estimate how much water may be protected instream through instream leases and transfers.

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Texas

Highlights

- Surface water operations in Texas are managed mostly at the state level by 24 river authorities established by the state legislature. Groundwater is managed locally by about 100 groundwater conservation districts (GCDs) covering almost 70 percent of the state. In the areas without a GCD, there is no regulation on groundwater withdrawals.
- Unlike most western states, Texas' groundwater laws are based on the rule of capture: groundwater belongs to landowners, granting landowners the right to pump as much water as they choose without liability to surrounding landowners who might claim that the pumping has depleted their wells. However, GCDs may pass local regulations requiring measuring and reporting, productions limits, and collect taxes, penalties, and extraction fees.
- The state has developed authoritative models to manage surface and groundwater resources: the surface water availability model predicts the amount of water that would be in a river or stream under a specified set of conditions. Groundwater availability models are regional groundwater flow models based on the USGS MODFLOW codes that have been accepted by TWDB for groundwater planning purposes.
- The Texas Water Conditions Report summarizes statewide and regional conditions monthly for 114 major water supply reservoirs, 29 streamflow measurement stations, and 17 key groundwater monitoring wells.

Introduction

Texas is the second largest US state both in area and population. From west to east, the climate and landscape of Texas gradually changes from desert and low mountains in Big Bend National Park and the El Paso area, to plains and prairies in the central region, and humid lowlands in the coastal plains of the eastern part of the state.

The minimum and maximum temperatures in the western city of El Paso average 51.8°F and 77.5°F, with average annual precipitation of 9.69 inches. In Laredo, in the mid-south, the temperature range is much higher, with a minimum average temperature of 63.2°F and a maximum of 85.1°F. Precipitation in Laredo averages 20.15 inches per year, mostly in summer. The eastern city of Beaumont has minimum and maximum average temperatures of 58.9°F and 78.3 °F, with 60.38 inches of annual precipitation. Snowfall often occurs in winter months in northern Texas.

Texas has 15 major river basins and eight coastal basins that flow into the Gulf of Mexico. River discharges are highly variable, including seasonal and inter-annual fluctuation, multi-year droughts, and major flooding Short-term changes in flow can vary significantly from daily, monthly, and annual means and low and high flow values (Wurbs 2015).

Agriculture is a sizable part of the economy. Total irrigated lands amount to 5,920,000 acres, or slightly more than half the irrigated acreage in California (Maupin et al. 2014). The state leads in cattle, cotton, hay, sheep, and goat production.

Principal demographic, economic and water-related indicators in Texas

Population (in 2010):	25.1 million
GDP (in 2010):	$1,203 billion
Agriculture Value Added:	1.7% of GDP
Annual Precipitation:	27.08 inches
Total Water Withdrawals:	27,800 TAF
Urban Use:	22%
Agricultural Use:	31%
Thermoelectric Use:	46%
Other Uses:	1%
Surface Water:	42%
Groundwater:	53%
Desalination:	5%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, source of water withdrawals —surface and groundwater— is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

The 1967 Water Rights Adjudication Act authorized merging historical water rights systems to facilitate statewide surface water oversight and management. The Act required any person with a historical right (other than for domestic use and livestock watering) to file a claim with the state for the right by 1969. Prior to this Act, pre-code water right claimants were not required to file any claim for water. All riparian and appropriative rights were reviewed, and final rights were issued as certificates of adjudication. Since then, all surface water rights are subject to prior appropriation and are granted by the Texas Commission on Environmental Quality (TCEQ) (Texas Water Development Board n.d.).

Groundwater laws are based on the "rule of capture," which allows landowners to withdraw water lying under their property. It wasn't until after 1949, with the Texas Groundwater Act, that locally formed groundwater conservation districts could start regulating withdrawals. By 2001, 87 Texas GCDs covered roughly half the state's land area and regulated a great percentage of water withdrawn from the state's nine major and 21 minor aquifers. There are currently about 100 groundwater conservation districts (GCDs) covering almost 70 percent of the state (Wythe 2014).

Regulatory Overview

Institutions

Oversight agencies

Texas has two main statewide water oversight institutions, four watermaster controlled basins, and local groundwater conservation districts.

The two principal statewide water agencies collect significant amounts of information on water availability and use, and jointly support water resource planning and management by local and regional entities. TCEQ is broadly responsible for administering surface water rights, managing public drinking water system programs, and administering surface water quality programs. It is also primarily responsible for water rights allocation, including permitting processes, and maintaining water availability models and input datasets for determining water availability. The Texas Water Development Board (TWDB) supports regional and statewide water resource planning, maintains several databases on the state's natural resources, provides financing for local water projects, and administers the Texas Water Bank and Trust.

For the most part, groundwater is managed by the cities, farmers, and property owners who drill and operate wells. However, local and regional water management entities play an important role in managing groundwater. Groundwater conservation districts are the principal means of managing groundwater in Texas. GCDs are diverse in their oversight programs and capabilities. GCDs may pass local regulations requiring measuring and reporting, productions limits, collect taxes, penalties, and extraction fees, though not all GCDs may exercise these powers.

TCEQ established watermaster areas in several river basins in the more arid southern and southwestern parts of the state. Watermasters oversee the distribution of surface water in these basins and ensure proper allocation of water to individual water-right holders through local monitoring of streamflow, reservoir levels, and water diversions. Water diverters within a watermaster area must install a measuring device, notify a watermaster before diverting, receive approval for the diversion from the watermaster, and continuously report actual diversion amounts to the watermaster. Watermasters keep track of how much each right holder has diverted and records this amount against the annual authorized appropriation of water defined in their water right. The watermaster maintains an account for each water-right holder for tracking compliance and billing. Reported diversions and actual use are self-reported on the honor system and watermaster field staff deputies may only conduct field inspections in response to requests. While the self-reported data may not be accurate or precise, it is the most accurate diversion data collected in Texas. Texas Water Code also requires TCEQ to establish a Watermaster Advisory Committee (WAC) for each watermaster area. WACs consist of 9–15 water rights holders from different parts of the basin, representing a wide range of beneficial uses and diversion sizes. WACs evaluate proposed annual budgets for the watermaster program and provide recommendations to the watermaster on water administration activities. The lower Rio Grande River basin is one of the oldest watermaster areas in the state, and has a different water rights system than the rest of Texas. This is partly because of interstate and international water sharing agreements for Rio Grande water and shared storage facilities. As directed by the state legislature, at least once every five years TCEQ evaluates basins that could benefit from a watermaster program. TCEQ evaluated the Canadian and Red River basins in 2015 and will evaluate Sulphur River and Cypress Creek Basins in 2016.

Texas has 24 river authorities established by the legislature. These public agencies have authority to develop and manage surface waters. River authorities own and operate 22 major water supply reservoirs, with a combined storage capacity of more than 10 million acre-feet. Most river authorities are major water wholesalers, controlling an estimated 43 percent of surface water in the state (Griffin 2011). River authorities can operate dams and reservoirs, supply raw untreated or treated water to municipal, industrial, and other customers, operate wastewater facilities, control drainage and floods, supply water for irrigation, and provide hydroelectric power. River authority responsibilities and powers are separate from watermaster programs. River authorities may find watermaster programs useful for increasing water accounting capabilities on rivers and streams. Some river authorities have robust water accounting and information systems.[94] Some river authorities have individual contracts with USGS to install real-time surface water flow monitors, accessible through the USGS website.

For planning purposes, Regional Water Planning Groups are responsible for water budgeting estimates every five years, and GCDs assess available groundwater resources and future yield estimates every five years.

[94] For example see the Brazos River Authority 2014 Reservoir Accounting Summary.

Water supply operations agencies

About 40 percent of the water supply storage capacity in Texas is contained in 30 reservoirs owned and operated by the US Army Corps of Engineers (USACE) and two reservoirs operated by the International Boundary and Water Commission. River authorities and municipal water districts contract for water supply storage capacity in USACE reservoirs (Wurbs 2015). Many smaller reservoirs owned and operated by river authorities, water districts, and cities make up most of the remaining 60 percent of the total statewide storage capacity. The US Bureau of Reclamation (USBR) constructed four reservoirs that are now owned and operated by non-federal sponsors.

Funding

TCEQ's operating budget for 2016 fiscal year was $474 million for the water, air, and solid waste programs, including baseline and contingency appropriations. Almost 90 percent of this budget is funded by program fees, the remaining 10 percent is funded by federal funds, general fund revenues, and other sources.

TWDB's fiscal year 2016 operating budget was $203 million. About 40 percent of the operating budget (or $79 million) was funded by the Texas General Revenue Fund. Federal funding amounts to nearly 30 percent of the total operating budget, and the remainder of the funding is sourced from special funds (Texas Water Development Board 2015).

Local watermaster programs are funded with fees assessed by TCEQ on individual water-right holders.

Legal Framework

Water rights

Texas surface water law is generally based on the prior appropriation doctrine, but also recognizes riparian water rights and other types of water rights that pre-dated statehood and the modern surface water code. To incorporate historical water rights into the modern water code, Texas issued certificates of adjudication to historical users of water following the 1967 Water Rights Adjudication Act. Obtaining a permit required claim holders to prove their claim and confirm it in state district court. District courts reviewed the evidence presented and issued a certificate of adjudication with a priority date indicating the time when the water use first occurred based on historical record and other evidence. Following the filing of historical claims to use, the Texas Water Commission (predecessor of TCEQ) undertook a statewide adjudication process, which was completed in the 1990s (Griffin 2011). Some river basins in Texas are fully appropriated by water rights holders.

New water rights are issued as permits, which require no judicial review, but do require an assessment of water availability using Water Availability Modeling (WAM) System described below. New permits and modification to existing permits are approved subject to no adverse impacts on other water right permit holders. Approval also includes consideration of impacts to instream flows and environmental issues. Texas also issues term permits that allow users to use water that is already fully appropriated but not yet being fully used. These permits are generally issued to industrial, mining, and agricultural purposes. Finally, "Temporary Permits" are issued for up to three years for road dust suppression, mining, agriculture, and firefighting.

Texas groundwater belongs to landowners and is subject to the rule of capture in many parts of the state, granting landowners the right to pump as much water as desired without liability to surrounding landowners who might claim that the pumping has depleted their resources. The rule of capture has been followed by the courts since a 1904 Texas Supreme Court decision. The Supreme Court re-examined the rule of capture doctrine in 1999 during a dispute between neighboring groundwater pumpers. The courts re-affirmed the rule of capture, but also strengthened tools available to GCDs for local groundwater management. GCDs can be established legislatively, by TCEQ, or by landowner petition. According to the Texas Water Code, the purpose of GCDs is to provide for the conservation, preservation, protection, recharge, and prevention of waste of groundwater and to control subsidence caused by withdrawal of groundwater. To accomplish these objectives, GCDs prepare a groundwater management plan, adopt rules to achieve the objectives of that plan, and issue permits for certain users. Common objectives of a management plan include achieving efficient use of groundwater, responding to drought conditions, and creating long-term balances. Common rules include metering and reporting, production limits, and well spacing requirements (Cheney 2014). The Edwards Aquifer is a unique exception to the rule of capture. As GCDs begin to issue permits for some groundwater users, the rule of capture is being supplemented with other styles of groundwater allocation that suit the individual needs of GCDs (House Committee on Natural Resources 2014).

Water trading

A water permit is transferable to other users or uses. This transferability applies to the selling of a water permit (perpetual transferability) or entering into a contract to sell the water made available by the permit for discrete periods of time (temporary transferability). Contracts for water (called leases) may range from annual arrangements to 50-year obligations. Contracts are generally used to sell water to wholesale and retail customers (Griffin 2011). Any transfer that requires amending or changing the original water right—including change in the place, purpose, or amount of water used; method or rate of diversion; or location at which surplus water is returned to the stream—must be reviewed and approved by TCEQ. These complex evaluations may involve public notice, especially if the amendment is likely to negatively impact other water-right holders in a basin.

Texas allows interbasin transfers (permanent and temporary), which have allowed for some water marketing. Protections to control the basin of origin expanded in 1997, when the Texas legislature passed the Junior Rights Rule. The rule states that when surface water rights are transferred for beneficial use in another basin, the right loses its seniority and becomes junior to any other right in the originating basin. This rule reduces the reliability of a water right during drought and effectively precludes interbasin water marketing (Griffin 2011).

TWDB manages the Texas Water Bank, created in 1993, “to facilitate the voluntary transfer of water and/or water rights, either surface or groundwater, between willing buyers and sellers” (Texas Water Development Board n.d.). The water bank acts as a bulletin board and registry of water and water rights for potential buyers and sellers. Use of the bank is optional, and water rights may be bought or sold outside of the bank. As of August 2015 the Texas Water Bank had eight water bank deposits, about 24 registered sellers, and two registered buyers. The Texas Water Bank may play a minor role in water rights transactions, while other types of water transfer arrangements are plentiful locally—including groundwater access marketing, which is the leasing of land to cities and other major water users for access to groundwater resources. This type of trading is unregulated by TCEQ, and has led to serious depletion in some areas. Some GCDs are actively trying to regulate groundwater access marketing to reduce groundwater depletion.

The Texas Water Trust, administered by the TWDB, is responsible for holding water rights for environmental flow maintenance purposes, including instream flows, water quality, fish and wildlife habitat, or bay and estuary inflows. TCEQ must approve all water rights placed into the trust. Water rights may be placed in the trust temporarily or in perpetuity.

Legal treatment of environmental water use

The Texas Instream Flow Program assesses how much water is needed to maintain a healthy ecological environment.[95] Recommended flow standards for the environment are established through a state-sanctioned process consisting of data collection, analysis, and stakeholder outreach (Texas Water Development Board 2008). Data for assessing sub-basin instream flows include USGS gage data, federal/state/local reports and studies, current water quality models and standards. Original data is also collected for hydrological, biological, and geomorphic evaluation of different flow regimes. The final sub-basin report includes a description of flow recommendations and ecologically significant flow components. Follow-up legislation improved the implementation of this process by creating scientific advisory committees responsible for overseeing the sub-basin flow recommendation studies, and created scientific and stakeholder groups for major bays and basins. The result is improved environmental review and set-asides of unappropriated flows for the environment in some basins (Jackson 2009).. As of September 2015, adopted environmental flow standards (set-asides) have been created for 19 major river basins in Texas. Adopted environmental flows are issued a priority date based on when the scientific group made their recommendation. During drought conditions, there is no guarantee of meeting environmental flows, as these adopted flows tend to have junior water rights.

Environmental flows are defined as a beneficial use in the water code. The process for obtaining a permit for environmental flows is not yet fully developed. One method of achieving environmental instream flows is through reservoir re-operation for estuary health. By law, reservoirs built with financing from TWDB must reserve five percent of annual firm yield to the Texas Parks and Wildlife Department for environmental flows that reach salt-water bays and estuaries. Implementation of this law has been a challenge (Jackson 2009). All reservoirs built after 1985 may also have special permitting conditions to provide environmental flows to coastal bays and estuaries.[96]

Another common approach to maintaining ecological values in rivers and streams is by placing conditions on new appropriations that will protect environmental concerns. The “instream uses staff” of the Resources Protection Team (TCEQ) perform environmental technical reviews to evaluate the impact of new appropriations of water on fish and wildlife habitat, water quality, and other instream uses. The instream uses staff may recommend modifications to the proposed water right according to the findings of their technical review.

Prioritization of particular uses

Texas Water Code describes a secondary system of priority based on the type of beneficial use for determine the relative priority of two permits with the same priority date. The highest priority beneficial use is domestic and municipal uses, followed by agricultural and industrial uses, mining and recovery of minerals, hydroelectric power, navigation, recreation, and finally all other beneficial uses. Ambiguity about when this hierarchy is applicable arises because this secondary system of prioritization is not referenced in the water code section on water shortages and curtailments (Smith and Ellsworth n.d.).

[95] Legislation SB 2 directed the TECQ, Texas Parks and Wildlife Department, and Texas Water Development Board to “jointly establish and continuously maintain an instream flow data collection and evaluation program...” See Texas Water Development Board 2008.
[96] According to Texas Water Code §11.147.

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

Monitoring surface and groundwater usage is performed at several scales across the state, and for several purposes. TCEQ and TWDB both collect information on surface water use (and TWDB collects some groundwater use data).[97] TCEQ is responsible for collecting user-supplied monthly surface water diversion records from all water rights holders annually, as they are responsible for overseeing administration of surface water rights. TWDB collects annual water consumption data from nearly all community public water systems and significant industrial facilities (Annual Water Use), as they are responsible for regional surface and groundwater availability modeling activities and supporting regional and state water planning programs. Watermasters continuously monitor both availability of surface water resources and water diversions in four western river basins, as they are responsible for allocating water to rights holders under the state's priority system.

With the exception of water right holders in watermaster areas, each holder of a water right issued by the TCEQ must report monthly usage every year (due March 1st of every year). Water-right holders must report three metrics: 1) month diversion amounts, 2) monthly consumed amount, and 3) monthly return flows. Units of measurement are standardized mostly in acre-feet. TCEQ assesses penalties to individual right holders for not submitting usage reports on time. It is unclear if the state verifies the accuracy any information submitted in the annual usage reports. Annual reports may be submitted to the state by US mail or by email. Some small surface water diverters (riparian diverters for domestic or livestock usage and storages of no more than 200 acre-feet) are not required to apply for water rights permits and are exempt from reporting annual diversion to the state.

The TWDB administers an annual water use survey, distinct from the TWDB's "Annual Water Conservation Report and Water Loss Audit." There are two types of mandatory water use surveys: municipal and industrial. The survey asks major municipal and industrial water users to report self-supplied groundwater by aquifer and well, self-supplied surface water by water right number and by basin, self-supplied direct and indirect re-use, and purchased water volumes.

Mining water-use estimates are based on an annual water use survey and an estimate of the water used in the secondary processes for oil and gas recovery. Livestock water-use estimates are derived from annual livestock pollution estimates produced by the Texas Agricultural Statistics Service, and is estimated on a per-animal unit based on research by the Texas Agricultural Experiment Station. Irrigated agriculture water use estimates are based on annual crop acreage from the NRCS and the Farm Service Administration (after 2001), with irrigation rates per acre based on estimated potential evaporation, and final estimates reviewed by local authorities.

Water consumption and use data in the Water Use Survey may duplicate data provided to TCEQ and local districts (GCDs). However, "resources do not currently exist to coordinate the collection of water data between all agencies, districts, and authorities involved."

The TWDB also administers an annual conservation report among water retailers, wholesalers, and any individual, irrigation district, agricultural operation or industrial operation that has a water right with TCEQ. These annual surveys require information on water diversions, imported water, water supplied, consumptive use, and non-consumptive use. These data are used for tracking statewide conservation activities.

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[97] Because local and regional data collection is inconsistent for state planning purposes, TWDB conducts an annual survey of public water suppliers and major manufacturing and power entities, providing water use estimates for municipal, manufacturing, and steam-electric power categories. Response to this survey is mandatory (Section 16.012(m) of the Texas Water Code, as amended by the 78th Texas Legislature in 2003).

Within the state's four Watermaster areas, water rights holders must notify the watermaster of proposed diversions and indicate the amount of water they need to divert on a continuous basis. This is especially useful during a drought, when the watermaster must allocate water according to the water rights priority system. Watermaster programs also require most water rights holders to meter their diversion pumps.

Groundwater usage in Texas is partially tracked by TWDB and partially tracked by GCDs who can collect detailed groundwater pumping within their district through locally enforced measuring and reporting programs. At the state level, TWDB administers an Annual Water Use Survey that collects information on source aquifers and pumping, along with surface water use and other variables. The survey results and other specialized groundwater usage studies performed by the Water Use Survey team provide an overall picture of groundwater usage in Texan groundwater basins.

As stated in the 2012 State Water Plan "groundwater conservation districts are the state's preferred method of groundwater management." These local agencies may regulate and track the use of groundwater within their district boundaries. This includes a mixture of well registration, required metering, collection of pumping reports, and fee collection. Only some GCDs have decided to exercise their authority to require measuring and diversions among groundwater users. Each of the 100 GCDs has their own mix of locally enforced rules and regulations, some of which pertain to measuring and reporting pumping. Exemptions for registration of wells, metering, reporting, and fee collection differ across GCDs. The Edwards Aquifer is a unique example of tightly managed groundwater resources, in which the groundwater users are metered and closely monitored.

GCDs work at the Groundwater Management Area scale to decide on desirable future conditions of their aquifers, this is part of a larger planning process to balance future groundwater supplies and demands. TWDB performs groundwater availability and water-use studies within groundwater management areas to assist in these planning activities. Local groundwater use estimates can be provided by the TWDB or the local GCDs for incorporation in modeling.

System Analysis and Management

The TWDB Surface Water Division is responsible for "aiding water resources planning and management efforts by providing scientific data and engineering expertise in support of TWDB's statutory requirements" (TWC 16.012). TWDB defines water availability for planning purposes as "the amount of water available at the source during the drought of record" as measured by an estimate of the physical and legal supply available to entities under existing (current) conditions. TWBD uses the Water Availability Modeling (WAM) System maintained by the TCEQ to determine annual water availability at the statewide level for use in regional and state water planning over a 50-year planning horizon (Western States Water Council 2014).

TWDB also creates public-facing datasets for transparency reasons. The collection and presentation of physical surface water availability is found in two publications: 1) monthly Texas Water Condition Reports and 2) Water Data for Texas, a public online portal for daily streamflow and reservoirs storage data (and other variables). TWDB also provides historical surface and groundwater use estimates on their public website.

The Texas Water Conditions Report presents raw data from 114 major water supply reservoirs, 29 stream flow measurement stations (un-impaired flows from USGS stations), and 17 groundwater monitoring wells. Conditions reports are available to the public, and provide water general water availability information to water managers, stakeholders, and the public.

The TCEQ defines water availability as the "amount of state water that the stream furnishes, with the amount of state water already appropriated to others subtracted, any amount of water left over is water available for appropriation" (Western States Water Council 2014). In evaluating a water permit application, TCEQ will determine if unappropriated water is available, existing water rights are impaired by the request, applicant intends conserve water where possible, and the proposed permit is consistent with regional water planning priorities (Wurbs 2015). TCEQ uses WAMs to help determine if water would be available for a new water right appropriation or amendment to a right, or if an amendment might affect other water rights.

The TCEQ Water Availability Modeling (WAM) System consists of the generalized Water Rights Analysis Package (WRAP) modeling system, which can be applied anywhere in the state, and individual WRAP input datasets covering the 15 major river basins and eight coastal basins of the state. A water availability model (WAM) consists of WRAP and the appropriate input dataset from the WAM System. The models can assess two broad categories of water right applications: new permanent water rights or amendments (evaluated using a "Full Authorization" dataset) and new term (temporary) water rights and amendments (evaluated using a "Current Conditions" dataset). Full Authorization simulation evaluates the amount of water that would remain available for appropriation if all currently permitted perpetual water rights holders withdraw their full authorized amount of water. The Current Conditions simulation model shows the amount of water that would remain available for appropriation if all permitted water rights holders withdrew the amount of water they are now using, including return flows. The WRAP software and documentation are maintained by Texas A&M University. If water is available, the Full Authorization and Current Conditions simulations estimate how *often* unappropriated water would be available at a monthly timestep. Applicants are encouraged to use the models when preparing an application to appropriate through a new water right or an amendment. In evaluating new appropriations, TCEQ also consider recommended environmental flow needs where they have been defined.

General rule of thumb adopted by TCEQ for new permits is as follows: 1) Municipal water use applicants must show that they can meet 100% of demand 100% of the time as predicted in a WAM model, 2) agricultural must be able to supply 75% of the demand 75% of the time as predicted by a WAM model. No new appropriation is allowed to show significant impact to other water users in a basin.

TWDB annually measures the groundwater levels at nearly 2,000 wells in the 30 major and minor aquifers in Texas. Water levels are measured using steel tape or other manual methods, and are generally measured during cooler months when the groundwater pumping is minimal. TWDB also cooperates with half of the groundwater conservation districts (GCDs), the USGS, and other municipal agencies to collect water-level measurements. This larger network provides 8,000 measurements annually, and half of these are considered ideal for water-level monitoring by the TWDB based on spacing and coverage.

As of April 2014, TWDB maintained 184 water-level recorders equipped with satellite telemetry to provide data in near-real-time to TWDB. The TWDB posts these data in Water Data for Texas as a "daily water level." These automatic recorders are equipped on wells in 79 counties, and the program is growing as GCDs purchase equipment and begin to collect data. TWDB is now seeking funds to install more automatic recorders in other counties.

Groundwater availability models (GAMs) are regional groundwater flow models based on the USGS MODFLOW codes that have been accepted by TWDB for groundwater planning. The TWDB hosts and maintains GAMs to predict 50-year trends in the water available (called "Modeled Available Groundwater") in an aquifer based on hydrogeologic principles, actual aquifer measurements, and stakeholder guidance (called "Desired Future Conditions"). GAMs incorporate comprehensive information on each aquifer including, recharge, subsurface geology, surface water interaction, water levels, and pumping activities. TWDB states that "each model is calibrated to ensure that the models can reasonably reproduce past water levels and groundwater flows."

TWDB uses GAMs to estimate Modeled Available Groundwater (MAG) or "the amount of water that the executive administration [of TWDB] determines may be produced on an average annual basis to achieve a desired future condition established under Section 36.108."[98] TWDB provides these 50-year predictions (in 10-year increments) to GCDs in a groundwater management area and the appropriate regional water planning group. By law, local GCDs and Regional Water Planning groups must use MAGs in their management and regional water plans, respectively. MAGs analysis outputs can be specified by county, river basin, regional water planning area, groundwater conservation district, or any other area defined in the desired future conditions resolution (Texas Water Development Board 2014). In this sense, the TWDB not only monitors groundwater levels across the state, but also estimates and projects available groundwater resources for local and regional planning efforts based on local policy preferences. There are currently 33 GAMs developed either by TWDB or by collaboration with private consulting firms.

Most GAMs explicitly evaluate the physical interaction of surface water and groundwater (e.g. GAM for the Edwards-Trinity and Pecos Valley Aquifers of Texas, 2009; GAM of the Seymour Aquifer in Haskell, Knox, and Baylor Counties). As part of the Texas Administrative Code, groundwater management plans (completed by local GCDs) must consider including elements related to conjunctive use, recharge enhancement, and return flows, representing various types of interconnection between ground and surface water, where applicable. For example, in the North Trinity Groundwater Management Plan, the North Trinity GCD acquired estimates of total annual recharge from precipitation within the District and annual water volume that discharges from the aquifer to springs and surface water bodies. These estimates were produced by the TWDB using a GAM for specific aquifers on which GCDs are located. GAMs for each aquifer are updated and run to produce data inputs for GMA and GCD planning processes.

TCEQ collaborates with the TWDB to evaluate groundwater use and water level declines across the state to identify Priority Groundwater Management Areas. These are basins are experiencing or expected to experience, within 50 years, critical groundwater overdraft. TCEQ will perform availability and use studies, and make a recommendation on groundwater conservation district (GCD) creation.

Quantitative water balance modeling is a critical component of water resource planning in Texas. This strong regional planning framework began after a statewide drought in 1996, which precipitated SB1 in 1997 and SB2 (2001) establishing the regional water planning process: a framework for strong "bottom-up" water planning (Texas Water Development Board 2012).

By regulation, local, regional and statewide water management entities are required to participate in planning exercises every five years. These efforts are a coordinated effort at different spatial scales and levels of government. At the end of each five-year regional water planning cycle, agency staff compiles information from the approved regional water plans and other sources to develop the state water plan, which is presented to TWDB's governing Board for adoption. The final adopted plan is then submitted to the Governor, Lieutenant Governor, and the Texas Legislature. The 2017 State Water Plan will be the tenth state water plan and the fourth plan based on the regional water planning process.

Allocation During Periods of Scarcity

In Texas, curtailments have occurred during droughts for surface and groundwater rights. The curtailments are carried out according to the prior-appropriation doctrine. Curtailments are effectuated by TCEQ, or watermasters under the oversight of TCEQ, in response to calls from senior water rights holders. Curtailments are by priority

[98] As defined by TAC §356.52(a)(5)(A) and TWC §36.1071(e)(3)(A).

date, where older water rights receive water before water rights with junior priority dates. This was recently confirmed when the Texas Supreme Court declined to hear a petition by TCEQ to review a lower court ruling that requires strict application of prior appropriation during curtailments. The Court sided with farmers, ranchers, and other longstanding water rights holders in the Brazos River basin by denying TCEQ's attempt to give a special treatment to cities or power generators over senior water rights (Malewitz 2016).

The only basin in which curtailments are by use rather than priority date is the Middle and Lower Rio Grande, in which municipal and industrial water rights have priority over irrigation rights when water supplies must be allocated due to scarcity.

For determining surface water curtailments, TCEQ may run the Water Availability Model (WAM) to determine water allocation by priority date during times of scarcity. TCEQ also responds to drought by consulting public water systems on drought implementation plans, tracking public drinking water systems under water use restrictions, conducting training in TCEQ regional offices for inspectors in non-watermaster areas to measure and monitor surface water flows to ensure the proper functioning of priority system, sending out curtailment notices, and convening weekly meetings and public updates on drought conditions. Watermasters continuously monitor both availability and calls on surface water resources, as they are responsible for allocating water to rights holders under the state's priority system. Because of this, the watermaster programs include staff "deputies" who inspect authorized diversions for compliance.

For groundwater curtailment, some GCDs can place pumping restrictions on local groundwater pumpers established through adoption of local district rules.[99] But this practice is inconsistent across the state.

Environmental flow standards established by the TCEQ pursuant to the 2007 Senate Bill 3 are incorporated in the WAMs with a priority date based on when the scientific group made their recommendation. Thus, during drought conditions, there is no guarantee of meeting environmental flows, as these standards tend to have junior water rights.[100]

Public Information Provision

Water Rights

TCEQ maintains and publishes a spreadsheet with all active and inactive water rights on the Data on Water Rights and Water Use website. It provides the water right number, type, date issued, owner information, use, priority date, volume of water for consumptive uses, acreage irrigated (for agricultural uses) and location, restricted to surface water rights only. The database is refreshed with application activity, at least every two weeks.

A spreadsheet of pending applications, called the Data on Water Rights and Water Use, is made available through a public website. It has information on the solicitor, date, application, water right number, and location. The information is updated according to when application are made. Since some applications require a public notice, a TCEQ Public Notices search engine is available online with all notices from December 17, 2004 onward. The search engine includes public notice type, dates, TCEQ program areas, county, region or zip code, and TCEQ ID.

The Data on Water Rights and Water Use website also has spreadsheets with information on water use for non-watermaster areas. It provides data from previous years' self-reported water use. The site includes data on the water right number, type (application/permit, claim, or temporary permit), application number, use, year, owner

[99] For example, see the Fayette County GCD Management Plan.

[100] Personal conversation with Ralph Wurbs on September 18, 2016.

information, monthly diversions, return flows, and water consumed. Water use data in watermaster areas are protected by watermasters, but may be available by request.

The site also offers the Water Rights Analysis Package (WRAP) for processing basin input files for each river basin. It includes GIS files on water rights, including shapefiles with legal representation of all features (reservoirs, diversion points, discharge points, etc.) authorized in the water right, as well as control point shapefiles with the water rights as modeled in a Water Availability Model (WAM). The model used by TCEQ includes WRAP. All WRAP Input files and GIS files by river basin exist online.

For groundwater permit data, the GCD should have relevant information. TCEQ publishes a list of GCDs with their contact information. Contact information and groundwater management plans are also available through the Texas Water Development Board. The TCEQ also has a Water Well Report Viewer, an online map-based locator of over 800,000 historical reports for water wells. Reports include well location, depth, construction, water level, local geology, driller, and original owner. The data can be viewed through an interactive map called the Groundwater Data Viewer.

System Monitoring

The TWDB's water data platform provides water-related data in a single platform. For surface water, information is found on the Surface Water Resources Division; additional data not hosted on the website are available upon request, as well as data from USGS and other sources. The information includes conditions for most major water supply reservoirs, stream flow measurement stations, and some key groundwater monitoring wells. To complement this information, TWDB publishes monthly water conditions with summary reservoir conditions (available from 1996 onwards). Also, a list of all river basins, lakes, and reservoirs is available with average operating levels.

Monthly and annual precipitation and evaporation rates are provided in the TWDB website, including historic values. TWDB uses national weather station information as well as the state's cooperative stations. Drought indices also are online including the Crop Moisture Index, Palmer Drought Severity Index, Standardized Precipitation Index, Keetch-Byram Drought Index, Reservoir Storage Index, and Streamflow Index—all developed and updated daily, weekly, or monthly.

Through the Hydrographic Survey Program, TWDB publishes bathymetric and sedimentation data on reservoirs, elevation-area-capacity calculations, and GIS data. There are also estimates on bay and estuary conditions including coastal hydrology, estuary circulation, salinity models, and freshwater inflow needs among others.

Data on water quality including temperature, conductivity, level, and salinity are published hourly at select locations in estuaries. Some information also can be found for dissolved oxygen, pH, and other parameters as part of special studies. This data is only available by request.

For groundwater, the TWDB uses its online platform to publish information on major and minor aquifers. The aquifer maps and reports undergo revision to reflect the latest information available. A groundwater database (GWDB) is uploaded with records of nearly 140,000 water wells (including nearly 2,000 springs). Data can be viewed through the Groundwater Data Viewer.

TCEQ determines basin physical and legal water availability through WAM and WRAP. Copies of water availability reports are in the Texas Digital Library dating from 2012–13.

Allocation During Scarcity

The Texas Drought Information website provides data on drought conditions, surface and groundwater regulations, and emergency procedures. Here, active priority calls on surface water rights are posted. This information is also posted through the Water Data platform. TCEQ is required to provide all holders of existing permits, certified filings, and certificates of adjudication in the river the projected amount of water that would be available: during a drought of record, when flows are at 75% of normal, and when flows are at 50% of normal. This helps communicate to permit holders the potential reduction in reliability due to drought.

Also, several guidance documents exist on procedures for making a call on the river or a complaint. TCEQ can issue curtailment notices to water rights holders via US mail. These notices, called "Alert for Permitted State Surface Water Diversions to Water Right holder," are uploaded on the "Letters to Water-Right holders" site.

Regarding groundwater, many GCDs publish drought status on their website, address drought goals in district management plans, and provide links to the US Drought Monitor.

Water Transfers

The forms required for approval of changes or transfers of surface water rights do not require the direct statement of the volume of water transferred nor prices paid. Deeds and other similar legal conveyance documents may state volumes traded and prices. However, there is not a systematized scheme for processing and publishing this information, other than periodic updates to the active water rights spreadsheet. If the transfer or water right change might result in impairment, TCEQ will publish a public notice, available online at the TCEQ Public Notices search engine. For groundwater right conveyances, GCD may share the information by request, since not all publish this information on their websites.

For information on water prices, the Texas Water Bank has a registry of water rights for potential buyers and sellers. It is not an active website, having eight water bank deposits, about 24 registered sellers, and two registered buyers after 22 years of being created. The Texas Water Trust information also is online and has had little activity since its creation.

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Utah

Case Study Highlights

- Utah has two main water oversight agencies within its Department of Natural Resources: the Division of Water Rights (State Engineer) is in charge of managing appropriation of public water for individual use, curtailment, and maintaining priorities among water right holders, whereas the Division of Water Resources is in charge of developing state-wide and regional 50-year plans, funding water projects, and protecting Utah's rights to interstate waters. At the local scale, river commissioners—recommended by the users of a distribution system and appointed and paid by the State Engineer— manage allocations in each distribution system or subsystem.
- The State Engineer developed a Personal Water Records Database Computer Program to unify water accounting reports throughout the state. This is a simple water record accounting program for River Commissioners to keep track of water allocations and diversions, prepare distribution system reports, and transmit records to the Division of Water Rights.
- There is and an active market for transfers in Utah. Water rights may be bought and sold independent of their current use facilities. The information for every water right in the state is also available to the public online.
- Forecasts of water supply availability for forthcoming growing seasons are done by Utah's USDA Natural Resource Conservation Service, and summarized in the Surface Water Supply Index (SWSI). The SWSI is a predictive indicator of total surface water availability within a watershed for spring and summer water use seasons. The index is calculated by combining pre-runoff reservoir storage (carryover) with forecasts of spring and summer streamflow based on current snowpack and other hydrologic variables.

Introduction

Utah has incredible geological diversity, from snowcapped mountains to well-watered river valleys to rugged deserts. The state's three distinct geological regions include the Colorado Plateau (covering more than half the state), the Rocky Mountains, and the Great Basin.

The Colorado Plateau in south-central and southeast Utah is home of the Colorado River and its tributaries. In La Sal, minimum average annual temperature is 34.5°F and the maximum temperature is 59.7°F. Average annual precipitation is 14.11 inches, with 51 inches of snowfall in the winter. This landscape has multiple protected parks and natural monuments. The Great Basin and the Great Salt Lake Desert lie to the west. Temperature ranges here are wider. In Ibapah, in the western corner of Utah, the average annual low temperature is 27.9°F and the average high is 66.3°F. Average annual rainfall is 10.9 inches in the western corner of the state. The Wasatch Range, part of the Rocky Mountains, runs through the center of the state. Portions of these mountains receive more than 500 inches of snow each year.

Utah is not a large agricultural state, even though it has appreciable crops, livestock, and dairy production. Agricultural products with the highest revenues are beef cattle and calves, dairy products, hogs, and hay.

The Utah Constitution recognizes historical claims to beneficial use. After 1903, state statutes required the state engineer to approve applications to appropriate surface water to establish water rights following the prior appropriation and beneficial use doctrines (Olds 2004). In 1935, the Water Code was modified to include groundwater. As a result, groundwater rights must also be permitted by the Division of Water Rights. Failure to use the right can result in the loss of the right and reversion of the resource back to the public for beneficial use by another user (Crowther n.d.).

Principal demographic, economic and water-related indicators in Utah

Population (in 2010):	2.76 million
GDP (in 2010):	$116 billion
Agriculture Value Added:	1.61% of GDP
Annual Precipitation:	13.56 inches
Total Water Withdrawals:	5,000 TAF
Urban Use:	18%
Agricultural Use:	78%
Thermoelectric Use:	2%
Other Uses:	2%
Surface Water:	75%
Groundwater:	23%
Desalination:	2%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, the source of water withdrawals—surface and groundwater—is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight agencies

The Utah Department of Natural Resources has seven divisions, three of which are actively involved in water management and/or planning: the Division of Water Rights, the Division of Water Resources, and the Utah Geological Survey. The heads of each division must report to the Executive Director of the Department of Natural Resources.

The Utah Division of Water Rights is in charge of appropriating public waters, managing water use, curtailment, and maintaining priorities among water right holders. The State Engineer is the head of this agency, so it is often referred to as the State Engineer's Office or simply the State Engineer. To reduce confusion about when the Division of Water Rights or the Division of Water Resources is being referenced, the Division of Water Rights will here be referred to as the State Engineer.

The State Engineer's Office is divided both by areas of responsibility and by geography. First, it is divided into four programs: applications and records, dam safety, technical services, and field services, which are overseen by Assistant State Engineers. Within the Field Services program, the State Engineer manages well drilling applications, adjudication, and sub-basin water management districts known as distribution systems. Geographically, the state is divided into seven regional areas, each with a delegated engineer who is responsible for providing agency services through a local office. The seven regions are further divided into water right areas based on hydrologic boundaries, of which there are close to 50 across the state. Water right areas are used to address water appropriation issues with geographically specific policy. All decisions of the state engineer are appealable to the state district court.

The Division of Water Resources (UDWR) is charged with developing state-wide and regional 50-year plans, funding water projects, and protecting Utah's rights to interstate waters. Within UDWR, there is a Board of Water Resources that is the division's policy making body.

Distribution systems are local water allocation oversight entities that exist within Water Right Areas with greater water scarcity and conflict. These systems have formed in over-appropriated regions where surface water rights must be regularly curtailed. There are 38 active distribution systems in the state, some of which are divided into two or more subsystems. A river commissioner manages each distribution system or subsystem. River Commissioners are recommended by the users of a distribution system and appointed by the State Engineer. The State Engineer is required to appoint based on the users' recommendation if there is majority consensus, otherwise the state engineer makes the determination for them.[101] Currently, all serving River Commissioners were selected by the users.

Water supply operations agencies

There are no major state owned or operated water supply projects in Utah.

US Bureau of Reclamation (USBR) constructed several major water storage and conveyance projects in Utah, including the completed sections of the Central Utah Project. The Central Utah Project is the largest water development program in the state, providing Utah with the opportunity to beneficially use a significant portion of its legally authorized share of Colorado River water. Water from this project is used for cities, industry, irrigation, hydroelectric power, fish, wildlife, conservation, and recreation.

Local entities are responsible for operation and maintenance of projects within the Central Utah Project, along with several other water supply projects such as the Emery County project, Hyrum project, Moon Lake project, Ogden project, Provo River project, Strawberry Valley Project, and Weber Basin project among others.

Funding

The state engineer has a total budget of $10,922,400 for the FY 2015-2016. Items funded by this budget include $438,000 for special masters appointed by the judicial system to speed up the water rights adjudication process (Office of the Legislative Fiscal Analyst 2015).

Legal Framework

Water rights

Utah's water code specifies that all waters are public property and are administered according to the principal of prior appropriation. A senior water appropriator's water right, whether surface or groundwater, must be satisfied before a more junior appropriator receives any water. Priority dates may be established by claim or application depending on whether the beneficial use began before or after the enactment of the surface (1903) or groundwater (1935) codes.

Claims to historical beneficial use of surface or groundwater may be filed with the Utah Division of Water Rights as a "diligence claim." Claims are subject to public notice, judicial review, and may be barred by decree in some areas of the state. Priority dates for a claimed beneficial use may be established based on evidence suggesting when the initial appropriation occurred.

Water rights for surface water appropriated after 1903, or groundwater after 1935, must be obtained by submitting an application to the state Division of Water Rights. The permitting process is identical for surface and

[101] According to Utah Code 73-5-1(2).

groundwater and requires several steps. First, a user must submit an application identifying the nature, quantity, time of year, and location of use in addition to the dimensions of the diverting channel. Applications for irrigation also must include acreage and soil information.[102] Once received by the State Engineer's office, the application is posted for two weeks in the local newspaper to allow for public notice. Protesting parties notify the state engineer within 20 days of the public notice. Next, the State Engineer investigates, may hold hearings, and either approves or denies the application based on specified statutory factors. Regionally developed duty values are used to set a maximum reasonable diversion limit for irrigation applications. Some other uses have associated reasonable duties which are used in the absence of site specific science. If approved, the applicant is given a set amount of time to develop the project described in the application and place the water to beneficial use. After the system is built and the water in use, the applicant must hire an engineer or surveyor to document the system and send a report called "proof of beneficial use" to the State Engineer. If the documents are satisfactory, the State Engineer issues a certificate to "perfect" the water right.

The basic attributes of a water right include:

- A defined nature and extent of beneficial use;
- A priority date;
- A defined quantity of water allowed for diversion by flow rate (cfs) and/or by volume (acre-feet);
- A specified point of diversion and source of water;
- A specified place of beneficial use.

Several basins are administratively closed to new appropriations of water. In basins with recurring conflict between water rights holders over when and how much water they may divert, either the district court or the State Engineer may decide to create a local oversight program called a distribution system. The State Engineer determines the extent of the system and appoints a river commissioner to regulate the diversion of water according to the priority of water rights. While distribution systems vary by technical, managerial, and financial capacity, most distribution systems require that water users install control structures and measuring devices that meet state requirements. River commissioner salaries and operating costs of the distribution systems are funded by water user assessments.

There are no specialized water courts to rule on water right priorities or other water-related issues. Water right conflicts are adjudicated through the state court system where cases are distributed among all judges along with other civil and criminal issues. When water rights are being adjudicated, statute allows for the state and federal courts to call upon the state engineer for assistance, collect facts and make surveys. State statutes also allow for a general adjudication of all water rights from a source as a joint effort between the State Engineer and the district courts. The State Engineer prepares recommendations to the court known as proposed determinations of water rights (PDETs), which are finalized by the court if there are no objections. If there are protests to the State Engineer's recommendations that cannot be resolved through negotiation, and the court makes a final ruling. The entire state is either adjudicated or currently undergoing adjudication. Two basins completed the adjudication process in the first half of the 20th century while the rest began in the second half, and have yet to be completed.

Water trading

Since several basins do not allow new appropriations, creating a new diversion or changing a beneficial use requires changing the terms of existing water rights. Modifications to water rights must be approved by the State

[102] Hydropower and mining applications also have additional requirements according to Utah Code § 73-3-2.

Engineer through a change application process similar to the Application to Appropriate Water as described above. The State Engineer may also permit temporary transfers not to exceed one year. Short-term transfers are evaluated using a simplified criteria based on impacts on existing water rights (Western Governor's Association and Western States Water Council 2012.). Conversion of existing water rights for instream uses is the principal mechanism for achieving instream flows in Utah. Only state agencies and designated non-profit fishing groups may execute this type of conversion to instream flow. Average processing time for an uncontested water transfer is 90 days. Protested applications take 1–2 years or longer depending on complexity (Szeptycki et al 2014).

There is no established water bank in Utah to facilitate water transfers, but there is an active market for transfers. Water rights may be bought and sold independent of their current use facilities. All water right records in Utah are public records which are accessible during business hours. The information for every water right in the state is also available to the public online. Through this information and other privately advertised offerings, individuals seeking water rights can search for potential sellers. About 2,800 water right transfers a year are currently being processed by the state engineer.

Legal treatment of environmental water use

Utah's instream flow water right program is subject to statutory constraints that have limited successful transfers for instream flows to only eight over the past two decades. The most constraining factor may be that the state water code does not authorize new appropriations of water for instream flows. Instream flows are an existing condition of public waters and individual rights for that purpose must be procured by the conversion and acquisition of existing water rights to protected instream flows by the Division of Wildlife Resources and the Division of Parks and Recreation (Ibid).

Beyond the two state agencies, the only other entities authorized to file change applications for instream flow and hold instream water rights are non-profit "fishing groups" such as Trout Unlimited (Ibid). Instream flows acquired by private non-profit organizations may only be dedicated to protect habitat for three native species of trout. Non-profit groups must also form Candidate Conservation Agreements with US Fish and Wildlife Service to hold instream water rights. While state agencies may apply for both short and long term instream flow rights, non-profit fishing groups may only obtain transfers for longer than one year and less than 10 years.

Prioritization of particular uses

Utah has a secondary system of water priority effective during temporary water shortage emergencies. According to this hierarchy, the use of water for drinking, sanitation, and fire suppression, and agricultural use have a higher preference than any other uses and water can be diverted out of priority for the use if compensation is provided for the taking. Although higher preference uses at times occur through agreement between willing parties, there has been no occasion where the statutory preference has been employed based on a governor declared water shortage emergency.

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

Reporting of water use varies across the state. Every water user is required by statute to install measurement and control works for each water diversion source. The State Engineer may request records from water users but generally does not enforce measurement requirements unless there is a present need for the information. There are systems in place to enforce measurement and reporting from distribution systems and industrial and public utilities. Agricultural water use is often estimated using aerial imagery rather than direct measurement of diversion. Agricultural pumpage from wells is also tracked through an annual program where the USGS estimates quantity of water pumped based on energy consumed by pumping.

All but three of the 38 active distribution systems only manage surface water. Only four or five systems manage both surface and groundwater or groundwater exclusively. Within a distribution system, the river commissioner and the users determine the extent to which water supplies are measured and the methods used. Often, every user in a system must install a measuring device, but reading and reporting of the device is sometimes done directly by the river commissioner instead of the user. In several higher conflict regions, streamflow and diversion measurements are being recorded in real-time using automated instruments. At the urging of the State Engineer's Office, more regions will be implementing telemetry-enabled water measurement devices.

Outside of distribution systems, industrial and public utilities in Utah are required to annually report their monthly use through the Water Use Program. The program is a joint effort between the USGS, State Engineer, Division of Water Resources, and Division of Drinking Water. In January, the State Engineer mails a form to larger suppliers to report their monthly use in the previous year. Results are compiled into an annual Water Use Summary. Standards have not been developed and reports are sometimes based on poorly documented estimates. The accuracy of Water Use Program reports was recently called into question through a legislative audit. The State Engineer has initiated a program to validate the data and create an interactive online reporting system. Greater water user responsibility has also been addressed by requiring the report be submitted only by certified water system operators and holding them professionally responsible for the contents of the report.

As mentioned above, only a few distribution systems include groundwater reporting. Utility suppliers who divert groundwater report their use, but these reports are not always very accurate.

Indirect measurement of water use (top-down approach)

To support the water use reports, agricultural water use is often estimated using aerial imagery, crop-type, and acreage information. This is especially true when information on agricultural use of groundwater is needed.

System Analysis and Management

For information on water availability, the state engineer consults different local, state, and federal services. Each service operates and maintains different monitoring networks, without a common comprehensive approach for the accounting system. The most extensive satellite network of stream-gaging stations in the state is operated by USGS for the Utah Water Science Center (WSC). Information is gathered on a real-time basis for stream stage, streamflow, and water-quality. More than 150 sites collect streamflow information, while water quality information is measured at 24 sites.

Another important platform is the Natural Resource Conservation Center (NRCS) provided by USDA, which publishes a "Water Supply Outlook Report" monthly from January to June. The report presents information on streamflow, snowpack, precipitation, soil moisture conditions, and water storage levels for 48 of Utah's largest irrigation reservoirs.

At a local level, water availability is accounted for by distribution systems, water user associations, and water districts. For example, the Bear River Basin distribution system provides real-time river, canal flow data, reservoir levels, and climatic information from nearly 160 monitoring sites in their watershed. The Sevier River Water Users Association is equipped with solar-powered weather, canal, reservoir, pond, and river monitoring stations transmitting real-time information. Some other water distribution systems have automated systems to measure water and operate controls.

With this information, river commissioners use several methods to determine water availability and curtailment decisions. These range from simple mass-balance spreadsheet calculations with manual flow data input to advanced allocation models with data input from automated real-time flow gages. The chosen method for a given system depends on the size and level of conflict of the distribution system (Berger et al n.d.). Many smaller distribution systems use an offline spreadsheet model. The State Engineer developed the Personal Water Records Database computer program (PCDIVERT) to support basic water accounting responsibilities for river commissioners. This simple water accounting program is used for keeping track of water records and diversions, preparing distribution system reports, and transmitting records to the Division of Water Rights.

Access to groundwater data is much more limited. To assess groundwater availability, USGS provides real-time data for only one station in the state. USGS was specifically contracted to conduct more comprehensive groundwater studies across the state. The tools used in the studies vary by region and follows standard methodologies, including the Prism method. Basin-specific MODFLOW models were developed for several of these groundwater availability studies.

The National Oceanic and Atmospheric Administration (NOAA) Colorado Basin River Forecast Center provides daily updates on river conditions, including up to 10-day projections on precipitation, reservoir levels, and flooding. It also includes seasonal forecasts on snow conditions and water supply forecasts, among others.

The USDA Natural Resources Conservation Service (NRCS) estimates a Surface Water Supply Index (SWSI), a predictive indicator of total surface water availability within a watershed for the spring and summer water use seasons. The index is calculated by combining pre-runoff reservoir storage (carryover) with forecasts of spring and summer streamflow based on current snowpack and other hydrologic variables. NRCS' Utah Snow Surveys also display the SWSI as a percentile in terms of the probability of hydrological conditions—for example, an SWSI of 75% means that a year's water supply is greater than 75% of all historical events. These estimates are published monthly in the Water Supply Outlook Report.

State and regional water plans are developed by the UDWR to summarize water uses, identify important water management and quality issues, recommend solutions, and determine the state's current and future needs. Utah has a statewide long-term plan along with regional plans for 11 basins. Updates are made on an as-needed basis. The most recent state plan was created in 2001 and only four basin plans have been updated since their creation (Utah Division of Water Resources 2015). To help develop these plans, UDWR works in cooperation with other state and federal agencies to collect data and run models. Data is collected from hydrologic databases, the aforementioned agricultural land-use surveys, and the Water Use Program. River simulation models and water supply and demand models also are employed.

Allocation During Periods of Scarcity

Surface water rights are curtailed regularly throughout the state except on the main stems of the Green and Colorado Rivers where supply is generally plentiful. Distribution systems have formed in the regions where curtailment is needed with oversight from a river commissioner. The restrictions follow the prior appropriation doctrine (Olds 2004).

Only one groundwater basin is requiring users to reduce their depletions. The basin was recently found to divert nearly twice the annual safe-yield of the aquifer and a Critical Management Plan was adopted in 2012.

Even though groundwater rights are also subject to the prior appropriation doctrine, the plan outlines a different restriction scheme (Crowther n.d.). It sets an incremental reduction in consumptive use (not pumped water) that must be met over the next 100 years to bring the basin back into safe-yield. Rather than meeting reductions through state-ordered curtailments, users chose to develop and implement a voluntary plan to meet the water balancing objective. Studies are being done on two more basins that are likely in overdraft as well. More analysis will be completed before a Critical Management Plan is developed for those basins.

Public water supply is generally protected under scarcity or drought conditions. Small domestic uses with a junior water right are technically subject to curtailment, but in practice, river commissioners rarely curtail these users. Instream flows for the environment may be curtailed according to priority date.

River commissioners determine water availability and curtailment decisions employing methods that range from simple mass-balance spreadsheet calculations to advanced allocation models. However, the State Engineer promotes real-time monitoring within distribution systems to determine curtailment decisions. For this purpose, it recently began developing additional online water allocation and accounting tools that allow river commissioners to publish curtailment decisions online and enable users to see how those decisions are made. Transparency is a key feature of the new model. An online spreadsheet model is in operation on the Weber Basin and in development for the Sevier and Provo basins.

Public Information Provision

Water Rights

The state engineer maintains the Searching Water Right Records platform with an online file for each water right of the state, including information about the application, correspondence, and other pertinent documents. Various search engines are available to access the database. Information can be found through the water right number, owner/source, point of diversion, or place of use, among others. Data on the water right number, diversion type, well log, location, status, priority, use, and flow (in cubic feet per second) or volume allowed (in acre-feet) can be displayed. There is also an interactive map search. The water right data available on the State engineer website is part of the agency water right process and updates are applied in real time as activities occur.

A list can be found of all titles that are being processed online. It provides information on the water right number, submitting party, date when it was received, and, if completed, date when it was amended and by whom. It classifies this information according to the status of the case, regarding if it is pending, completed, held, and other categories. The same information can be gathered through a search engine called Report of Conveyance (ROC) process status search.

Through the Applications in Current Advertising Cycle platform, all protests made for new appropriations and changes in water rights can be found online. Information including filing number, reasons for objection, protester's name, return address, and hearing requests are published. The platform is updated daily.

System Monitoring

The Water Use and Streamflow Records website was developed by the state engineer to align all information provided to the public. The site links to a USGS website for the Utah Water Science Center (WSC) with real-time and historical data on streamflow, groundwater, water quality, lakes and reservoirs and precipitation. It provides information linked to USGS stations that typically are recorded with intervals between 15 to 60 minutes and transmitted every one to four hours. Data on discharge and gage height of several points across the state is provided. Also, real-time water level and height for one monitoring station is provided as well.

The Real-time Distribution System Information platform provides water measurements from automated systems within different water distribution systems across the state. The level of updates varies across different distribution systems, as well as the way the information is displayed. In some places, the information can be located through an interactive map with daily updates and historic records available.

The site also links to Utah StreamStat, a USGS web-based GIS application for water resources planning, management, and engineering design. It generates streamflow statistics for available gaged sites, including mean annual flow, and the 7-day, 10-year low flow.

For climatic information, the AgWeather Net by the Utah Climate Center provides real-time, hourly, and daily statistics on different parameters. Updated every 15 minutes, it provides information on temperatures, humidity, wind, evapotranspiration, and precipitation, among other characteristics. It includes information for different stations across the state, which can be displayed graphically.

Monitored streamflow data is available to the public through the Stream Gage Records Viewer (GAGEVIEW). Many gages are operated in cooperation with USGS. Not all records are active. Active sites provide hourly and daily discharge using tables and plots, or monthly summaries of gage rating and peak discharge.

For groundwater information, the WELLVIEW Well Information Program provides data online. For selected groundwater right wells, samples are taken at regular drilling intervals and the information is updated in the "Geologic Logs for Wells." The data also can be accessed through an interactive map.

Allocation During Scarcity

The USGS website for the Utah WSC provides a Water Watch tool, where information on drought, current flow conditions, water-quality, and groundwater may be tracked. It is linked to the Utah DroughtWatch, a platform showing USGS's National Drought Watch with a 7-day average streamflow conditions.

For curtailments information, the State engineer maintains the DVRTINFO Distribution System Comments platform, with information on water restrictions for the different distribution systems. It includes notices of warning and of notices when the priority cuts have already been placed. The information is updated at any time depending on when the information is made available.

Water Transfers

Information regarding volumes of water transferred is required on applications for changing or transferring water rights. The information is updated in the Report of Conveyance (ROC) process status search and in the Water Right Records platform once the process is completed. Both databases are publically accessible online. However, the State does not process nor systematize the information in specific transfer reports. The forms do not have to be accompanied by any warranty deeds or other instrument of conveyance, where trading prices are disclosed.

Any change or exchange protest can be viewed through the Applications in Current Advertising Cycle platform.

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Washington

Highlights

- The Washington Department of Ecology is the state's primary agency for overseeing water resource management. At the local level, County Water Conservancy Boards assist with processing water-right transfer and change applications. While there should be a Water Conservancy Board in every county, only 17 of 39 counties have one. Most existing Boards are in semi-arid eastern Washington. Irrigation Districts are common in the eastern part of the state. They often support water distribution at a local level.
- Most existing large and all newly permitted surface diversions must now be measured and reported every year. Withdrawals from groundwater sources that support vulnerable fish stocks must be measured by an approved device. Proposed modifications to surface or groundwater rights to allow for expansion of irrigated acres or for adding a beneficial use(s) must be evaluated using the Annual Consumptive Quantity calculation as defined in state law. Estimates of annual return flows are made through evapotranspiration rates for crops using the Washington Irrigation Guide or other accepted methods, and by determining the efficiency of the project's irrigation equipment.
- Water Resource Inventory Areas (WRIAs), delineating every major watershed in the state, provide a useful way to organize information on factors that constrain water supply availability. Instream flows rules have been established in 29 of 62 WRIAs, plus the mainstem of the Columbia River.
- In response to past droughts, the state legislature established the Water Supply Availability Committee (WSAC). WSAC establishes a collaborative drought planning and response protocol, and includes representatives from federal, state, and local agencies.

Introduction

Washington's climate is influenced significantly by its location and topography. A marine climate prevails between the Pacific Ocean and the Cascade Range, with relatively mild temperatures, wet winters, and dry summers. The climate becomes drier east of the Cascade Range with large areas of semi-arid steppe and a few arid deserts in the rain shadow of the Cascades. This semi-arid condition covers much of eastern Washington, especially in low-elevation areas of the central Columbia River Plateau just east of the Columbia River from the Snake River to the Okanagan Highland. Other important rivers include the Snake River and the Yakima River, both within the Columbia River watershed.

Temperatures and precipitation patterns vary between western and eastern Washington. In the western coastal city of Long Beach, the average minimum and maximum temperatures are mild, being 43ºF and 57ºF respectively. In this coastal region, the windward slopes are facing southwest and thus receive high precipitation—on average, 78.61 inches a year. In Yakima, east of the Cascade Mountains, the mean annual temperatures ranges from 36ºF to 63ºF, with an average annual precipitation of just 8 inches and 23 inches of snowfall. The temperatures are milder in the northeastern corner of the state. In Newport, the average annual minimum and maximum temperatures are 33ºF and 56 °F respectively. The average annual precipitation is 26 inches a year, and there is snowfall of around 54 inches per year on average.

Due to its diverse climate and rich soils, Washington is a productive farming state. It produces about 300 crops, the most important being apples, milk, wheat, and potatoes. Washington's apples account for 70% of national production.

The state water law defines water rights and creates a basis for subsequent water regulations. Since it was adopted in 1917, surface water rights have followed the prior appropriation doctrine and the beneficial use concept. The state groundwater code was enacted in 1945, and requires users to obtain a water right permit or certificate to legally withdraw groundwater. The groundwater code does not require a permit or certificate for certain (typically small) exempt uses. Water rights not exercised, without good cause, over a period of five or more consecutive years may revert back to the public for beneficial use by another user.

Principal demographic, economic and water-related indicators in Washington

Population (in 2010):	6.72 million
GDP (in 2010):	$358 billion
Agriculture Value Added:	2.59% of GDP
Annual Precipitation:	44.01 inches
Total Water Withdrawals:	5,560 TAF
Urban Use:	30%
Agricultural Use:	64%
Thermoelectric Use:	1%
Other Uses:	5%
Surface Water:	67%
Groundwater:	32%
Desalination:	1%

SOURCES: Population, water withdrawals and water source: USGS 2014; Annual Precipitation: NOAA 2016; Real GDP in chained dollars by state 2010 (chained 2009 dollars): Bureau of Economic Analysis (US BEA) 2015.

NOTES: All data in this chart is from 2010 because that is the most recent year of USGS's water use estimates and we sought consistency in water use data across all 12 states in our study. While user categories are assessed from total water withdrawals, the source of water withdrawals—surface and groundwater—is only assessed for agricultural and urban uses because the remaining uses are mostly non-consumptive. Agriculture value added includes both "Agriculture, forestry, fishing and hunting" and "Food and beverage and tobacco products manufacturing" industries.

Regulatory overview

Institutions

Oversight agencies

The Washington Department of Ecology (Ecology) is the state's primary agency overseeing water resource management. Ecology's principal water management functions include drought planning, administration of water rights, providing water supply information, instream flow protection, facilitating trade of water, regulating well drilling, adjudication of water rights, and measurement and reporting of water use. Other Ecology water-related functions include floodplain management, water pollution control, and coordination of watershed management. Besides water, Ecology also supervises and promotes management of air and land resources.

At the local level, Water Conservancy Boards are authorized to assist Ecology with processing water-right transfer and change applications and issuing records of decision. Transfer and change applicants have the option of using their local Water Conservancy Board, using Ecology's consultant-based cost-reimbursement process, or having Ecology internally process their application. All board decisions are ultimately reviewed and affirmed, modified, or reversed by Ecology. While the law allows for a Water Conservancy Board in every county in the state, only 17 out of 39 counties have one. Most of the existing boards are located in semi-arid eastern Washington, where water right transfers and changes are most common. In counties where boards have not been established, the regional offices of Ecology are responsible.

Ecology can appoint watermasters to regulate water supply and oversee compliance of the rules when a basin has been closed to the issuance of new water rights and curtailments are needed. Watermasters are currently working in several counties. For groundwater, Ecology has the authority to limit withdrawals by defining groundwater areas or sub-areas. It designates separate depth zones in each area so that withdrawals are controlled to prevent overdraft.

Water supply operations agencies

There are no major state-owned or -operated water supply projects in Washington.

At the federal level, US Bureau of Reclamation (USBR) operates several irrigation facilities and reservoirs for the Columbia Basin Project (CBP). This project currently serves about 671,000 acres, and future incremental expansion of the project is possible depending on future needs. The principal storage features of the project include Franklin D. Roosevelt Lake and the Grand Coulee Dam. The CBP includes over 300 miles of main canals, about 2,000 miles of laterals, and 3,500 miles of drains and waterways. USBR also operates the storage division of the Yakima River project, including oversight over all natural and stored water supplies in the project, which has 1 million acre-feet of storage capacity spread across several reservoirs. The Okanogan Project is another major irrigation supply, storage, and conveyance project constructed by USBR and managed by the Okanogan Irrigation District. The Chief Joseph Dam on the Columbia River provides water for irrigation in central Washington, with maintenance and operation responsibilities delegated to local irrigation district.

Irrigation districts are entities developed to distribute water at a local level. They are involved in the construction, reconstruction, repair, operation and maintenance of infrastructure for the distribution and irrigation of lands within the operation of the district, among other functions. Irrigation districts are formed when at least 50 or a majority of land owners in an area agree to its creation. Urban water supplies are managed by publicly or privately owned water utilities.

Funding

Ecology had a $1.5 billion biennial budget for the 2013-2015 budgeting period, of which $458 million were allocated to operating costs. Nearly three-quarters of the combined operating and capital budget was passed through to local communities, mostly in the form of capital projects.

Water quality projects were allocated $567 million, or 38 percent of the total biennial budget. The Water Resources Program, including the drought preparedness program, water rights processing, water rights tracking system, grant and loan programs, along with capital projects, was allocated $193 million or 13 percent of the total biennial budget. Within the Water Resources Program operating budget of $37.9 million, notable expenditures include $13 million (36%) for managing water rights, $8 million (21%) for providing water resources data and information, and $4.7 million (or 12 percent) for assessing, setting, and enhancing instream flow. The remaining portions of the budget were spent on other environmental protection and restoration programs.[103]

Legal Framework

Water rights

Surface and groundwater rights (except for groundwater permit exempt uses) are required for putting water to beneficial use. Both surface and groundwater rights are defined by a point of diversion (surface water) or withdrawal (groundwater), the rate of water that can be taken (instantaneous quantity), a maximum annual

[103] Information on Department of Ecology's budget sourced from Ecology 2013.

quantity, the purpose of use, as well as the place, and season of use (Washington River's Conservancy 2009). Riparian (only pre-1932) and appropriative surface water rights are currently in existence.[104] There are also vested groundwater rights for beneficial use initiated before 1945 and post-1945 groundwater permits (Washington Rivers Conservancy 2009). Water rights are prioritized by seniority according to the prior appropriation doctrine.

Surface and groundwater rights are conferred through a state permitting system according to state water codes in 1917 and 1945 respectively (in Washington, perfected (beneficially used) water rights are issued a certificate of water right). The permit is issued by the state and allows applicants to proceed with the construction of the water system and the beneficial use of water. A certificate is issued after confirming that the permitted use is perfected, will not affect other water rights, and meets administrative conditions (Washington Rivers Conservancy 2009).

Certain groundwater uses are statutorily exempt from the permitting process: 1) for stock-water purposes, 2) for the watering of a lawn or of a noncommercial garden not exceeding one-half acre in area, 3) for single or group domestic uses in an amount not exceeding five thousand gallons a day, and 4) for an industrial purpose in an amount not exceeding 5,000 gallons a day.

A "notice of intent" must be submitted to Ecology prior to drilling a groundwater well. This notification allows Ecology the opportunity to oversee and inspect the construction of new wells. Afterward, Ecology may approve, limit, or prohibit the establishment of the groundwater use according to the water available (Department of Ecology 2006).

Under the Water Right Claims Registration Act of 1967, vested surface and groundwater users and exempt groundwater users had to register the location and quantity of their claims with Ecology. Ecology has thus far recorded about 166,000 claims, of which about 70 percent reflect uses of groundwater under the permit exemption (Department of Ecology 2006). Like other states requiring registration of claims to historical water use, filed claims do not represent legal validation of a water right. Only a small portion of the claims have been adjudicated in court. Adjudication cases pose such demands on judicial resources that, at the current pace, it is estimated it will take more than 200 years to fully adjudicate all the water right claims. Specialized water courts that could speed up this process have not been developed, despite calls for them.[105]

For sustainability considerations, Water Resource Inventory Areas (WRIAs) were developed to delineate 62 major watersheds in the state and consolidate information on factors affecting water availability in each of them. Ecology publishes public information on factors like instream water dedications, stream closures, and other resource and cultural issues that impact water availability in a basin. Ecology develops instream flow rules specific to each WRIA. Instream flow rules have been established in about half of the state's watersheds. Instream flow rules also have effective dates based on when the rules were established, which means that the rules primarily impact new or modified appropriations.

Water trading

Although water rights are appurtenant to the land or the place where water is used, transfers and other modifications are allowed with certain conditions. Modifications include conveying a water right to another water user or changing it to another point of diversion or withdrawal, place of use, manner of use, and type of use, without losing its priority. An application for change or transfer must be evaluated to verify that a transfer or change occurs without injury to existing rights. Broadly speaking, this means that the net use of a water right cannot increase as a result of a modification.

[104] A Supreme Court decision allowed riparian doctrine water users a period of 15 years to put their water to use after the passage of the 1917 water code.
[105] A Board for Judicial Administration Water Court Work Group in 2004 filed a report suggesting the need of specialized courts.

Ecology's Water Resources Program must evaluate the change in annual consumptive quantity of water as a result of a proposed additional beneficial use or expansion of irrigated acreage under a water right. In 2004 (revised in 2016), Ecology clearly defined a method for evaluating net water use using Annual Consumptive Quantity (ACQ). ACQ is the estimated or actual annual amount of water diverted pursuant to the water right, reduced by the estimated annual amount of return flows, averaged over the two years of greatest use within the most recent five-year period of continuous beneficial use of the water right. Return flows for irrigation practices are determined by using application rates, irrigation equipment efficiencies, and evapotranspiration (ET) rates for crops using the Washington Irrigation Guide, the Public Agricultural Weather System, or other crop consumptive use estimates. Consumptive use of water for other uses may be estimated using unit-based estimates (e.g., number of customers served, head of livestock, etc.).

Water right changes and transfers can be processed by the Water Conservancy Boards. Applicants are charged a processing fee that varies from $200 to $1,450 per application. The process can be completed in 6 to 12 months after the submission. In general, Ecology's regional offices take longer to process transfer applications, but charge a lower application fee ($50).

Ecology also allows applicants to pay, under full cost-reimbursement, to have an approved contractor complete and process transfer applications. The contractor processes the application on Ecology's behalf, but Ecology retains final decision-making authority. This process might cost an applicant around $10,000 and might result in a shorter processing period.

Seasonal or temporary modifications in the point of diversion (withdrawal) or place of use of the water right can also be approved, as long as they don't cause harm to existing rights. Seasonal and temporary changes require the permission of Ecology or the water master.

Legal treatment of environmental water use

Ecology and other state natural resources agencies in Washington divided the state into 62 Water Resource Inventory Areas (WRIAs) to delineate the state's major watersheds. Ecology developed a profile of factors that limit water availability in each of these. Approximately half of them have minimum instream flows established through Instream Resource Protection Plans (IRPPs), including the main stem of the Columbia River (Washington Rivers Conservancy 2009). Ecology has fish biologists on staff, and seeks assistance from other state, tribal, and federal agencies to determine minimum instream flows and to generate the IRPPs. Once adopted, an instream flow rule acquires a priority date equal to that associated with a water right, and thus, water rights secured after the rule adoption date will be "junior" to the instream flow (Department of Ecology 2003). The IRPP flows are supposed to be reviewed at least every five years (or more frequently if needed), but this rarely happens due to the significant staff time required. Instream flow recommendations are currently being studied in several WRIAs.

Prioritization of particular uses

In the Revised Code of Washington (RCW), there is no established hierarchy among beneficial water uses to be applied in cases of scarcity. Allocation of waters "shall be based generally on securing maximum net benefits for people of the state."

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

By law, Ecology has been authorized to require reporting from each surface water right following amendments to the Water Code in 1993. However, this provision was not put into practice until 2002. Ecology may also require groundwater withdrawals to be metered and reported as a condition for issuing a new water right permit.

All surface water diversions of more than 1 cubic foot per second (cfs)—1.983 acre-feet/day—must measure and report diversions, as well as diversions of surface or groundwater from sources where fish stocks are classified as critical or depressed by the Washington Department of Fish and Wildlife. These surface water diverters are required to record monthly diversions if they use less than 10 gallons per minute (gpm) or around 16 acre-feet a year, biweekly if they divert between 10-50 gpm or between 16 and 80 acre-feet/year, and weekly if they divert over 50 gpm. Reports are to be filed once a year, by January 31, for all diversions from the prior year. Ecology prefers water users to do electronic filing of metering data. If the water user does not have internet access, the data can be mailed to the local Ecology office. Meter technology standards are specified for different types of water diversions. No withdrawal or diversion of water can be made unless the corresponding measuring devices are in proper operating condition.

All groundwater withdrawals require a properly operating measuring device. While reporting requirements vary by water right, most groundwater rights do not have to report annually (Western States Water Council 2014). Completed groundwater use reports are filed online or mailed to Ecology by every groundwater right holder subject to reporting requirements. Reports are made once a year, but the recording must be made either weekly, bi-weekly, or monthly.

Ecology's current initiative is to ensure that diversions and withdrawals in basins are fully metered, when required. As a result of a legal decision in 2001, Ecology monitors water use in the 16 fish-critical basins around the state due to concerns of fish survival and habitat. Also, each region agreed to pursue metering of 80 percent of the water use in those basins; some regional offices have already achieved this goal.

Indirect measurement of water use (top-down approach)

The USGS's Washington Water Science Center (WAWSC) has produced statewide water-use estimates every five years from 1985 to 2010. The data is reported by source (surface water or groundwater, fresh and saline, and total), category of use, and area type (county). For the collection and reporting of the total withdrawals, USGS works with local, state, and federal agencies as well as academic and private organizations.

A more comprehensive approach for providing more frequent and detailed information on water use has not been adopted statewide. However, surface and groundwater uses, as well as aquifer recharge sites, are studied for the establishment of minimum instream flows (described above), but these analyses are rarely reviewed at the intended five-year intervals.

System Analysis and Management

Ecology compiles water supply information from different local, state, tribal, and federal sources. In an effort to consolidate information, Ecology has developed the Washington Water Supply Information platform. The platform provides a collection of links to websites with current and monthly information on different water supply variables from different agencies.

For system analysis, the information is obtained primarily from the WAWSC. USGS provides a data collection network and different water resource studies through the "Hydrologic Investigations Program." Most of these activities are funded through partnerships between USGS, other federal agencies, state and local governments, and tribes. The WAWSC's current data collection network includes more than 350 sites in Washington for acquiring information on surface water, water quality, groundwater, and precipitation. Nearly all streamflow data and runoff can be accessed on a real-time basis, along with continuous water-quality data from about 65 sites.

- **Snowpack.** The National Oceanic and Atmospheric Administration (NOAA) and Natural Resources Conservation Services (NRCS) provide the state with information about snowpack. Specific reports on snow, precipitation, streamflow, and reservoir storage are obtained daily from monitoring stations and published on a publicly accessible online data-viewer.
- **Rainfall.** Rainfall measurements are obtained from the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). There are about 100 telemetry stations transmitting data every three hours to Ecology. The data is transmitted by satellite transmitters or a standard dial-up modem connection. The information is logged every 15 minutes and transmitted in three-hour blocks, where it is automatically imported and published.
- **Groundwater.** Statewide Water Level Data Compilation is a project to consolidate several independent groundwater data sets in the Ecology Environmental Information Management (EIM) system. The project hasn't been completed yet and will focus on consolidating manual measurements of water levels and incorporating continuous transducer data. The WAWSC has groundwater level data in real-time from only four sites. Groundwater data can be accessed through historical records or can be compiled from USGS groundwater investigations conducted across the state. These investigations are usually done at a watershed or regional scale, and include the development of computer models that can simulate groundwater flow and connections between groundwater and surface water. Environmental Investigation Wells (EIWs) are temporary wells used for a rapid reconnaissance or site screening prior to the installation of permanent monitoring wells. EIWs are often installed using direct push methods such as Geoprobe. Direct push technologies are also used to install permanent monitoring wells.
- **Surface-groundwater interaction studies.** Currently, four state-sponsored studies are in development: in the Spokane River along Inland Empire Paper's property, in the Lower White River, Stillaguamish River, and in Wide Hollow. The studies also evaluate the thermal and water quality influences of groundwater discharges. WAWSC also does surface-groundwater interactions studies; they are done on a regional basis and somewhat sporadically. For example, during the summer of 2015, the data for the Raging River Temperature study was collected, including data on surface and groundwater interactions. Also during 2015, the South Fork Nooksack River Basin surface and groundwater interactions and processes study was published. Interaction studies are done on an as-needed basis for different spatial scales and purposes.
- **Forecasts**: The information provided through the Water Supply Information Platform includes monthly basin reports and forecasts. The Water Supply Information Platform is supported with data from NOAA's Northwest River Forecast Center and the National Water and Climate Center at the NRCS. They provide daily data and maps with a precipitation forecast extending out 5–10 days, along with seasonal forecasts. The Office of Columbia River, with Ecology, produces a long-term water supply and demand forecast for eastern Washington.

The Watershed Planning Act was established by the state legislature in 1997. This new planning framework was part of an integrated approach for managing water resources in Washington. WRIA planning units meeting the Act's requirements were authorized to apply for funding assistance for planning and implementing watershed plans. A total of 44 planning units initiated watershed plan development with state funding between 1998 and 2012, and 33 plans have been adopted. Most planning groups continue to implement priority actions from their watershed plans.

Allocation During Periods of Scarcity

Ecology monitors winter weather patterns and snowpack to anticipate drought conditions that may develop in certain regions of the state. The information is retrieved mostly from the Seasonal Drought Outlook available at the Climate Predictor Center of the National Weather Service or other federal platforms. This is the case with the Northwest River Forecast Center that provides a 10-to-120-day forecast on precipitation and temperature. Also, for some rivers, a Forecast Center has been developed to warn water users about possible future curtailments.

Curtailments

Ecology has the authority to execute and enforce curtailments. Although surface water curtailments can be widespread during severe droughts such as the one the state faced in 2015, Ecology curtails surface water to irrigators somewhere in the state almost every year. For groundwater, Ecology has the authority to limit withdrawals, though this option is not used frequently. Curtailments are done according to seniority for appropriative uses. Curtailments are done when junior water users are impairing senior water right users, or if there is a risk of impairment because of insufficient water supply.

To enforce curtailments, Ecology's field staff verifies that stream gages are at the right height and pumps are turned off when they are supposed to be. Ecology's capacity is not always adequate to fulfill this responsibility, however, and the state is seeking additional funding to hire more watermasters to support regular curtailments.

Drought preparedness and response

In response to past droughts, the Water Supply Availability Committee (WSAC) was established by the state legislature in 1995. The committee serves as a multi-agency advisory council for increasing drought preparedness and responding to drought. Committee members include representatives from federal, state, and local agencies.

In the event of a governor-declared drought declaration, more than 30 types of projects and activities are eligible for drought relief funds in the form of grants and loans. For 2015-16, $16 million was appropriated by the legislature for biennial drought relief. Grants to public entities were used to modify an existing water source or deepen an existing groundwater well; develop an emergency or alternate water source; purchase or lease water or water rights to be used during the drought; construct an emergency interconnection; build transmission pipelines, diversion structures, or storage devices, acquire pumps and accessories for moving water; detect and repair leaks; and line water canals.

Public Information Provision

Water Rights

Ecology maintains the Water Resources Explorer (Web Map), a GIS-based platform where water right records can be searched by document/record number or by the name of the water-right holder or claimant. The search engines also include location and priority of the water right. Through the query, users can access scanned images of water resource documents, including water right certificates, water use permits, applications for water use, and claims of water use. The platform includes documents and data regarding the authorized, claimed, or requested quantity of water (both instantaneous and annual) and number of irrigated acres, the purpose of water use, priority date or date of first use, the name of record, as well as information regarding metering, if required.

The Well Log Viewer is a publicly accessible platform for viewing groundwater well locations. It enables locating wells that have well reports and viewing them using a variety of search tools, including an interactive map tool. The search engine includes location parameter, well depth or diameter, and dates of the well completion or log report received. The information is regularly updated, usually weekly.

The Pending Water Right Applications platform includes information on applications currently in process. It provides the location of pending water right applications, including change or transfer applications. It provides information on the application number, priority date, instantaneous and annual quantity of water, type of document, and use of the water right among other characteristics.

System Monitoring

Information on current and monthly water availability can be accessed through the Washington Water Supply Information website (described above). The website contains links to different water information websites:

- Links to the Ecology Streamflow Monitoring Network (interactive map) are provided for information on streamflow. Monitoring stations measure data every 15 minutes and publish data online every three hours (using telemetry systems) to the Ecology Streamflow Monitoring Network. The network provides information about the stage height, discharge, and water and air temperature. It also provides information from rain gages.
- Information on other monitoring stations can be found through the USGS Real-Time Data for Washington, with current, daily, and monthly reports on gage heights and discharge. The USGS WaterNow website allows for users to subscribe and receive reports on different parameters of water data directly to their mobile phones.
- The Washington Water Supply Information website provides links that enable users to see the information in maps, including the USGS Today's Streamflow Conditions in Washington, USGS Waterwatch, and USGS and Ecology Streamflow Gages. The USGS and Ecology Streamflow Gages maps show all monitoring stations classified by color according to the level of stream discharge.
- The Washington Water Supply Information portal help users find links to data on snowpack and precipitation. Maps of daily updated and archived SNOTEL Current Snow Water Equivalent indicators can be accessed through the Washington Water Supply Information portal. Links to the National Operational Hydrologic Remote Sensing Center provide daily Regional Snow Analyses for the Northwest Region. The CoCoRaHS Network provides daily precipitation parameters across the state. The Washington Water Supply Information portal also links to summary reports published by state and federal organizations.
- The Washington Water Supply Information portal also connects users to the US Bureau of Reclamation website providing information on major storage reservoirs in the Yakima River Basin. The portal displays available water, reservoir levels, and streamflow for some gaging stations, and is updated on a daily basis. NRCS produces annual reports on precipitation, snowpack, and reservoir levels, including forecast reports.
- For weather conditions, the portal links users to US Climate Data for different cities.

Allocation During Scarcity

The Washington Drought Watch offers information on the drought situation across the state, including rain and snow conditions and seasonal forecasts. It is linked to the US Drought Monitor Washington and Washington SNOTEL, which provides updates on snow water equivalents (SNE). The Drought Monitor platform is updated weekly and SNOTEL is updated daily. The Drought Watch platform also maintains data on prior drought years, offering archived information, water supply data, as well as an economic view. All these references can also be accessed through the Washington Water Supply Information portal. The portal also provides links to the emergency drought, flooding, and weather alert system platforms. Emergency alerts are normally updated every two to three minutes.

Also, information about the WSAC meetings can be found online, including agendas and other documents that the WSAC uses to evaluate current and forecasted water supply conditions.

When a curtailment is required, the general notification process for irrigators with junior and interruptible water rights is the following: First, irrigators may receive an informational advisory letter that they may have to stop using water at certain time. When curtailment becomes necessary, users receive a letter or are personally contacted by a water master or Ecology field staff with an official curtailment order or notice. These notices sometimes contain a curtailment hotline number. In some cases, diverters must call the number daily to know if they can withdraw water on a particular day.

Water Transfers

Information regarding volumes of water to be transferred is required on the application forms sent to Ecology for approval of changes or transfers of water rights. However, the state does not consolidate this information into an overview report on trading in the state. The state does not record trading prices.

Water markets such as the Yakima River Basin Water Exchange offer online statistics on monthly transactions. Records of transaction include volumes, but not prices. This water bank is mostly used for flows to mitigate impacts of diversions or groundwater withdrawals on streamflows.

Also, any notice of seasonal or permanent transfer can be seen through the Washington Newspaper Publishers Association (WNPA) public notice search platform. The notices include information on the water right number, location, volume, and priority that is being changed, as well as other information.

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Australia

Highlights

- Although water resource management is primarily at the state level, Australia's national government provides technical support and data products for water accounting. For example, a central information platform collates and analyses national near real-time data from agencies and authorities monitoring reservoirs, stream levels, diversions, and groundwater levels. The platform also presents climate data that can be integrated with local modeling to help users manage their systems.
- The National Water Initiative Agreement of 2004 required states and territories to commit to creating water markets and opportunities for trading within and between states and territories. Signatories agreed to facilitate operation of efficient water markets where water systems are physically connected and minimize transaction costs through compatible entitlements, regulatory arrangements, and clear flow of information on all water access entitlements and trades within each basin. Australia's water markets successfully reallocate water to more valuable uses.
- Advances in water entitlement and planning frameworks driven by the national water reform agenda have increased certainty and transparency in the allocation of water resources in some major river basins. These sophisticated allocation systems are actively administered by water managers responsible for determining and communicating the amount of water available to each user on a regular basis. A national summary of current water restriction information for urban water authorities is also published each year.
- Some state agencies have studied environmental flow requirements for every major regulated and unregulated river for determining environmental values in a basin. Some environmental flows are met before allocations to other end-users. In fully allocated basins, Commonwealth and state governments have bought water rights for environmental uses.

Introduction

Australia is the world's sixth largest country. Because of its size, Australia has a variety of climates. Temperatures can range from below 32ºF in the Snowy Mountains in the south to extremely high temperatures in the Kimberley region in the northwest. There are two main seasonal patterns, of either temperate zone seasons or tropical seasons.

The southern city of Adelaide, in the temperate zone, has an average maximum temperature of 84°F in summer and 59-60°F in winter. Average annual rainfall is 22 inches, mostly during winter. In sub-tropic and tropical cities, such as Brisbane, average minimum and maximum temperatures are 61 and 77 ºF. The highest rainfall in sub-tropic and tropical zones is in summer, which sometimes brings thunderstorms and floods. Central Australia is an arid and semi-arid desert region with high daytime temperatures and little rain.[106]

Drought is common. Prolonged droughts include a decade-long drought that began in 2000 with significant agricultural impacts (Maddocks 2013). This economic sector is almost 3 percent of Australia's total gross domestic product (GDP) of which more than 60 percent is exported. Major agricultural products exported include wheat, beef and milk.

The three most prominent rivers in Australia are the Murray, the Murrumbidgee, and the Darling. Together with another 20 rivers, they provide water for the Murray-Darling Basin. The Basin's size is over 386,000 square miles, almost one-seventh of Australia. By the 1980s, the Murray-Darling Basin and many of Australia's surface and groundwater systems had been fully allocated (National Water Commission 2011).

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[106] Unless otherwise noted, climate information is sourced from http://www.australia.gov.au/about-australia/australian-story/austn-weather-and-the-seasons.

Principal demographic, economic, and water-related indicators in Australia

Population (in 2010):	21.5 million
GDP (in 2010):	$1,454 billion
Agriculture Value Added:	2.5% of GDP
Annual Precipitation:	21.02 inches
Total Water Withdrawals:	18,322 TAF
Urban Use:	16%
Agricultural Use:	74%
Other Uses:	10%
Surface Water:	67%
Groundwater:	33%

SOURCES: Population: US Census International Programs, 2014; GDP, Agriculture Value Added, Annual Precipitation, Total Withdrawal and usage %: World Bank, 2014; Surface/groundwater %: (Harrington and Cook 2014).

Based on the water acts of the various states, water rights have been defined mostly as entitlements that allow access to a share of water from a specified consumptive pool. The volume of water available to a water entitlement may change with the water available in a water management area. Water delivery rights and irrigation rights are entitlements that allow receiving water from a specific irrigation infrastructure operator (IIO). Water access rights are conferred by the state and are given in perpetuity. Water allocations are made against the water access entitlement on a seasonal basis. In addition, there may be riparian rights for landowners whose property adjoins a body of water, and "stock and domestic rights" for domestic and on-farm purposes.

Groundwater entitlements have traditionally been tied to land rights; however, under the National Water Initiative (NWI), this has been gradually changing. The license associated with a groundwater entitlement generally specifies matters such as the conditions of use, length of tenure, and water volume permitted for extraction. Other issues of the NWI are to return currently over-allocated or overused systems to environmentally sustainable levels of extraction (Harrington and Cook 2014).

Regulatory overview

Institutions

Oversight agencies

Under the Australian constitution, states have the power and responsibility for the management of land and water resources. However, starting in the early 1990s, it was becoming apparent that Australia was getting a poor economic and environmental return from the collective management of its water resources. This led to a series of national and state discussions about national water policy, resulting in legislative activity, national water programs, and multi-state water policy agreements, starting with agreement to the Council of Australian Governments' (COAG) Water Reform Framework in 1994, and the National Water Initiative (NWI) in 2004. With these national agreements, state governments committed to reshaping water allocation and planning practices to increase the certainty and tradability of water rights and become more resilient against a highly variable climate and hydrology.

As part of the NWI, a National Water Commission (NWC) was formed by the Council of Australian Governments (COAG) as an independent statutory authority providing advice to COAG on national water issues and independent assurance of the governments' progress on water reform. Both the COAG Water Reform

Framework and the National Water Initiative (NWI) provide the blueprint for Australia's modern water reforms and established a foundation for state-level and inter-state actions like managing over-allocated water systems, creating clear water entitlement and allocation rules, developing standards for water accounting, and expanding trade in water, among others. The core responsibilities of the NWC included monitoring, auditing, and assessing water policy reforms, including the objectives and commitments made under the NWI. The National Water Commission Act of 2004 was formally repealed in 2015, resulting in abolition of the NWC. Various critical national functions of the NWC were distributed across different agencies in the Commonwealth Government. Despite the abolition of the NWC, the multi-state agreement (NWI) remains as the nation's framework for water reform. Independent auditing of NWI will continue under the national Productivity Commission, including triennial assessment of progress towards NWI goals, outcomes of state and territory water policies, and an independent audit of the Murray Darling Basin Plan. The Department of the Environment also will monitor implementation of inter-governmental funding agreements for the Murray-Darling Basin reform. The Department of Agriculture and Water Resources assumed responsibility for monitoring water markets. Finally, the Bureau of Meteorology will closely coordinate with state and territory governments on national performance reports for the urban water sector. There is some concern that diffusing NWC responsibilities across several agencies may halt progress towards NWI objectives and result in backsliding (National Water Commission 2014).

The Commonwealth Water Act of 2007 was an important step in defining the Commonwealth's role in water policy by assigning oversight responsibilities to different arms of the Commonwealth government. Principal features of the act include establishing a Commonwealth Environmental Water Holder within the Department of Environment, incorporating water information and accounting functions within the Bureau of Meteorology, creating the Murray-Darling Basin Authority with a requirement to create the Basin Plan, and delegating responsibility for developing and enforcing water market rules in the MDB to the Australian Competition and Consumer Commission.

State-level regulation of water resources is done differently in each state and territory. In general, state water management oversight includes water pricing policy and economic regulation, water planning, water entitlement administration, water market governance, environmental management, and water quality management. In some cases, a single state agency will have multiple oversight responsibilities, such as the Department of Primary Industries in New South Wales, the Department of Environment, Land, Water and Planning in Victoria, Department of Natural Resources and Mines in Queensland, Department of Environment, Water and Natural Resources in South Australia, and the Department of Water in Western Australia. Depending on the state, water quality management may be a function of the primary water resource agency or may be delegated to another division of the state government. Water pricing and economic regulation may also be the responsibility of another state-level agency such as an independent tribunal or a regulatory commission. In some states, the provision of water services may be undertaken by local urban, rural and catchment management authorities or corporations. In others, these may be provided by the state department.

Arguably the most important water resource management function is the initial assignment of water entitlements and the determination of water allocations, which provide water access entitlement holders with the volume of water that they can then use or trade each water year in regulated river systems. While state natural resource agencies are responsible for administering and recording water rights, they may collaborate with other agencies for active administration of rights and allocation decisions. Seasonal determinations (or allocations) are the responsibility of either primary state water resource agencies or the water corporations who actively manage the reservoirs and dams on regulated water systems.

In Victoria, water corporations may have an array of responsibilities including the administration of surface or groundwater licenses, metering surface and groundwater extractions, determining water allocations, and initiating proposals to curtail water rights during extreme scarcity conditions (referred to as a "qualification").

Water supply operations agencies

Within states and territories, water supply operations are managed by government-owned water corporations or utilities. In Western Australia, South Australia, and the Northern Territory, bulk (wholesale) and retail water distribution is by state-owned companies. In Queensland and Tasmania, local governments are responsible for water services. In New South Wales, Victoria, and southeast Queensland, state-owned bulk water suppliers distribute water to retail water service companies owned by either local or state government. In general, government-owned water corporations provide bulk and/or retail water services for a wide range of uses including irrigation, industrial, or urban water supply. They often manage capital intensive water works like reservoirs, dams, waterways, and water distributions systems. In the Victorian water system, some water corporations with storage management responsibilities are also appointed as resource managers with the task of making seasonal determinations specifying the water available to holders of water shares, supply by agreements, and bulk entitlements in regulated river systems. Each state has a different configuration of water oversight and operations entities, with varying levels of resource management responsibility delegated to the water supply operators.

Funding

While the vast majority of water resource management activities and infrastructure are funded by water users, the Australian government funding supports the implementation of the Commonwealth Water Act and improvement of the national hydrological monitoring network. Most of this funding is directed to implementing the sustainable diversion limits established by the Basin Plan through investment in more efficient water and irrigation infrastructure and water purchase (Morton et al 2014). For the FY 2013-14, the total budget for the national weather, climate, ocean, water, space and environmental information functions of BOM was US$245 million, US$110 million for the Murray-Darling Basin Authority, and almost US$7 million for the National Water Commission (Commonwealth of Australia 2013). To help water data providers strengthen their water monitoring systems, BOM spent US$55 million for 463 projects through its Modernization and Extension of Hydrologic Monitoring Systems Program between 2007 and 2012 (Morton et al 2014).

The Commonwealth has committed $15 billion to water reform and irrigation efficiency improvements since 2002 (Department of Environment 2014). The Water for the Environment Special Account was created in 2012 to fund environmental management programs. Since 2012, US$1.2 billion has been directed to water efficiency projects and facilitating the recovery of environmental water. More than US$1.1 billion is available to support the recovery of environmental water and US$142 million is provided to resolve constraints that limit the outcomes achievable with environmental water (Morton et al 2014).

Legal Framework

Water rights

The administration of access to and use of water is the responsibility of state and territory governments, as defined by legislation in each state and territory. In 1994, under the COAG WFR, every state and territory agreed to reformulate their water rights systems to align with new national standards based on a water access entitlement and planning framework. This framework was continued in the NWI and aims to "enhance the security and commercial certainty" of water rights and provide a statutory basis for environmental and other public benefit outcomes in surface and groundwater systems, among other objectives. While some states had already started some aspects of these reforms earlier, the COAG agreement followed by the NWI signified a long term commitment to water rights and planning reform among states and territories.

Despite some differences in terminology, several common themes run across water rights systems in Australia. The fundamental components of a state's water rights system are water access entitlements and water allocations. A water access entitlement is a perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool. The important attributes of a water access entitlement include whether or not the water access entitlement is bundled or unbundled, for surface or groundwater, from a regulated or unregulated water source, and the reliability of the entitlement. Some water access entitlements —bundled— are grouped together with other types of entitlements that dictate how or where a water access entitlement may be used, including land, water use, or irrigation delivery entitlements. Water access entitlements also may be separated (or unbundled) from these other types of entitlements. Unbundling allows water access entitlements to stand apart, thereby creating a relatively standardized water product for trading and market transactions. Australian states have a mixture of surface and groundwater resources, with some resources being regulated. Regulated systems are surface water systems where river flows are controlled through releases from structures like dams and reservoirs. Some states have statutory mechanisms to convert bundled water rights in regulated water systems into unbundled water access entitlements. Unbundling water access entitlements on regulated systems allows for improved management, which benefits water-dependent economic activities like agricultural irrigation and urban water systems, along with the environment. Another unique feature of water access entitlements in regulated systems is a characterization of reliability, or "the frequency with which water allocated under a water access entitlement is likely to be supplied in full." Water access entitlements with reliability attributes are generally categorized as high or low reliability. The actual volume of water available to a low or high reliability water access entitlement will depend on the inflows to the storage which will be allocated according to a set of known rules. Reliability is not a feature of all water access entitlements in Australia. Water access entitlements in regulated systems are more likely to have reliability attributes than those in unregulated water systems, with some exceptions.

The complementary feature of a water access entitlement is a water allocation. A water allocation is a "specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan." Water allocations for some unbundled water access entitlements are announced as a percent of the total share to each water access entitlement holder. The announcement is generally made intra-seasonally depending on climatic and hydrological conditions in the water resource area and pre-determined allocation rules for the particular regulated water system. State governments, or water authorities acting on behalf of the state government, determine and announce seasonal allocations for specific regulated water systems on an on-going basis throughout the irrigation season. Allocations in unregulated systems (which may include surface or groundwater resources) are determined with alternative (and often less dynamic) methods compared to allocations in regulated systems.

Australia has other types of surface water rights as well, including riparian rights, stock and domestic rights, and water rights specifically related to users served by irrigation systems including water delivery rights, irrigation rights, and native title. The water entitlement framework is flexible, as it allows each state to concurrently use multiple allocation and oversight techniques scaled to the water resource conflicts and management needs of different water systems in their state. At the same time, national acceptance of the unbundled water access entitlement and allocation framework created a range of water products facilitating effective resource management and market transactions. Currently, there is a mixture of bundled and unbundled water access entitlements with varying approaches to allocation.

As part of the NWI, signatories also agreed to implement state water registries acting as the definitive record of all water-related entitlements and transactions within and between those entitlements in each state and territory. Water registers provide publically accessible information about water entitlements, ownership of entitlements, and prices and volumes traded through the water market.[107]

Victoria has historically been a leader in modern water management techniques in Australia, including early adoption of the entitlement and planning framework. Victoria has a number of regulated surface water systems in which water rights and licenses have been unbundled from land, allowing for seasonal allocation against unbundled water access entitlements (called "shares" in Victoria), carry over of seasonal allocation from year to year, reliability attributes (high or low), and an active market for both seasonal allocation and unbundled water access entitlements. Allocation of water in regulated water systems (where unbundling has occurred) is done by seasonal allocation, expressed as a percent of the entitlement. Water resource managers make initial allocations early in the year based on current volume of water in storage and estimated inflow during the season based on the historical record and seasonal streamflow forecasts. Initial allocations may be low due to intentionally conservative forecasts of reservoir inflows. Allocations are updated regularly during the growing season (in some cases, every two weeks) as additional hydrologic and climate information becomes available. Victoria also has unregulated surface water and groundwater systems with different types of entitlements. In general, unbundling has not been undertaken in many of these systems and therefore unbundled water access entitlements ("shares") are not available in these systems.

Allocation of unregulated surface and groundwater is through bulk entitlements and bundled water access entitlements (often referred to as water use licenses). Bulk entitlements may be held by state-owned rural and urban water corporations who act as large water wholesale or retail operations delivering water to customers by contract. The principal type of bundled entitlement for individual use of waters from unregulated or groundwater sources are called "take and use licenses." These licenses are fixed term entitlements to take and use water from a waterway, catchment dam, spring, soak, or aquifer. Responsibility for issuing take and use licenses may be delegated to local water resource entities acting on behalf of Victoria's Minister for Water. Take and use licenses are issued and managed in a way that recognizes the interaction of surface and groundwater systems. The licensing process incorporates surface and groundwater availability determinations for evaluating the impact of new extractions on other water right holders and sustainable limits on diversions from streams and aquifers.

Water allocations in unregulated streams are managed under local management plans enforced by water corporations. Water corporations may impose a roster, restrictions, and bans on water extractions when water resources are scarce (e.g., very low streamflows in the river or dropping groundwater levels) (Victoria Department of Environment, Land, Water and Planning 2015).

The Victorian government has designated groundwater management areas or water supply protection districts in some areas where groundwater is at risk of rapid depletion. Within these groundwater management areas, groundwater licenses are quantified according to Permissible Consumptive Volumes (PCVs) that are adjusted to local groundwater management objectives. Groundwater users also may be subject to metering and monitoring requirements. Groundwater rights in designated areas may also be restricted on a temporary basis for a specified period, which is also referred to as qualification of rights.

Victoria has a very sophisticated Water Register maintained in collaboration with an independent registrar, the Victorian Department of Environment, Land, Water and Planning, and rural water corporations.

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[107] For example see the Victorian Water Register.

Water trading

The NWI Agreement of 2004 required states and territories to commit to creating water markets and opportunities for trading within and between states and territories. Signatories agreed to facilitate operation of efficient water markets where water systems are physically connected and minimize transaction costs through compatible entitlements, regulatory arrangements, and clear flow of information on all water access entitlements and trades within each basin.

Tradeable water rights in Australia also are referred to as water products. Bundled and unbundled water access entitlements are the most commonly traded water products in Australia. At the most basic level, water access entitlements are either for surface or groundwater. If a water access entitlement is for surface water, the entitlement may be from a regulated or unregulated water source. A surface water entitlement from a regulated water source may be unbundled or bundled and may be either low or high reliability. Terminology for each water product differs among states, but generally speaking every state has comparable types of water products.

There are three principal forms of trade in Australian water markets, the lease of a water access entitlement, the permanent transfer of a water access entitlement, and the trade of a water allocation. Water access entitlement trades are "transactions to transfer a water access entitlement from one legal entity to another, with or without a change in location, perpetually or for a specified term." Water allocation trades are transactions to "transfer a water allocation from one legal entity to another, with or without a change in location, for the remaining water year or for a specified term that may be less than the end of the water year or carried over to subsequent years (i.e. lease)."

Victoria is an early adopter of regulatory and administrative tools for water marketing. Since the 1980s, Victoria has been unbundling water entitlements from land in some regulated systems. Victoria also developed a comprehensive state water register to compile definitive information on water entitlements and trades in Victorian basins. Four main types of trades occur in Victoria, depending on whether a surface water entitlement is in a declared or non-declared system.[108] In unbundled systems, individuals may trade or transfer water shares or water allocated to those shares every season (an allocation trade). In other systems, individuals may trade entitlement volume (volume of water specified in a bundled entitlement like a Take and Use license) or change ownership of their water entitlement (Victoria Department of Environment, Land, Water, and Planning 2015). Nearly 2,700 GL (2.2 MAF) of water were traded in Victoria between 2014 and 2015. About half of all trades over this period involved trades of environmental entitlements.

Legal treatment of environmental water use

As defined in the NWI of 2004, a water plan is a statutory mechanism used by states for defining specific management objectives and allocation rules for a given surface or groundwater source. Water plans define management approaches to meet environmental outcomes for water systems and establish rules for determining risk and security of water access entitlements. Environmental water planning frameworks, created as a result of state responses to the NWI, include methods for identifying environmental watering objectives in basins and methods for acquiring water to satisfy those objectives. The following description characterizes Victoria's environmental water planning and entitlement framework, one of the more advanced among Australian states.

Victoria's Water Act of 1989, the blueprint of Victoria's modern water entitlement and planning framework, created a foundation for environmental watering in the state. During the process of converting existing water rights into legally defined bulk entitlements (the "conversion" process), the state defined rules on minimum

[108] The difference being that water entitlements are unbundled in declared systems into water access entitlements and allocations (collectively called "shares" in Victoria).

passing flows, established limits on extraction from river diverters in some basins, and created an entitlement category for the environment with specific target volumes establish for some catchments.

According to the Victorian system, water resources dedicated to the environment are referred to as the Environmental Water Reserve. This is made up of planned environmental water and environmental water access entitlements (also called "held environmental water"). Planned environmental water provisions are environmental flow obligations embedded into bulk entitlements. Planned environmental water provisions in regulated systems can be annual flow rates, seasonally adjusted flow rates, or volumes kept in storage. Passing flow rules are obligations on the bulk entitlement holder and must be met before the allocation of water from a regulated system to water shares. In unregulated systems, planned environmental water provisions take the form of target flow regimes met by enforcing local allocation and management rules.

The other general category of environmental water is referred to as environmental water access entitlements, referring to shares of water in a regulated storage system. Environmental water access entitlements are created via three methods: the bulk entitlement conversion process, certain programmatic investments in water conservation that return water to the environment, or direct purchases of water on the open market.

At the national level, the Commonwealth Environmental Water Office and the Commonwealth Environmental Water Holder (CEWH) plans, manages, and monitors a large portfolio of environmental water entitlements. CEWH was established by the Water Act of 2007 within the Department of the Environment. CEWH has major obligations under the Murray-Darling Basin Plan to deliver and trade environmental water in a way that supports the environmental objectives of the plan as defined in the Basin annual environmental watering priorities.

In Victoria, the Water Act of 1989 created an environmental water reserve objective to reserve environmental water to protect environmental values and the health of ecosystems. The Act created the Victorian Environmental Water Holder (VEWH) to hold, protect, and trade environmental entitlements. The VEWH may delegate the management of environmental entitlements and watering activities to local entities.

Along with an environmental entitlement scheme, Victoria has a strong water planning framework that helps environmental water holders identify the most valuable uses of their holdings. Environmental water planning actions include long-term evaluation of environmental water issues and opportunities in catchments, environmental flow studies, and seasonal prioritization of specific environmental watering projects according to statewide criteria. Criteria include the extent of environmental benefits obtained from a proposed project, certainty of success, ability to sustain the project over the long term, implications of non-action, engineering feasibility, risks and cost-effectiveness. The process of project identification, prioritization, and implementation is executed by collaboration among local waterway managers, the VEWH, and scientific experts. Waterway managers identify worthy projects with the help of local knowledge and environmental flows studies. Projects proposed by the waterway managers are considered by the VEWH and then incorporated into a statewide seasonal watering plan describing all potential environmental watering in the year to come. Decisions to authorize environmental watering are communicated through the Seasonal Watering Statement, authorizing waterway managers to undertake environmental watering projects.

Prioritization of particular uses

Each state defines the prioritization of particular uses in the administration of water entitlements and when water systems cannot meet demands of competing users. During the Millennium Drought, temporary qualifications of water entitlements were affected to maintain water for essential human needs (Piure 2014).

The Victorian Guidelines for Temporary Qualification of Rights states that essential human and stock needs generally are prioritized higher than other uses of water during times of emergency. This hierarchy of uses is only implemented during times of serious water shortage.

Ability to Account for Water

Water Use

The NWI signatories agreed to develop water accounting systems "to support public and investor confidence in the amount of water being traded, extracted for consumptive use, and recovered and managed for environmental and other public benefit outcomes." As defined in the NWI, water accounting systems are measurement, monitoring, and reporting systems for water supply and environmental watering in all jurisdictions within a state or territory. States and territories committed to: 1) establishing accounting standards, 2) standardizing accounting formats to facilitate comparison of water use, compliance against entitlements, and accurate trading information, and 3) implementing water resource accounts that facilitate compilation and aggregation of data on a regular basis. In 2009, the NWC published the "National Framework for Non-Urban Water Metering Policy Paper" with the primary objective of creating national metering standards that provide for an acceptable level of confidence within a five percent error limit. The national framework defined acceptable metering designs, and protocols for operating, maintaining, and replacing meters.

In response to the NWI's requirement for state-level water accounting products, the Victorian Department of Environment, Land, Water, and Planning (DELWP) generates the Victorian Water Accounts report annually. This annual report is a systematic appraisal of water balances within every basin, aquifer, and distribution systems in the state, reporting on volumes of water available and used during the year (Victoria Department of Environment, Land, Water, and Planning 2015). Basin accounts provide detailed accounting of water flowing into a basin and track inflows until they are either diverted or flow into another basin or the sea. Datasets used for basin accounting are sourced from water corporations, catchment management authorities (CMAs), Victorian Environmental Water Holder (VEWH), DELWP, major users of water, and the Murray Darling Basin Authority. As described below, water corporations have significant water measurement and reporting obligations as defined by agreement. Groundwater catchment accounts include detailed information about license and groundwater use in the catchment and trends in groundwater depletion. Data on groundwater is limited to licensed permissible use, which is tracked by the licensing authorities. Groundwater take and use licenses are administered by local water corporations on behalf of the state. Accounting of distribution systems characterizes the path of water after being diverted from a waterway, aquifer or other source to the time it is delivered to a customer (Ibid). Data on the distribution of water is collected directly from water corporations that operate these systems. Victoria's19 water corporations must account for and report on the water that flows through their systems. Water corporations use a variety of measurement, reporting, and estimation techniques (Ibid).

In response to the national mandate to incorporate national non-urban water metering standards in Victoria, DELWP defined a non-urban water metering policy in 2014. The policy recognizes that measurement of water should occur only where the data is useful for water resource management decisions. The state is principally concerned with implementing water measurement requirements for bulk entitlements (representing the vast majority of water use in the state). According to the state, a decision to measure at the individual entitlement level would be determined by a bulk entitlement holders' prerogative to measure use for resource management or billing purposes.

Rural water corporations, along with Melbourne Water, Coliban Water, and Lower Murray Water, are responsible for non-urban water metering in Victoria. When a delegate of the state issues, renews, or approves the transfer of a license to take water for non-urban uses, basic metering standards will be applied to the license. Water meter assets are owned by these water corporations and managed as a fleet. Responsibility for ongoing and capital replacement costs is borne by the corporations, but often these costs are passed on to individual water users. Victoria intends to eventually equip all non-exempt non-urban extraction sites with approved meters according to the national metering technology standards. Exemptions include stock and domestic entitlements (unless significantly impacting other users or Environmental Water Reserve), among others.[109]

Almost every significant surface diversion and groundwater extraction in the state is metered. Collection of data (meter reading) is done by local authorities who are transitioning from manual meter reading to electronic data collection. Compliance officers from local authorities periodically inspect meters for tampering and interference.

System Analysis and Management

Water availability in Australia is measured by a well-developed network providing information on different surface and groundwater variables across the country. Monitoring stations generally make real-time measurements and are networked for remote access. Data from these monitoring stations are inputs for public online water information platforms offering information at various scales and resolutions.

The Bureau of Meteorology is in charge of collecting all the hydrologic and climate information from more than 200 organizations nationally. This information is used to prepare reports on national water availability, basin conditions, and water use in a standardized way. Public websites display precipitation and temperature information, satellite images, weather maps, and other climate variables. They also report streamflow and water storage in different key points across the country. Since the information is ultimately sourced from state-level agencies, it is updated according to the information systems in each state. The frequency of information sharing between states and BOM vary from daily to annual transmission depending on the metric being shared. Streamflow data recorded from flood prediction monitoring stations are supplied to BOM electronically every 15 minutes.

BOM also provides a national assessment of Australia's public surface water storage. This product covers over 96% of Australia's publicly owned accessible surface water storage. It is built with inputs from approximately 25 local agencies providing information on their storage levels. BOM provides a snapshot of current storage volumes as well as a historical comparison of surface water storage availability and trends. In addition to data on individual storages, it calculates aggregate available storage for capital cities, states and territories, and major drainage divisions (including the MDB).

Information on actual groundwater availability is retrieved by BOM from state and territory agencies responsible for groundwater monitoring. Units and terminology were standardized under the National Aquifer Framework, the nation's first nationally agreed system for naming and grouping hydrogeologic units. It aggregates state-level information to ensure that hydrogeologic unit information is nationally consistent. This allows groundwater information to be consistently analyzed at all levels.

The National Groundwater Information System (NGIS) is a spatial database for geographical information system (GIS) specialists that contains bore locations and associated logs. Two- and three-dimensional aquifer geometries also are available for some areas. Lithology log tables, construction log tables, and hydro-stratigraphy log tables are used to build 3D construction and hydro-stratigraphy logs for the Groundwater Explorer tool. Hydro-stratigraphy logs also are

[109] Source information on measurement and reporting standards in Victoria sourced from Victorian Non-Urban Water Metering Policy.

used to create Hydro-stratigraphy GeoRasters and GeoVolumes. NGIS contains more than 800,000 bore locations, water registry records associated with lithology logs, bore construction logs, and hydro-stratigraphy logs.

At the state level, departments like the Victorian Department of Environment, Land, Water and Planning gather and distribute their own data on water resources. The Western Australian Department of Water supports Western Australia's growth and development by managing the availability and quality of water. The department has a network of 3,000 bores and more than 300 river gauging stations fitted with the latest technology.

On the modeling side, there are different models with different purposes at the national and state level. Australia has a widely-used hydrologic modelling platform called eWater Source. This software simulates water resource systems to support integrated planning, operations, and governance from river basin scales to urban water systems including human and ecological influences. The modeling platform provides a consistent hydrologic and water quality modelling and reporting framework to support transparent urban, catchment, and river management decisions. It was designed for flexibility, making it readily customizable and easy to update as new science becomes available. Integration of surface water and groundwater is explicitly considered in eWater Source model. All states are incorporating eWater Source into their resource modeling scheme, though this is expected to take many years.

It is also interesting to highlight the Australian Landscape Water Balance. The hydrologic information, shown in a web portal, comes from a model known as AWRAMS. AWRAMS provides nationally consistent estimates of Australian landscape water fluxes and storage. It simulates the flow of water through the landscape from rain to the movement of water through the vegetation and soil, and then out through evapotranspiration, runoff, or deep percolation to groundwater.

The Groundwater Dependent Ecosystem (GDE) Atlas was developed with help from the National Water Commission, SKM, and CSIRO with input from every state and territory as part of the Groundwater Action Plan. It collates existing information on groundwater-dependent ecosystems and displays ecological and hydrogeologic information on them, as well as ecosystems that potentially use groundwater. It assists the consideration of ecosystem groundwater requirements in natural resource management, including water planning and environmental impact.

Finally, BOM has developed a tool aided by climatic and hydrologic models called the Seasonal Streamflow Forecasts. Forecasts are based on probabilities of streamflow based on relationships with recent and forecast climate and catchment conditions. Forecasts are available for 140 locations nationwide, primarily clustered in southeastern Australia. More forecasts are planned for other rivers and catchments in the next two years.

At the state level, allocation models help in water operations. In Victoria, the Resource Allocation Model (REALM) can simulate the operation of both urban and rural water supply systems during droughts and periods of normal and high streamflows. Any water supply system can be configured using REALM as a network of nodes and carriers representing reservoirs, demand centers, waterways, pipes, among others. REALM uses a fast network linear programming algorithm to optimize the distribution of water within the network for each time step of the simulation period, in accordance with user-defined operating rules. While Victorian water systems were initially modeled with REALM, these models will soon be replaced by the eWater Source model. The Victoria's Department of Environment, Land, Water and Planning also developed a model, STEDI, to simulate the impact of existing or proposed dams on streamflow.

On the planning side, the Australian Water Resources Assessments (AWRA) was a biannual report to provide consistent, scientifically valid water information on: climate conditions and landscape characteristics; patterns and variability in water availability over time; surface water and groundwater status; floods, streamflow salinity, and inflows to wetlands; and urban and agricultural water use.[110]

The Assessments drew from BOM's water information systems for receiving, modelling, estimating, and analyzing water data across Australia. It uses the Australian Water Resources Assessment (AWRA) Modelling System. It was developed by the Water Information Research and Development Alliance, formed between the Bureau and CSIRO, for reporting on water availability. This modelling system is the first to integrate all water balance modelling components (surface water, groundwater and regulated systems). It generated outputs on water availability in each basin, a valuable tool for increasing transparency and public knowledge.

BOM also compiles and publishes an annual National Water Account for ten nationally significant water management regions. The National Water Account complements the Australian Bureau of Statistics' Water Account, to provide information on the supply and use of water within the Australian economy. Together these accounts inform water resources planning, water market activity, investment, and environmental management decisions. The annual account summaries are prepared according to the Australian Water Accounting Standards (AWAS) as adopted by the Water Accounting Standards Board (WASB). WASB's membership includes representatives from each state and territory's lead water agency, major urban and rural entities, and Commonwealth agencies.

Allocation During Periods of Scarcity

The following section presents an overview of approaches to allocation during periods of scarcity in the state of Victoria. Some aspects of allocation have already been described in the section on the entitlement (water rights) framework. This section will refer to Victoria's water entitlement and allocation framework described in previous sections.

According to the Water Act of 1989, the Victorian Minister for Water (Minister) maintains the power to declare a water shortage and order a change to any legal water entitlements, referred to as a qualification of rights. The qualification may be temporary or permanent. Permanent qualification addresses long-term declines in surface or groundwater availability that has a disproportionate effect on the environmental water reserve, water allocated for consumptive purposes, or water quality. The Minister may not order a permanent qualification until 2021, and these qualifications may not occur more frequently than intervals of 15 years.

Temporary qualifications are short-term changes in water sharing arrangements to ensure that critical water needs are met in extreme circumstances. Temporary qualifications may be ordered in response to extreme drought or temporary water quality emergencies like a wildfire in the watershed. The Minister completed numerous temporary surface water qualifications throughout the extreme drought period of 2006–09. As a result, DELWP developed guidelines describing criteria, processes, and agency roles in executing a temporary qualification. Any temporary qualification of surface water rights must apply to all rights in the same proportion, unless otherwise specified by the Minister. A typical exception might include a situation where urban and irrigation shares are qualified in different proportions.

The proceedings leading up to a temporary qualification are driven by a "proponent" who usually represents a significant entitlement interest in the water system. By default, the proponent is a water corporation with bulk entitlements. Proponents who have identified a potential water scarcity crisis work with a case manager assigned by the DEPI to create a qualification proposal. Each proposal must include an analysis of monitoring data and

[110] AWRA was used in 2010 and 2012, and has since been replaced by other water resource assessment products like Regional Water Information, Water in Australia, and Monthly Water Update (discussed in the Provision of Information section below).

other information demonstrating a water shortage. Demonstrating a water shortage requires proponents to: forecast storage levels, forecast water quality, characterize water use demands for domestic and major industrial users, describe existing contingency measures, and describe current and future daily demands over the period of the proposed qualification. Proponents of qualifications also are responsible for assessing, and often must mitigate, the impacts of a qualification.[111] A typical example includes the qualification of environmental planned entitlements like passing flows during extreme drought. Water corporations who requested the qualification mitigated negative impacts on environment due to the reduction in passing flows.

Public Information Provision

Water Rights

The National Water Account is an annual report that provides a picture of water resources management on the previous financial year for nationally significant water regions. The report is currently conducted for 10 regions: Adelaide, Burdekin, Canberra, Daly, Melbourne, Murray–Darling Basin, Ord, Perth, South East Queensland, and Sydney. It includes general information on water storage and streamflows, water rights, and water use. Water rights can be identified for surface or groundwater source, and according to type of use.

Also, the Australian Water Resources Assessment (no longer done) provided regular reports on the availability, quality and use of water resources at a national scale. It included urban and agricultural water use, reporting trends at a local, regional and national level over timescales of months to decades. This report was done biannually and the last one available online dates from 2012 (Bureau of Meteorology 2012). This information can also be retrieved from the Regional Water Information platform. Data on the Australian Water Resources Assessment can be retrieved through different search parameters, including hydro-climatic conditions, water use or trends, data and assessment type, region, and time. The information can be displayed on a map, graph or as plain statistics.

The annual Water in Australia report provides a national snapshot of water availability and use in a particular financial year. It is built on the former biennial Australian Water Resource Assessment and the annual National Water Account summary with the difference that the report is produced annually and covers the entire country. It addresses physical water resource conditions, water available for use, and water use (Bureau of Meteorology 2015).

For groundwater, BOM developed the Groundwater Information site, where nationally consistent groundwater data and information products are available for government, industry, and general public use. The Groundwater Insight is an interactive map of hydrogeologic data with information on licenses, entitlements, bore density, and groundwater management areas. The same site hosts the National Groundwater Information System (NGIS).

For detailed information on each water right, the NWI included as part of their objectives the introduction of registers and standards of water rights reporting for water accounting. Each state and territory government has a water register for recording water access entitlements, including ownership details, and transactions. As an example, the Victorian Water Register is the public register of all water-related entitlements in Victoria. It provides data on water entitlements, including information on the shares, volume given, and reliability. It contains records of past information, as well as allocation account records, and allocations made to the water share throughout the year. It is updated daily.

[111] Source information on qualifications of water rights in Victoria sourced from Victoria DEPI Qualification of Water Rights.

The Register provides information on water availability and use of the entitlements. It publishes seasonal determinations made by resource managers specifying water available to holders of water shares. The frequency of updates depends on each state. For Victoria, the seasonal determination is done every two weeks.

System Monitoring

The former biannual Australian Water Resources Assessment included water information regarding climate conditions and landscape characteristics, patterns and variability in water availability over time, surface water and groundwater status as well as floods, streamflow salinity, and inflows to wetlands. It has since been replaced by other water information products: *Water in Australia*, *Regional Water Information*, and *Monthly Water Update*. *Water in Australia* provides a countrywide picture of water availability, addressing physical water resource conditions. This information can be retrieved easily from the Regional Water Information platform. For detailed information, the Monthly Water Update website provides an overview of rainfall patterns and streamflow status across Australia. Information for most regions is provided through interactive maps or direct download.

For current or real-time information, BOM gathers and publishes data on climatic variables and water availability. Their website displays precipitation and temperature information, satellite images, weather maps, and other climatic variables. The data can be downloaded daily or monthly for different climatic stations, and past records may also be accessed.

BOM also hosts national reports on streamflows. High quality and long-term streamflow information can be accessed through the Hydrologic Reference Station platform. Here, information can be shown as snapshot, data, trend, station facts, or data can be downloaded. Through the Water Data Online portal, reports on streamflow level and gage discharge at 3,400 sites can be found through an interactive map. The portal provides a search engine allowing users to look up stations names, ID numbers, and owners. The data can be downloaded or viewed graphically for daily, weekly, monthly and other timeframes.

The Environmental Information Explorer platform provides information about environmental monitoring sites owned and managed by different organizations across Australia. The portal allows users to identify specific environmental monitoring sites by location (for example stream gages or weather stations), what observations and measurements are taken there, and who owns and operates the site.

The Climate Resilient Water Sources is another platform providing data on alternative water sources including recycled water and desalinated water. It provides a national overview on capacity, production, water sources, and use through national and state and territory filters. The platform provides interactive maps and tables with plant details. Data may be either downloaded or provided to BOM through a managed upload process.

BOM also develops the Australian Landscape Water Balance, an interactive website providing nationwide information on soil moisture, runoff, evapotranspiration, deep drainage, and precipitation in near real time. Information is updated daily and can be displayed on interactive maps or downloaded. The information is available at a daily, monthly, and annual time step from 1911 on.

At the same time, information products are available for government, industry, and the general public to use regarding groundwater availability through the Groundwater Information site, detailed above. For example, in the interactive Groundwater Insight map, hydrogeological information is provided and allows for downloading or analysis.

BOM also provides a national assessment of public surface water storage. This product covers over 96% of Australia's publicly owned accessible surface water storage. It is built with inputs from the different local agencies and the information on their storage levels. In general, it provides a snapshot of current storage volumes as well as a historical comparison of surface water storage availability across the country and trends over time (Morton et al 2014). The product can be accessed either through the Bureau's website or through an iPhone application.

A Climate Outlook platform presents forecasts of temperature or rainfall. It shows the likelihood of the next three months being wetter or drier, warmer or cooler, than typical conditions using interactive maps and reports.

For streamflow forecasting, BOM provides a 7-day Streamflow Forecasts platform. It provides forecasts with a lead-time of up to seven days, updated daily. For a longer forecast, a Seasonal Streamflow Forecast service is also provided. It is expected to be released monthly to complement the Seasonal Rainfall Outlook and Seasonal Temperature outlook.

BOM also provides for a National Flood Forecasting and Warning Service. The service uses direct rainfall and streamflow observations compiled in the Rainfall and River Conditions platform, while adding numerical weather predictions and hydrologic models to forecast and warn for possible floods across the country. It is linked to the Flood Watch that provides advance warning to emergency service providers of potential riverine flooding and communities at risk of flooding.

For more technical management tools, the Australian Hydrological Geospatial Fabric (Geofabric) registers the spatial relationships between hydrologic features such as rivers, water bodies, aquifers and monitoring points on a GIS based platform. Also, the Design Rainfall platform provides design rainfall data in the form of Intensity–Frequency–Duration (IFD) information, for the design of gutters, culverts, bridges, and stormwater drains, and Probable Maximum Precipitation (PMP), estimating the design of large dams and for floodplain management.

Allocation During Scarcity

Since water entitlements assure a share of the total availability, the allocation during droughts is also subject to seasonal determinations made by resource managers. The frequency of seasonal determinations varies by state and territory policies. While BOM provides high quality information on hydrological and meteorological parameters, most irrigators will access water information relevant to their entitlement (like their seasonal allocation) from the website of local rural water authorities.

The use of groundwater resources in a defined management area also may be restricted during droughts or shortage periods. Permissible Consumptive Volumes (PCVs) cap the total volume of licensed entitlement in an area, while a temporary qualification of rights restricts a licence holder's right to take water under that licence for a period. Both are published in the Water Right Registers of each state.

Information on water restrictions of any type can be found at a national level on the Water Restrictions website. Here, water restrictions information for urban communities can be searched by state or territory, water agency, and restriction name.

Water Transfers

The Australian water markets report provides information on market activity in Australia, including water entitlement trade and water allocation trade volumes and prices, trade processing times and environmental water holdings and trade, particularly in the Murray Darling Basin (Department of Agriculture and Water Resources 2015). National accounting summaries of water transfers are also contained in the National Water Account. This report includes volumes of water traded, extracted, and managed for economic, social, cultural, and environmental benefits. Allocation trade information is updated weekly and entitlement trade information is updated monthly at a national level on the Water Market Information platform. Also, each state and territory government in their water register has information regarding transaction of water access entitlements and other water rights. In the

Victorian Water Register, for example, the trading history of the water entitlements is shown, as well as summary reports of average prices for each water system. Daily updated information on volumes and prices are provided among other data in tables or graphs.

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Spain

Highlights

- Water resources are managed at the basin level. Spain is divided into 16 River Basin Organizations (RBOs), or *Confederaciones Hidrográficas*, which are autonomous agencies in charge of hydrologic planning, water resources management, public domain protection, water rights concessions, water quality control, and the deployment of infrastructure plans, among other responsibilities.
- Spain has been developing a comprehensive water monitoring and management system since 1983. An "automatic hydrological information system" is developed for each basin organization with six main functions: flood management, drought management, risk management, environmental flow control, water quality control, and technical support. The condition of the water resource system is measured in near real-time across roughly 2,500 control points. Most of these data can be obtained online.
- Water use has not traditionally been measured at the field level in Spain. The Measurement Order of 2009 requires the measurement all surface and groundwater diversions and all surface return flows and water discharges. This requirement has not yet been entirely fulfilled. Historically, water use has been estimated indirectly using different methods and calibrated with the data from the comprehensive monitoring system. Large diversions are measured by the RBOs through the automatic information systems and the official network of gaging stations.
- To minimize the negative environmental, economic, and social impact of drought, RBOs have developed drought plans. Scarcity is monitored closely with a system of alarms, and droughts are declared when specified thresholds are surpassed. Urban agencies that supply water for more than 20,000 inhabitants adopted mandatory emergency plans that define immediate actions in response to scarcity conditions.

Introduction

Spain contains three climatic types: continental, maritime, and Mediterranean. Madrid, at the center of the country, has a continental climate that is primarily dry and periodically extreme. Madrid is sunny and has a hot and dry summer. Summer temperatures reach 90ºF on average, while winters can be cold with frequent frosts at night. Annual rainfall here averages almost 17 inches, with November being the wettest month.

North of the Cantabrian Mountains, running east-west at the northern region, the climate has a rainy pattern and a maritime climate. In the northern city of Bilbao, for example, mild winters and warm summers predominate, with average temperatures in summer (ranging between 55°F and 78°F) being much cooler than the national average. This region has higher average rainfall, nearly 50 inches per year, and relatively less sunshine than continental regions.

Other important mountain ranges are the Pyrenees, the mountains of Sierra Nevada, the Central, and Iberian ranges. The Mediterranean climatic region occurs south of the Pyrenees. It runs along the southern and eastern coasts to the Andalusian Plain. Temperatures here are higher and total rainfall is lower than in the rest of Spain.

High precipitation in the northwest gradually shifts to more arid conditions in the southeastern regions. Temperatures are colder in northern Spain and shift to warmer temperatures in the southern regions by the Mediterranean, with the exception of the Ebro River.

As in the other semi-arid and agriculture-intensive regions of the world, food production is the largest water use in Spain. The 2010 European Union Farm Structure Survey reported more than 23 million acres of arable land, permanent grassland and meadow, and permanent crops and kitchen gardens in Spain, the largest such area in Europe. Olive production is the greatest agricultural product followed by the production of fruits.

Principal demographic, economic, and water-related indicators in Spain

Population (in 2010):	46.51 million
GDP (in 2010):	$1,404 billion
Agriculture Value Added:	2.5% of GDP
Annual Precipitation:	25.04 inches
Total Water Withdrawals:	26,348 TAF
Urban Use:	18%
Agricultural Use:	61%
Other Uses:	11%
Surface Water:	78%
Groundwater:	22%

SOURCES: Population: US Census International Programs, 2014; GDP, Agriculture Value Added, Annual Precipitation, Total Withdrawal and usage %: World Bank, 2014

Spain has more than 1,800 rivers. Many rivers, especially in the Mediterranean side, are quite short and only flow part of the year. The five main rivers in Spain are the Tajo, Ebro, Duero, Guadiana, and Guadalquivir, all flowing south and west into the Atlantic Ocean. The Ebro River flows into the Mediterranean Sea.

Since the 1886 Water Law, water rights have been required for appropriating surface water. Groundwater rights were added to the Water Law in 1985. Water rights are given by RBOs, taking into consideration the water allocations established in the river basin management plans. The Water Resources System Simulation Model is used to establish the water allocation in river basin management plans. Each water right is defined by its use (similar to the beneficial use doctrine), which also establishes the order of preference.

With the 1999 Water Law reform, water-right holders can engage in voluntary water trading. Basin authorities have to set up water banks or trading centers for times of scarcity.[112] The beginning of the 21st brought much change to Spanish water law, due to the adoption to the European Union’s Water Framework Directive and approval of the Spanish National Hydrological Plan and its subsequent amendments that dominated Spanish water policy debates until 2005.

Regulatory overview

Institutions

Oversight agencies

The General Directorate of Water (Dirección General del Agua, or DGA) under the Ministry of Agriculture, Food, and Environment is in charge of Spain’s water accounting system. DGA develops the National Hydrological Plan, the information system on water resources; water treatment and reuse of treated water, and other duties. Since 2001, Spain has also been adopting the institutional structures promoted by the European Union Water Framework Directive (WFD) (Font & Subirats 2010). Spain has improved some aspects of water accounting in the implementation of the WFD. Hydrologic planning, groundwater management, water quality, water heritage conservation, and environmental management are examples of WFD best practices.

[112] The source of information on Spanish water law is sourced from Garrido and Llamas 2009.

At the operational level, Spain is divided in 16 River Basin Organizations (RBOs) —in Spanish, *Confederaciones Hidrográficas*— which are autonomous agencies in charge of hydrologic planning, water resources management, public domain protection, water rights concessions, water quality control, and the deployment of infrastructure plans, among other responsibilities. If a river basin lies within more than one "autonomous community" (similar to a state in the United States), the RBO is under national government delegation. When a river basin is completely within an autonomous community, the RBO depends solely on the autonomous government. RBOs guarantee participative decision making between the Governing Board, User's Assembly, Withdrawal Committee, Operating Boards, Basin Water Board, and Committee of Competent Authorities (Garcia & Galvan 2010).

Water supply operations agencies

RBOs are the principal agencies responsible for integrated water resource management in Spain. They operate and oversee water supply projects at the basin level. Spain has approximately 1,200 operative dams. Most of these 1,200 reservoirs are under the oversight or direct management of the RBAs. The oldest active dams are Cornalbo, Proserpina, and El Belcial, which have been in operation since the 2nd century.

Urban water supply and treatment are under municipal jurisdiction. When a city is supplied by surface water, the supply operations are usually managed by the RBO. A groundwater permit is needed if the city is supplied through groundwater.

Irrigation districts are also key in water supply management as they are in charge of supplying, managing, and allocating water resources locally. Significantly, they also manage groundwater in over-drafted basins.

Funding

The water management budget of Basin Organizations totaled $1 billion in 2015.[113] The Guadalquivir Basin alone spent $380 million, the most of any Basin Organization (Spanish Government 2015). A small part of this budget is diverted to information and monitoring technologies. For the implementation of the WFD directives, especially in the improvement of the monitoring network, the Spanish government spent more than $73.6 million dollars (De Stefano & Hernandez-Mora 2012).

Legal Framework

Water rights

Spain has a large diversity of water rights, including public, private, and collective water rights all co-existing within the current legislative framework. According to the Water Act, all surface and groundwater is considered public domain and beneficial uses are subject to administrative concession. The only exception is when springs, and streams originating from those springs, are completely on private land. Water generated through desalination or recycling are also considered public water resources.

The right to use water for consumptive and non-consumptive uses is gained through legal disposition or administrative concession. Concessions can be revoked if the conditions change, and a "use it or lose it" rule applies. Furthermore the Water Law explicitly bans the abuse and waste of water resources.

The Regulation of Hydraulic Public Domain establishes that for both surface and groundwater resources, all water use above 3,000 cubic meters per year (2.4 acre feet/year) needs to be justified for beneficial use, and all water uses above 7,000 cubic meters per year (5.7 acre feet/year) need an administrative concession.

[113] Author estimated by adding State's Budget for Duero, Ebro, Jucar, Miño-SIL, Cantábrico, Tajo, Guadiana, Guadalquivir and Segura Basin Organizations Budget.

All concessions are reviewed by the Basin Organization to assess their compatibility with current uses and water availability in the basin. Although concessions are originally linked with a water source (surface, groundwater or other), the Basin Organization can change the source of an existing concession to optimally manage the basin. With the consent of the concessionaire or licensee, the Basin Organization can grant limited-reliability concessions that do not impose any liability on the Basin Organization when there is inadequate availability of water resources.

The SIMPA model is a resource assessment tool for evaluating water availability for proposed water right appropriations. It was developed by Centre for Hydrographic Studies and is used to distribute and model hydrological operations on a monthly basis (Estela 2014).

Spain's water rights follow a priority-based allocation. The priorities by default are established in the Water Act, though they can be modified in the river basin management plans. The priorities are:

- Urban supply, including industries connected to the urban public supply network;
- Irrigation and other agriculture uses;
- Industrial uses for power generation;
- Other industrial uses;
- Aquaculture;
- Recreational uses;
- Navigation and aquatic transport, and
- Other uses

When conflicts occur within water use categories during times of scarcity, preference goes to the user with greater public utility or those using technologies that increase water efficiency.

In every water basin, the Basin Organization is the highest authority regarding disputes. Even though Basin Organization decisions are administratively final, they may be argued in regular courts.

On the Mediterranean coast, traditional law courts for water management dating back centuries are still active. The Water Tribunal in Valencia and the Council of Wise Men in Murcia are recognized under Spanish law. Maintaining the tradition, water cases and disputes are presented to the court orally. Judges are not lawyers but citizens with technical knowledge, and no records are kept. Nowadays, it is held mostly as a tourist attraction. Nonetheless, they still receive cases and the decision of the court is final and cannot be appealed in a higher court.

Water trading

In 1999 the Water Law was reformed to allow water-right holders to exchange water by leasing concessions temporarily or permanently. There are only two ways to exchange public water rights: voluntary agreements between water-right holders on specific terms of trade who jointly file a request in the Agency to lease-out the water holder's entitlement for a number of years, and water bank operations (or water exchange centers, as they are called in the 1999 Water Law). In practice, the water exchange centers or water banks have only functioned as buyers of water or water rights, especially in buying water during droughts for environmental purposes (Garrido et al. 2012).

There are a number of legal, institutional, and environmental barriers that limit the number of transactions and volumes of water traded in Spain (Garrido et al. 2012). Significant public agency market power and uncertainty related to the definition and priorities of water rights are disincentives for trading. The main institutional constraint results from the political division of water resources, which hampers interbasin trading. Finally, environmental barriers posed by public agencies responsible for the stewardship of the ecological quality of rivers, based on modeling evidence and that is hardly to be contested, also imply a transaction cost.

Legal treatment of environmental water use

According to Article 59 of the Water Law, the environmental flows or demands are considered as a general restriction imposed on the management of water resource systems rather than as a water use.

Surface water environmental requirements are included in each River Basin Management Plan (RBMP) as developed for each Basin Organization. Public domain flows are established in the plans to support recreational activities such as fisheries and tourism (Garrido and Llamas 2009). Basin Organizations may use a variety of management strategies to fulfill environmental needs, including temporal leases during droughts and permanent transfers of water rights.

The methodology used to define the ecological flows in the River Basin Management Plans is established and standardized in the order ARM/2656/2008, warranting an acceptable level of homogeneity in the different Spanish basins.

Ability to Account for Water

Water Use

Water use reporting (bottom-up approach)

According to the Water Law, the Basin Organization can require all water right holders to install and maintain measurement devices that provide accurate information on water use. Non-consumptive uses also must measure return flows.

Although the Water Law established the basis of water measurement requirements, they were not mandatory until the approval of the Measurement Order of 2009.This act set forth the obligation to measure all surface and groundwater diversions, along with surface return flows and water discharges.

Although this regulation is now several years old, it is not common to measure diversions and extractions by water-right holders. Basin Organizations have instead wielded this power to tightly manage some critical areas.

Indirect measurement of water use (top-down approach)

Each Basin Organization produces an annual exploitation report that includes all water uses from different user categories. Basin Organizations have automatic data-gathering systems for large surface diversions from irrigators and data from urban utilities and other uses. Nonetheless the monitoring and control network, especially for irrigation areas, is still insufficient and not accurate enough to ensure reliable reporting. As mentioned above, direct measurement of water use is not yet common, so Basin Organizations track water use by different means.

Urban water use volumes are estimated using population estimates and consumption per capita, which are verified with data provided by urban utilities. Irrigation water use volumes are estimated through irrigated acreage, land use surveys with detailed crop acreage analysis, and crop demands. Remote sensing for determining crop demands is also done in some regions, especially over-drafted groundwater-dependent irrigation areas such as the Mancha Oriental Aquifer region.

Finally, these water use estimations by sector are tested by using water balance models. Real-time streamflow and diversion data is available in most basins, so surface supply data can be analyzed to test these estimations.

System Analysis and Management

Since 1983 Spain has been developing a comprehensive water monitoring and management system. An Automatic Hydrological Information Systems (SAIH in Spanish) is developed for each Basin Organization to support six main functions: flood management, drought management, risk management, environmental flow control, water quality control, and technical support.

Each SAIH has four main components:

- Control points are locations where measuring devices are installed. Devices include pluviometers and/or snow gages and other meteorological stations; reservoir level measurement stations; and river and channel flow gages. There are nearly 2,500 active control points in Spain: 504 stream gages in rivers, 335 channel gages; 363 reservoir stations; and over 500 meteorological stations including precipitation, snow gages, and other meteorological measurements.
- Control centers are information centers in each Basin Organization where all information is automatically transmitted. The information is processed with internal models, and presented in real-time on large screens to show the current state of the system. The control centers can directly operate some major system infrastructure or communicate directly with system operators.
- Concentration points are locations where information is received, processed, and transmitted to the control centers. Satellite devices have drastically improved how information is transmitted, so the concentration points have almost become obsolete.
- Telecommunication networks are critical for connecting dispersed points. There are many different ways to transmit the information, they are fundamentally divided into radio and satellite communications.

Groundwater monitoring has traditionally been done by Spain's Institute of Geology and Mining (IGME). Its piezometric network currently includes about 3,000 points. Basin Organizations recently assumed powers over groundwater monitoring (Garrido and Llamas 2009). As mentioned earlier, groundwater withdrawals are not usually measured in Spain—except for critical basins with tight management. An example in which more than 90 percent of groundwater withdrawals are measured is the Vinalopó-Alacantí area in the Júcar River Basin District. The Measurement Act of 2009 could require Basin Organizations to increase groundwater withdrawal monitoring.

Spain has a long tradition of water resource systems modeling. Aquatool (Andreu et al. 1996) has been the preferred planning and management platform for nearly every Basin Authority. Aquatool is a decision support system that provides various tools for solving issues that arise in the analysis of Water Resources Systems (WRS). Aquatool has been used since 1996 by the Centre for Hydrographic Studies of CEDEX for analyzing national unified water management. The results were used in writing the White Book of Water in Spain and the annex of hydrological systems analysis of the National Hydrological Plan.

Although Aquatool is essentially a surface water system model, it includes surface and groundwater interactions. For more detailed groundwater modeling purposes, MODFLOW models have been developed in some regions (Pulido-Velazquez et al. 2015).

Water supply forecasts are not common in Spain, but drought plans have implemented a series of warning levels that trigger actions based on thresholds of the monitoring network, that are actually being used to foresee supply problems and implement legal and management actions that can improve water supply allocation during droughts.

The implementation of the European Water Framework Directive required approval of a River Basin Management Plan for each river basin district by 2009 with an update in 2016. The directives establish Spain's first-ever coordinated water resource accounting and needs assessment programs.

Allocation During Periods of Scarcity

The Spanish Water Act established the obligation for each Basin Organization to set forth a system of hydrological indices to foresee drought conditions and minimize negative environmental, economic, and social impacts of drought. Basin Organizations have developed drought plans that set forth specific drought resilience actions. Finally, urban agencies that supply water for more than 20,000 inhabitants adopted mandatory emergency plans for drought situations.

When a drought is declared in a basin, it must be declared officially by the Cabinet Council. Drought declaration and response protocols are defined in the Water Act and are incorporated into drought plans for each Basin Organization.

As directed by the WFD, when a drought declaration is in place, a Permanent Drought Commission is formed with the different basin stakeholders, including Basin Organization representatives, water users, and other stakeholders. Stakeholders are involved in decision making, thereby reducing conflict and increasing transparency.

The allocation of water follows, in general, the prioritization schema mentioned earlier. Stakeholder involvement in decision making during droughts involves some flexibility. In some cases, higher priority users can be curtailed to minimize costs to lower-priority users.[114]

Public Information Provision

Water Rights

All approved surface and groundwater rights and their modifications are collected in a Water Registry (*Registro de Aguas*). A Royal Decree in 2013 strengthened and modernized the registry. For example, it requires Basin Organizations to develop specific Water Registry Offices making the registry available to the public. The Royal Decree homogenised the registry's content and structure, and required the incorporation of geographical information systems. The ALBERCA software was developed to help Basin Organizations incorporate spatial information. Spain has also been developing an online platform for this registry that is composed of data and geographic information. It includes characteristics of water use (legal characteristics, capture and use) as well as its description and administrative elements such as computer records, photos, and any administrative or judicial documents recognizing the right.

A Central Water Database is also being developed with information from the registry, along with temporarily protected data on Private Waters Catalogue and data held by the Water Authorities of the Autonomous

[114] The priority schema does not mean that urban users (with highest priority) are not curtailed since all the water users are not using any water. Basin Organizations try to, with stakeholder involvement in decision making, minimize economic, social and environmental costs across water users.

Communities. This database is only accessible to public employees for management decisions, and is not available for the public.

Each Basin Organization produces an annual surface water exploitation report available to the public either online or at their offices (De Stefano and Hernandez-Mora 2012). An updated nationwide groundwater use overview is not yet available (Andreu et al. 2012).

System Monitoring

At a national level, the "Gaging Information" is a map-based platform with hydrological data supplied annually by the Hydrographic Confederations and Basin Organizations. It provides information for each station on monthly or annual flows from rivers, reservoirs, pipelines, canals, and evaporation stations associated with reservoirs. It also provides detailed information on the station, the monitoring device it uses, and the years of data for download.

For real-time information, the automatic hydrological information systems provide online data on the hydro-meteorological and hydraulic status of each basin. Basin Organizations can use this system and publish the information through their websites (Andreu et al. 2012). The interactive map platform provides information on river, reservoir, and rainfall monitoring stations.

A weekly "Hydrological Bulletin" is published online by the Department of Hydrological Information. It contains information on water volumes stored in most reservoirs, operating conditions, reserves for irrigation and stock watering, hydroelectric energy stored (calculated) and actual energy produced, the flows of major rivers in each basin, and weekly rainfall information.

Allocation During Scarcity

From 2010 to 2014, a monthly summary report, the "Hydrologic Drought Situation," was published online. This report showed the evolution of hydrological indicators including rainfall, water in reserves, soil moisture, and drought index. It also provided maps with an overview of the operating systems for every watershed in the country. The definitions of indicators, their thresholds, and measurements were carried out using a technical process led by the Basin Organizations. The process included the participation of users through the Water Board and society as a whole. Also, each basin develops and publishes a special action plan for drought alerts (Garcia and Galvan 2010).

Since the allocations are mostly defined by water available in reservoirs, most Basin Organizations have data and graphics on reservoir levels online. Depending on the level of organization of the Basin Organization, actual information on allocations is published online as well.

Water Transfers

Information regarding water volumes transferred is not required in the forms received by the Basin Organizations to approve permanent or temporary transfers of water rights. However, each form must be accompanied by an affidavit describing changes to water diversion volumes before and after the transaction. The information is not processed or published. Trading prices may be published in public documents showing the successive chain of transfers.

Also, Basin Organizations set up water banks or trading centers to facilitate transfers (Garrido and Llamas 2009). Here, the Basin Organizations publicize offers of permanent water rights acquisition. Up to 2010, only the Basin Organizations of Guadalquivir, Guadiana, Júcar, and Segura basins had developed water banks (Navarro 2010). Only the Guadiana trading center had actively facilitated transactions among private users during a drought.

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