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Accounting for California's Water[1]

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Introduction

California's variable climate means it must manage water carefully. Droughts are common, and even in wetter years the state faces multiple, often competing demands for water. To allocate its water supplies efficiently and fairly and reduce conflicts over water, California needs a more reliable, thorough, and transparent system of water accounting to measure, process, and disseminate information on water availability, rights, and use.

The latest drought has highlighted critical weaknesses in California's water accounting that challenged effective oversight and management of the state's water resources (Gray et al. 2015, Hanak et al. 2015). The following examples illustrate key problem areas:

- **Surface water allocations.** Gaps in information about surface water availability, rights, and use hampered the ability of the State Water Resources Control Board (hereafter, the "water board")—the state's top water regulator—to enforce cutbacks in watersheds where supplies were insufficient to meet all demands.[2]
- **Groundwater use.** The absence of groundwater accounting in many rural areas—including clear rules on pumping rights and measurement of volumes pumped—has contributed to long-term depletion of groundwater in many basins. These information gaps heightened tensions during the drought, as water tables declined and wells went dry from increased pumping.
- **Water for the environment.** The lack of consistent and clearly defined requirements regarding the volume, timing, and quality of water designated to support fish, waterbirds, and other riparian and wetland species hindered environmental management efforts, pushing some species closer to extinction. Incomplete information on water availability in many streams—and

[1] Supported with funding from The David and Lucile Packard Foundation, the S. D. Bechtel, Jr. Foundation, the US Environmental Protection Agency, and the Water Foundation, an initiative of the Resources Legacy Fund.

[2] As one example, the water board recently withdrew a case against two irrigation districts with senior water rights that challenged its order to stop diverting water. The board concluded that it lacked adequate information on water availability and uses, and therefore was unable to prove that flows were inadequate to support the districts' diversions in light of the demands of more senior water-right holders (State Water Resources Control Board 2016). For a broader discussion of the issues related to the water board's authority in such matters, see Gray et al. (2015).

difficulties linking water availability with key ecological data such as the locations of sensitive fish species—compounded these problems. These information gaps also caused uncertainties for other water users.

- **Water trading.** The temporary or longer-term trading of water from right holders to other users is an important tool for sharing supplies and reducing the costs of drought. Lack of public information on water rights, water available for trade, and prices—and lack of clarity on how much water can be traded—limited trading during the drought.

These challenges have focused policy attention on strengthening California's water accounting on several fronts:

- **Measuring surface water use.** Legislation enacted in 2009 required all surface water-right holders to submit reports every three years on the amount of river water they are using. Senate Bill (SB) 88, enacted in 2015, now requires them to measure (rather than just estimate) their diversions monthly, and to report this information annually at minimum.[3]
- **Managing groundwater.** The 2014 Sustainable Groundwater Management Act (SGMA) establishes a more coherent basis for managing this resource, which supplies about a third of statewide water use on average and as much as 60 percent during the latest drought. SGMA requires groundwater users in the most stressed basins to establish local groundwater sustainability agencies (GSAs) by mid-2017, adopt and begin implementing management plans by 2020, and attain sustainability by 2040.[4] GSAs will have authority to monitor, measure, and regulate pumping and to fund regulatory services and projects to recharge groundwater basins. Although GSAs will be required to report key groundwater basin performance metrics to the state, SGMA leaves many of the details on groundwater management and accounting up to local discretion.
- **Defining environmental flow standards.** State regulators—including the water board and the Department of Fish and Wildlife—are in the early stages of developing transparent environmental flow standards on some of the many streams that currently lack them.[5]
- **Improving information on water trades.** Key stakeholders have made proposals to improve California's water market, including more clarity on trading rules and better information on

[3] The law requires surface water-right holders who divert more than 10 acre-feet per year to measure and annually report their diversions and use (Water Code §§ 1840, 1841 & 5100-5107). For information on the water board's implementing regulations, see State Water Board–Measurement Regulation (accessed May 17, 2016). Senate Bill 85, enacted in 2015, also made groundwater well logs public (Water Code § 13751).

[4] The requirement to develop sustainable groundwater management plans applies to 127 high- and medium-priority basins, accounting for 96 percent of annual groundwater pumping (Department of Water Resources 2014). The deadlines noted in the text are for 21 basins in critical overdraft, including most of the San Joaquin Valley and important farming regions in the Central Coast (Department of Water Resources n.d.). The remaining priority basins have an additional two years to adopt and implement their management plans. For detailed information and recommendations on the implementation of SGMA, see Moran and Cravens (2015), Moran and Wendell (2015), and Kiparsky et al. (2016).

[5] In late 2010, under the terms of the 2009 Delta Reform Act, the water board submitted to the legislature a prioritized schedule and estimate of costs to complete instream flow studies for two categories of rivers and streams: (1) high priority rivers and streams in the Delta watershed, and (2) major rivers and streams outside the Sacramento River watershed. The water board requested resources to work with the state Department of Fish and Wildlife to tackle the highest priority streams, and methodology and field work on the first set of streams is now underway. For information on these efforts, see State Water Resources Control Board (n.d.) and Department of Fish and Wildlife (n.d.).

market transactions (Association of California Water Agencies 2016, Sellers et al. 2016). In 2016, the legislature has been considering proposals to provide online information about water trades and, more generally, better information related to the water system.[6]

These are important steps toward arming Californians with information they need to better manage water scarcity today and in a warmer, and possibly drier, future.[7] But California cannot stop here. The state still has major gaps in strategic water information, and it lacks a framework for organizing this information so that managing agencies, water-right holders, policymakers, and the public can put it to practical use.

This report assesses critical gaps and recommends ways to strengthen water accounting in California. We draw insights on best practices from a comparative analysis of water accounting practices in California, 11 other western states (Arizona, Colorado, Idaho, Kansas, Nebraska, Nevada, New Mexico, Oregon, Texas, Utah, and Washington), and 2 countries (Australia and Spain). All of these places share resource-management challenges common to advanced economies with dry and variable climates: allocating surface water during periods of scarcity, managing groundwater sustainably, and dedicating adequate water to support the natural environment. Many of these places have practices from which California can learn as it envisions, designs, develops, and implements an accurate, consistent, and affordable water accounting system.

We begin with a brief overview of the key clients and components of water accounting. The following section assesses how well California is collecting, organizing, and disseminating information on water availability and use, and it identifies important gaps. We then propose priorities for improving water accounting in California to address key water management challenges. A technical appendix includes the comparative analysis and case studies summarizing accounting system characteristics in California and the 13 other jurisdictions.

Accounting for Water

Water accounting is the foundation of effective water management. It consists of methods, tools, and practices to assess the volumes of water available and used throughout a water system. It is critical to water management at all scales, from large river basins to local irrigation districts or urban water utilities.

Although some forms of water measurement and tracking have long traditions, the use of the term "water accounting" is relatively new. It reflects recent efforts in Australia and by international organizations to draw parallels to the financial field of accounting and develop comparable standards for tracking water.[8] The parallel with financial accounting is straightforward. Water is

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[6] Assembly Bill (AB) 1755, still active at the time of this writing (early June 2016), would require integration of existing datasets and information on water trading. AB 2304, withdrawn in May, would have created an information clearinghouse on water trades.

[7] This latest drought—marked by record-low precipitation combined with record-high temperatures—foreshadows the conditions California is increasingly likely to experience as the climate warms (Dettinger et al. 2015, Diffenbaugh et al. 2015). Heat compounds the effects of drought by reducing water storage in the mountain snowpack, increasing plant water needs, and increasing water temperatures, which complicates efforts to manage cold water for fish. Climate models also project that California's precipitation will become increasingly variable.

[8] On the Australian approach, see Vardon et al. (2007) and Water Accounting Standards Board (2014). For international efforts see United Nations Statistics Division (2012), Karimi et al. (2013), and Godfrey and Chalmers (2012).

an asset that can be used in the present, saved for future use, and traded or exchanged. And water rights and other claims on available water (e.g., environmental obligations and restrictions) are liabilities on California's water assets. Given the complexities of the water cycle and the difficulties of accurately measuring many aspects of water availability and use, even sophisticated water accounting systems contain more uncertainties than traditional financial accounting. But the accounting concept is a useful one for organizing water information to facilitate strategic decisions on water system oversight and management at all levels.[9]

Water accounting can serve a variety of clients and has several key elements, described briefly here.

Who Are the Clients of Water Accounting?

Principal clients of water accounting include two broad types of managing entities: those with oversight responsibility and those with operational missions. Many of these entities are also collectors and producers of water information. Accounting systems should also provide information to water-right holders, end users, elected officials, and the public.

Oversight agencies need information to alert water system participants to supply and demand conditions, to enforce legal compliance with water allocation rules, and to resolve disputes among competing claims and uses for limited water resources. Accurate accounting of water rights also facilitates water trading, an important tool for reducing the economic costs of water scarcity.[10] California has several key oversight agencies:

- The water board oversees the exercise of surface water rights and some water transfers, regulates water quality, and will have ultimate responsibility for groundwater basin oversight if local groundwater sustainability plans developed under SGMA fail to achieve their objectives.
- The state Department of Fish and Wildlife (DFW)—along with the US Fish and Wildlife Service and the National Marine Fisheries Service—establish and oversee environmental water requirements to protect species listed as threatened or endangered under the state and federal endangered species acts. DFW and the water board can also regulate dams to protect downstream fisheries.
- In some parts of California, local agencies and watermasters already regulate groundwater use, and this will increase with the implementation of SGMA.
- California's courts also have jurisdiction over water rights and water quality disputes for both surface water and groundwater.

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[9] Because our interest is in the entire process of collecting, organizing, and disseminating water information for use in water system oversight and management, our assessment of water accounting is broader than the approach of the Australian Water Accounting Standards Board (2014) and related literature. The Australian accounting standards focus on presenting information on water availability, rights, and use in a standardized, auditable framework. That effort presumes that the underlying information is available—something generally true in population and farming centers within Australia, thanks to rigorous systems of water information collection and management.

[10] As a recent example, water trading among California farmers during the latest drought—including temporary fallowing of some annual crops to make water available for orchards, vineyards, and vegetable crops that would have been more costly to fallow—significantly reduced economic losses (Howitt et al. 2015).

Operational agencies of various types and sizes serve urban and agricultural customers. Many operate water storage and delivery systems.[11] They need information to manage these systems well and serve their customers effectively under varying supply conditions, while also complying with environmental regulatory requirements.

- Two very large water projects serve customers across much of California—the Central Valley Project (CVP), run by the US Bureau of Reclamation, and the State Water Project (SWP), run by the state Department of Water Resources (DWR). The Bureau of Reclamation also supplies large volumes of water from the Colorado River for irrigation and urban uses in southern California.
- In addition, California has more than a thousand regional and local water agencies, ranging from very large wholesale agencies such as the Metropolitan Water District of Southern California (which serves roughly half the state's population) to hundreds of large urban utilities and irrigation districts that each serve thousands of homes, businesses, and acres of farmland, to many small community systems that serve a handful of customers.[12]

Water-right holders and end users of water need clear information to facilitate their own management of available supplies, including decisions on when and what to plant and produce, and whether to engage in water purchases or sales. California's agricultural sector is particularly dependent on water as a production input; crop irrigation uses roughly 80 percent of all water allocated for business and residential uses in the state.[13]

Elected officials and the public—though not involved in day-to-day water management—also need transparent, reliable information to ensure accountability of water supply and management agencies and to make informed decisions about water policy. Stakeholder groups representing environmental interests and the interests of disadvantaged communities are important information clients in this category.

What Are the Key Elements of Water Accounting?

Water accounting employs several categories of water information.

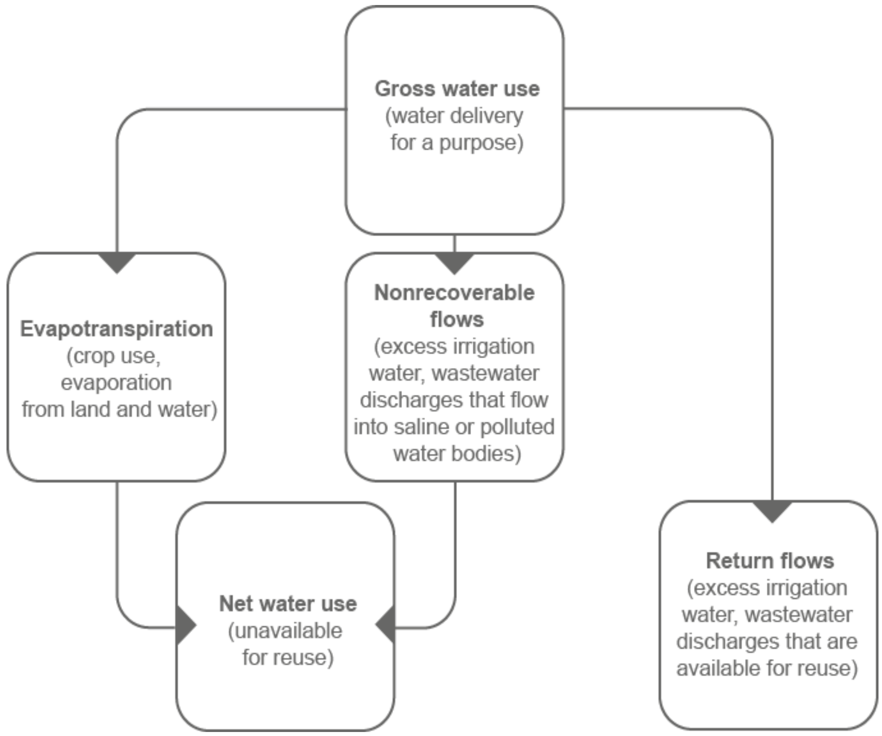
- **Water availability (assets).** This includes current and expected water sources: water flowing in rivers and streams, as well as water stored in surface reservoirs, aquifers, snowpack, and soils. Understanding availability is key to making informed decisions about water allocation. It generally requires both measuring or estimating these volumes and assessing how management decisions—including allocation to water users—will affect water supplies throughout the system. In many California river basins, surface water and aquifers are hydrologically interconnected, so that using one source affects the other. Accounting for water availability therefore requires understanding how water moves between rivers and aquifers.
- **Water claims and uses (liabilities).** This includes both anticipated claims on California's water system and the amount of water actually used. Claims include obligations to serve water-right holders and to meet requirements for environmental flows and water quality. Understanding claims is essential for making water allocation decisions, particularly when supplies

[11] These systems often provide flood protection as well as water supply services, and many generate hydropower and provide water for recreational use.

[12] For a description of California's water agency structure, see Hanak et al. (2011), pp. 107-122.

[13] In 2012, 92 percent of California's harvested crop acreage was irrigated; among US states, only Arizona and Nevada had higher shares (96%). (Author calculations using data from the 2012 Census of Agriculture [US Department of Agriculture 2015]).

Figure 1. Some Water Returns to the System after Use



Source: Adapted from Hanak et al. 2011, Box 2.1.

Note: Net uses 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 non-recoverable flows—discharges into the ocean or saline lakes or groundwater basins, where the water is not reusable without significant treatment.

are scarce. For example: Does the system have unclaimed supplies that could support new uses? Which uses have priority when supplies are insufficient to meet all claims? The water rights system and environmental laws determine how allocations are adjusted when the system cannot meet all claims.

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 that is actually consumed at the place of use (Figure 1). The difference is called "return flows"—the water that returns to rivers, streams, or aquifers and is available for reuse. Return flows come from sources such as urban wastewater discharges and irrigation water not consumed by crops. These flows are often substantial.[14] Understanding gross

[14] 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, irrigated agriculture may return 10 to 60 percent of applied water to the system.

and net use and return flows is important to verify compliance with allocation rules and to ascertain how much water remains available in the system for other uses.

The effectiveness of an accounting system depends on several additional factors that determine how information is managed: standards and compatibility, information sharing, and attention to cost.

- **Standards and compatibility.** Standards can facilitate efficient information sharing and use, reduce confusion, and avoid costly duplication. Key factors that would benefit from compatible standards include the size of reporting units, frequency of data collection and reporting, measurement and estimation methods, and data platforms. This is especially important for developing consistent water balances across different levels of management, ranging from local systems to larger river basins.[15] Consistent, credible standards are also important for reducing disputes. And because there are uncertainties in measuring and estimating water, accounting systems should include reports on the accuracy of data and a process for inspection, audit, correction, and improvement.[16]

  California's 10 hydrologic regions provide a natural basis for consistent water accounting (Figure 2). These hydrologic regions are large areas where rivers and streams drain into the same aquifer systems, often with common outflow points. For many purposes—ranging from tracking environmental flows to managing aquifers—it is also essential to understand water balances in the smaller watersheds that lie within these basins. California's regional and local water agencies operate within—and sometimes across—these hydrologic boundaries. Water accounts at all these levels need to be compatible.
- **Information sharing.** Information sharing among managers with different roles is essential for effectively meeting the sometimes competing objectives of various water uses. Likewise, providing accurate, transparent, and timely information to the public can facilitate better business and water stewardship decisions by end users. It can also build trust among public agencies and the stakeholders affected by their decisions.
- **Attention to cost.** Collecting, organizing, and communicating information about water systems can be costly. While accurate, real-time information is needed for some decisions, more approximate estimates and less frequent tracking may be adequate for others. The key to improving decision making by both water managers and users is to have the right information, in the right place, and at the right time.

Gaps in California's Water Accounting

California is a large, geographically diverse state, and its water systems are both physically interconnected and institutionally fragmented. Water storage and delivery infrastructure connects the state's northern watersheds to its southernmost communities, and rivers of the Sierra Nevada

[15] Water rights or contracts that are liabilities in the accounts of an entire river basin become assets for the regional or local system that holds those rights. The same logic applies further down the water supply chain: liabilities for wholesale water suppliers are assets for their local retail agency customers. The numbers need to be consistent across these levels.

[16] Even measured water quantities contain some error. For example, most urban water systems in the US are fairly well metered, but often have 5 to 10 percent unaccounted-for water due to leaks, unmetered connections, and measurement error.

Figure 2. California has 10 hydrologic regions

Source: California Department of Water Resources.

Notes: These regions are used by the Department of Water Resources for water accounting. For oversight of water quality laws, the water board uses similar boundaries, but it splits the South Coast region into three administrative regions, based on watersheds: Los Angeles, Santa Ana, and San Diego (demarcated with dotted lines in the map).

to the coast. Yet California's cities, suburbs, and farms are served by hundreds of independent regional and local water systems. In most places, California also has separate approaches to managing surface water and groundwater—even though the use of one often affects the availability of the other. An additional layer of complexity is the lack of clarity on how much water is reserved for environmental purposes.

This combination of interconnectedness of flows and fragmentation of management makes it especially important—but also very challenging—for Californians to understand water availability and use from the statewide and regional perspectives, not just in a local context.

Here we review the key elements of California's water accounting, with a focus on identifying gaps that hinder water management and oversight and make it more difficult to support both a healthy economy and the environment. We draw on our comparative analysis of water accounting in 11 other western states and Australia and Spain to identify common difficulties as well as best practices that California may wish to emulate (see the technical appendix). We also note local and regional examples of best practices within California that can serve as models statewide.

We start with a look at California's water assets and liabilities. We then examine how California manages and shares water information. Table 1 summarizes the current status of different elements of water accounting.

Understanding Water Availability

Understanding the asset side of the balance sheet requires tracking available supplies and how they change as water is allocated and reused throughout the system. Tools include field-level monitoring and models. The federal government is a major partner, especially for surface water, as are many local agencies. California has fairly advanced systems for understanding surface water but has significant information gaps for groundwater.

- **Surface water.** California has relatively strong monitoring for surface supplies in major river basins, including streamflow, water in surface reservoirs, and snowpack. These efforts include an extensive cooperative snowpack monitoring system, combining federal, state, and local data, and stream gage networks run by the US Geological Survey (USGS) and the Department of Water Resources. The two big federal and state water projects have a useful model for understanding system availability for planning purposes.[17] And many regional and local 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 systems.[18]

  However, the various tracking systems are not well-integrated into broader state- or basin-level water accounting systems. And there are concerns about declines in the USGS stream gauge network, and major gaps in monitoring for many smaller streams that are critical for environmental flows.[19] This drought also revealed shortcomings in the CVP's ability

[17] DWR and the US Bureau of Reclamation jointly developed and use CALSIM for simulating operations of the State Water Project and the Central Valley Project.

[18] These SCADA systems collect data from sensors throughout their system, store these data in a database, and sometimes access models of system behavior to support management decisions.

[19] The water board has found that California lacks any federal or state stream gauges on 72 percent of its 981 "HUC 10" watersheds (hydrologic unit code 10, a standard federal classification for watersheds averaging 170 square miles or 107,000 acres each). It lacks gauges on half of the 250 HUC 10 watersheds that contain critical habitat (personal communication, Barbara Evoy, April 15, 2016).

Table 1. Key Gaps in California's Water Accounting

Accounting system element	Current status
Understanding water availability	
Surface water	Moderate gaps
Groundwater	Major gaps
Surface–groundwater interactions	Major gaps
Understanding water claims	
Surface water rights	Moderate gaps
Groundwater rights	Major gaps
Environmental claims	Major gaps
Understanding water use	
Surface water diversions	Moderate gaps
Groundwater pumping	Major gaps
Return flows	Major gaps
Environmental uses	Major gaps
Managing and sharing information	
Consistent accounting and data standards	Major gaps
Authoritative and transparent models	Major gaps
Useful public information	Moderate gaps

to model water temperature in large reservoirs, important for managing flows for salmon and steelhead trout (Mount 2015). Finally, the capacity to forecast water availability beyond a few days or weeks, which is particularly important for drought planning, is still limited. Although its initial focus will be on improving near-term weather forecasting for flood management, NOAA's new National Water Model should ultimately help improve this longer term forecasting as well.[20]

- **Groundwater.** Understanding groundwater availability requires a comprehensive network of wells that monitor groundwater levels, along with models that simulate how aquifers function (e.g., how quickly they recharge and how water moves within them). California has some strong local agencies that are armed with these tools—especially in adjudicated basins, where pumping rules have been established by the courts, and in special districts with groundwater management authority, such as the Orange County Water District. But major monitoring and modeling advances will be needed in many areas now required to develop sustainability plans under SGMA. DWR's California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) holds promise for filling information gaps in a region facing major

[20] NOAA is the lead agency for weather forecasting services in the US. This new model, expected for preliminary release in June 2016, will enhance the nation's river forecasting capabilities by delivering forecasts for approximately 2.7 million locations, up from 4,000 locations today (National Oceanic and Atmospheric Administration 2016).

groundwater challenges.[21] As described below, improvements in the measurements of both gross and net water use will also be needed.

- **Groundwater-surface water interactions.** California is one of the few regions in our comparative review that does not generally administer groundwater and surface water rights within a unified system (Figure 3A). Most western states have a single state office (often called a state engineer) that oversees both surface water and groundwater rights, and Australia and Spain administer these resources jointly at the river basin scale. This legal separation in California carries over to water accounting. Some local agencies actively manage their surface water and groundwater supplies jointly—especially by recharging aquifers with excess surface water in wet years—but the state has weak systems for understanding (and managing) connections between these two resources.[22] Western states have done best in this area where the two resources need to be tightly managed because of obligations to downstream states under river basin compacts (e.g., Kansas, Nebraska, Colorado, and New Mexico) or in-state obligations to more senior surface water users (Colorado and Idaho). SGMA will require detailed attention to this issue.[23]

Understanding Water Claims

Claims include water rights and regulatory requirements to provide water for environmental purposes. California has significant gaps in establishing and quantifying these claims (Gray et al. 2015).

- **Surface water rights.** Appropriative rights are the most common water rights in California and other western states. They designate a specific volume available for use in a specific place and season, with a fixed priority *vis-à-vis* other appropriators. In California, the water board generally has reliable information on these aspects of the appropriative rights that it administers through a permitting and licensing system established in 1914. The most senior water rights in California, however, are not well defined, and their volumes are still significant on many streams.[24] Most "pre-1914" appropriative rights—established before the per-

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[21] C2VSim has been linked to a hydro-economic model of agriculture in the Central Valley—the Statewide Agricultural Production Model (SWAP). This facilitates economic analysis of water management alternatives for the region. Another promising model for groundwater in the Central Valley is the US Geological Survey's Central Valley Hydrologic Model (CVHM). The fact that there are still large discrepancies between C2VSim and CVHM—both developed by strong modeling teams—indicates that there remains significant room for improvement in understanding water balances in this system.

[22] For an analysis of how this interconnection matters for ecosystems, see Howard and Merriman (2010). Some adjudicated basins formally manage the two resources jointly—e.g., the Scott River and the Mojave Basin—and many local agencies manage basin recharge by coordinating the use of surface water and groundwater, even though there is no formal legal connection between the two resources. C2VSim enables integrated analysis of groundwater and surface water in the Central Valley.

[23] Under SGMA, the water board must ensure that local groundwater sustainability plans prevent pumping that unreasonably affects surface flows and water quality. If a local plan fails to correct these problems by 2025, the board may directly establish an interim sustainability plan "to remedy a condition where the groundwater extractions result in significant depletions of interconnected surface waters" (Water Code § 10735.8(h)).

[24] Water use reporting data from 2010–2013 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 shown in Figure 2). Pre-1914

mitting system was created—have not been authoritatively documented and quantified, and they are not subject to direct regulation by the water board.[25] In addition, riparian rights—which are available for use on land adjacent to rivers—are not limited to specific volumes. Riparian-right holders collectively have top priority to water allocations in times of shortage, and are also exempt from direct regulation by the water board.

Other jurisdictions we examined are ahead of California in clarifying surface water rights. All western states had some appropriative rights established before the introduction of permitting, but they have made more progress documenting and quantifying these rights. Like California, some western states and Australia also recognized riparian rights, but these other jurisdictions have limited and effectively quantified these rights (Figure 3B).[26] Clarifying all significant surface water rights is important for the orderly enforcement of water rights, including curtailment when water supplies are especially scarce, as during the latest drought. Clarity also facilitates water trading.

- **Groundwater rights.** California is also one of the few western states that does not issue permits for groundwater use (Figure 3C). It is also the last—with the 2014 enactment of SGMA—to require comprehensive groundwater oversight. Outside of roughly two dozen adjudicated basins, where courts have established rules to limit overdraft, rights to pump groundwater are not quantified.[27] This situation has contributed to significant declines in groundwater levels in many basins and the depletion of stream flows in some places.[28] As we recommend below, defining and capping pumping rights as part of SGMA implementation would facilitate sustainable groundwater management.

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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.

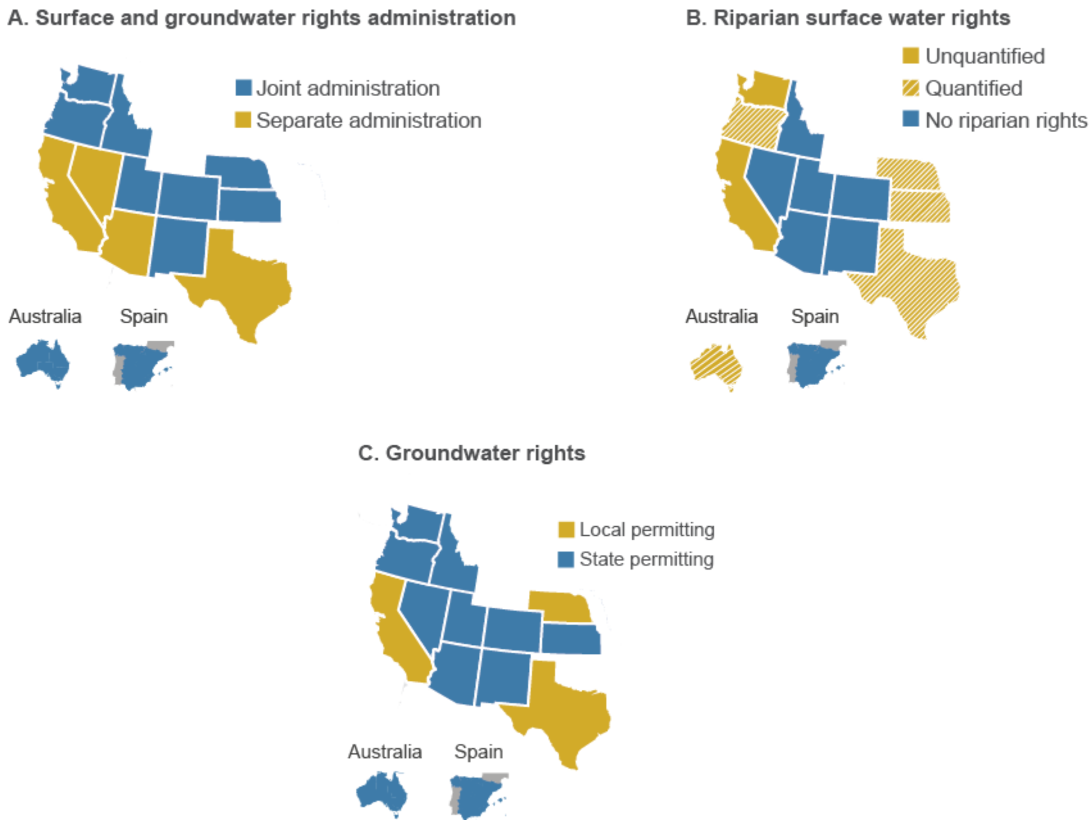
[25] The water board does have jurisdiction to ensure that riparian and pre-1914 appropriative rights comply with the reasonable and beneficial use requirements of Article X, Section 2 of the Constitution, as well the public trust and other environmental laws.

[26] Most of the western states that originally recognized riparian rights enacted statutes in the early 20th century that barred prospective riparian claims. Several 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. In the Water Commission Act of 1913, which created the permitting and licensing system described in the text, the California Legislature attempted to extinguish all riparian rights that were not exercised for any 10-consecutive-year period 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.

[27] By law, they are limited to not cause harm to others in the basin, but this is a vague standard that has rarely been enforced. Some adjudicated basins in California manage overall groundwater levels without assigning pumping rights to individual users (Langridge et al. 2016).

[28] For instance, groundwater pumping within the Russian River watershed has reduced flows available for endangered salmon and steelhead.

Figure 3. California has Relatively Weak Systems for Tracking Surface and Groundwater Rights



Source: Author compilations from the comparative review (see technical appendix for details).

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: Permitting is less comprehensive in states with local permitting. In Spain, groundwater permitting is done by basin authorities.

- **Environmental claims.** Most environmental water claims in California are legal requirements to meet water quality and flow standards, rather than water rights.[29] These standards—

[29] These include flow and quality standards established under the federal Clean Water Act and the state Porter-Cologne Water Quality Act, water needed to protect fish listed for protection under the state and federal endangered species acts, releases from dams required by California Fish and Game Code § 5937, flows in state and federally designated wild and scenic rivers, and water that must remain instream to fulfill the mandates of the reasonable use and public trust doctrines. From an accounting perspective, these requirements can be understood as claims because they are legal obligations to provide water for environmental purposes. California also allows existing water-right holders to dedicate all or a portion of

which can include volume, timing, and quality requirements for water in rivers, lakes, estuaries, and wetlands—protect habitat for aquatic, riparian, and wetland species, as well as water quality for human uses. Environmental claims—particularly for the volume and timing of flows—are poorly defined in many watersheds, however, and there is inadequate coordination among different (often overlapping) regulatory programs. Moreover, the priority of environmental flows relative to water rights is not always well understood, making allocations during drought a particular challenge. Australia, Spain, and several western states have made more progress in defining and dedicating water for the environment. Australia, Colorado, and Oregon have also established significant water rights for the environment.

Understanding Water Use

As noted above, water use generally has several components: (1) the gross volume of water put to a particular use, (2) the net volume of water actually consumed by that use, and (3) return flows. Return flows are the difference between gross and net use—water that is returned to rivers or aquifers, where it becomes available for reuse. Despite recent progress, California still has important gaps in understanding these quantities in many watersheds and groundwater basins. Indeed, as of June 2016, DWR's last official water use estimates for the state and its hydrologic regions are for 2010.[30]

- **Surface water diversions.** Surface water diverted and used from rivers, lakes, and streams constitutes gross water use. Although operators of large water projects have been measuring and reporting large diversions for some time, the broader reporting requirements introduced in 2009 gave the water board basic information on all surface water diversions for the first time.[31] During the latest drought, these self-reports helped in estimating demand and determining whether some right holders needed to stop diverting.[32] But the reports were of uneven accuracy, because the rates and volumes of many diversions were estimated.

  The water board recently adopted new measurement regulations, which go into effect in 2017. These regulations are an important next step in obtaining a more accurate picture of water use in California, although the new reporting requirements still may not provide information frequently enough to inform operational decisions.[33]

  Colorado and Spain are both on the cutting edge in this area, measuring large diversions on a near real-time basis and employing telemetric systems—remote monitoring systems that

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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).

[30] These estimates are reported in DWR's *California Water Plan Update* (Bulletin 160). The last update was released in 2013, with data through 2010.

[31] Measurement has been common for diversions from the CVP, SWP, and some large regional and local projects.

[32] Lord (2015) presents a model for managing curtailments using surface water rights reporting data and information on water availability.

[33] Regulations established for implementing SB 88 require all surface water users who divert 10 acre-feet or more annually to measure diversions. Large diverters will be obligated to install telemetric reporting devices. The frequency of required monitoring ranges from hourly for diversions over 1,000 acre-feet annually, to daily for diversions over 100 acre-feet, to weekly for diversions over 10 acre-feet. All users will be required to report their use annually and more frequently when supply and demand in a watershed approach a critical balance or shortage. See State Water Board–Measurement Regulation (accessed May 17, 2016).

rely on radio or satellite signal to automatically transmit information to central, user-accessible data repositories.

- **Groundwater pumping.** Water pumped and used from wells is also gross water use. Because production from most wells in California is not consistently measured, monitored, or reported, groundwater use on a regional and statewide basis has to be roughly estimated—using land use and crop surveys and crop water requirements—often with significant delays.

  Australia, Spain, and most other western states require measurement and reporting of volumes pumped. So do most of California's adjudicated basins and some special groundwater management areas.[34] Recent state-level progress includes a 2009 law that requires counties to report groundwater levels—useful for tracking seasonal and longer-term trends.[35] SGMA will require local groundwater sustainability agencies to report some overall basin performance metrics—including volumes pumped—but local agencies will determine whether individual users must measure and report pumping. According to recent estimates, only about a third of agricultural wells are now metered.[36]

- **Return flows.** Understanding return flows is a critical challenge in dry regions. Surface water discharges from wastewater treatment plants and large irrigation systems can be measured, but irrigation water that returns underground can only be estimated.

  California's methods for estimating return flows at the state and regional level are weak.[37] The state collects wastewater discharge data for tracking compliance with water quality laws, but it does not systematically evaluate this information to understand water use. Nor does it require reporting on irrigation discharges into rivers, even though many irrigators discharge their return flows through pipes or weirs, making flows easy to measure. California's estimates of water that returns to aquifers are conducted as part of the overall water balance estimates for hydrologic regions, and the imprecision of these estimates is compounded by significant delays in reporting, as noted above.

  Several western states—particularly Colorado, Idaho, and Nebraska—have best practices in this area, with state- or basin-wide models that inform management decisions, including water-trading approvals and curtailments.[38]

- **Environmental uses.** To develop state and regional water balances, DWR tracks environmental uses in four categories: water in rivers protected as "wild and scenic" under federal and state laws, water required for maintaining habitat within streams, water that supports wetlands within wildlife preserves, and water needed to maintain water quality for agricultural and urban use. On average, these uses accounted for roughly half of statewide gross water use from 1998–2010 (Mount and Hanak 2016). However, the meth-

[34] Some irrigation districts require members to report pumping, for internal management purposes.

[35] For information on the California Statewide Groundwater Elevation Monitoring (CASGEM) Program, see http://www.water.ca.gov/groundwater/casgem/ (accessed June 4, 2016).

[36] This estimate is from the Center for Irrigation Technology at Fresno State University (Pottinger 2015).

[37] As one reviewer noted, local managers often have a relatively good understanding of return flows within their areas, but this information is not shared at the regional or state level.

[38] Colorado's StateCU model and Nebraska's CROPSIM model are useful examples, as is Idaho's "Mapping EvapoTranspiration at High Resolution with Internalized Calibration" (METRIC) model, which uses remote sensing data to estimate return flows. Idaho also measures surface water return flows in sensitive basins.

ods for estimating and reporting environmental water uses are not transparent, which heightens tensions over environmental water allocations.

The lack of transparency of these estimates reflects the problems noted above: lack of clarity on environmental water claims, lack of coordination among different, often overlapping regulatory programs and requirements, and gaps in monitoring on environmentally sensitive streams.[39]

Managing and Sharing Information

Finally, although California shares many different types of water-related data online, its usefulness for managers and the public is limited by gaps in standards and platforms for collecting, validating, and organizing this information.

- **Consistent accounting and data standards**. Having a standard way to account for water is especially important in a state where water management is both physically interconnected and institutionally fragmented. Standards are necessary for aggregating up to the regional and state levels and for making valid comparisons across localities and regions. Standard accounting also facilitates audits, which enhance accountability and reliability in water contracts and agreements. California has been improving in this regard—for instance, with efforts to standardize information that urban suppliers provide in their Urban Water Management Plans. But the state lacks a framework for assembling information collected by different agencies into consistent water accounts. Australia—which pioneered water accounting standards—does this especially well.[40]
- **Authoritative and transparent models.** Models used for accounting also need standards. Model assumptions, data, methods, and results should be electronically documented, publicly available, and capable of ensuring that the results can be replicated.

  Most helpful are authoritative models—that is, models that serve as an accepted standard for determining allocations and settling disputes. Australia, Colorado, Idaho, Spain, and Texas all have adopted authoritative models to streamline decisions on matters ranging from water allocation, to groundwater management, to water trading. California has several state-supported water models—as well as scores of local and regional models—but does not have authoritative models, a clear policy on modeling standards, or a process for model testing and improvement.[41] These gaps pose major challenges for the implementation of SGMA, where

[39] For instance, it is hard to track the cumulative volumes of water made available for different programs in the Sacramento–San Joaquin Delta and the greater watershed, including water dedicated for salmon under the Central Valley Project Improvement Act, Endangered Species Act requirements to protect delta smelt and salmon, and water quality standards under the Porter Cologne Water Quality Act and the federal Clean Water Act.

[40] Australia's National Water Initiative (2004) required the development of water resource accounting to ensure "adequate measurement, monitoring, and reporting systems are in place in all jurisdictions, 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." The Bureau of Meteorology, through the Water Accounting Standard Board, had the mission to develop the standard methodology and practical guides to help local and state institutions fulfill the requirements of the National Water Initiative.

[41] The most significant state models are CALSIM (the model used to guide CVP and SWP operations), C2VSim (the Central Valley groundwater model described above), and Dayflow (used to assess inflows and outflows from the Sacramento-San Joaquin Delta).

multiple local entities will be developing their own plans for the management of interconnected water resources.

- **Useful public information.** California needs to improve how it provides water information to make it more useful for the range of accounting system clients.

  One key issue is improving data platforms. For instance, the state has not yet established consistent protocols for submitting and documenting data, so the required reports of surface water diversion and use cannot be easily compared to estimates of water availability. As another illustration, local water agencies in the Sacramento Valley now must go to multiple websites to get a picture of water availability and environmental water constraints—including key ecological indicators such as locations of sensitive species. Yet this information is critical for decisions on allocating water to irrigators. Two good examples of integrated platforms are Colorado's Decision Support System and Australia's national and state-level water information portals.

  Another issue is filling gaps, such as information on water trades. Again, Australia leads the way: Victoria's Water Register presents information on water rights, allocations, and trading.

  Finally, California could improve accountability and enhance decision making by issuing simple digests of key information. Providing public information on water availability and use in easily understandable forms can contribute to better understanding of complex issues and can enhance public acceptance of austerity measures or garner support for needed improvements in water infrastructure. The Texas Water Conditions Report and the National Resource Conservation Service's State Water Supply Outlook reports are interesting examples.

Accounting Priorities for California

Although California is making progress on water accounting, more efforts will be needed to enable the state to manage scarce water supplies efficiently, fairly, and transparently. Here we present 12 priority actions to strengthen California's water accounting by addressing key gaps in understanding water availability, claims, and uses, and improving the management and sharing of information. We organize the discussion around four management challenges where better accounting can make a big difference: improving surface water allocation in times of shortage, enhancing groundwater management, strengthening environmental water management, and expanding water trading opportunities.

As a first step, California needs to adopt an overarching goal of modernizing its water accounting. Key state agencies—including the water board, the Department of Water Resources, and the Department of Fish and Wildlife—should develop a common water accounting framework, including a process for timely vetting and updating information they receive from water-right holders. This accounting framework should be administered by a standing interagency office with dedicated funding. An oversight committee of key stakeholders and independent technical and legal experts should guide and support this process, oversee periodic auditing, and ensure that the system provides users with information needed to manage water effectively and to hold managing agencies accountable.

This statewide effort should seek to leverage the strong SCADA systems that most large urban utilities and many irrigation districts already use to support their daily operations and planning. These systems are already funded, tested, and relied upon locally and could become the basis for assembling larger regional and state accounting systems needed for administering water rights, implementing SGMA, managing ecosystems, and other purposes.[42]

Improving Allocation of Scarce Surface Water

Several actions can position California to administer its water rights system and allocate surface water more effectively in times of shortage.

1. Develop Centralized, Real-Time Flow Estimation and Monitoring for River Basins

To improve understanding of water availability and use, California should consolidate and strengthen its surface water monitoring systems. 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. California has elements of such a system—for instance, most USGS and DWR monitoring stations are equipped with telemetry—and SB 88 will now require this for large diverters. To make the most of this information, California needs to gather it in a centralized platform, control its quality, and make it available for use by water managers, water-right holders, and other clients of water accounting. Better real-time information would allow 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.

2. Firm Up Surface Water Claims

To improve understanding of water claims, California should follow the lead of other western states and validate and quantify riparian water rights and validate appropriative rights established before the adoption of the modern water code in 1914.[43] Adopting an authoritative, streamlined system of oversight—by extending the water board's permitting jurisdiction to all surface water rights, not just those established since 1914—would reduce uncertainties about allocation during droughts.[44]

3. Improve Estimates of Net Water Use and Return Flows

Addressing major information gaps in water use will require focused efforts on improving estimates of net water use and return flows. Better estimates are key for tracking surface water availability, managing groundwater recharge, and determining the volumes of water that can be traded without harming other water users. California should harness available measurements of discharges into rivers from wastewater treatment plants, begin measuring large agricultural discharges (as Idaho does), and standardize estimates of return flows into aquifers (as Colorado

[42] Some additional SCADA standards could automate and document regional data acquisition from these effective local systems, and reduce reporting costs to local users. More formal quality control would probably be desirable.

[43] The details of this proposal can be found in Gray et al. (2015). The water board has recently begun the process of validating pre-1914 appropriative rights in some parts of the Sacramento-San Joaquin basin. No plans are underway as yet to quantify riparian rights, as other states and Australia have done (Figure 3B).

[44] As described in Gray et al. 2015, this should include a requirement that riparian water-right holders choose between maintaining riparian or appropriative rights on the same land. This would not change the amount of water these landowners could use—it would simply prevent them from frustrating the administrative system by toggling between rights.

does). Many agricultural discharges in California now come out of pipes, making measurement straightforward. Establishing authoritative regional estimates of net crop water use can assist in standardizing aquifer return flow estimates. California should also push to incorporate remote-sensing data on crop water use from satellite imagery, now standard in Idaho and under development in many other places.

Enhancing Groundwater Management

California's choice to rely on local development and implementation of groundwater sustainability plans under SGMA will harness local knowledge and likely improve the quality of both solutions and enforcement, but this approach raises the risk that local agencies will use inconsistent local water accounting systems. Some consistency is essential because groundwater is interconnected at a broader scale than local agency boundaries: it moves within sub-basins, between neighboring sub-basins, and between groundwater and surface water users. The state needs accounting standards to reduce conflict and foster creative and realistic management approaches.

4. Define Groundwater Accounting Standards

A priority for effective management and sharing of information on groundwater is groundwater accounting standards for use by GSAs. Statewide standards are needed on matters such as units and frequency of measurement to enable comparability, auditability, and consistent analysis and management.[45] Methodological guides should be developed on how to build these accounts—such as those developed for Australia's national water accounting standards.

5. Develop Groundwater Modeling Standards and Authoritative Groundwater Models

California also needs standards regarding groundwater models, a necessary tool for understanding groundwater availability. These models need to be sufficiently comprehensive to take into account the interrelationships between adjacent sub-basins and interactions between groundwater and surface water. Many local agencies will have incentives to use customized models that provide the best results for them, but not necessarily for their neighbors. If different districts are able to use dueling models, this invites conflict and costly litigation. Standards for model assumptions, methods, documentation, and replicability of results can reduce this risk.

New regulations requiring open-source code for models used for groundwater sustainability plans—whereby the original source code is made freely available and may be modified—should improve transparency (Department of Water Resources 2016).

But California would benefit even more from establishing authoritative groundwater models that serve as a default, with protocols for improvement and potential replacement over time. Within the Central Valley, the C2VSim model could be used as a base, with more detailed, finer-scale models developed for use in individual sub-basins, following established protocols. California can learn from Texas in this regard. Texas' groundwater law also emphasizes local planning and oversight, but the state has invested in authoritative groundwater models to support this process.

[45] This list would include variables such as groundwater recharge from precipitation, irrigation, and active recharge; groundwater withdrawals from pumping; horizontal movement of groundwater; hydrogeological parameters, and other factors. See Lund and Moran et al. 2016.

6. Firm Up Groundwater Claims

Firming up groundwater claims would address a key information gap for sustainable basin management. SGMA authorizes groundwater sustainability agencies to limit individual pumping of groundwater, but the law does not require this action. Nevertheless, California's groundwater users would benefit from defining and capping pumping rights, as is done in most other western states, as well as Australia and Spain. Quantifying rights would increase incentives to invest in groundwater recharge. It would also facilitate trading within basins, which can lower the costs of limiting pumping. Trading has helped water users in the Mojave and Chino basins in Southern California, for instance (Hanak and Stryjewski 2012). Legislation enacted in September 2015 provides a streamlined pathway for groundwater users to adjudicate their rights (Chappelle and McCann 2015).

7. Account for Groundwater Use and Recharge

Better accounting for groundwater use and recharge can fill key gaps in the understanding of water availability and use. Although SGMA does not require measurement of groundwater pumping by individual users, better accounting of groundwater use and recharge will facilitate basin-level reporting and create incentives for users to manage this resource sustainably.

SGMA has also spurred widespread interest in using available surface water supplies to more actively recharge groundwater basins. Active recharge can happen on lands permanently designated as recharge basins, as well as on farmers' fields. "Inefficient" flood irrigation is already a major source of recharge, and recharge could be increased through other farming practices such as flooding fields before the irrigation season. Establishing transparent estimates of volumes recharged, and crediting land owners who implement such practices on their fields, can incentivize additional recharge by defraying costs to land owners for activities that benefit the broader basin.[46]

Strengthening Environmental Water Management

To improve the state's capacity to manage water for the environment—and reduce uncertainties for other water users—the state needs more clarity on water reserved for environmental uses, better information on water availability in many streams, and consolidated information on flows and key ecological indicators.

8. Monitor Flows in Environmentally Sensitive Streams

California needs to fill critical gaps in monitoring smaller, environmentally sensitive streams. Setting up alarms or triggers that alert managers when flows or quality standards have been missed can help identify areas that need urgent attention. Colorado, Idaho, and Kansas all use this practice.

9. Define Environmental Water Budgets

Lack of clarity on environmental water claims is a major information gap. In all but a few watersheds, California still needs to comprehensively define environmental flow requirements under different hydrologic conditions. State officials recognize this need, but have had found it challenging to address this gap within a reasonable timeframe. A pragmatic path forward is to

[46] For an interesting pilot project for "net metering" groundwater recharge in the Central Coast, see Fisher (2016).

adopt a process for the local development of integrated, watershed-based environmental water budgets (EWB), combining a state mandate and local authority to flesh out details (Gray et al. 2015).[47] Within California, the Yuba River Accord is a promising example of better regulatory clarity, where environmental flows have been defined as part of a negotiated settlement on water uses within the Yuba basin.

Defining a significant share of the EWB as a water right would provide environmental water managers with more flexibility than if it were defined entirely as a set of regulatory set-asides. In the Australian state of Victoria, for example, the Victoria Environmental Water Holder manages water for fisheries and wetlands with the same type of rights as other water users, and it may trade environmental water to make the best use of scarce supplies under changing hydrologic conditions (Mount et al. 2016b). California's Proposition 1, a state water bond approved by voters in 2014, sets aside $200 million for the acquisition of water rights for the environment. This is a step in the right direction, but falls far short of what is needed to make a significant difference. By way of comparison, the Australian federal government allocated the equivalent of more than $2.3 billion (at current exchange rates) for environmental water rights acquisitions, and several Australian states used additional sums for this purpose.

10. Consolidate Information on Water Availability and Ecological Indicators

Better management and sharing of information is also a priority for environmental management. California's water managers have an urgent need for data platforms that bring together information on water availability, water-quality metrics such as temperature and salinity, and ecological indicators such as locations of protected fish and other species.

As a biodiversity hotspot, California needs to lead the way in using state-of-the-art information to tackle its tough environmental water management challenges—challenges that will become more difficult as the climate warms. The state has had a positive experience during the latest drought, when tracking information on the location of waterbirds was used to determine when to use scarce water supplies in Central Valley wetlands.[48] But much more needs to be done, especially to manage temperature-sensitive fish like salmon and steelhead.

Expanding Water Trading Opportunities

The following accounting improvements can make it easier to trade water. Trading can get water to where it is most needed—supporting farms, cities, and the environment—while compensating those who make their water available. This is an important way to lessen the costs of water scarcity.

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[47] The water board would assign interim EWBs based on the requirements of applicable environmental laws. Local water users would develop procedures for meeting these requirements, and they could return to the board with alternative proposals for meeting the same environmental goals. These EWBs would vary by season and type of water year (ranging from critically dry to wet), and would be subject to periodic revision and review. To ensure consideration of the effects of both surface water and groundwater use on streamflows, the plans would need to be tied to the local groundwater sustainability plans developed under SGMA.

[48] For a discussion of coordinated wetlands management actions during the drought, see Hanak et al. (2015). One particularly interesting program is The Nature Conservancy's Bird Returns program, which uses a reverse auction to pay farmers to temporarily flood their fields to create "pop up" wetlands in strategic locations, using crowd-sourced bird monitoring data (Robbins 2014). Reiter et al. (2015) show how Landsat satellite imagery can be used to track waterbird habitat in wetlands and on farms.

11. Clarify How Much Water Is Tradable

Addressing information gaps in water claims is one priority for water marketing. An important obstacle to more fluid trading in California is lack of clarity on the share of water rights that can be traded without harming other water users or the environment. These constraints vary by location, and often by the distance between trading parties. Such information is a key feature of Australia's water market, where trades are approved within a matter of hours or days, not the weeks and months that are the norm in California. Two of the recommendations above will help: developing transparent, default estimates of net water use and return flows (#3) and clarifying environmental flow needs (#9). Establishing protocols for estimating the amounts of water that can be safely traded for a set of common situations is another promising approach (Gray et al. 2015, Association of California Water Agencies 2016, Sellers et al. 2016).

12. Increase Public Information on Water Trading

Better management and sharing of information is also a priority for water trading. California would benefit from more detailed, publicly disseminated information on volumes, prices, and locations of water trade agreements.[49] Australia again provides a model. The Victorian Water Register, for example, shows the trading history of each water right along with daily updates of trading volumes and prices in different locations. This information has facilitated the development of privately run trading platforms that enable users to rapidly conclude both temporary and permanent trades of water rights. Idaho also has an active, extensively used water supply bank with online information.

Conclusion: Toward a Common Framework

Regions with drought-prone climates need reliable accounting of water availability and use. Authoritative water accounting is a foundation for the transparent, reliable, timely administration (and, when necessary, curtailment) of water rights, groundwater management, water trading, and protection of the environment. The latest drought has spotlighted serious gaps and fragmentation in California's water accounting system, hampering such actions.

California has been making progress on several fronts, but continued action is needed. The recommendations highlighted in this report will lead to a more robust, integrated accounting system, and improve California's ability to meet often competing economic, societal, and environmental water demands of a growing population in a warming climate. Table 2 summarizes how our 12 recommendations address key gaps in California's water accounting system.

Better information alone will not solve California's water problems, but it is essential for effectively managing the state's scarce water resources. Making a commitment to comprehensive, authoritative, and user-oriented water accounting now will help California address periodic droughts and prepare for a challenging future.

[49] The water board posts application information for transfers that it must approve, but that is only a subset of trades; information on trades approved by other agencies is generally only available upon request.

Table 2. Priority Actions to Address Key Accounting Gaps

Accounting system element	Key gaps	Priority recommendations
Understanding water availability		
Surface water	- Monitoring network insufficiently organized, available for managers, end-users - Most small streams (key to environmental flows) lack gages	- Develop centralized, real-time monitoring at river basin scale - Monitor flows in environmentally sensitive streams
Groundwater	- Inadequate understanding of how aquifers function limits basin management	- Account for groundwater use and recharge - Develop groundwater modeling standards and authoritative groundwater models
Surface–groundwater interactions	- Water rights administered separately and supplies managed separately, despite hydrological connections	- Develop centralized, real-time monitoring at river basin scale - Account for groundwater use and recharge - Develop groundwater modeling standards and authoritative groundwater models
Understanding water claims		
Surface water rights	- Significant invalidated pre-1914 rights and unquantified riparian rights hamper management of shortages and limit trading	- Firm up surface water claims - Clarify how much water is tradable
Groundwater rights	- Unquantified pumping rights encourage excessive pumping and limit trading	- Firm up groundwater claims - Clarify how much water is tradable
Environmental claims	- Lack of clarity on volumes, timing, and quality of water reserved for the environment impedes effective management	- Define environmental water budgets
Understanding water use		
Surface water diversions	- Monitoring network insufficiently organized, available for managers, end-users	- Develop centralized, real-time monitoring at river basin scale

Groundwater pumping	- Incomplete network of metered wells hampers basin management	- Account for groundwater use and recharge
Return flows	- Lack of consistent estimates of surface return flows and aquifer recharge limits trading and hampers basin management	- Improve estimates of net use and return flows - Account for groundwater use and recharge
Environmental uses	- Lack of clarity on environmental claims, flow monitoring gaps, and lack of transparency in official estimates of environmental water uses increases tensions over allocations	- Monitor flows in environmentally sensitive streams - Define environmental water budgets
Managing and sharing information		
Consistent accounting and data standards	- Lack of standards on accounting and data platforms limits comparability, usefulness of information	- Develop centralized, real-time monitoring at river basin scale - Define groundwater accounting standards
Authoritative and transparent models	- Lack of modeling standards and authoritative models increases risks of inconsistent groundwater sustainability plans	- Develop groundwater modeling standards and authoritative groundwater models
Useful public information	- Information on water flows, quality, and ecological indicators is scattered - Missing information on volumes, prices of water trades limits market access	- Consolidate information on water availability and ecological indicators - Increase public information on water trading

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